

# Assessing and forecasting the impacts of global change on Mediterranean rivers. The SCARCE Consolider project on Iberian basins

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Received: 3 March 2011 / Accepted: 27 June 2011  
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## Abstract

**Introduction** The Consolider-Ingenio 2010 project SCARCE, with the full title “Assessing and predicting effects on water quantity and quality in Iberian Rivers caused by global

change” aims to examine and predict the relevance of global change on water availability, water quality, and ecosystem services in Mediterranean river basins of the Iberian Peninsula, as well as their socio-economic impacts. Starting in

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Responsible editor Thomas Braunbeck

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December 2009, it brought together a multidisciplinary team of 11 partner Spanish institutions, as well as the active involvement of water authorities, river basin managers, and other relevant agents as stakeholders.

**Methods** The study areas are the Llobregat, Ebro, Júcar, and Guadalquivir river basins. These basins have been included in previous studies and projects, the majority of whom considered some of the aspects included in SCARCE but individually. Historical data will be used as a starting point of the project but also to obtain longer time series. The main added value of SCARCE project is the inclusion of scientific disciplines ranging from hydrology, geomorphology, ecology, chemistry, and ecotoxicology, to engineering, modeling, and economy, in an unprecedented effort in the Mediterranean area. The project performs data mining, field, and lab research as well as modeling and upscaling of the findings to apply them to the entire river basin.

**Results** Scales ranging from the laboratory to river basins are addressed with the potential to help improve river basin management. The project emphasizes, thus, linking basic research and management practices in a single framework. In fact, one of the main objectives of SCARCE is to act as a bridge between the scientific and the management and to transform research results on management keys and tools for improving the River Basin Management Plans. Here, we outline the general structure of the project and the activities conducted within the ten Work Packages of SCARCE.

**Keywords** Mediterranean rivers · Global change · RBMP · SCARCE

## 1 Introduction

The Mediterranean basin is one of the world's regions most vulnerable to global change (Barceló and Sabater 2010) and one of the “hot spots” for oncoming problems in water availability (Giorgi and Lionello 2008). Current climate change models forecast that the Mediterranean region will likely register increased summer drought and stronger rainfall events (IPCC 2007); thus, average river discharge is predicted to decrease and water temperature and the frequency of large floods to increase (Calbó 2010). Low summer flow and large floods in autumn and winter are characteristics of rivers under Mediterranean climate (Gasith and Resh 1999), but the forecasted scenarios suggest several points of concern, including decrease hydrological connectivity and increase in the concentration of pollutants during droughts, changes in biological communities as a result of harsher environmental conditions, and a decrease of biological processes like nutrient uptake, primary production, or decomposition. Furthermore, the increased pressure on shrinking water resources

will compound the impacts on river ecosystems (Sabater and Tockner 2010).

Since freshwater ecosystems deliver important services to society (Millenium Ecosystem Assessment 2005), such as supply of water and waste treatment, water scarcity affects both the ecosystems and human beings, especially in semi-arid areas like the Mediterranean region where it becomes a major constrain for the socio-economic development. Rising pressures on water resources result from socio-economic activities of growing human population and include changes in land use or the large number of dams and reservoirs (Tharme 2003). The extent of river regulation increases steadily in the Mediterranean region, resulting in extensive river segments which become disconnected from each other (Nilsson et al. 2005). The imbalance between the available water resources during extended droughts and the increasing anthropogenic water demand results in acute environmental and socio-economic problems. In consequence, water availability and also its temporal variability, quality, and the survival of ecosystems associated to water bodies, has become a major issue for all Mediterranean regions.

Within this context, SCARCE is a research project that aims to examine and predict the relevance of global change on water availability, water quality, and ecosystem services in Mediterranean river basins of the Iberian Peninsula, as well as their socio-economic impacts. As one of the Consolider-Ingenio 2010 projects (Spanish Ministry of Science and Innovation), SCARCE is a 5-year project that has been active since December 2009. The project has the full title of “Assessing and predicting effects on water quantity and quality in Iberian Rivers caused by global change”. The consortium assembles a multidisciplinary team of 11 partner Spanish institutions, as well as the active involvement of water authorities, river basin managers, and other relevant agents as stakeholders. Scientific management of the project is carried out by the Institute of Environmental Assessment and Water Research of the Spanish Council for Scientific Research of Barcelona. The project integrates various disciplines that range from hydrology, geomorphology, ecology, chemistry, and ecotoxicology, to engineering, modeling, and economy, in an unprecedented effort in the Consolider-Ingenio 2010 framework.

SCARCE has two complementary objectives. The first one tackles basic research questions and will attempt to define the long-term patterns and the mechanisms that operate in the hydrology, sedimentary processes, water quality, habitat dynamics, and ecosystem structure and functioning of Mediterranean basins. The second objective is related to the effects of climate and human footprint on the ecosystem services of selected river basins. This is connected to the urgent need to implement and eventually

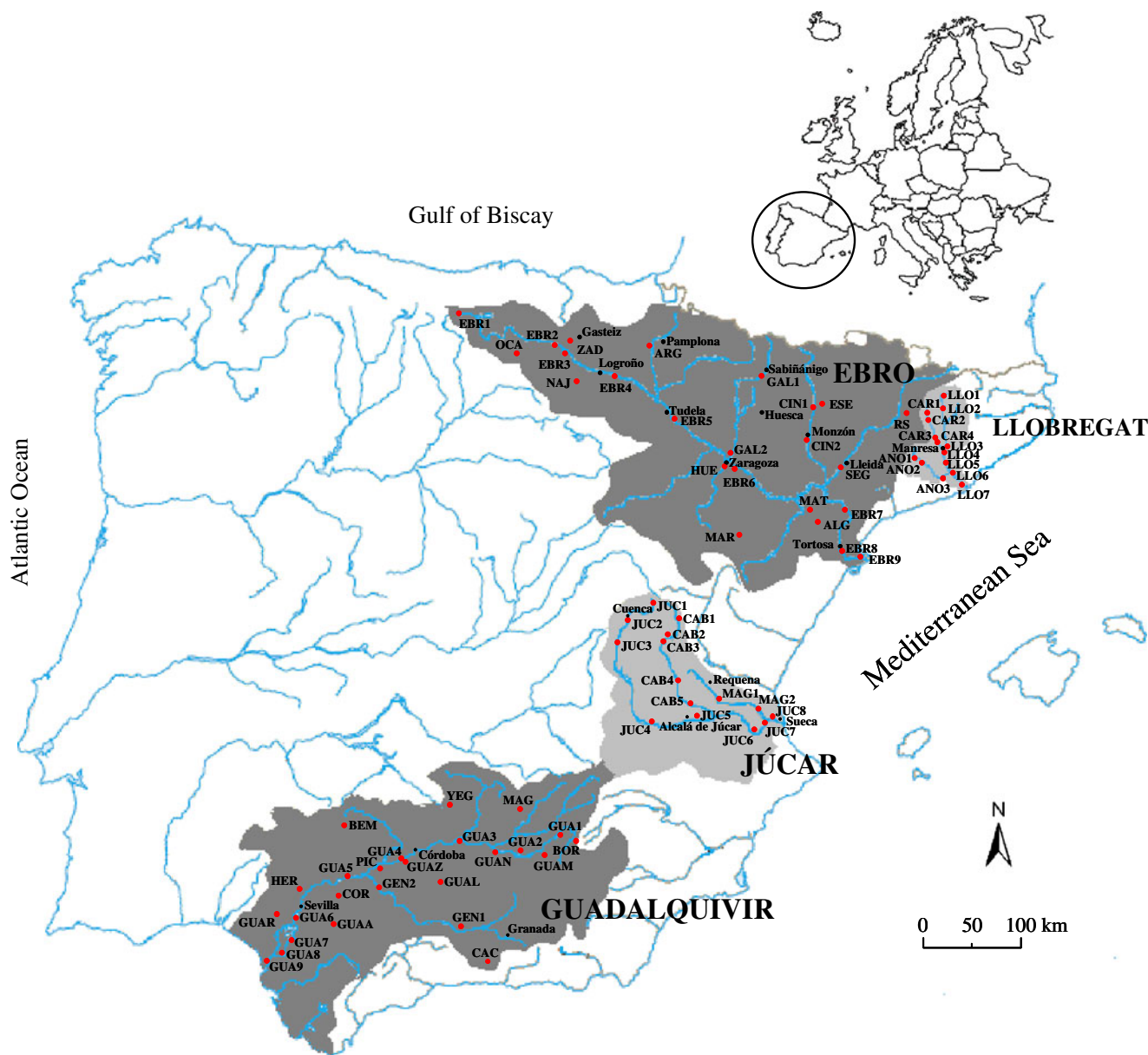
redefine the River Basin Management Plans (RBMP) demanded by the EU Water Framework Directive. Therefore, the project emphasizes linking basic research and management practices in a single framework.

