

Assessment and Provision of Environmental Flows in Mediterranean Watercourses

- Basic Concepts, Methodologies and Emerging Practice

Mediterranean Case Study

THE RHONE RIVER: HYDROMORPHOLOGICAL AND ECOLOGICAL REHABILITATION OF A HEAVELY MAN-USED HYDROSYSTEM

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THE RHONE RIVER: HYDROMORPHOLOGICAL AND ECOLOGICAL REHABILITATION OF A HEAVILY MAN-USED HYDROSYSTEM

This case study considers how environmental flow assessments informed river restoration planning in the Decennial Rhône Hydraulics and Ecological Rehabilitation Plan (2000) for the Rhône River. This is discussed in the context of evolving Water Laws in France and the Water Framework Directive (2000), which provides for restoration of “good ecological status” on rivers in EU-Member countries by 2015.

1. BACKGROUND

The study area: location and geography

The Rhône River Basin encompasses 98,000 km² of land in France and Switzerland. The Rhône is the longest river in the basin (750 km). It originates with snow and ice melt from the Rhône Glacier (at 1773 m. elevation) in Switzerland, which discharges into Léman Lake (Lake Geneva). Downstream of Geneva, the Rhône flows southward for 512 km in France before it forks in two branches that form a delta in the Camargue region (see Figure 1). It then flows into the Mediterranean past built up flood embankments.

The main tributaries of the Rhône are the Arve River, which rises near the Mont-Blanc mountains; the Ain River; the Saône River, which join the Rhone at Lyon; and the Isère, Drôme, Ardèche, and Durance rivers that all intersect the Rhone at various locations in its mid to lower reaches.

The hydrology of the basin is complex. This is because its location and varied topography result in several different climatic influences on the basin. The average annual discharge from Léman Lake is 570 m³/s and at Beaucaire, upstream Arles near the end of the river course, it is 2,300 m³/s.

Typically the Rhone floods in spring and autumn. Flood peaks of 13 000 m³/s were recorded in autumn of 2003. The river also has a relatively high gradient (0,625 ‰). These characteristics help explain why the Rhône, formerly named the “King” River, has been known for its poor navigability, but good hydroelectric potential.

The historical pattern of development of the Rhône

Over the last 400 years the Rhône was developed in successive phases for different purposes. Starting in the 17th Century, levees were built as flood defences. In the 18th Century groins and ripraps were constructed to create a more navigable river. Toward the end of the 19th Century hydroelectric development became increasingly important. The first dam spanning the Rhone was built in 1872. In the past Century, withdrawals for irrigated agriculture development have added to the many river uses. The

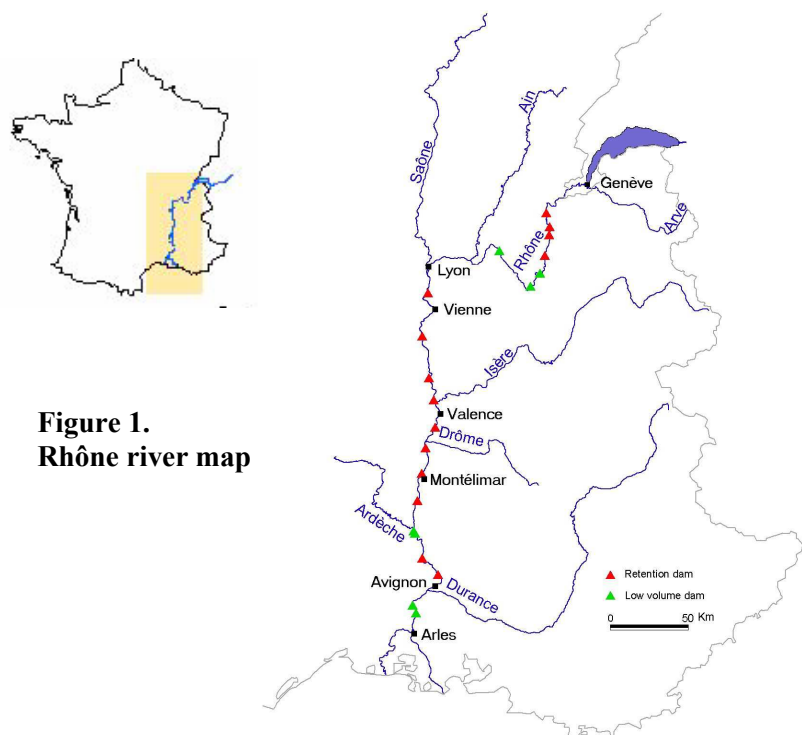


Figure 1.
Rhône river map

construction of the Brégnier-Cordon dam, upstream of Lyon in 1986 was the last major dam development on the Rhône.

