Environmental Management (2012) 50:123–139
DOI 10.1007/s00267-012-9862-1

ENVIRONMENTAL ASSESSMENT

River Restoration in Spain: Theoretical and Practical Approach in the Context of the European Water Framework Directive

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Received: 25 March 2011 / Accepted: 30 March 2012 / Published online: 9 May 2012

Abstract River restoration is becoming a priority in many countries because of increasing the awareness of environmental degradation. In Europe, the EU Water Framework Directive (WFD) has significantly reinforced river restoration, encouraging the improvement of ecological status for water bodies. To fulfill the WFD requirements, the Spanish Ministry of the Environment developed in 2006 a National Strategy for River Restoration whose design and implementation are described in this paper. At the same time many restoration projects have been conducted, and sixty of them have been evaluated in terms of stated objectives and pressures and implemented restoration measures. Riparian vegetation enhancement, weir removal and fish passes were the most frequently implemented restoration measures, although the greatest pressures came from hydrologic alteration caused by flow regulation for irrigation purposes. Water deficits in quantity and quality associated with uncontrolled water demands seriously affect Mediterranean rivers and represent the main constraint to achieving good ecological status of Spanish rivers, most of them intensively regulated. Proper environmental allocation of in-stream flows would need deep restrictions in agricultural water use which seem to be of very difficult social acceptance. This situation highlights the need to integrate land-use and rural development policies with water resources and river management, and identifies additional difficulties in achieving the WFD objectives and good ecological status of rivers in Mediterranean countries.

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Keywords River restoration · Spain · Water framework directive · Water resources management · Forecaster · National strategy

Introduction

River restoration is an emergent activity in many countries for several reasons (Clewell and Aronson 2006; Feld and others 2011). First is the perception of the loss of landscapes, ecosystems and species that has occurred in many areas during the last century as a result of intense demographic and economic growth, which has produced ecological and social disruption by limiting the availability of water resources, reducing the natural biodiversity and contributing to the decline of important environmental services (Nilsson and Berggren 2000; Tockner and Stanford 2002; Meybeck 2003; MEA 2005; Mooney and others 2009).

A better understanding of the effects of the environmental degradation of rivers on the well-being of people has resulted in various legislative measures to prevent further degradation and assure biological conservation. In European countries, recent directives such as the Water Framework Directive (WFD) (2000/60/EC 23 October 2000), the Flood Directive (2007/60/EC 23 October 2007) and the Pesticide Directive (2009/128/EC 21 October 2009) explicitly require the Member States to produce integrated river basin management plans (RBMPs) which shall include programs of restoration measures to prevent further deterioration and ameliorate the ecological status of river ecosystems.

Over the past 20 years, since the restoration of rivers began, many approaches have been considered, and they have ranged from the idealist objective to re-establish the pre-disturbance aquatic functions and related physical, chemical and biological characteristics, removing all human impacts (NRC 1992), to a more realistic approach that considers restoration to be the human-assisted improvement of river integrity through the recovery of natural hydrologic, geomorphic and ecological processes, assuming the many financial, political, social, natural and scientific constraints that are unavoidable in human-dominated systems (Dufour and Piegay 2009; Laub and Palmer 2009). Large financial investments have been made during these years in an attempt to enhance river status, and different approaches and types of restoration projects have been initiated based on the considerably varying starting points and available financial and social resources among the countries and their rivers.

Spain, like other many countries, underwent extensive economic development during the last 25 years with an associated significant environmental impoverishment. According to data published by OSE (2006), between 1987 and 2000, the area occupied by artificial surfaces increased nearly 30 %, which represents approximately one third of the surface area transformed over the previous centuries. Because of the construction of more than a thousand large dams before 1990 (MMA 2006), more than 200,000 ha of irrigated land were developed during the period (1987–2000), with an increase in the areas inundated by reservoirs of more than 20 %, more than 60 % of which was previously natural valley forested areas. This major landscape transformation also implied significant river degradation caused by intensive flow regulation, river channelization and water pollution. The associated effects of such pressures seriously compromise river dynamics, water quality and sediment-water-vegetation interactions (Batalla and others 2004; Ollero and others 2006) and eventually promote the invasion of multiple exotic species (Elvira and Almodóvar 2005; Sabater and others 2009).

To prepare the aforementioned RBMPs including programs addressing river restoration measures required by the WFD, the Spanish Ministry of the Environment with the scientific and technical assistance of the Polytechnic University of Madrid, began the development of a National Strategy for River Restoration in 2006 (Yague and others 2008), which rationale and contents are described in this paper. Several years after the organization of this National Strategy, many actions and restoration projects have been implemented with varying ecological relevance and degrees of success. During 2008–2010 the European research project FORECASTER (Facilitating the application of Output from Research and Case Studies on Ecological Responses to hydro-morphological degradation and rehabilitation) was developed with the main objectives of (1) assessing research output, both national, European and North American, and case studies concerning the ecological effects of hydro-morphological degradation and (2) positioning hydromorphology in river rehabilitation strategies. Within this Project we analyzed sixty restoration case-studies undergone in Spanish rivers, promoted by different Institutions and with different objectives. The results showed a clear tendency of enhancing river structure (e.g., riparian vegetation or fish-passes) without considering other options addressed to ameliorating river processes (e.g., environmental flow regimes, enlarging dimensions of the active floodplain, improving land-use planning for better quantity and quality of water).

As restoration and mitigation measures attempt to reverse human-caused degradation and improve the ecological status of rivers, a clear understanding of the Driver-Pressure-State-Impact-Response scheme (EEA 2007) is needed, with an initial and crucial step being the identification of the main constraints for habitat heterogeneity and biodiversity (Palmer and others 2010; Hooper and others 2005; King and Hobbs 2006). In many temperate European rivers, sufficient water quality and quantity are guaranteed to support biodiversity and to achieve restoration success, and the most frequent restoration measures consist of retaining fine sediments and nutrients from runoff by riparian buffers, increasing species richness by in-stream habitat enhancement or gaining connectivity by removing weirs (Feld and others 2011), all of which have an assured social acceptance. However, in Mediterranean regions, inadequate water quality and quantity represent the main drivers and pressures of river degradation (Hooke 2006; Grantham and others 2010) and restoration measures may aggravate the severe competition for water resources and limit traditional rural development. There is an extensive bibliography on restoration ecology theory and practice mainly derived from rivers in humid-temperate regions (i.e., Feld and others 2011), but little is available from the Mediterranean regions where water scarcity and its associated social and economic constraints seriously reduce river restoration possibilities.

With this paper, we attempt to highlight not only the Spanish experience in establishing river restoration objectives and strategies on a national scale showing the contrast between theory and practice, but also the differences between Mediterranean and temperate European countries in relation to natural water availability, main water uses and difficulties in achieving WFD objectives and undertaking river effective restoration activities.

Natural Characteristics and Human-Induced Water Quantity and Quality Problems in Spanish Rivers

Flow Regulation to Mitigate the Imbalance Between Water Availability and Water Demands

Spanish rivers flow across very complex hydrological regions, with different climatic influences acting on distinct tectonic and geological systems and with high levels of spatial heterogeneity in stream flow regimes within river basins (Sabater and others 2009). Because of the natural climatology, much of the natural water resources are in the northwestern part of the country, where precipitation is relatively high. Demand for water resources is especially concentrated along the south and eastern Mediterranean coast, where the most intensive agricultural and urban development is promoted by desirable temperatures and little rainfall. This imbalance between the natural availability of water and human consumption has been traditionally solved on a national and regional scale by a powerful infrastructure of dams, reservoirs and water transfers across the country, including more than 1,200 large dams (MMA 2006), most of which were built between 1960 and 1990, and several large inter-basin water transfers.