## 2 Study basins

SCARCE applies a multidisciplinary cross-scale approximation combining data mining with field-based research in four representative basins in Spain: Llobregat, Ebro, Júcar, and Guadalquivir (Fig. 1). These basins cover a substantial area of the Mediterranean Iberian Peninsula, as well as a

rich set of socioecological conditions: forested mountain areas, highly populated basins, agricultural regions, and industrial clusters depending on groundwater resources. These four basins were not only selected for their characteristics but also considering their previous inclusion in other European and national projects. This fact increases the amount of data available and allows a better and more detailed study of the river processes.

The Llobregat River (NE Spain) is 156 km long and drains a 4,957 km<sup>2</sup> catchment. From the hydrologic point of view, this is a typical Mediterranean river, its flow being highly variable as a result of seasonal differences in rainfall. Periodic floods and droughts lead to frequent morpholog-



**Fig. 1** The four River Basins (Ebro, Llobregat, Júcar, and Guadalquivir) studied in SCARCE with indication of monitoring sites

ical variations in the riverbed. Its basin is heavily populated with more than three million inhabitants. This river is one of Barcelona's major drinking water resources. Together with its two main tributaries (rivers Cardener and Anoia), the Llobregat suffers a heavy anthropogenic pressure, receiving extensive urban and industrial wastewater discharges as well as surface runoff from agricultural areas that cannot be diluted by its natural flow. Consequently, waters have high concentration of nutrients, pesticides, surfactants, pharmaceuticals, and estrogenic compounds with important effects on the biological communities (Muñoz et al. 2009; Ricart et al. 2010b). During droughts, dilution capacity decreases, increasing the risk of pollutants in the environment, which might affect the functioning of the river ecosystem. Main watercourses are regulated by three large dams that impound around 35% of the basin's mean annual runoff. Further downstream, the river receives brine leachates from natural salt formations and mining operations, which have caused a chronic increase in water salinity downstream. The river is heavily managed in its lower course and water that once run to the sea is now pumped upstream to increase the natural flow, recharge the delta wetlands and control seawater intrusion. Moreover, several activities of managed aquifer artificial recharge are either in service or planned. It is, thus, an illustrative example of an over-exploited river (Ginebreda et al. 2010). The Llobregat River basin was included as a typical Mediterranean river basin in the European Union Sixth Framework Programme (EU FP6) project MODELKEY (contract no 511237-GOCE). MODELKEY aimed at developing interlinked tools for an enhanced understanding of cause–effect relationships between poor ecological status and environmental pollution (Brack et al. 2005).

The Ebro River is 910 km long and drains an area of 85,534 km<sup>2</sup>, from North Central to NE Spain. It has a complex hydrological regime, as it receives water from tributaries under contrasting climates, from snow-fed Pyrenean Rivers to more typical Mediterranean tributaries in the southern part of the basin. Despite its much larger size, the Ebro basin has a smaller population than the Llobregat, some 2.7 million inhabitants, of which 45% live in the five biggest cities in the region (Navarro et al. 2006). Most of the Ebro Basin is agricultural land, making it one of the most irrigated areas in Spain, but lately industry has been a growing sector (CHE 2008; Navarro et al. 2010). A feature of interest is the Ebro delta, as it hosts both intensive agricultural areas where rice, fruit (in particular citrus), and vegetables are harvested, as well as the Ebro Delta Natural Park, one of the most important coastal wetlands in the Western Mediterranean region. The Ebro is largely regulated by dams (187 dams with a global impoundment ratio of 67%) and channels, which have

altered its hydrological and sedimentary regime. During the twentieth century, the mean annual flow decreased by approximately 30%, due to increased irrigation, evaporation from reservoirs, and extensive changes in soil uses. Sediment yield is currently 1.5% of the estimated before dam construction and extensive land use changes took place (Vericat and Batalla 2006). Abstraction of ground and surface water, irrigation, and industrial activities concentrated close to the main cities have also deteriorated soil and water quality, where pollution caused by organic compounds is relevant. The inclusion of the Ebro river basin into the EU FP6 project AquaTerra (contract no. 505428) led to an extensive monitoring of persistent organic pollutants (Lacorte et al. 2006). A comprehensive 4-year monitoring program was conducted in order to assess the levels of contaminants in the Ebro river basin and to evaluate their environmental risk (Navarro-Ortega et al. 2010). In addition, the fate and behavior as well as the risk caused by a broad spectrum of emerging contaminants like pharmaceuticals, illicit drugs, brominated flame retardants, and polar pesticides were investigated in the Ebro river basin throughout the project, from 2004–2009. This information together with ecological and hydrological issues of the Ebro river basin has recently been compiled in a book (Barceló and Petrovic 2011).

The Júcar River (E Spain) is 498 km long and drains a 21,632 km<sup>2</sup> catchment. Its hydrology is typically Mediterranean, with rapid alternance of droughts and floods. The human population living in the basin (over one million people) makes an intensive use of the available water, the demand being often in excess of water supply (Estrela et al. 2004). Nowadays, agriculture accounts for nearly 80% of water demand (1,394 hm<sup>3</sup> y<sup>-1</sup> for 200,000 ha of irrigated crops), but agricultural demand appears to be stabilized or decreasing, whereas urban/industrial demand is forecasted to rise (Estrela et al. 2004; Paredes-Arquiola et al. 2010). The Júcar is highly regulated, with a total reservoir capacity of 2,643 hm<sup>3</sup>. The management of the system is very complex, with many users and considerable hydrologic variability. Water quality problems appear in the medium and lower parts of the basin. In the medium part, agriculture leads to high nitrate concentrations in groundwater and surface water, whereas in the lower part there is a combination of agriculture, urban, and industrial pollution (Paredes-Arquiola et al. 2010). Furthermore, groundwater overextraction has unbalanced the hydrological system, severely affecting the river flow, and causing water scarcity and salinisation of the mouth of the river. Nowadays, periods of zero flow into the sea are common, and marine intrusion is producing a salt wedge of more than 3 km long. The Júcar drains to the Albufera de Valencia, a large coastal lagoon, and an important protected wetland. The Júcar basin was designated as a European Pilot River Basin

(PRB) for the implementation of the Water Framework Directive. The Júcar PRB exercise started at the end of 2002 and since then, much of the information concerning the current status of the basin has been analyzed (Estrela et al. 2004).