The Rhône Law of 1921 was the first to authorize construction of large-scale navigation, irrigation and hydropower works. The Compagnie Nationale du Rhône created in 1934 (CNR, see ref. to website) was subsequently given the mandate to construct these works with an integrative economic development perspective. Since 1934, CNR has developed 19 hydroelectric schemes. These account for 20-25% of the French hydroelectric production, or 3-4% of the total national electricity production. A similar development scheme is repeated at each different location along the river, where canals straighten and shorten the watercourse to facilitate navigation, thus by-passing the old river channel (“vieux” Rhône). An upstream dam on the original Rhône first diverts the water and a second low-head dam, within the navigation canal, provides regulation with lock and turbines. At least 150 km of the by-pass sections of the main river are allocated minimum flows ranging from 1/326th to 1/5th of the ADF. These flows were negotiated on a case-by-case basis as each dam was built.

The contemporary state of the hydrologic system and river ecology

Today the flow regime of the Rhone is regulated by several large storage reservoirs (7 billion m³, which represent about 7.3 % of the annual runoff of 96 billion m³). Nearly 80% of this storage capacity is located downstream of Geneva. It is provided by dams such as the Vouglans dam on upper Ain River, several dams on Isère River (which together account for 30% of total storage capacity) and the Serre-Ponçon dam on Durance River. The Serre-Ponçon dam is one of the largest in Europe and it provides 43% of the basin’s storage capacity.

The Rhône corridor is today a densely populated and industrialized area with more than 2.5 million inhabitants. The Rhône’s “guaranteed income” has contributed to the economic prosperity of the riverside cities and their inhabitants. In ecological terms, the effects of change in physical habitat have been considerable: the morphology of the river channel has changed from braided to straight and canalized, often eroded and incised; the level of the ground water has been lowered; several natural biotopes disappeared; the riparian forest evolved to hardwood forest due to ground water depletion; and dams block the migration of amphibiotic fish (shads, eel, lampreys), where numerous lateral communications with tributaries or side channels have been modified, sometimes cut off. Overall the biodiversity of the river has been reduced. There is scarcity of species whose life histories are linked to a dynamic fluvial system. Rheophilic species have declined and communities shifted to more limnophilic habitat species.

Emergence of new paradigms

During periods of active economic development the general public had turned their back on the river because they perceived it as heavily polluted, artificial and potentially threatening due to floods. In the 1980s, awareness of environmental values was demonstrated in the strong opposition to the last dam development project, Loyette at the confluence of Rhône and Ain. That project was abandoned. Since the early 1980’s numerous reaches of the river and alluvial plain have been classified as protected areas. More than 10,000 ha are now considered as important from a naturalistic point of view and for biodiversity. Local actors and successive management schemes have anticipated a more holistic approach for rehabilitation of the River consistent with contemporary environmental values. The 10-year rehabilitation plan supported by 1,5 million € aims to return to a “healthy and running” river with its ecological status restored. The main measures to restore the hydraulic functioning of large reaches of the river are morphological reconstruction of side arms to rebuild some connectivity between the main channel and abandoned side arms, and to increases of minimum flows in by-pass sections of the original channel (now one third of the total length of the Rhone).

The need for models for Ecological Flow Assessments

One objective in the restoration plan was to establish priority measures for each of the 19 by-pass sections. This involved identifying the minimum flows needed to rehabilitate rheophilic communities. To

do that, models were needed that linked taxonomic and functional responses of stream populations and communities to hydraulic changes. Models developed in the last decade were used, supported by fundamental research work done by multidisciplinary teams.