Flow Regulation Impacts

Flow regulation impacts have been extensively addressed in the current literature (i.e., Poff and Zimmerman 2010), in which it is widely accepted that a naturally variable regime of flow is required to sustain freshwater ecosystems (Bunn and Arthington 2002; Arthington and others 2006). Dam operations clearly impact the transverse hydro-geomorphic disturbance gradients controlled by the frequency, amplitude and timing of floods that are crucial for habitat creation and vegetation succession (Hughes and Rood 2003; Corenblit and others 2007).

In Spain, many authors have documented the significant ecological effects of intensive flow regulation in the form of degradation of macroinvertebrate, fish and riparian communities downstream from reservoirs (García de Jalón and others 1992; Navarro-Llacer and others 2010), promotion of non-native invasive species (Elvira 1995; Elvira and Almodóvar 2005), contribution to eutrophication processes (Camargo and others 2005) and induction of significant hydrological (Batalla and others 2004) and channel morphology changes (Ollero 2010). More recently, Tena and others (2011) studied the Ebro River, which is the largest in Spain, and estimated the value of the mean annual load transported in its lower part in the last decade (1998–2008) as less than 1 % of what was transported at the beginning of the twentieth century, in the absence of dams and under different land uses. Thus, the research has highlighted the sediment deficit downstream from large dams, which, together with the alteration of the natural flow variability, may be responsible for most of these physical and biological impacts.

After several years of dam operation, a large portion of the downstream floodplain areas become dry and therefore favorable for growing irrigated crops or urbanization. New human settlements are established in these relatively dry floodplains as a consequence of the decrease in flood frequency, and subsequently, river channel alignment, embankment and piping in urban reaches are promoted, multiplying the stress on fluvial ecosystems and the difficulty of improving their ecological status. For example, Ollero (2010) has documented the relationships between channel changes and floodplain management in the most dynamic sectors of the middle Ebro River attributable to the construction of dams and associated land use changes (i.e., the extension of agricultural and urban land) and flood control. As a consequence, between 1927 and 2007, areas covered by water, bare gravel bars and first pioneer species decreased by 80, 25 and 40 % respectively, meanwhile mature riparian forests increased by 279 % and urban land-use by 587 %.

Irrigation as a Major River Pressure and Constraint for Environmental Flow Allocation

Irrigation represents the main reason for the presence of the powerful flow regulation infrastructure (Fig. 1), accounting for more than 80 % of total water use (see Table 1). Therefore, most Spanish rivers show significant alterations in their natural Mediterranean pattern, having lower discharges in winter when water is being stored in reservoirs and higher discharges in summer when water is released for irrigation (Fig. 2). Rivers that are regulated for irrigation not only have a significant decrease in the normal winter floods that many native fish species require to survive, as well as a dramatic increase in summer monthly flows, which inhibits the settlement of riparian species, but they also have a large reduction in the annual and intra-annual variability to which Mediterranean species are adapted (Resh and others 1988; Bonada and others 2007; Ferreira and others 2007).

Implementing environmental flow regimes is essential for the conservation of freshwater ecosystems (Arthington and others 2006; Hughes and Rood 2003). However, there are considerable difficulties in applying these flow regimes in Spanish rivers (García de Jalón 2003). Social and political resistance to restricting water allocation related to irrigation use for environmental purposes is very strong because of the high profit associated with irrigated crops in some areas (i.e., olive trees, horticulture in the southeastern basins) or because no productive alternatives exist in rural areas, which is the case in extensive parts of Extremadura and Andalucía (in southwestern Spain). New water demands from growing urban areas and golf courses along the Mediterranean coast are also significant contributors to the water deficit that is in conflict with environmental uses (Grindlay and others 2011). Furthermore, the sequence of dams and reservoirs along the river drainage system has

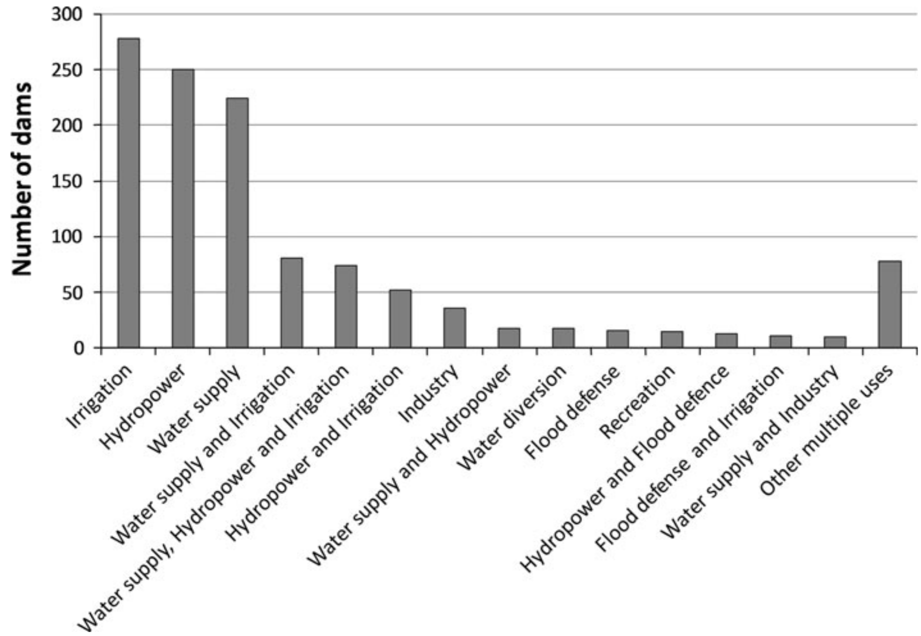

Fig. 1 Main use of Spanish reservoirs storage water (MMA 2006)

constituted the main pressure for the designation of heavily modified water bodies, which represent the majority of the middle and lower reaches of Iberian river networks.

Water Quality Associated with Water Quantity

Water quantity problems are often associated with water quality, in a synergistic response to uncoordinated water resources and land-use management. The reduction of flow dilution capacity as a result of agriculture consumption reinforces the effects of urban wastewater inputs and prevents biological recovery. Frequently, most of the river flows of Mediterranean streams come from urban treated-wastewater discharge or irrigation return-flows, which have considerable mineral and nutrient content that limits the growth of non-tolerant pollution species, as it is the case of the Congost stream studied by Prat and Munné (2000). Paredes and others (2010) have estimated that 90 % of the Manzanares River discharge crossing the Madrid urban area comes from the effluent of the 8 large wastewater treatment plants in the area, which are the main cause of the river's organic pollution (i.e., high contents of ammonia, conductivity, DBO_5). In addition, groundwater abstractions for irrigation, together with urban development, may determine seasonal fluctuations in the depth of the water table, changing streams from permanent to temporary and having a significant effect on stream water quality and biology. Menció and Mas-Pla (2010) studied the stream-aquifer relationship in a Mediterranean watershed of Gerona (Cataluña, in northeastern Spain) and estimated these water table oscillations to be between 4 and 12 m in the dry season, as a result of the capture of the stream discharge during the summer months, in contrast with humid periods, when the water table rose to 0 to 4 m below the surface. This implies that during the dry months, nearly all of the river flow comes from the effluents of urban wastewater treatment plants and causes a significant loss of hydro-morphological, physico-chemical and biological river quality.