The Guadalquivir River (S Spain) is 657 km long and drains a 57,527 km<sup>2</sup> catchment. The entire basin is under a Mediterranean climate, receiving some influence from the Atlantic Ocean in the lowest part. Summer droughts are especially severe as a result of high temperature and lack of rain. More than seven million people live in the basin, 60% of them in cities, and 30% of urban and industrial sewage is poured untreated into the Guadalquivir (Martín et al. 2010). More than 700,000 ha of the basin are devoted to agriculture, with very extensive production of rice, olives, or fruits. As a consequence of agricultural, urban, and industrial uses, water pollution is common along the middle and low reaches of the Guadalquivir. Furthermore, the river is heavily regulated, 26% of the total volume of water within the entire basin being stored in reservoirs (Martín et al. 2010), especially for agricultural purposes (85% of the demand). The river is navigable up as far as Seville (a major inland port about 90 km upriver), producing serious erosion and pollution problems. The Guadalquivir basin is one of the most diverse in Europe, harboring almost one half of the plant species in the continent and most of those in the North African region. The estuary harbors Doñana National Park, a wetland area of outstanding importance, which nevertheless receives inputs of heavy metals. The Guadalquivir River has been lately included in several EU projects: AQUAMONEY (contract no. SSP1-0022723) and RAMWASS.

An extensive network of 77 sampling sites has been established in the four selected river basins. These sampling sites do not only cover the most impacted areas, for chemical, hydrological, morphological, and ecological analysis but also reference sites in the river sections in which best quality is expected. All the field studies that will be performed among the different Work Packages (WPs) will consider all or some of these sampling sites. The basic research element of the field-based study is the kilometer-scale river reach, including the river channel, the alluvial plain, and associated groundwater, as well as the river reaches downstream from dams. At this scale, we are evaluating the impacts of global change on several processes affecting freshwater ecosystem services (e.g., nutrient processing and contaminant retention, sediment transport, community assembling, and habitat integrity). Results will be upscaled from the river basins studied to the whole Mediterranean region in Spain using different mathematical models. Information of the project is regularly updated and available at the SCARCE Website (<http://www.idaea.csic.es/scarceconsolider>).

### 3 The structure of SCARCE

SCARCE is structured across ten thematic WPs that coordinate the various scientific goals (Fig. 2). The WPs deal with data collection (WP DATA), hydrology (WP HYDROL), sediment transport, and river channel morphology (WP MORPH), chemical and biological quality (WP QUALITY), ecosystem processes (WP PROCESS), modeling (WP UPSCALE), socio-economic scenarios (WP ECONOMY), ecosystem services (WP SERVICES), river management (WP FRAME), and coordination (WP MANAGE). All of them can be classified in one or more of the three defined main topics (data mining, field and lab research, or upscaling and integration). Exceptions are WP MANAGE, which deals with the project coordination, dissemination and training activities, and WP FRAME, whose main objective is the transfer of all the findings to the stakeholders and policy makers for its future application in the management of the river basins. Among all of them, the Scientific Steering Committee coordinates and monitors the progress of the work carried out in each research line and the External Advisory Committee ensures social and political feasibility of the proposed management methods.

SCARCE works throughout four different spatial scales: microscale, mesoscale, water body, and catchment. The work in each WP lies in one or several of these scales. WPs collecting new data (HYDROL, MORPH, QUALITY, and PROCESS) mostly operate at micro- and mesoscales (from m<sup>2</sup> to km reach). Other WPs (UPSCALE, ECONOMY, SERVICES, and FRAME) undertake analysis to provide responses at higher scales (water body to catchment, Fig. 3).

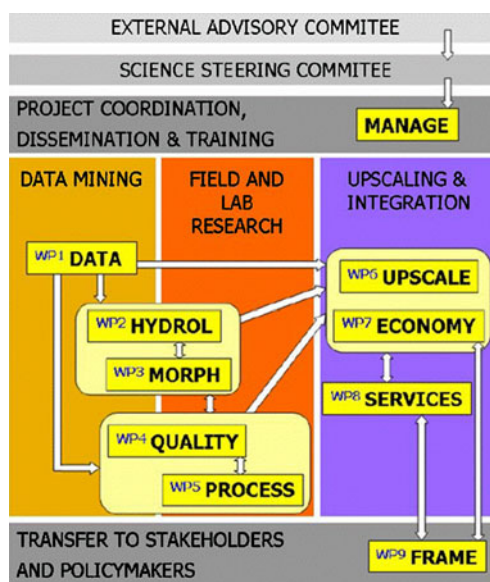
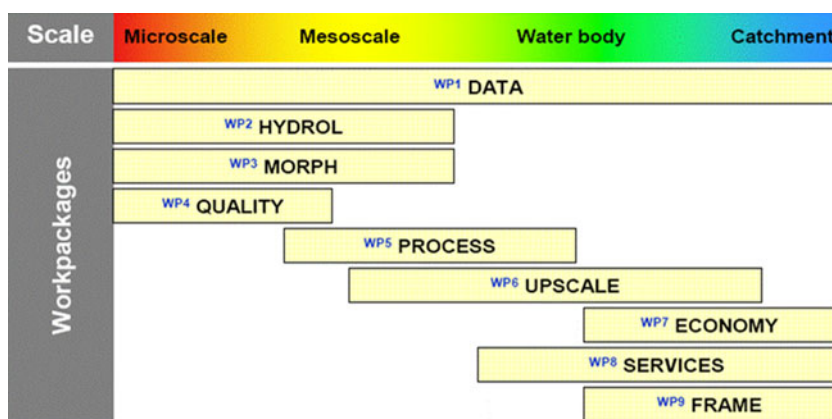


Fig. 2 SCARCE project structure and interaction between WPs

**Fig. 3** SCARCE project structure in relation to working scales (see Fig. 2 for details on the interrelation between Work Packages)



WP DATA attempts to gather in a common framework long-term observations of hydrology, water quality, sediment transport, biological communities, society, and economy, available in the four study basins to build a standardized database, which is an essential tool for this type of consortium (Lindenmayer and Likens 2009). For this purpose, research teams participating in WP HYDROL, MORPH, QUALITY, and PROCESS are working together with the water agencies and firms (Agencia Andaluza del Agua, Confederaciones Hidrográficas del Ebro, del Júcar y del Guadalquivir, Agencia Catalana del Agua, and Aguas de Barcelona) to create and standardize a vast database. This database will include historical and present data taken by the agencies, as well as data obtained in the field and in the laboratory by the research teams. The data so gathered will be analyzed for temporal trends, and spatial patterns at the regional scale will be made explicit by GIS tools. Overall, WP DATA provides an assessment of global change effects on Iberian rivers and assists WP UPSCALE, PROCESS, and SERVICES in detecting adequate hot spots to be used as calibration sites for models simulating key river ecosystem processes. This WP also checks for climate and global change effects in studied basins following the IPCC attribution guidelines (Weyhenmeyer 2004). The results obtained will feed different research needs across WPs.