2. THE NATIONAL AND EUROPEAN LEGAL FRAMEWORK

One of the first environment laws in the modern era was the Nature Protection Law (1976). The scientific and technical content of the impact studies required by the Nature Protection Law however was not sufficient to assess the quantitative impact of different scenarios of dam development and flow management. For example: scientific knowledge of the structure and functioning of large rivers was limited, there were a lot of gaps; few models were available to link biology to physics (e.g. changes in hydraulics); and, there was no global watershed management perspective. All these elements have been progressively improved in time and have been reflected in the evolving legal context.

The freshwater fishing law (FFL, 1984)

The Freshwater fishing law was one of the first to explicitly deal with environmental flows. This law was based on the principle that the management of freshwater systems and the environment had to strike a balance between use and protection. Some of the measures dealt with legal minimum flows. These flows were defined in quantitative terms that depended on the stream size and use, as follows:

1. Stream or river with ADF < 80 m³/s
 - Existing water abstraction: Legal Minimum Flow (LMF) = 1/40th ADF
 - New water abstraction: LMF = 1/10th ADF
2. Stream or river with ADF > 80 m³/s
 - Existing water abstraction: Legal Minimum Flow (LMF) = 1/80th ADF
 - New water abstraction: LMF = 1/20th ADF

Moreover, end users had to produce an impact study to prove that these legal values were sufficient to assure, in permanence: the life, the reproduction and the circulation of the aquatic species inhabiting the water body. The Rhin and Rhône rivers were exempt from this law because of their international status.

The 1984 Law also introduced a requirement to draw up a synthetic cartography (Departmental Freshwater Fishery Scheme) for all the French streams and rivers. This was a tool to visualize the knowledge of the natural environment and inventory of human pressures (Souchon and Trocherie, 1990). One example, was a river map produced by Rhône Méditerranée Corse Water Agency (RMC WA, 1992). This proved to be as good planning tool to analyze and synthesize the ecological and the “anthropogenic” status of the different Rhône reaches (see Figure 2).

The Water Law (WL, 1992)

This Water Law expanded on the 1984 Law. It asserted the principles of sustainable management of hydro-systems and river basin management. Basin-scale

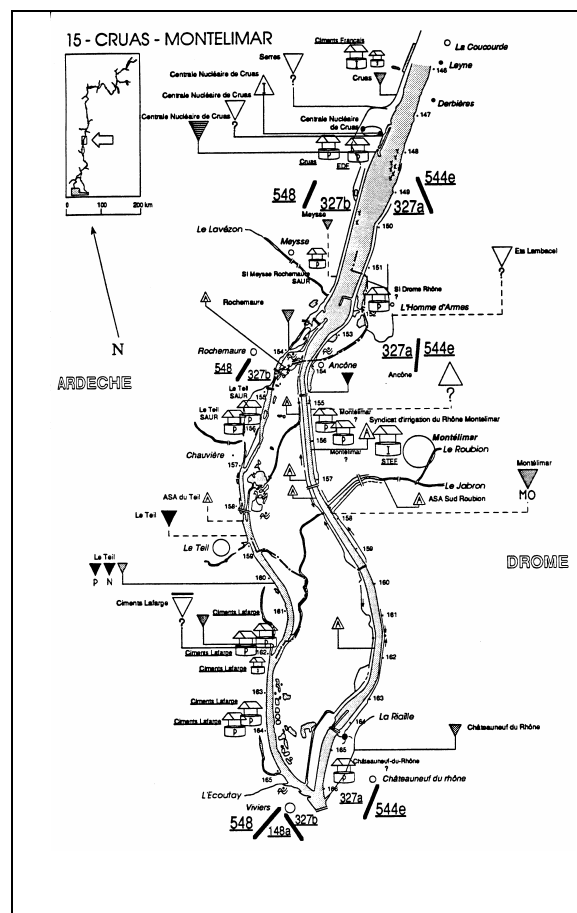


Figure 2. Rhône river map at Montélimar «schéma de vocation piscicole, Zylberblat, 1991». Inventory of point pressures at the reach scale. The methodology is described by Souchon and Trocherie (1990).

management was to be supported by framework documents articulated at different management scales. This included a director (master) scheme at the watershed scale, e.g. Rhône river basin (SDAGE “Schéma Directeur d’Aménagement et de Gestion de l’Eau”), which defines the general directions; and more local schemes (SAGE “Schéma d’Aménagement et de Gestion des Eaux”). At sub-basin scale (e.g. Drôme river noted on Figure 1) the actions needed to apply the SDAGE orientations, for example, were defined.