The Spanish National Strategy for River Restoration

In the context of the WFD, the Ministry of the Environment initiated a National Strategy for River Restoration in 2006 to introduce new river management concepts and procedures necessary to achieve the WFD environmental objectives. To do so, scientific assistance by the Polytechnic University of Madrid were required to help the Ministry to define principles and actions to improve the environmental backgrounds of administrative managers, to delineate restoration and rehabilitation goals and to put in practice pilot restoration projects that would encourage public participation and stakeholder involvement in restoration activities (Yague and others 2008; MMAMRM 2010).

Following previous river restoration strategies and experience from the literature (e.g., FISRWG 1998; Rutherfurd and others 2000; Land and Water Australia 2002, 2006; Giller 2005) and general principles for achieving restoration success (Palmer and others 2005), seven consecutive steps were followed to implement the National Strategy (Fig. 3).

Table 1 Values of natural runoff and water demands in the main Spanish Water Basins. (Data extracted from the respective RBMPs documents, inside the section of "Water resources and water demands", which were available in the official web-pages of each Water District in 2011)

Water district	Natural runoff (hm^3/y)	Runoff coefficient	Water storage in reservoirs		Water demands (hm^3)					Total water demand/natural runoff (%)	Agriculture demand/natural runoff (%)	Agriculture demand/water storage (%)
			hm^3	% Natural runoff	Urban	Agriculture	Industrial	Other	Total			
Miño-Sil www.chminosil.es	12,689	0.56	3,040	23.96	114	306	15	1	436	3.44	2.41	10.07
Cantábrico www.chcantabrico.es	13,881	0.57	559	4.03	260	54	504	3	821	5.91	0.39	9.66
Duero www.chduero.es	13,660	0.28	7,667	56.13	329	4,501	46	8	4,884	35.75	32.95	58.71
Tajo www.chtajo.es	10,883	0.3	11,135	102.32	599	1,712	284	0	2,595	23.84	15.73	15.37
Guadiana www.chguadiana.es	4,414	0.16	8,843	200.34	222	2,907	24	0	3,153	71.43	65.86	32.87
Guadalquivir www.chguadalquivir.es	8,601	0.23	8,867	103.09	444	3,490	83	0	4,017	46.70	40.58	39.36
Ebro www.chebro.es	17,967	0.31	7,702	42.87	506	6,310	250	0	7,066	39.33	35.12	81.93
Catalunya www.gencat.net/aca	2,787	0.23	772	27.70	592	388	150	8	1,138	40.83	13.92	50.26
Júcar www.chj.es	3,432	0.16	3,349	97.58	721	2,789	147	0	3,657	106.56	81.26	83.28
Segura www.chsegura.es	803	0.11	1,223	152.30	143	1,662	46	30	1,881	234.25	206.97	135.90
Cuencas mediterráneas www.juntadeandalucia.es	2,351	0.25	1,319	56.10	390	1,159	72	0	1,621	68.95	49.30	87.87
Total	91,468		54,476		4320	25,278	1,621	50	31,269			
%				59.56	13.82	80.84	5.18	0.16	100.00			

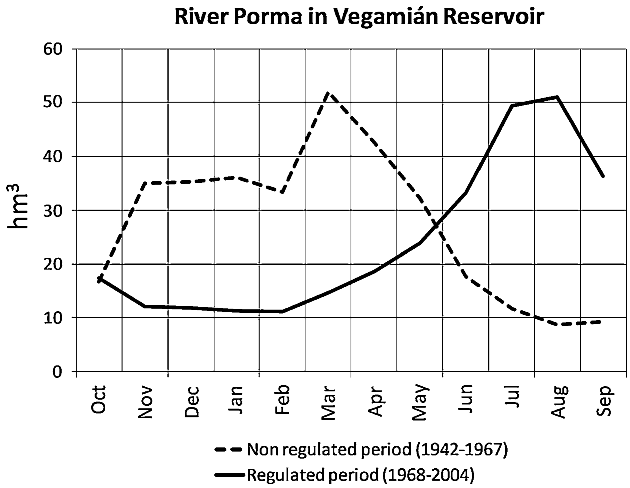

Fig. 2 Flow regime of Porma River in Vegamián reservoir at pre- and post-dam erection periods, showing the typical hydrological alteration due to irrigation

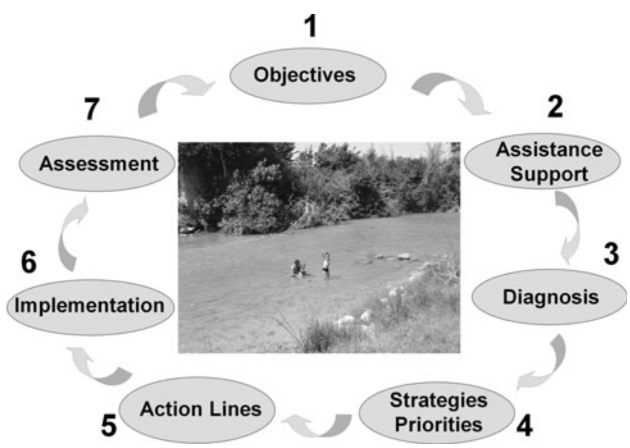

Fig. 3 Steps of the Spanish national strategy for river restoration (MMAMRM 2010)

Objectives

Special interest was initially focused on defining goals, desired targets and required actions. On the national scale, the goals were formulated broadly as follows:

1. To improve the scientific background related to integrated river science of the managers of Spanish rivers and to unify ecological restoration concepts, terminology and goals
2. To assist river basin agencies in applying the WFD and defining restoration measures to be included in the RBMPs
3. To promote transdisciplinary approaches by integrating restoration and conservation activities in traditional water resources management, flood protection projects, land-use planning and rural development programs
4. To promote public participation and stakeholder involvement in water resources management and river restoration activities and to encourage volunteer participation in them
5. To start with pilot projects to demonstrate restoration possibilities in Spanish rivers.

Participation and Support

The guidelines of the Spanish National Strategy for River Restoration were developed by a group of experts from the Polytechnic University of Madrid under technical assistance to the Ministry of the Environment. Once these guidelines were established and internally accepted, the next step was to promote the dissemination of information and participation in the National Strategy to obtain the necessary technical and social support.

Seeking participation and public support to undertake administrative actions characterizes democratic societies and results in stronger, more sustainable and more successful results in both the medium and the long term. As Reichert and others (2007) and Boulton and others (2008) pointed out, better communication by extensive discussions, documentation of the prediction of effects, analysis of alternatives and conflicts, etc, allows integration of different perceptions and attitudes and promotes transparency and creation of proposal with a greater degree of consensus. To achieve this, several internal workshops with scientific experts and major official water authorities as well as open conferences to promote discussions and encourage participation were organized and later extensively referenced in regional journals. Additionally, six specific working groups addressing flow regulation, channelization and dredging, agriculture, urbanization, invasive species and river conservation were created, to prepare initial reports including diagnosis and proposals.