WP HYDROL approaches the interactions between surface water and groundwater, especially those occurring from centimeters upwards to microscale (cm to m). These interactions are important because although aquifers can become crucial reservoirs to supply water for drinking, agricultural, industrial, or ecological purposes, this function can compromise processes occurring at these interfaces. For instance, sediments occurring in dams might release compounds that affect the biota. Therefore, WP HYDROL in collaboration with WP MORPH analyzes the impact of the interaction between water and sediments accumulated in dams, river beds, and infiltration ponds on water quality in the study basins. It also characterizes the effects of artificial

recharge operations on water quality in one specific site (the Llobregat basin), together with WP QUALITY. Artificial recharge has become an attractive tool for sustainable water management practices since groundwater reservoirs are widely available, unaffected by evaporation losses and requiring moderate infrastructures (Greskowiak et al. 2005). But the impact of artificial and induced recharge on water quality is largely unknown. Finally, this WP determines the likelihood of chemical compounds to reach the water bodies in concentrations exceeding a given threshold (Bolster et al. 2009). This likelihood is governed by the presence of uncharacterized soil and aquifer heterogeneity, where facies directionality and connectivity are key factors (Sánchez-Vila and Carrera 1997; Fernández-García et al. 2002; Trincheró et al. 2008).

WP MORPH examines the main morphosedimentary processes in selected river reaches from the micro to the mesoscale (m<sup>2</sup> to km reach) and assesses the implications for physical habitat in a series of scenarios of change. New baseline data are provided, and insights on river dynamics will be helpful to ongoing and updated RBMP. Special emphasis is placed on the analysis of impacts of river regulation onto sediment transfer (direct relation to WPs QUALITY and PROCESS) and their implications for the downstream sediment budget and channel morphodynamics and sedimentology (Singer and Dunne 2001; Vericat and Batalla 2006). Data are used to assess the sediment load at various temporal scales (e.g., flood and seasonal), sediment transport regimes (e.g., frequency and magnitude and variability of yields), quantitative assessment of sedimentary status (e.g., grain-size distribution and riverbed structure and stability) and channel morphology (e.g., hydraulic geometry and pool-riffle sequence) and the design of an index of morphosedimentary change. Data will feed a model of sediment transport regimes under changing hydroclimatic scenarios that will be developed by WP UPSCALE.

WP QUALITY determines the presence and concentration of priority and emerging contaminants in the four

selected river basins from the Iberian Peninsula. The effects of pollutants on the biota (algae and bacteria, macro-invertebrates, and fishes), and the interactions between pollution and water scarcity, are assessed by combining field surveys and laboratory experiments, looking at biodiversity patterns and toxicity tests under environmental stress (Guasch et al. 2009; Muñoz et al. 2009). The effects of multiple stressors are addressed from a multi-biomarker perspective, including structural (chlorophyll *a*, EPS, community composition, etc.), and functional (photosynthesis, enzymatic activities, etc.) descriptors. Results are feeding the understanding of WP PROCESS and together with those of WPs DATA, HYDROL, and MORPH contribute to form the basis of WPs UPSCALE, SERVICES, and FRAME. The potential human health risks in the river basin are assessed through mathematical approaches, crucial to provide a suitable decision making to stakeholders (Nadal et al. 2008). “Intelligent Testing Strategies” will be applied for a large number of chemicals to assess the risk of appearing in a given water body. Finally, the potential effects of global change in ecosystems and humans, in terms of risk assessment, will be upscaled by modeling tools connected with the WP UPSCALE.

WP PROCESS has the objective of identifying and quantifying the effects of global change on both biodiversity and ecosystem processes (Schroter et al. 2005), focusing on three main stressors (changes in the hydrological and temperature regimes, alterations in channel form, and decreasing water quality) and three main ecosystem processes: metabolism, nutrient dynamics, and breakdown of organic matter. For example, the duration of floods after rainfall has important ecological consequences in dry stream beds (Sand-Jensen and Pedersen 2005). Very short flood pulses (typical in flashy urban streams) release nutrients, thus increasing in-stream productivity in adjacent reaches. Hence, the relative extent and the dynamics of the temporary channel network, as well as its spatial distribution within a catchment, may influence the capacity of an entire river network to produce, transform, and store nutrients and organic matter. These changes can be understood combining on-site analysis, mesocosmos analysis, and upscaling of relevant processes occurring in river segments, which should be related to the variations in hydrology, water chemistry, and sediment dynamics. To assist this process, WP PROCESS combines and develops tools to assess the effects of global changes in streams and rivers, and evaluates effects of disturbances on nutrient cycling and metabolism of Mediterranean stream and rivers, by using a space-by-time design on the sites analyzed. This WP will provide results to the WP UPSCALE through the development of the mechanistic model.

WP UPSCALE uses mathematical models to extrapolate the state variables of interest from observations to scenarios

of global change. It also builds and tests a series of deterministic and statistical models devoted to simulate hydrological, geomorphological, chemical, and ecological processes in the basins under study. Therefore, this WP is directly connected with most other workpackages: it is fed with information and data from WP DATA, it uses meso- and water body scales, as well as new conceptualizations of the processes involved (from WPs HYDROL, MORPH, QUALITY, and PROCESS), and it will assist the models applied in WP SERVICES (with input data series and water body conceptualizations). Two different sets of models are used in WP UPSCALE, namely process oriented and system oriented. The proposed process-oriented models are distributed in space to cope with the natural spatial variability of the water cycle within the catchment. New hydrological modeling capacities of the rainfall-runoff model TETIS (Francés et al. 2007) are built in order to deal with climate and environmental changes affecting the water cycle as well as associated processes. The system-oriented models are defined at the river network (water body scale) and take into account the integration of the water cycle into the management of water resources at the catchment scale in Decision Support Systems (DSSs) (Andreu et al. 1996; Nelson et al. 2009). To accurately assess and value the effects of global change on ecosystem services via changes of water budgets, we are adapting two robust DSS environments: AQUATOOL, to generate scenarios for allocation of water resources; and InVEST, to quantify ecosystem services. Once updated, these two DSS will be applied in WP SERVICES to evaluate alternatives, and to analyze planning decisions in the context of the RBMP.

WP ECONOMY approaches the economic assessment of ecosystem services, and describes the likely socio-economic scenarios for future conditions. Humans derive important services from ecosystems, but at the same time, human activities may impact ecosystem functioning (Millennium Ecosystem Assessment 2005). Although human well-being obviously depends on healthy ecosystems, this fact is not fully reflected by the economic system. The price mechanisms governing markets ignore the goods and services provided by ecosystems which are not traded. The main methodological question addressed by the WP ECONOMY is how to estimate the relevance of ecosystem services for the economic organization of human societies. Ecosystem services identified in cooperation with WP SERVICES are classified under economic criteria in *market traded* and *non-market provided*. Services grouped under the first label can be partially valued in monetary terms, and are currently perceived as commodities by economic agents. On the opposite, non-market services – despite their sometimes crucial relevance for the ecosystem and ultimately for human survival – are neglected by

the economy. The value of these services can be only partially approached through indirect monetary assessments, like the cost to restore damaged ecosystem functioning or the cost of an artificial alternative (if it exists). Other more comprehensive ways of trying to confront the incommensurability of these valuation problems include: the use of multicriteria assessments with different metrics of value, and the use of social deliberative processes that go well beyond quantitative. When the analysis period grows longer, as it is the case of the SCARCE project, the information provided by prices becomes banal. For this reason, a relevant topic in WP ECONOMY is to analyze the different types of uncertainty involved in the valuation exercise and to propose methods to best deal with it, in the mid- and short run.