These documents were developed in a process of intensive dialogue between all the water actors. This approach also benefited from a long tradition of watershed management around the structure of Water Agencies, basin institutions built up in the 1970’s, and adoption of the polluter-pays principle.

The European Framework Water Directive (FWD, 2000)

The FWD seeks to ambitiously move EU member states into a new era of freshwater body rehabilitation. Good status in surface and groundwater sources is to be achieved by 2015. The main indicator of a good ecological status¹ is biology, in its variety of forms (e.g. fish, macroinvertebrates, primary production). Chemical status that has dominated evaluations until present appears now more as a mirror for biology. The physical status serves on one hand to define the best situations classified as references, and on the other hand, to sustain biological processes. This legislation emphasizes results more than it prescribes the means. All the process could be view as adaptive, with logical chronological phases: classification of water bodies, description of references, present status evaluation, inventory of pressures and economical uses, rehabilitation action planning, and monitoring and revision of actions.

3. THE DECENNIAL RHONE HYDRAULICS AND ECOLOGICAL REHABILITATION PLAN (DRRP, 2000)

Several river management plans have been developed for the Rhone with environmental objectives in mind, prior to the DRRP Their multiplicity indicates the dynamic and complex interplay between the numerous actors at different spatial and administrative scales. These actors include: a basin coordination préfet, who is in charge of the Rhône river in cooperation with the regional administration; the Water Agency; and the CNR (a public development company) in charge of the economic and environmental management of the river, which also played a key role in the decennial Rhône river rehabilitation plan.

To illustrate, the successive plans included:

- 1988: Complete diagnosis of the Rhône status
- 1992: Rhône River Freshwater Fishery Scheme, supported by maps for hydro system knowledge and impacts plus pressures (as illustrated with Fig. 2).
- 1992: Rhône Management Plan, which was resource and risk oriented
- 1996: SDAGE Rhône
- 1996: CNR Action Plan - with scientific studies of side channel typology, diagnosis of fish migration and barriers, migratory plan, and an inventory of sensitive sites to protect.

The DRRP thus is defined as the next step in a continuum of study and benefits from accumulated experience. In 1998, three state ministries (Economy and Industry, Transport and Communities Facilities, and Landscape Management and Environment) commissioned Rhône Méditerranée Corse Water Agency (RMC WA) and is watershed delegation to provide technical coordination for the DRRP. It is managed by a steering committee (See box 1 on the DRRP), with advisory support of a Scientific Committee and a Watershed Committee. The DRRP major objectives are to restore a “healthy and running river” (“fleuve vif et courant”) together with a better ecological quality.

Four restoration priorities were subsequently defined in the DRRP process:

¹ The good ecological status is discussed at a European level in order to calibrate and compare the different state evaluations: historical references, contemporary reference situations or models could help to define the good ecological status. For the Rhône river this evaluation is supported by models.

- the hydraulic restoration of the Rhône by-passed sections (Upper Rhône, Miribel Jonage, Péage de Roussillon, Montélimar, Donzère-Mondragon) with the instauration of increased minimum flows,
- the morphological restoration of the Rhône side arms and connected systems,
- the restoration of the fish migratory routes for the Rhône and its tributaries,
- the organization of a scientific monitoring for the entire DRRP and the development of connected actions towards the public awareness and the support to the actors.