The dissemination of information and social learning about the National Strategy were also achieved by means of the creation of specific sections of the general Ministry of the Environment web site (http://www.mma.es/portal/secchttp://www.mma.es/portal/secciones/acm/aguas_continent_zonas_asoc/dominio_hidraulico/conserv_restaur/index.htm) and by public participation in several radio and television programs that addressed the concepts and activities of the river restoration National Strategy.

Diagnosis

The same specific working groups mentioned above integrating scientific and administrative experts and stakeholders' organizations prepared detailed reports on the main problems of Spanish rivers and the alternatives and constraints for ameliorating their ecological status. Flow regulation by dams and reservoirs in nearly all of the major rivers for irrigation and hydro-power purposes was considered the most important stressor on Spanish rivers, affecting the majority of drainage networks. Accordingly, the possibility of improving flow variability and river dynamics to achieve success with other restoration measures, as suggested by Kondolf and others (2006), was extensively considered. Water pollution from agriculture and urban wastewater, channelization and floodplain alteration by agriculture and urban land use, and the invasion of exotic species were also considered by the participating working groups as the main sources of Spanish river degradation attributable to anthropogenic impacts, and these problems were found to be equivalent to those in other regions (Tockner and Stanford 2002; Klimo and Hager 2008; Tockner and others 2009).

During the discussions in the working groups, administrative and management problems were also highlighted, centered on the following aspects:

– Insufficient knowledge or little experience of the technical staff in integrated river basin management, environmental flows and restoration procedures.
– Little cooperation and frequent conflicts among administrative institutions that handle water resources, agriculture, urban planning and biological conservation.
– Urban and Agricultural development without taking into consideration structural water deficits and prevention of environmentally harmful runoff pollution (i.e., sediments, nutrients, pesticides).
– Insufficient staff to undergo environmental surveillance and river monitoring and scarcity of gauge stations, data on sediment budgets, morphological channel changes, etc.
– Little social awareness of hydro-morphological degradation and social demands for hydro-morphological river restoration and protection.
– Traditional inertia toward on-site repair of flood damage by river training immediately after occurrence, without enough analysis of the causes and the possibilities of more environmentally sensitive solutions.
– Scarcity of long-term river studies evaluating cumulative effects of flow regulation, channelization, and urbanization, and little social perception of cumulative hydro-morphological effects and their associated problems with invasive exotic species.

In parallel with these working groups within the National Strategy, other official technical documents were prepared concerning the main pressures and challenges for each water district (*Esquema de Temas Importantes*, or ETIs) needed for reporting the respective RBMPs. Scarcity of water and pollution were considered the main causes for the limited possibilities of achieving the environmental aims of the WFD in all of the river basins, followed by other aspects with the indicated ranking:

1. Excessive water withdrawal in rivers and in some aquifers
2. Pollution from urban or industrial sources
3. Diffuse pollution from agriculture
4. Degradation of fluvial and riparian landscape (inappropriate land use)
5. Degradation or drying of wetlands (inappropriate land use)
6. Invasion of exotic species

Strategies and Priorities

The following priorities were considered for improving the ecological status of Spanish rivers on a national scale:

Assuring Water Quality and Space for the Rivers

Water quality improvement, groundwater abstraction control and regulated flow regime improvement were considered as critical actions to be addressed before beginning other restoration activities. Previous national programs addressing water quality (Decree Law 600/2003 to assure urban sewage treatment) and groundwater-extraction control (Alberca Programme) were initiated before the National Strategy was in place. To facilitate more space for rivers, a new decree law was approved (Decree Law 9/2008 of January 11, 2008), which expanded the possibilities of identifying and protecting the river public domain (according to the Spanish Water Law, this includes all inland water and the space in which it flows). Since this legislation was passed, the river public domain, which includes the channel and the riparian zones, can be identified using not only hydrological criteria as before (in which space is limited by the average annual maximum discharge of the natural flow regime) but also geomorphologic and ecological criteria, taking into account the available historical references. For this purpose, the river territory identified in 1956–1957 aerial photographs was proposed as a reference point for delineating the river public domain, including natural riparian and floodplain areas. These aerial photographs are easily accessible and available for the entire country, and they show fluvial patterns corresponding to a period when relatively few dams existed and most Spanish rivers were not regulated but flowed under natural regimes.

Preventing Additional Degradation of Rivers

As a prevention measure, a moratorium on new dredging, channelization or culverting projects in rivers and streams was proposed to be followed by administrative river managers under internal administrative guidelines, as well as a more holistic catchment-scale approach for designing flood protection projects and urban development. Finally, following the EU Flood Directive, mapping of the flood-prone areas was initiated, assuming the dissuasive effect of knowing the vulnerability to flooding of the landscape for new agricultural or urban planning developments, and the new explicit responsibilities of the municipal managers emerged from these officially published maps.

Protecting and Conserving the Best Rivers

To protect the best, the identification of the river reaches with good or very good ecological status was considered urgent recognizing these river reaches as natural reserves and references for ecological restoration. The creation of the National Catalog of Fluvial Reserves (Catálogo Nacional de Reservas Naturales Fluviales; http://ambiental.cedex.es/reservas-fluviales.php) was started. This catalog was based on a previous inventory of river reaches where the riparian vegetation was better preserved (Lara and others 2004, 2008). From this initial inventory based on riparian vegetation, only the river reaches with no flow regulation and no significant human alteration of morphology and water quality were selected, resulting in a proposal of 357 river reaches that represented an approximate length of 3,000 km of fluvial ecosystems. As the last stage of creating this National Catalog, the proposed list of river reaches was sent to each river basin district committee to be verified in the field and revised according to the fish community and invasive species. The final results for each basin would be included in the respective RBMPs.

Information and Training

Finally, information and ecological training addressed to river managers, together with public participation and social learning which are strongly emphasized by the WFD (van Ast and Boot 2003) were considered to be of high priority in the success of the proposed goals. In this case, updating the knowledge of administrative managers in which the paradigm of hydraulic engineering was dominant was a crucial target, together with increasing the social perception of the physical degradation of rivers and of the associated biological and ecological effects.

One of the first activities within the National Strategy was the organization of international seminars and meetings with scientific and stakeholder participants, to encourage more environmentally-based river management, a field with strong tradition in the engineering and technical sciences but in which social learning bridging the gaps between biophysical aspects and social, cultural, aesthetic, economic, political and moral aspects seems to be crucial (Tippett and others 2005; Ryder and others 2008).

Lines of Action

Five main action lines were proposed within the National Strategy focused on education and training, conservation, restoration and rehabilitation, voluntary work, and documentation and research, in agreement with the aforementioned priorities.

The *education and training* line was devoted to improving the environmental social learning and technical backgrounds of river managers. The c*onservation* line was an attempt to coordinate all of the projects and studies aimed at identifying and preserving the best river reaches in the Spanish River network, beginning with the National Catalog of Fluvial Reserves. The *restoration and rehabilitation* line was designated to integrate all the programs of restoration measures expected to be defined in the RBMPs required by the WFD. The *Volunteer* action line aimed to coordinate volunteer cooperation in river field surveys (diagnosis and evaluation), questionnaires and public opinion polls, cleaning projects, environmental education, invasive species control and other types of actions. The *research and documentation* action line was for the coordination of future studies and centralization of databases, documentation and project reports, creating publications, dissemination activities, website maintenance, etc.

Implementation

Initially, the general ideas and proposals of the National Strategy for River Restoration were gradually accepted by the respective water authorities, although some expressed resistance to changing the old mindsets of river engineering and traditional water resources management, deeply rooted in Spanish water institutions.