WP SERVICES aims to quantitatively assess ecosystem services in river networks and associated wetlands, providing decision support for integrated RBMP (Nelson et al. 2009). This WP models and maps the delivery, distribution, and economic value of ecosystem services (Dodds et al. 2009) and, thus, helps users to visualize the impacts of potential decisions, identifying tradeoffs, and compatibilities between environmental, economic, and social benefits. It shows how different temporal and spatial scenarios affect ecosystem services (water quality and quantity, soil conservation, biodiversity, and the value of several marketed commodities such as agricultural crop products and rural residential housing). The maps show future costs and benefits of the decisions for people and the environment. For the integration in the RBMP, two types of DSSs, the ones developed with Aquatool and InVEST, are used to build a hybrid DSS for the study cases. The transversal component of WP SERVICES within SCARCE requires to be closely related to DATA, QUALITY, PROCESS, UPSCALE, ECONOMY, and FRAME. Thus, long-term data series gathered by DATA (hydrology, geomorphology, and chemistry), and QUALITY (biodiversity and human risk) are feeding the model; PROCESS provides a mechanistic functioning; UPSCALE supplies the tailored DSSs with appropriate mechanistic model of ecosystem functioning and supplies data on future climate change scenarios based on downscaling Global Climate Models; ECONOMY assists SERVICES with economic analysis of ecosystem services, and FRAME interacts with policy makers and stakeholders in order to work with realistic and targeted socio-economic scenarios.

WP FRAME fills the gap between research and management and aims to transform research results on management keys and tools. A two-way complementary process of knowledge transfer, connecting science and management practice is necessary, and is implemented in this WP through the use of a management and regulatory-oriented language, thus bridging the presently existing

communication gap between scientists and water managers/authorities. The main purposes of this WP are to identify new research needs under the light of the Water Framework Directive (Directive 2000/60/EC), to transform research results on management options and to provide sound scientific assessment to the forthcoming RBMP and the related Programs of Measures (PoMs). Work-Package FRAME has an intrinsic “horizontal” character, working as an interface between the other WPs and the managers or end-users, and its scope is essentially communication-oriented. Interactions with WPs ECONOMY, SERVICES, and MANAGE are particularly emphasized. From each WP, key questions or issues are generated from the scientific side or, conversely, compiled after assessing the management needs. These are conveyed by workshops and meetings with representatives of the water boards involved in the project. This exercise will ultimately lead to a check list or catalogue of relevant issues. The contents of those management outputs, tailored to each particular river basin, should be presented, discussed, and, if possible, agreed with the respective water managers/authorities, through appropriate knowledge diffusion actions (workshops, working sessions, etc.). The expected added value should be its ultimate use on the elaboration of RBMP and PoMs.

WP MANAGE aims at providing the necessary financial and administrative management for the project, and at ensuring the exchange of information among the partners, as well as a correct evolution of the Project with respect to tasks assigned. Within this WP all activities related with the recruitment and training of Ph.D. students will be coordinated as well as the dissemination activities aimed to ensure wide diffusion of the results of SCARCE within the scientific community and socio-economic sectors, and regulatory bodies involved in water Management such as river basins and water authorities.

#### 4 Work undertaken so far

Under WP DATA, contacts with water agencies have been established and data are being collected in all the basins and pre-treated, and a common database is being configured for the consortium. Data collected include water quality (both chemical and biological parameters), hydrology (long data series across the basins) and cartographic information (land uses, impacts, and flooding areas). Currently, nutrient data in the Llobregat River (from 2000 to 2006) are being analyzed in order to apply a Spatially Referenced Regression Model to estimate nutrient sources related to land uses. A user-friendly database is now designed in order to compile from each basin basic historical data and the new data generated during the project duration. This database will also offer specific information (webs and documents)

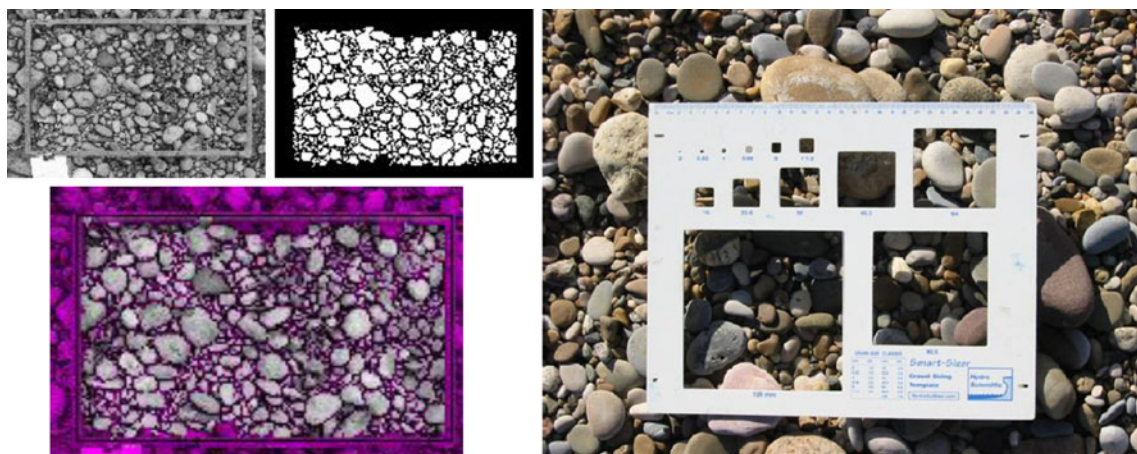


about the location of the complete data available in each basin. Several climatic change (CC) scenarios (meteorological and hydrological) have already been analyzed, processed, and used in different studies. Moreover, new climatic regional scenarios provided by the Spanish Meteorological Agency will be taken into account to generate new hydrological scenarios in order to analyze several impacts at the Júcar River basin. Contacts with other national institutions (Centro de Estudios y Experimentación de Obras Públicas, CEDEX) have been done to adapt their scenarios of climate change to the SCARCE objectives. CEDEX is currently downscaling different general climatic models to a 1-km<sup>2</sup> scale, and these results will be used to generate improved hydrological scenarios with TETIS-SCARCE.

WP HYDROL deals with processes taking place at a small to medium scale. At this point emphasis has been placed on hydro- as well as geo-chemical characterization in saturated soils/sediments. The fate of contaminants (both inorganic and organic) is driven by a number of processes. Among them, work has been performed along different lines. First, local-scale diffusion is causing chemical elements to interact. The amount and rate of interaction depends on the ability of reactants to mix. Laboratory experiments in 2D tanks aimed at characterizing the amount of mixing caused by temporal variations in water flow have been developed. It has been found that while temporal variations do indeed enhance mixing, the difference is not usually enough to consider variable pumping as a competitive method for remediation. On the other hand, it is true that water flowing would eventually reach different areas of the system characterized by different redox states. While this has strong implications in the variations in chemical signature of water along the percolation path, it is not obvious how this affects the degradation of micropollutants.

A number of batch tests have been carried out under controlled batch conditions to evaluate whether different micropollutants degrade under given redox conditions. This has allowed classifying the substances depending whether or not they degrade under specific redox conditions. Finally, a probabilistic approach to evaluate the potential risk of hydrological practices related to water supply systems based on the use of fault trees has been devised. Fault trees allow decomposing the assessment of health risk into individual manageable modules. The complexity within each module can be chosen individually according to data availability, parsimony, relative importance, and stage of analysis. The separation in modules allows for a true inter- and multidisciplinary approach, where different expert can take care of the different modules and the integration is externally performed by the fault tree. A traditional limitation of fault tree approaches is the need for the different sub-modules to be independent or weakly dependent. The need for this hypothesis has been weakened. Finally, total probability of system failure can be updated whenever additional information is incorporated into the system. This can be done by means of Bayesian analysis, which allows providing a posterior risk assessment. The proposed methodology allows the inclusion in a unified way of the uncertainty coming from very different fields (hydrology, chemistry, biology, medicine, social sciences, and economics) (de Barros et al. 2011).