Box 1
Decennial Rhone hydraulics and ecological Rehabilitation Plan (DRRP)

Composition of DRRP Steering committee

Regional administrations: Inland navigation, environment, industry
 Public institutions: RMC WA, Inland Fisheries Council, Electricity of France
 Representatives of associations of riverside commune
 Qualified persons

In coordination with

Scientific Committee
Watershed Committee

While the DRRP is based on the philosophy of sustainable development for the entire territory of the river basin, in practice, the rehabilitation actions rely on local initiative. Groupings of communes are the operators. For example a specific convention (Haut Rhône) involves several communes in the rehabilitation of three upper Rhône sites: the Syndicat Intercommunal de Protection des Berges et Bordures du Rhône en Savoie) in common with the Syndicats Intercommunaux de Défense contre les eaux du Haut Rhône dans les départements de l'Ain et de l'Isère. This practice guarantees strong involvement of the local stakeholders.

4. ENVIRONMENTAL FLOW APPROACH USED

Adaptation and validation of methodology for large rivers

In an environmental flow assessment one of the main challenges is to simulate and predict the aquatic biological responses to altered flows in a heavily modified river. However, most of the previous work in developing instream flow methodologies over the previous decade was based on smaller rivers. Because of the availability of extensive research on the Rhône it was nevertheless possible to build on and adapt existing models for use in the DRRP.

An earlier, first effort in this way was made in 1989 for the Montélimar by-passed section (Pouilly, 1994) (see Pouilly et al., 1996 for a similar experience in the Garonne River). This pioneer study set out the difficulties in adapting the existing methods to large rivers. Some of these challenges included: the difficulty in measurement of the key hydraulic parameters; inherent limitations in habitat models for fluvial fishes; and, the choice of weighting factors between species in multi-species assemblages (see also Stalnaker et al., 1989). These difficulties have been partly overcome in recent years, first by the description of hydraulic habitat for more fish species (Pouilly, 1994; Lamouroux et al., 1999a); secondly, through development of statistical hydraulic models (Lamouroux, 1997). Another important development was the linking of statistical hydraulic models to multivariate preference models to predict fish density indices versus different local hydraulic conditions for different flow discharges. These methods and their biological validation are described in a quite complex paper (Lamouroux et al., 1999b).

Advances in habitat modelling have also rendered some of the earlier criticisms of the dominant IFIM / Phabsim, or microhabitat methodology (Bovee, 1982; Mathur et al., 1985) null and void. For example: hydraulic parameters are now considered in a multivariate way (e.g. not as independent variables); the adapted method consider fish assemblages, not only target fishable fish; and biological validation at fish community level has been demonstrated.

Figure 3.1 illustrates the different possible combinations of tools to produce a habitat or a fish community index versus discharge that were available to use. The methodologies selected for the Rhône river case study are shaded in grey (note Stathab, Evha, Estimhab are acronyms of different habitat simulation software - see text and references)²

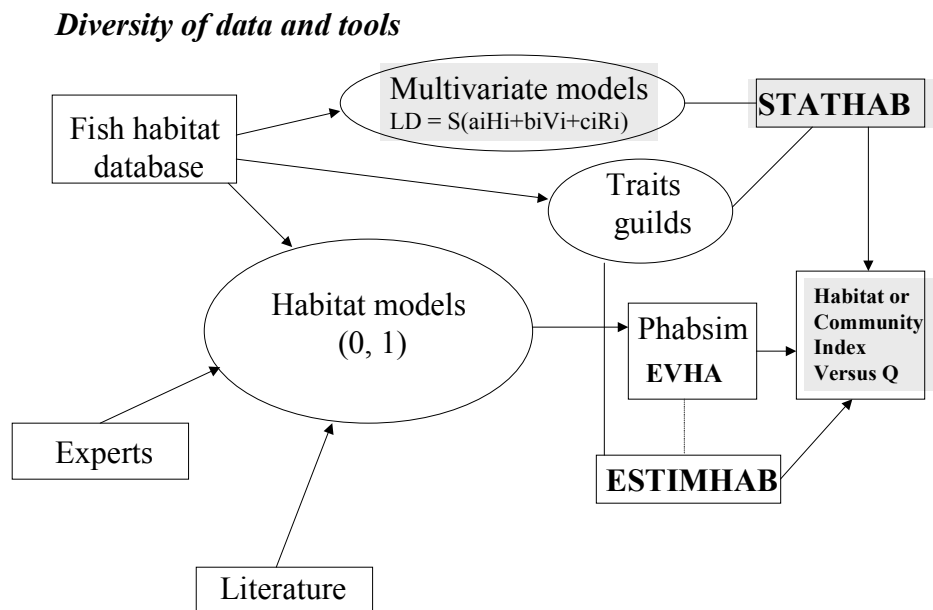


Figure 3.1. Environmental Flow Assessment – Diversity of data and Tools

In practice a number of methodologies can be used that essentially combine different fish habitat preference models and hydraulics models to produce a specified index versus discharge relationship.