In the area of education and training, a particular effort was made from the beginning to increase the knowledge of ecological river science among managers. Two international seminars on river restoration were organized in 2006 and 2007, with the presence of the relevant international scientific community (http://www.mma.es/portal/secciones/acm/aguas_continent_zonas_asoc/dominio_hidraulico/conserv_restaur/Jornadas_Publicaciones_ENRR.htm), and several publications were produced to facilitate the design and application of restoration measures (González del Tánago and García de Jalón 2007; Barreira and others 2009).

In the area of restoration and rehabilitation, several projects were initially prepared. Thirteen of these projects were later carried out (e.g., Rodríguez and others 2008), whereas others are in progress or are still under study (http://www.

mma.es/portal/secciones/acm/aguas_continent_zonas_asoc/dominio_hidraulico/conserv_restaur/index.htm).

In the area of the volunteer program, a guide to coordinate volunteer participation and projects was published (WWF-MMA 2007), and many activities undertaken by diverse volunteer groups were promoted (Sánchez Martínez 2008), related to river monitoring, river enhancing, field data gathering, river surveillance and environmental education.

Maintenance of the initiatives of the National Strategy in the following years was considered crucial to consolidation of the new approaches for river management in Spain. Continuity of the education program, reinforced by the inclusion of integrative river science in the curricula of certain degrees with competencies in water resources and river management (e.g., civil and agricultural engineers), was thought to be an effective task in the medium and long term for improving the ecological status of rivers. The maintenance of programs of environmental education and social learning was considered essential to gradually increase social awareness of river degradation and river restoration demands.

Assessment

After initiation of some of the stages represented in Fig. 3, methodologies for evaluating the efficiency of proposed actions were delineated to verify to what extent the objectives of the National Strategy were being achieved. According to the main goals of the National Strategy, specific interest was focused on evaluating the progress in the integrative river science education of managers and consultants, to what extent the project reports and execution procedures improved and to what extent the involvement of the public, the initiatives and cooperation of the stakeholders and social interest and learning increased.

To evaluate the success of this National Strategy in the short, medium and long term, the concept of "community capacity for riparian restoration" proposed by Thomson and Pepperdine (2003) was considered to assess the expected results, together with other ideas and proposals formulated by different authors (Downs and Kondolf 2002; Palmer and others 2005; Woolsey and others 2007). Assuming that river restoration should be a social task, the success of the National Strategy could be quantified not only through the ecological improvements achieved in the short term but also through social attributes on which the improvement of the ecological status of Spanish rivers will depend in the medium or long term. Indicators proposed to estimate the success of the National Strategy for River Restoration included social environmental sensitivity and culture related to the perception of problems, public participation and stakeholder involvement for ranking alternatives and implementing rehabilitation measures, information and communication, confidence in public institutions, transparency, appropriate legislation and administrative coordination (Table 2).

To evaluate the success of restoration projects, a monitoring assessment of the status of implemented projects and the responses of the respective rivers has been recently charged to technical consultants, with the results still to come.

As a general appraisal, we can conclude that the National Strategy has represented a productive source of ideas and new projects and has significantly contributed to communicate optimism and improve knowledge of fluvial ecosystems among river managers and environmentalists, especially in the area of fluvial geomorphology. It has also represented an important source of funds, which were at the beginning of the National Strategy invested in solving old problems with costly actions (e.g., channel instability using bio-engineering techniques, removal of old sewage pipes, mining sediments) or in the recreational conditioning of riparian areas (e.g., public access facilities, paths, riparian plantations). However, these funds are gradually being invested in cheaper and more ecologically based projects or in monitoring programs as the understanding of ecological river functioning by practitioners and administrative staff increases.

River Restoration in Practice: Present Constraints and Main Results

Proposal of Restoration Measures for the RBMPs Within the WFD

Following the concepts and principles of the National Strategy for River Restoration, a list of restoration measures to be included in the respective RBMPs reports were officially prepared (MMAMRM 2008), the majority of which addressed the amelioration of water quantity and quality degradation resulting from agricultural and urban pressures (Fig. 4).

Despite the previous Urban Waste Water Treatment Directive (91/271/EEC), which made it obligatory to provide collecting systems for urban sewage by the year 2000 for cities with populations above 15,000 and by the year 2005 for cities with populations between 2,000 and 15,000, water pollution emanating from urban areas is still considered a major barrier to achieving WFD environmental objectives in Spain. Because of that, a relatively large number of the restoration measures listed for the RBMPs reports are focused on ameliorating the quality of urban effluents which is urgent because Spain has been recently referred to the EU Court of Justice for non-fulfillment of

Table 2 Assessment criteria for evaluating the National Strategy success at medium and long-term, with indicators of ecological status of rivers derived from the WFD (biological and hydromorhological variables) and indicators of increasing the social capacity for undertaking river restoration activities derived from Thomson and Pepperdine (2003)

Elements	Variables
Biological indicators	Fish communities composition, abundance and age distribution
	Macroinvertebrate community composition and diversity
	Number of exotic species
	Natural regeneration of native riparian forest
Hydromorphological indicators	Environmental flow regimes minimum flows magnitude and season, flood magnitude and frequency, annual inter- and intra-variability
	Mobility and dynamism of river channels
	Width dimensions of riparian and flood-prone areas
Administrative and management context	Transdisciplinarity in river management, ecological background of river managers, administrative coordination, river restoration/conservation priorities in urban and landscape planning, use of non-engineered measures for flood control
Communication and public participation	Data availability, communication mechanisms and networks, cooperation between institutions, web-pages up-dating, administrative structures for public participation, open meetings and public attendance
Projects design	Stakeholder involvement, scientific assistance, spatial and temporal scales, roles and responsibilities, consistency and financial security, institutional support, maintenance and monitoring, post-project appraisals, flexibility and adaptability, transparency
Values and perceptions	River values and environmental services appreciation, awareness of environmental problems, perception of flow regulation effects, understanding of fluvial processes, appreciation of Mediterranean peculiarities, perception of river identity, ownership of problems and perception of solutions
Social outcomes	Perception of public health and safety, recreation use of rivers, social values of river sites, social organizations and implication in river management, public trust in river restoration, social pressure for river conservation, volunteer implication in river studies and works, social learning

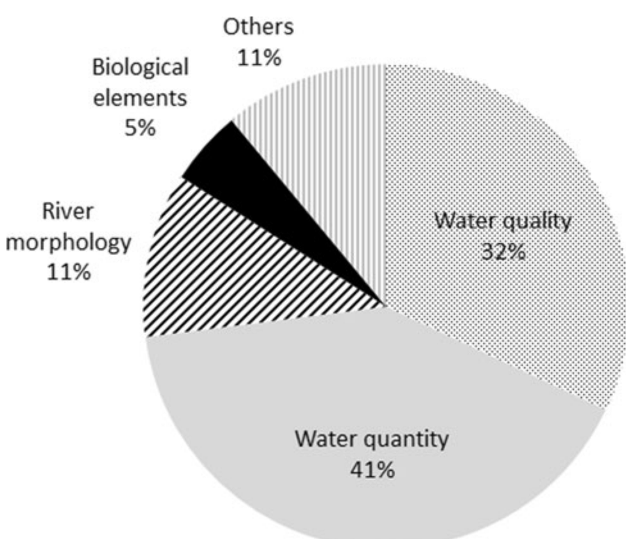

Fig. 4 Percentage of main river components to which the potential restoration measures of the Spanish RBMPs are addressed to (MMAMRM 2008)

the Urban Waste Water Directive. However, agriculture also represents a major source of fine sediments, nitrates and pesticides, which affect river water quality and require intense restoration measures. Claver and others (2006) detected 44 priority substances from pesticides in the Ebro River, whereas Torrecilla and others (2005) estimated that 64 % of the nitrate concentration in the same river is from agriculture; meanwhile, industry and urban areas were responsible for 88 % of dissolved inorganic phosphorus and 71 % of dissolved organic matter in ultraviolet loads. Moreno and others (2006) showed a strong influence of agriculture on river nutrient levels in south-central Spanish rivers, whereas García-Ruiz (2010) recently highlighted the severe environmental consequences of the expansion of irrigated areas and the trend toward larger fields, which increase soil erosion and result in both soil and water quality degradation.

