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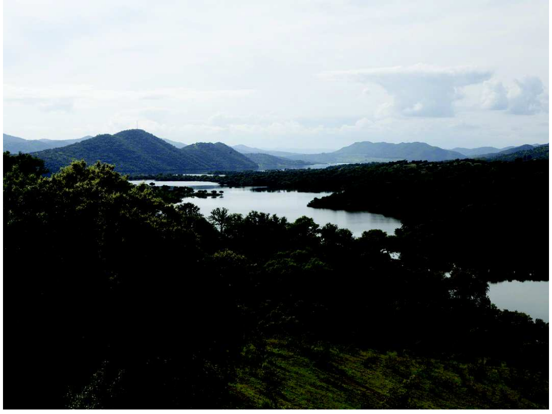
Key Data and Information Requirements in the Context of Current Debates on Water Management



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Top picture: Tajo-Segura Water Transfer (Guadalajara)
Leandro Moral

Bottom picture: Viar River (Seville)
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EXECUTIVE SUMMARY

This Deliverable builds on the five main themes that structure the work of SWAN project with respect to the issues of key data and information requirements for water management:

CURRENT PARADIGMS IN THE MANAGEMENT OF WATER RESOURCES AND HYDROLOGIC RISKS

Water management goals, methodologies, conceptual approaches and institutional frameworks have evolved significantly over the past 30 years. These transformations have been stimulated by the promotion of the Integrated Water Resources Management (IWRM) paradigm by experts, academics, managers and international institutions. However, the application of IWRM faces resistance from defendants of the previously dominating infrastructural and resource-oriented *hydraulic paradigm*. It is also challenged by the contradictions and limitations that emerge from the practical experiences in its implementation at different scales. From a general perspective, criticism against the *hydraulic paradigm* and the emergence and consolidation of IWRM can be understood as being a part, in the water policy arena, of the historical shift from the post-war Keynesian regulation model to the current neo-liberal globalization system or, in more specific terms, from the “administrative rationalism” stage to the current “neo-privatization” trend.

Increasing attention is being paid to the potential interconnections between the encouragement of *water governance*, a central focus of the IWRM approach, with wider global socio-economic processes that challenge existing democratic institutions. The wider hegemonic economic thought in which IWRM prescriptions are integrated, particularly the *commodification* processes and monetary reductionism of natural resources and the preeminence of the river basin as the *natural* scale for water resources management, is also coming under scrutiny.

From an epistemological perspective, the traditional separation of social and natural sciences has ignored the overlap of both fields of knowledge, which results in the limited theoretical and methodological development for their joint analysis, as well as the paucity of available data for management. The consideration of water as a socio-ecological patrimony requires linking biophysical and socioeconomic variables, a significant challenge given the current knowledge and modeling capabilities. There is a strong need for information on the complexity of *socio-hydrological systems*, which are reflexive, adaptive, non-linear and complex, and have feed-back loops, emerging properties and non-predictable responses to management interventions. In the context of the evolving paradigm for water management the recognition these knowledge limitations are of vital importance.

ECONOMIC CONSIDERATIONS IN EVOLVING WATER MANAGEMENT DEBATES

The paradigm of IWRM incorporates two basic economic principles: cost recovery and the polluter-pays principle. Nevertheless, under current ecosystem-based approaches to water resources management, the goal has become to protect and enhance the services provided to society by the good functioning of aquatic ecosystems. It would therefore be appropriate to substitute the term of polluter pays for the more ambitious concept of payment for the deterioration of ecological function of water ecosystems or, more broadly, for loss of ecosystem services.

The persistence of the traditional hydraulic paradigm and standard economic perspectives limit our ability to rigorously and comprehensively calculate costs that are outside their standard analytical and accounting frameworks. Under standard economic practice, environmental considerations are externalities outside the system, impacts that result from the use and consumption of water but are not compensated through the water pricing system. The main obstacle to overcome this scenario is the difficulty of precisely quantifying or valuing the degradation of complex natural ecosystems that result from human actions. It is difficult to translate that degradation into replacement costs and determine the price to pay by those that have caused it.

The difficulty of identifying and valuing ecosystem services derives from the diversity of dimensions that are encompassed by the concept (productive, ecological, cultural, etc.). Furthermore, ecosystem services often result from interrelations between different ecosystem components, thus adding complexity to any systematization and evaluation attempt. Even the classification of ecosystem services in non-overlapping categories is problematic. Many of these knowledge limitations are to some extent insurmountable, inherent to the complexity of socio-natural systems. Institutional arrangements are necessary to deal with these uncertainties (in the sense of ignorance) and the need to manage water resources and associated ecosystems in this uncertain and partially understood context. It may therefore be necessary to shift the emphasis from the quantification and deterministic approach to valuating trade-offs and management alternatives, toward a more deliberative approach, where interested actors can jointly discuss values, preferences, risks and alternatives.

NEW INFORMATION TECHNOLOGIES AND WATER RESOURCES MANAGEMENT

The proliferation of information and communication technologies (ICT) has caused profound changes in the availability of information about our planet, in its storage and processing capabilities, its distribution and dissemination. These processes also pertain to water-related information, so that the availability of key data for sustainable water management is evolving in relation with the development of the ICTs. That is particularly relevant in a context of a growing social and political support for open government and open data standards. However, there remain significant challenges to take full advantage of the opportunities offered by the ICTs, challenges that derive from the inertias of existing models of information generation and management.