What were the objectives?

Previous methodologies tell us what the physical behaviour of a particular reach of the river versus flow is and then to translate this to habitat or community indexes. But the remaining difficulty is to define thresholds in the predicted trends. There are other questions such as, “What altered flow could be considered as sufficiently significant to allow positive evolutions of the fish community?” and “What is the ecological objective to attain?” The methodology doesn’t define the objective, but is at the service of the objective. In other terms, the definition of the objective is not entirely the responsibility of the scientific experts, but the responsibility of the society – such as based on negotiation.

The objective has been defined in vague terms in the DRRP (i.e. to recover “a healthy and running river” (“un fleuve vif et courant”)). It was decided the best approach was to translate these aims into biological attributes. The best observable biological situation that is present in a by-passed sections river has been defined as one achievable objective of rehabilitation. This means deciding the discharges that are needed in the different by-passed sections, taking into account different existing morphologies and slopes. The

² A majority of these tools are available on the web <http://www.lyon.cemagref.fr/bea/lhq/logiciel.html>

biological attributes of the fish community are summarized in an index of more or less rheophilic characteristics. During the DRRP modelling of each by-pass reach was carried out. The results are compared in the same picture (as illustrated in Figure 3.2).

The different trends schemes versus discharges thus helped to define a hierarchy for the rehabilitation potential in different bypass sections. It is assumed that a higher minimum flow would also moderate the adverse impacts peaks that pass in transit the by-pass section. And also the aesthetics and landscape values that are associated with a large river are restored in the by-pass.

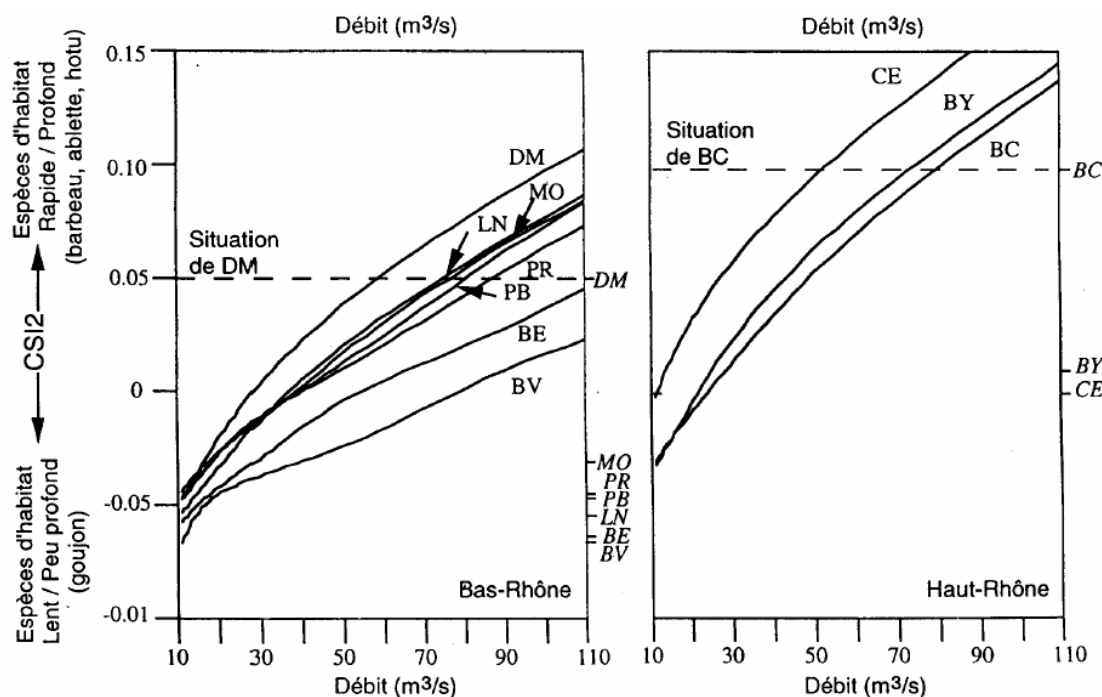


Figure 3.2. Simulation of fish community structure indexes (CSI) versus flow (débit: m^3/s) for different by-pass sections of the Rhône river³.