WP MORPH has undertaken an extensive field campaign to characterize key hydraulic, sedimentary, and vegetation parameters at the 77 selected sites along the four representative basins (details in Fig. 1). Reach length is determined based on morphological criteria (e.g., riffle-pool sequence). Measurements have been undertaken on grain-size distribution of riverbed materials, i.e., including both surface (Fig. 4) and subsurface sediments to identify river



**Fig. 4** *Left*, example of grain-size identification and particle measurement by means of the Digital Gravelometer®; *right*, template used during particle counts for surface sediments (figure prepared by D. Vericat and extracted from the WPs MORPH/PROCESS field protocol)

armouring and hence stability, and patches of fine particles (a total of 3,000 particles and 500 kg of material have been sampled and processed in the first fieldwork round). Grain-size parameters are also assessed by means of close-range photographs that are further analyzed with a Digital Gravelometer<sup>®</sup> (Loughborough University Enterprises Limited, Leicestershire, UK) (Fig. 5). Largest moving particle is also measured to assess flow competence at the section. Observations on channel incision and sediment-supply limitation are also taken. Hydraulic geometry is established based on measurements of channel cross section and longitudinal gradient; these data are obtained by means of a Geodimeter<sup>®</sup> 422 Total Station (Geotronics AB, Danderyd, Sweden) and a Leica<sup>®</sup> TCRP1201 Robotic Station (Leica Geosystems, St. Gallen, Switzerland). A total of 150 cross sections have been surveyed. Data will be used to derive information of the active and bankfull channel and associated flow depth and shear stress by means of hydraulic modeling with WinXSpro<sup>®</sup> (Stream Systems Technology Center, Fort Collins, Colorado, USA). Velocity profiles are also obtained which will also be later used to derive flood and representative habitat discharges with Hec-Ras<sup>®</sup> (Institute for Water Resources Hydrologic Engineering Center, Davis, California, USA). Long-term changes of river morphology are being assessed using the analysis of available air-photos series (typically time span ranging from the 1950s to the 2000s). An operating sediment transport and sedimentological network encompassing selected sites (rivers Esera, Isabena, Algar, Ribera Salada, and Cabriel) are also being set up; sites are labeled as *reference* and *modified* and will be representative of climate and degree of flow regulation in each of the basins. Impacts on channel and riparian corridor are also



**Fig. 5** Example of a monitoring site and ongoing fieldwork under the WP MORPH. (Site: River Huerva, Ebro Basin; date: June 15th, 2010; author: Jose A. López-Tarazón)

assessed during field surveys including impacts on longitudinal and lateral connectivity (e.g., dams, dykes, riprap, weirs, culverts, and other man-made structures), artificial changes in channel planform and adjustments of the riverbed (i.e., degradation/aggradation) as well as other impacts (e.g., sewers, water abstraction, and evidences of gravel mining). Finally, the composition, structure, and dynamism of both channel and riparian vegetation were assessed considering longitudinal and lateral connectivity. This was done combining field techniques and analysis of aerial photographs. Present surveys and photographs will be compared with historic aerial photographs to measure changes in channel dimensions and cover of riparian areas during the last decades. A database including sediment transport, channel sediment structure, and physical habitat characteristics of the study sites is also being elaborated. In particular, WP MORPH includes the generation of detailed sediment transport series; they will be the bases for a better understanding of the link between microscale and meso-scale riverchannel processes as well as to couple them with the long-term hydrological modeling.

Within WP4 QUALITY the first extensive sampling campaign has been undertaken. A total of 77 samples of water, 75 sediments, and 63 pools of fish were collected for chemical characterization. The levels of over 250 compounds belonging to different groups of priority (polycyclic aromatic hydrocarbons, organochlorine pesticides, and alkylphenols), and emerging contaminants (pharmaceuticals, drugs of abuse, personal care products, polar pesticides, perfluorinated compounds, endocrine disrupting compounds, halogenated flame retardants, and nanoparticles) are currently being determined using advanced analytical techniques based on gas chromatography-tandem mass spectrometry and liquid chromatography-tandem and hybrid mass spectrometry. Current work also involves a deep revision of the already existing methodologies and development and validation of methods for routine monitoring of these contaminants in different types of matrices (water, suspended solids, sediment, and biota). The developed methods are addressed to solve the drawbacks and pitfalls of those already in use, to improve the quality control and to ensure a reliable, high throughput, and low-cost monitoring.

Invertebrate community has been sampled in each basin along a toxicity gradient. The habitat (fine sediment) and sites were the same that those sampled for chemical characterization in order to find potential relationships between compounds concentration and organisms. The parameters analyzed in invertebrate community are: density, biomass, species composition, and biochemical markers (concentration of lipids and oxidative enzymes). Estimations of environmental risk in the studied basins for invertebrates are obtained with a treatment of historical

data (water agencies) of priority compounds and biological indexes.

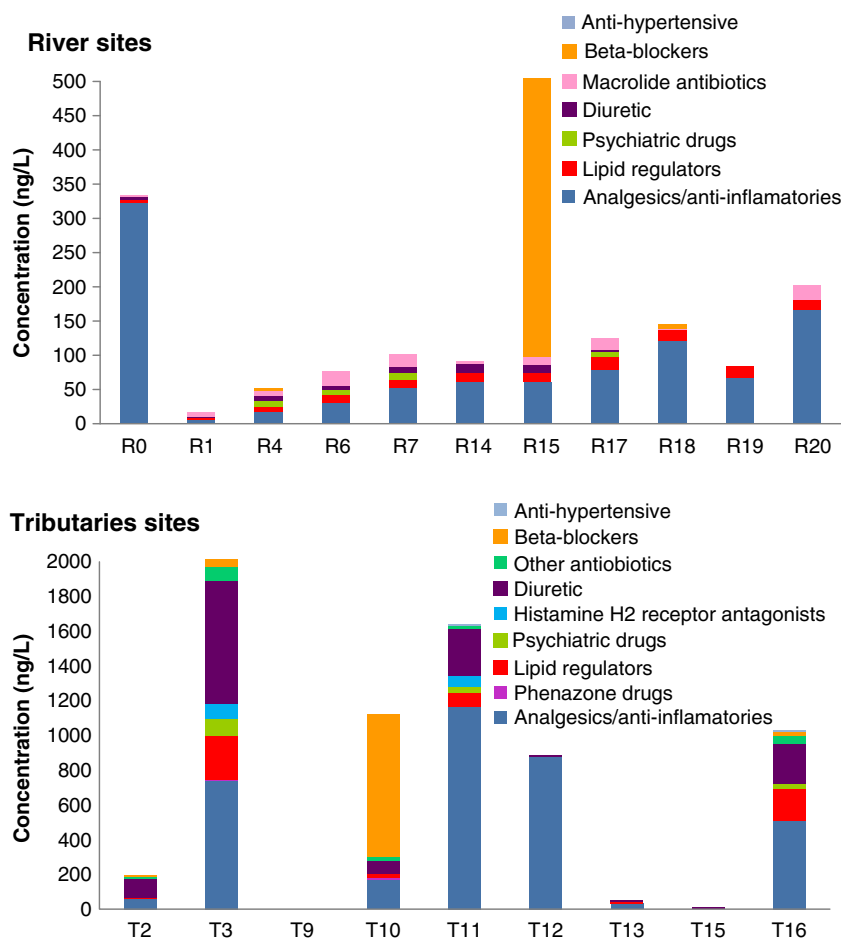
First results regarding loads and distribution of pharmaceuticals in the Ebro river basin shows that the spatial distribution is affected by the river flow at each sampling point and corresponding dilution factor, resulting in higher concentrations and higher loads in small tributaries than in the Ebro River (Fig. 6). The study showed that some compounds are preferentially found bound to suspended solids (Fig. 7) and not detected in river water. Compounds with basic characteristics ( $pK_a > 7$ ) showed higher tendency to remain in suspended solids. For example, famotidine, timolol, and nadolol, all with  $pK_a > 9$  were not detected in surface water. On the other hand, diazepam, gemfibrozil, and naproxen ( $pK_a < 5$ ) were only detected in surface water. The sediment samples generally presented lower concentrations than suspended solids. The highest concentrations obtained in sediments were for acetaminophen, mevastatin, and tylosin A and rarely exceeded  $200 \text{ ng g}^{-1}$ .