Only 11 % of the restoration measures proposed to be included in the RBMPs are focused on improving the geomorphologic conditions of rivers, 5 % are directly focused on improving biological communities, and another 11 % are for other purposes, with the rest 73 % devoted to improve water quantity and quality conditions (Fig. 4). The characteristics of such restoration measures clearly reflect the different river problems and restoration priorities that exist in European countries. The northern and central countries concentrate their efforts on recovering the natural geomorphologic conditions of rivers having a guaranteed quality and quantity of water to support natural biotic communities (e.g., restoration of the Skjern River in Denmark by means of re-meandering the pre-channelized river reach near its mouth, where water quality prior to restoration was very good and the potential for biotic recolonization was very high as stated by Pedersen and others 2007a, b), whereas in the other Mediterranean countries, the priority is still simply to have more water, or to have water of better physico-chemical quality.

Restoration Projects

During and after the development of the National Strategy, many local restoration projects have been undertaken in different rivers conducted by different administrations, the majority of them focused on improving riparian conditions (i.e., vegetation plantations), physical habitat (i.e., fish passage) and recreational conditioning (i.e., public access, riparian paths, pruning and clearing).

Sixty of these projects were reviewed by the European FORECASTER research project which among other objectives aimed to compare stated pressures and impacts with restoration measures and to evaluate restoration success. This review tried to include all the Spanish restoration projects with available information at that time. A detailed web-format database consisting of these 60 selected case studies was created in the FORECASTER project, and data about the project site and characteristics were incorporated into a GEO-WIKI system (http://forecaster.deltares.nl).

Many of these restoration projects corresponded to river reaches of large basins and were finished by 2010 (Fig. 5). In many cases, the projects were directly promoted by the Ministry of the Environment (i.e., as part of the National Strategy) which reflects small direct participation of local institutions in river improvement. A relatively high proportion of the projects (20 %) were co-financed by LIFE (European Union financial instrument supporting environmental and nature conservation projects), and in these cases, a more complete and available description of the project existed. In contrast, for the remainder of the projects, details about the river, measurements and even the objectives of the project or guiding images were difficult to find, and for most, no monitoring program or post-project assessment was conducted.

The analyses of the main aspects in the projects showed that planting riparian vegetation was the procedure most frequently undertaken, as a consequence of the proportion of sites where degradation of riparian areas was noted (Figs. 6, 7). Quite frequently, diagnosis of the problems and objectives did not correspond to the proposed measures. Although flow regulation was referred to as the main stressor in many sites (18 % of the reviewed projects) under different impacts (discharge diversion and returns, hydrological regime alteration, groundwater abstraction, impoundment, collinear connected reservoir, etc.), only 2 % of the projects included measures to improve water allocations for environmental purposes, even though many projects aimed to ameliorate fish habitat (11 %) and even geomorphologic river processes (8 %). Regarding sediment flows, only excess siltation as a consequence of soil erosion

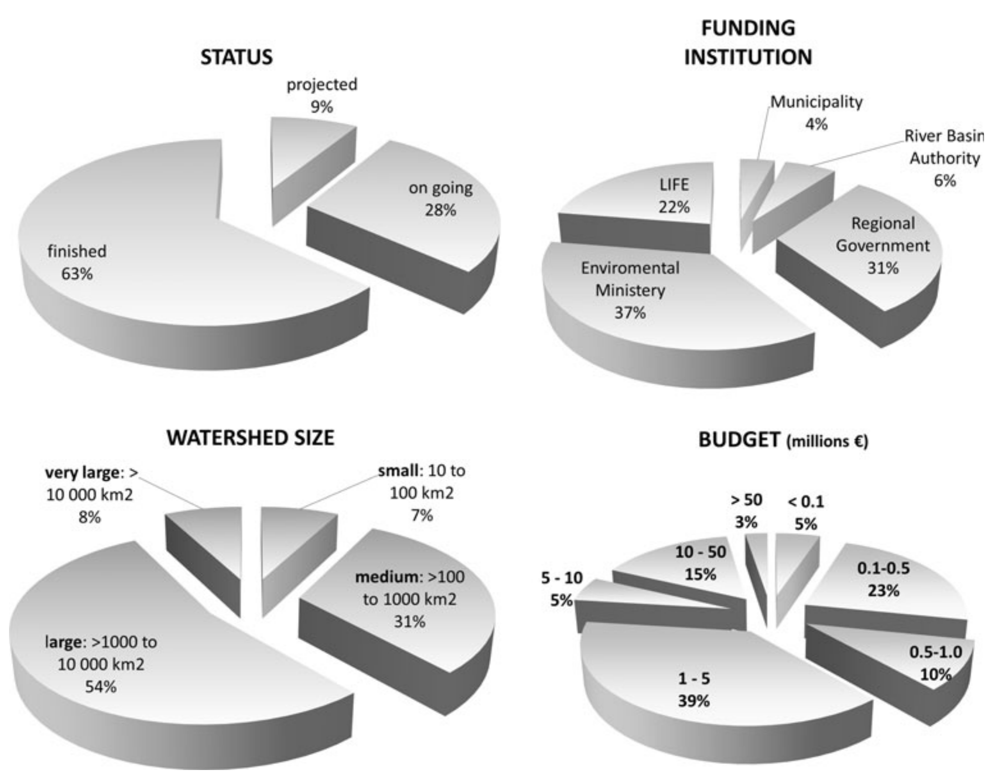

Fig. 5 Characteristics of 60 Spanish restoration projects reviewed within the FORECASTER Research Project (www.forecaster.deltares.nl)