In Figure 3.2 a low CSI value indicates a limnophilic community (e.g. gudjon) A high value indicates a rheophilic community (e.g. barbel, bleak, nase) that is more accord with a fluvial running environment (Lamouroux et al., 1999c). Notice that responses are different in each bypass section, due to different morphologies: that is, the same increase in the minimum flow does not produce the same increment of rheophilic habitat (the letters DM, MO, LM, etc, in the figure correspond to responses different bypass sections).

Implementation in an adaptive management perspective

The first decision to improve flows in the bypass-section to restore environmental values was taken for the Pierre-Bénite site. This is the first by-passed section downstream of Lyon. From August 2000, the minimum flow was increased from $10 m^3/s$ (in the September through March period) and $20 m^3/s$ (in the April through August period) to $100 m^3/s$. A power turbine has been installed in the dam to produce hydroelectricity with this discharge so as to help compensate for loss of energy production from the dam lower down in the new channel. Corresponding to the biological objective (see PB on Figure 3.2), it is predicted this will provide a more rheophilic fish assemblage, near the level of DM (Donzere-Mondragon) that was chosen as a benchmark. This decision is supported by a monitoring plan (2001-2004) to assess the future modifications and compare the observed values of fish community attributes to

³ Reproduced with permission of Bulletin Français de la Pêche et de la Pisciculture

the predicted ones. A “before modification” monitoring programme was also put in place 1995 to 1999. A battery of complementary indicators has also been established under the categories of: hydrology, hydraulics, sediment, fish, macrophytes, macroinvertebrates and aquatic landscape (stakeholders perception of the rehabilitated river). The data characterizing each category can be mapped (databases coupled with GIS) to help communicate complex information to managers and stakeholders. Elsewhere, precise simulations are underway in the upper Rhône river (at 3 bypass-section study sites) and in two downstream reaches (Montélimar and Donzère-Mondragon). The decisions in regard improving the environmental flow regime in these bypass sections will depend on the outcome of local dialogue and take into account the financial implications.

5. MANAGEMENT ACTIONS

In the past, river management strategies often identified flood defence, water quality management and water resource protection as a priority well ahead of the preservation of the river’s ecological integrity. The limitations of such perspectives are now more appreciated, especially by the public. The focus in watersheds management in basins like the Rhône is now clearly the rehabilitation, or re-naturalisation, in a more integrative perspective. Treatment of wastewater is an example where progress is being made with several years of accumulated experience.

However, less progress is made in the physical rehabilitation of the river. The general intention is provided in management schemes (see Figure 3), but their effective implement is lacking. We can identified at least three major causes for that matter of fact:

- (1) flow increases in by-passed reaches are often seen as an economical losses for previous uses (e.g. hydroelectricity), and not means to establish a new equilibrium between economy and ecology;
- (2) the complex functioning of hydro-systems is difficult to explain in terms easily understandable by a majority of people, and
- (3) few demonstrative and positive study cases exist.

The reversal of public opinion at the turn of the 1980s, expressed by a will to live and work with the river and not against it, is progressively influencing river management and associated actions. The DRRP is very illustrative of that evolution. The major political action has been the transformation of funds for channelization and navigation works into funds for river rehabilitation in 1998, following a national political decision.

The participation of the stakeholders through their representatives is also essential. All rehabilitation actions at local scale (e.g. a by-passed site) involved them, including their financial contribution in the financial plans. A tenfold increase in the minimum flow of a river is a measure that is visible to the naked eye. To strengthen this impact, it is also necessary to build objective indicators of change with effective monitoring. The DRRP objectives clearly identified this necessity and asked for a scientific framework to establish and monitor indicators. The financial cost of this framework is 3% of the total rehabilitation cost of (1,5 M€). It has also strengthened capacity to improve and build predictive models to evaluate the evolution of biota versus discharges changes. The results of the monitoring could be viewed as experience return on that models, in order to validate or to improve them.