WP PROCESS has followed a twofold track. First, in an attempt to gather some summary data on river ecosystem processes across multiple sites, experiments on decompo-

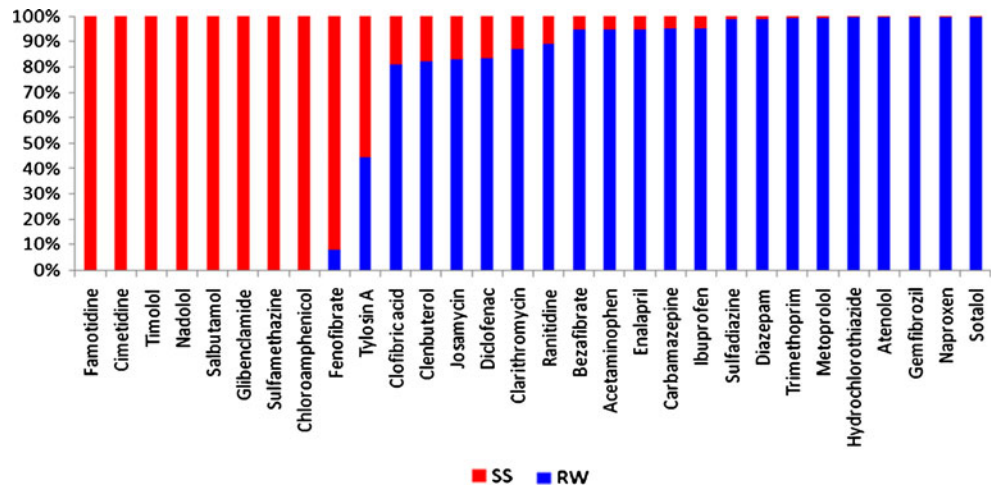
sition of organic matter (poplar tongue depressors) have been performed at all 77 reaches included in the project. The results will be analyzed by multivariate statistics to discern the main environmental factors governing wood breakdown in wet years, and the experiment repeated in the future, in dryer conditions, at least at some key sites. On the second hand, the dataset gathered by water agencies is being analyzed to screen sites with a good potential to estimate whole river metabolism based on continuous monitoring of oxygen, temperature, and discharge, based on the classic single site, open-channel method (Odum 1956; Izagirre et al. 2008). These sites will be studied in detail, and historical data will be used to define the response of river metabolism to environmental stress, as, for instance, comparing metabolism in wet and dry periods (Fig. 8).

WP UPSCALE has performed the implementation of external models for dynamic (slope and riparian) vegetation (Quevedo and Francés 2008) and inorganic nitrogen (Medici et al. 2010) into the TETIS-SCARCE. It is worth to highlight that the process-oriented model TETIS-SCARCE is distributed in space to cope all the natural spatial variability of the

**Fig. 6** Total aqueous (dissolved) concentration of 80 studied pharmaceuticals in the Ebro river basin (sampling sites R0-R20 are in the Ebro river from the source to the mouth; sampling sites T2-T16 in the tributaries; figure prepared by B. Ferreira)

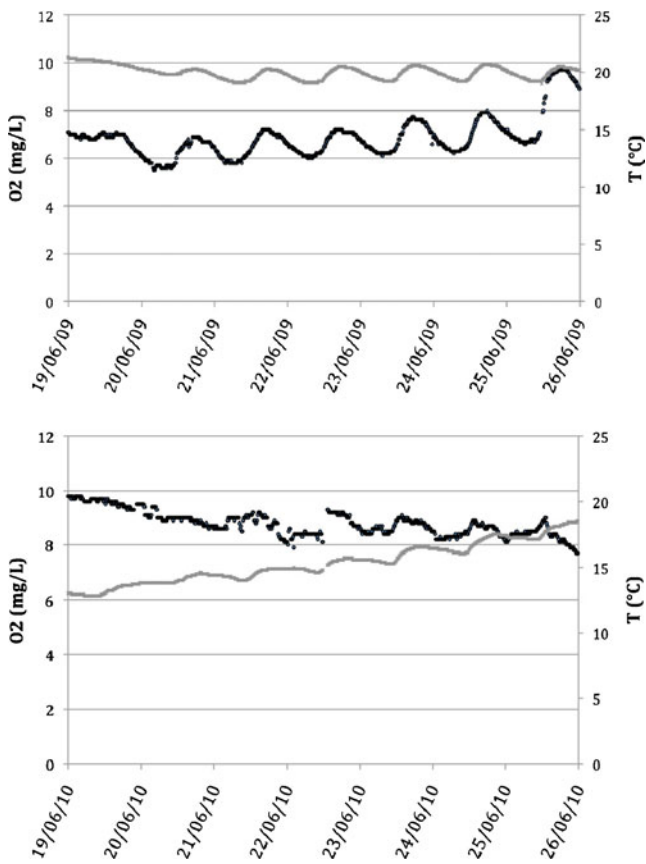


**Fig. 7** Distribution of individual pharmaceuticals between aqueous phase (*RW*) and suspended solids (*SS*) in water samples from the Ebro river basin (figure prepared by B. Ferreira)



water cycle and its associated processes within the catchment. However, in spite of all the attempts that have been made in the past, it is still difficult to establish an optimum spatial subdivision modeling that provides the best performance for a distributed hydrological model. To face this issue, the spatial discretization of the TETIS model effective parameters (as far, the static storage capacity parameter  $H_u$

and effective saturated hydraulic conductivity parameter  $k_s$ ) has been analyzed as well as its implications for the definition of a critical cell size. Moreover, also the importance of soil parameters sub-grid heterogeneities representation has been tested in terms of model performance improvement (Barrios et al. 2010). The rainfall-runoff model TETIS has already been applied to the Jucar river basin, obtaining satisfactory results for both calibration and validation processes (Ramos-Fernández and Francés 2010). The new data being collected within the WP DATA for the Jucar basin will certainly help to achieve better estimated parameter maps for the future TETIS-SCARCE model, obtaining also improved and more robust calibration results.