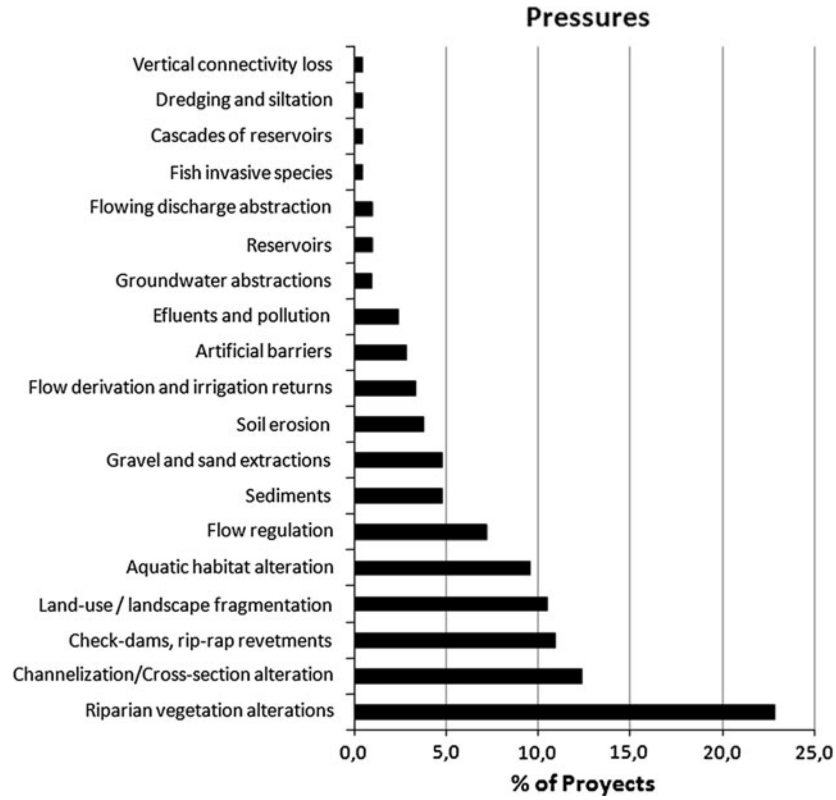

Fig. 6 Main pressures identified in the 60 restoration river sites reviewed within FORECASTER Project

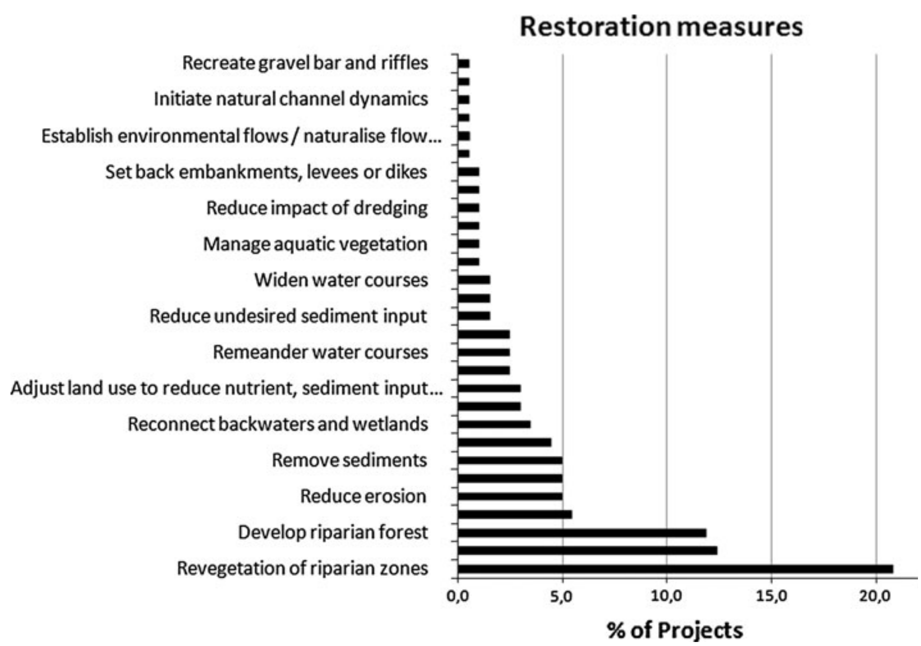

Fig. 7 Main restoration measures proposed in the 60 river sites reviewed within FORECASTER Project

from agricultural lands was perceived as a problem, whereas lack of coarse sediments because of their retention in reservoirs was not mentioned. In general, poor functionality associations were described between several impacts or pressures (i.e., flow regulation) and their effects (i.e., invasion of exotic fish species, aquatic habitat or riparian vegetation alterations); consequences of river degradation were frequently identified as pressures, and the intention was frequently found to repair the effects using measures such as planting riparian species or removing sediment in fish-spawning areas without first removing the causes (i.e., grazing, siltation, flow regulation).

Conclusions based on the FORECASTER results suggest that, on the one hand, too much emphasis on riparian vegetation in the diagnosis of pressures (27 %) and restoration measures (22 %) and still-common channel stabilization works that use bio-engineering techniques (12 %) conceive of restoration as consisting of engineering projects in which some type of structure must be built, although without an ecologically based vision for guidance. On the other hand, little attention is paid to processes and management, significantly avoiding flow improvement (including related restoration measures in only 2 % of the sites) or floodplain landscape planning (which is not considered as a restoration alternative in the reviewed projects).

In recent years, weir removal, in combination with the construction of fish passage structures, is gaining ground as a restoration measure to increase the longitudinal connectivity in Spanish rivers. After long administrative processes, many small, obsolete weirs have been removed, especially in the northern and Basque country districts, where 74 small weirs were removed between 2007 and 2010 (http://www.chcantabrico.es/index.php?option=com_content&view=category&layout=blog&id=191&Itemid=247&lang=es). Arenillas (2008) documented the check-dam demolition strategy conducted in a protected area near Madrid, and Alonso and others (2009) have reported methodologies and ecological arguments to remove 20 small dams sited in rivers of special ecological interest that have not been used for more than 3 years, supporting the previous reports of Brufao (2006, 2008).

Environmental Flow Regimes

As mentioned, the allocation of environmental flows is the most crucial river restoration measure for Spanish rivers, although it has not been addressed appropriately because of resistance on the part of the irrigation and hydro-power stakeholders supported by politicians, to assume the river's ecosystem water rights as proposed by Naiman and others (2002).

The Spanish experience in determining environmental flows was reported by García de Jalón (2003). Until very recently, ecological flows were identified with minimum flows, as single values that each dam had to release downstream to maintain the aquatic ecosystem, while allowing maximum water withdrawal for other uses. In the last years, significant attempts have been made to review procedures for allocating environmental flows (Magdaleno 2005) and to adapt methodologies to quantify hydrological alterations (Martínez and Fernández Yuste 2006). Furthermore, social awareness of the necessity of improving river discharges has significantly increased. However, social conflicts related to water use are intense, and political support for irrigation and hydro-power continues to be high. As a result, the environmental flow regimes have been estimated in the RBMPs very poorly, based on minimum flows that represent less than 10 % of the monthly rates of natural flows in most of the rivers and without seasonal variability (Fig. 8).

Although considerable effort and investment have been devoted to improving water use efficiency by updating irrigation systems, illegally irrigated areas have increased considerably over the last years before the RBMPs are completed and officially approved. These conditions increase the actual structural water deficit in the southern basins, as in the case of Guadalquivir, Segura and other Mediterranean basins. In June of 2011, the European Commission referred Spain to the EU Court of Justice because it had failed to submit its plans for managing river basins to the Commission according to schedule (i.e., December of 2009). Final approval of the RBMPs is pending because of these social and political pressures regarding environmental flow regimes that should restrict new agriculture or urban developments. This debate constitutes an area of enormous controversy between political parties as well as between regions.

Learned Lessons and Looking Ahead

The European directives are legal impositions from abroad that include obligatory environmental requirements. They become essential for undertaking river restoration projects where strong social and political resistance to change traditional water resources management exists, as it is the case of Spain and many other Mediterranean countries. Because of its remarkable educational trend, the WFD has significantly contributed to increase environmental consciousness of the majority of river managers and politicians and presents a major challenge for the Spanish water administration.