6. LESSONS LEARNT AND KEY CHALLENGES

The Rhône river rehabilitation illustrates an adaptive approach to river restoration supported by environmental flow assessment. It shows what can be achieved in the rehabilitation of a river that has supported urban, agricultural and industrial development for a long time, without due consideration to its environmental, values and attributes. The degrees of freedom for physical rehabilitation are not numerous because of the densely populated and equipped catchment. Nevertheless, some actions are still possible to balance the delivery of water between by-passed sections and channelized parts of the river, and to rebuild some connectivity between the main channel and abandoned side arms. To be efficient and to keep a general coherence, the actions of rehabilitation are to be defined at the scale of the entire river. In

that sense, general management schemes are useful to harmonize the spatial and temporal scales and to define priorities for the actions between the numerous partners of the river.

It is also essential that local representatives and their organizations are involved in local projects, to adapt the global management locally and to find the good pedagogy towards the riverine stakeholders. It is also essential to build up a dynamic process, beginning with a good collective definition of the objectives before the actions, following by an adapted monitoring defined for the entire river. The first rehabilitation cases could serve as pilot sites, and could benefit of a more intensive evaluation by a before after control procedure. In the field of the applied science, such experiments are very challenging. It could be said that a majority of questions have been solved in the last two decades.

Choosing the right method

A major difficulty remains for the managers to choose among more than 100 methodologies developed all around the world (Tharme, 2004). Fortunately, all these methodologies can be gathered in three main families: hydrological, hydraulics and microhabitat IFIM like methodology (Bovee, 1982). The two first families do not incorporate explicit biological considerations. In the Rhône river case, an adapted microhabitat methodology was the basis of the evaluation. Nevertheless, it may be argued it is not possible to adopt the same strategy in rivers or countries where the biological knowledge is not as advanced. Others may claim that such methodologies are very time consuming, expensive to apply and require a high level of expertise.

Emerging Methodologies

While these remarks may apply to the standard approaches it is also possible to apply simplified versions of the microhabitat methodology. This is demonstrated from the experience acquired on Rhône river and on more than 100 other streams conducted by Lamouroux and co-authors (Lamouroux and Capra, 2002; Lamouroux and Souchon, 2002).

The principle of the simplification is based on the relationship between the hydraulic geometry of a stream or river segment and the statistical distribution of the habitat parameters, like velocity and depth. These properties explain some very promising links between indicators of hydraulics such as a dimensional Froude or Reynolds numbers and ecological characteristics of the fish assemblages.

Another exciting perspective is the utilization of ecological traits of biota. This approach permits simulations in situations where the individual habitat preferences for species are not still described. This improves the transferability of models to a large number of streams and rivers types. On the other hand, refinement in the approaches of the two other families of flow assessment methods (hydrological and hydraulics methods) could serve as complement to refine the environmental flow definition. For example there can be improvements in terms of seasonal regime or of necessary hydraulic events (e.g. flushing flow to maintain healthy habitat, or to eliminate fine sediment clogging the substrate).

Another set of new challenges relate to the extension of the biological resolution of the microhabitat modelling, like biota of biofilm, macrophytes and macroinvertebrates. In all the cases, the progress needs sufficient data of good quality. In particular, long term series are essential to build in order to determine the influence of altered flow among the different other signals potentially responsible of the dynamic of the biota. The future will inform us if the strong tendency towards the rehabilitation of rivers, translated in the present case by the modification of minimum flows, signals the beginning of a movement towards their sustainability, or simply a therapeutic correction of a heavily modified system.

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- Ministry of Ecology and Sustainable Development <http://www.environnement.gouv.fr/>
- Scientific monitoring of Rhône rehabilitation (in French) <http://www.graie.org/zabr/sites/site5.htm>
- References of Lamouroux, Souchon are available in pdf format @ <http://www.lyon.cemagref.fr/bea/lhq/publications.html>