**Fig. 8** Dynamics of temperature (*gray line*) and oxygen (*black dots*) at river Zadorra (Ebro basin), measured every 10 min during 1 week in June, in two contrasting years. *Left*, drier year 2009 ( $Q=3.6 \text{ m}^3 \text{ s}^{-1}$ ); *right*, wetter year 2010 ( $Q=8.1 \text{ m}^3 \text{ s}^{-1}$ ). River flow has a great impact on ecosystem metabolism

The work performed in WP ECONOMY depends on the results obtained by the other WPs. For this reason, the activities of this WP in the first year of SCARCE project are restricted to the conceptual approach that will be used in the future. This approach considers that incidence of climate change on human well-being depends on: (1) the impact of this phenomenon on the ecosystems, (2) the state of ecosystems for being able to cope with external disturbances and (3) which ecosystems services are required with more or less intensity by society. Addressing this issue in the horizon of 2050 shows that there is a significant room for articulating alternative societal responses to increase ecosystem’s adaptative abilities. It is also possible to vary social well-being standards in order to maintain or even create socio-ecosystems’ resilience (Walker et al. 2002) against the effects of climate change on water ecosystem. Exploring, anticipating, and building-up socio-ecosystems resilient pathways require the contribution of an extended peer community, beyond the scientific community as it is necessary to deal with complexity, ignorance, uncertainty, and risk of irreversibility (Funtowicz and Ravetz 1994). In order to tackle this explorative and transitional challenge, participative-scenario methods have been identified as

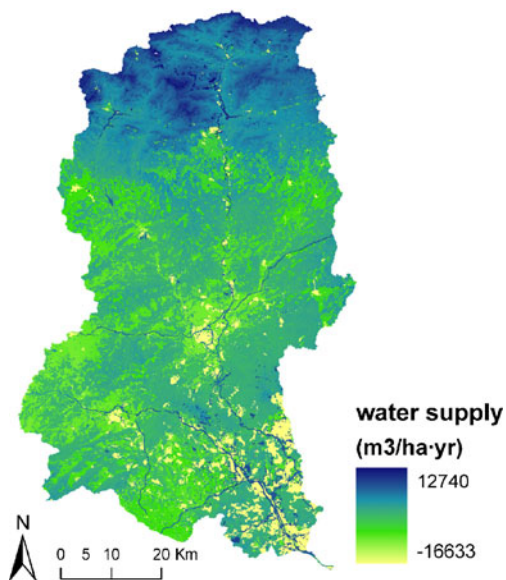
useful tools (Kay et al. 1999; Walker et al. 2002). In this WP, participative scenarios will be adopted aiming a double orientation: futures exploration and transitional pathways identification.

WP SERVICES has started the development and adaptation of the InVEST software to the Llobregat basin, which was selected as a pilot basin to adapt the model to the Mediterranean conditions. So far, the data needed to run the model was gathered and first simulations on a reduced set of services were performed. One example is the first estimation of the service “water provisioning” at the Llobregat basin (Fig. 9). This service has been calculated using the terrestrial module of InVEST at a spatial resolution of  $30 \times 30$  m and considering mainly precipitation, evapotranspiration, and human demand. In this sense, the services water provisioning, waste treatment, and sediment retention were selected among the whole set of considered services to be used in the developing phase of the model. During this initial phase, new modules are being developed to complement the current InVEST version. Thus, a module on the role of in-stream processes is developed, as well as modules for the calibration and sensitivity analyses. These analyses can help to reduce uncertainty in method operation and determine the stability of its outputs by illustrating the impact of introducing changes to specific input parameters. The tool allows evaluating and checking model appropriateness to the problem, promoting a better understanding of the model outcomes. The development of these new modules is performed by members from different institutions that participate in SCARCE, as well as by the InVEST

developers from the Stanford University. Furthermore, WP SERVICES has been involved with members from WP MORPH, QUALITY, and PROCESS in the definition of river reaches for the characterization of in-stream processes as a function of the most important abiotic factors (e.g., hydrology, canalization, regulation by reservoirs, water pollution, and water abstraction).

WP FRAME has developed several activities related to the communications of the objectives and the strategy of the project to the river basins management authorities and end-users. Thus, several meetings were maintained with the Water Agencies from Andalusian and Catalanian and with other authorities/agencies of the river basins (Confederaciones hidrográficas del Guadalquivir, Júcar, and Ebro). A wide number of researchers, end-users, stakeholders, and management authorities participated in the kick-off meeting of the project, which was held in Barcelona in April 2010, showing a high interest for the objectives of the project and providing significant feedbacks for updating the research needs at basin level. The collaboration activities between members of the SCARCE project and the water/agencies authorities have continued during the first year of the project by delivering data to gather relevant existing knowledge for all basins, as it has been mentioned previously in WP DATA, and participating in different events. Thus, in the First SCARCE Annual Conference “Understanding effects of global change on water quantity and quality in river basins” held in Girona in December 2010, there was active participation. A survey will be submitted to management authorities, policy makers, stakeholders, and end-users to identify the knowledge that is necessary to generate new scientific management tools.

Additional project activities have included various specialist meetings (Kick-off meeting: Barcelona, 7 April 2010; 1st SCARCE annual conference; Girona, 2–3 December 2010), the publication of internal reports and international peer-reviewed manuscripts (Barceló and Sabater 2010; Boix et al. 2010; Elosegi et al. 2010; García-Galán et al. 2010a; García-Galán et al. 2010b; Gaudes et al. 2010; Guerra et al. 2010; Kuster et al. 2010a; Kuster et al. 2010b; López-Serna et al. 2010; Llorca et al. 2010; Marcé et al. 2010; Mas-Martí et al. 2010; Paredes et al. 2010; Petrovic et al. 2010; Puy-Azurmendí et al. 2010; Ricart et al. 2010a; Ricart et al. 2010b; Sánchez-Vila et al. 2010; Stevenson and Sabater 2010; Tornés and Sabater 2010; Vázquez-Roig et al. 2010; Ylla et al. 2010; Barahona-Palomo et al. 2011; Carmona-Catot et al. 2011; Fernández-García and Sánchez-Vila 2011; Jelic et al. 2011; Köck-Schulmeyer et al. 2011; Ramos-Jiliberto et al. 2011) and the organization of training courses: “Structural and functional responses of river ecosystems to multiple stressors” (Bilbao, 21–22 October 2010) and “Analysis, fate and risks of organic contaminants in river basins under



**Fig. 9** Water provisioning service in the Llobregat basin ( $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ ), calculated with the terrestrial module of InVEST at the spatial resolution of  $30 \times 30$  m

water scarcity” (Valencia, 7–8 February 2011). This is complemented by a series of press releases and public newspaper appearances.

### 5 Final remarks

SCARCE aims to bring together a large group of researchers, stakeholders, and policy makers across a wide range of disciplines to understand the relevance of water scarcity in river functions. This challenge is met by communication tools including an Internet Platform for data Exchange but also many scientific meetings among the various groups. The structure of SCARCE into work packages allows sharing responsibilities between researchers who are specialists in their respective fields. The work performed by the different workpackages expands through different scales, starting from the monitoring and modeling studies to the river basin scale. This goal has been set from the very beginning of the project by the fundamental objective to provide the foundations for an improved understanding of the effects of the global change on water availability, water quality, and ecosystem services and economy.

**Acknowledgements** This work has been supported by the Spanish Ministry of Science and Innovation through the project Consolidar-Ingenio 2010 CSD2009-00065. Special thanks are due to all partners of the SCARCE consortium and the peer review panel for ensuring quality results and fruitful collaboration within the project.

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