Definition of guidelines for river restoration framed within a national strategy has represented a relatively easy task and has always counted on a general agreement regarding river problems and the desired objectives. Difficulties have arisen in applying these guidelines, due to discrepancy in approaches among the administrative staff without enough environmental background and the small experience in participating and being involved in management of the stakeholders. In this context, education and training have been crucial and should be maintained, although most of the results will not be evident until the medium term. Little experience in public participation and stakeholder involvement exists, and in this case, European Research Projects involving the scientific community as well as the administration and stakeholders seem to be extraordinarily helpful.

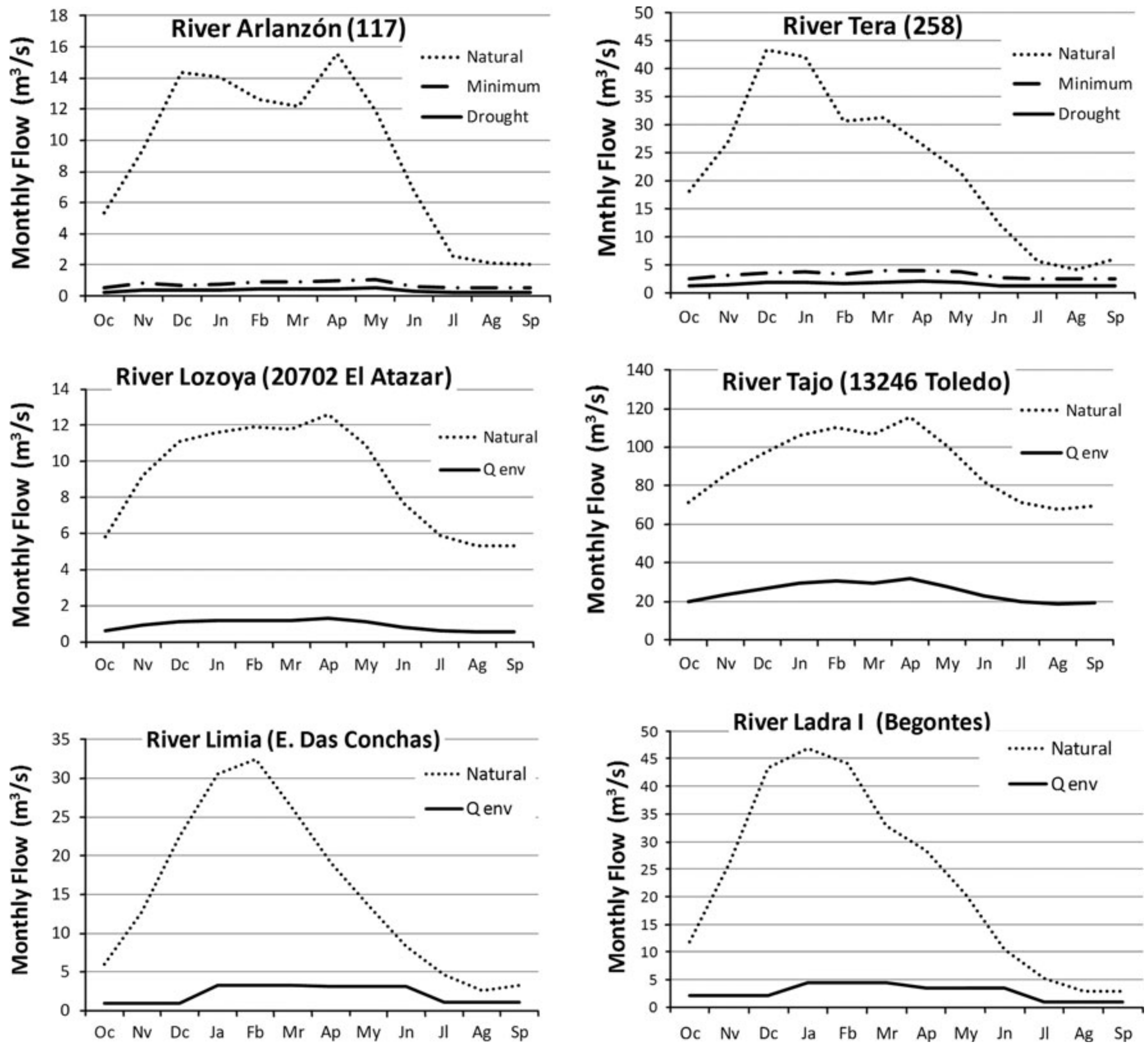

Fig. 8 Environmental flow regimes recently proposed for different water bodies in several Spanish RBMPs: Rivers Arlanzón and Tera in the Duero Basin; Rivers Lozoya and Tajo in the Tajo Basin; Rivers Limia and Ladra in the Miño-Sil Basins. *Each graphic shows* natural simulated monthly flows and proposed environmental flows in terms of minimum flows, drought flows defined for the drier periods or ecological flows (Qenv). (Data from www.chduero.es; www.chtajo.es; www.chminosil.es)

A considerable distance exists among the officially listed measures (i.e. mainly to improve water use efficiency and water quality, see Fig. 4), the restoration measures most frequently undertaken until now (i.e., riparian vegetation enhancement, fish-passes or weir removal) and the restoration measures that are actually needed to achieve better ecological status (e.g., environmental flow regimes, increasing river room, re-meandering). Flow regulation effects are still not assessed sufficiently, although nearly all the Spanish rivers requiring improvement in ecological status are intensively or very intensively regulated, and more social consciousness and better understanding by technical staff are strongly needed.

Proper allocation of in-stream flows for environmental purposes that restrict other consumptive water uses is an outstanding task in Spain, and represents the main challenge for river restoration in the Mediterranean countries, where an integrated framework for river management and landscape planning, combining human and ecosystem water needs, is considered essential. Such a framework will prevent misguided agricultural and urban development along the sea costs and shores of the rivers that will significantly increase water demands and seriously compromise the environmental achievements of the WFD. The expected growth in the urban population and climatic changes may increase the stress on water resources (IPCC 2007; Morán-Tejeda and others 2010) and aggravate the conflicts between environmental and social water demands.

Although the European directives have been approved by political agreement among the European members, they do not always sufficiently consider the countries' different starting points and social constraints to achieving the objectives. In comparison with the temperate regions, the Mediterranean countries experience additional constraints for the ecological improvement of river systems because of the scarcity of water, the severe competition for water resources and the high spatial and temporal variability; social and political resistance to allocating flows for environmental aims while restricting water use for agriculture or other uses is very strong and public and stakeholder acceptance of environmental flows is much more troubled. These conditions of Mediterranean countries severely compromise the fulfillment of EU environmental legislation objectives and schedules.

Acknowledgments The National Strategy was formulated under two administrative contracts between the Polytechnic University of Madrid and the Ministry of the Environment in 2006 and 2007. The review of restoration projects corresponds to FORECASTER project results (IWRM-NET CGL2008-03082-E/BTE). The authors express their recognition to Cristina Narbona, Jaime Palop, Jesús Yague, Ricardo Segura, Luis Babiano and Javier Sánchez from the Ministry of the Environment for their political and administrative support. M. Aldaguer, I. Doadrio, R. Garilleti, D. Gómez Orea, M. Gutiérrez, F. Lara, I. Lastra, M. Múgica, A. Ollero, I. Rodríguez, R. Romeo, R. Sánchez-Navarro and J. Serrano coordinated the working groups with remarkable effort and positive results.

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