In the European Union there have been several initiatives that attempt to harmonize existing public information systems, limit duplicities and redundancies and improve public access to information. However, public administrations are still reluctant to accept the public right to access environmental information and, to a large extent, have not reorganized their information management procedures and systems in order to facilitate knowledge generation and information integration. The pending issue for water policy in the field of information is to ensure that information gives rise to knowledge truly useful for participatory planning and management. This implies the need to facilitate the conditions in which knowledge is produced through collaborative methods and is disseminated and shared in an open, free and easy way, in accordance with the characteristics and potentialities of the new networked society. The collaborative generation of information has, surely, institutional implications concerning changes in the geometries of power, that is, potential changes in the identity of the agents that control information and, as a result, the decision-making processes.

MODELING HYDRO-SOCIAL SYSTEMS: REFLECTIONS ABOUT KEY INFORMATION AND DATA REQUIREMENTS

Adapting water management to current challenges requires taking systemic approach to water resources, overcoming the simple, reductionist and static perspectives that still persist. The development and use of dynamic modeling techniques to develop hydro-social models can help us move in the right direction. Building dynamic models is a laborious process since it requires going beyond the requirements of traditional hydrologic model building. Dynamic models incorporate the views and perspectives of managers, decision makers and stakeholders in the characterization and diagnostic phases, as well as in the definition of objectives and management alternatives. This approach enables the combination of the analyst's technical expertise with the range of incommensurable perspectives that affect socio-ecological systems.

The combination within the same model of natural and social parameters—the essence of hydro-social models—, implies such level of complexity that the models can only hope to represent specific geographic and hydro-social realities. It requires a new institutional and technical framework to overcome current limitations to the involvement of the public and stakeholders in the definition of water management alternatives.

The lack of good quality information is the most significant limiting factor for a successful modeling exercise of complex hydro-social realities. Scale aspects of knowledge bases are also important, particularly in order to better understand how to consolidate information gathered at different spatial levels. Bridging scales enables better integration of local knowledge into global models and data sets, that is, integration of scientific and indigenous knowledge, which may strengthen the accuracy and contribute to its translation into effective policy strategies addressing global environmental changes.

TRANSPARENCY AND PUBLIC PARTICIPATION AS KEY COMPONENTS OF THE NEW WATER GOVERNANCE

Traditional transparency and public participation efforts have focused on the need to disseminate information to the public rather than on collaborative generation of information for water planning and management. This has been the dominant *rational comprehensive planning* approach, where public participation is not *inherent* to the planning process, but rather *instrumental* to improve knowledge in the diagnostic phase.

The emphasis on public participation mechanisms to legitimize public policy decision-making processes found its theoretical grounding in the deliberative democracy theoretical framework. However, after more than two decades of general acceptance and widespread implementation of this approach, there is a growing body of work that is critically questioning the limits of the *participatory governance* perspective to natural resources management and its true impact on final decisions. This critical work is framed within the debates of *post-politics* or *post-democracy* in the context of the global neoliberal globalization processes.

Too often, in the final stages of decision making processes there is a *political externalization* of key final operational decisions. Water managers (or politics) impose decisions that are not coherent with scientific, integrated and participatory processes that precisely aim to understand, anticipate and direct sustainable management decisions. There is a lack of understanding about these informal decision making processes. Research about the links between science and politics must incorporate information about the factors that drive and help explain these fundamental mechanisms.

1. INTRODUCTION AND BACKGROUND

The SWAN project (FP7-INCO-2011-7) aims to promote trans-disciplinary scientific cooperation between the US and the EU through collaborative work of project partners along three transverse themes: 1) Climate change and uncertainty; 2) Risks and vulnerabilities; and 3) Water demand and sustainability. The collaboration builds on the experience of the International Research Center (UMI) "*Water, Environment and Public Policy*", established in 2008 by the French CNRS (Centre National de la Recherche Scientifique) in collaboration with the University of Arizona, at the latter's campus in Tucson. SWAN has interrelated scientific and institutional objectives: defining a common framework for interdisciplinary research on water resources management that can serve as a scientific basis for a permanent collaborative institution, the Sustainable Water Center (as originally conceived) or a Network for Transatlantic Water Dialogue, as currently envisioned.

The debates on emerging scientific and water management paradigms, new and collaborative ways of generating information and meeting growing information requirements, and integrative modeling and scientific approaches are all fundamental components of SWAN's research work. These debates are part of Task 3.2, which is the responsibility of the University of Seville (SWAN Partner 4), in close collaboration with the University of Arizona (SWAN Partner 1) and the Bulgarian Academy of Sciences, BAS-NIGG (SWAN Partner 5). This working paper presents a first approach to these debates. It identifies key themes that will be further developed in the remaining years of the SWAN project.

This Deliverable draws on the results of a workshop organized around the theme of *New paradigms for water resources and risk management: Data and information requirements for sustainable water management,* organized by the University of Seville SWAN team in January 2013. Preliminary conclusions were discussed and enriched with contributions from seminar participants and other SWAN team members and are being published in the Spanish Geographer Association Bulletin (Pita *et al.*, 2014).

The Deliverable builds on the five main themes that were discussed in the January 2013 Workshop and that structure the work of SWAN with respect to the issues of key data and information requirements for water management:

- Current paradigms in the management of water resources and hydrologic risks. Resulting information needs
- Economic considerations in evolving water management debates.
- New information technologies for the management of water resources. Resulting opportunities and requirements.
- Hydro-social systems modeling. Information needs and key data.
- Transparency and public participation as key components of the new water governance. Resulting information needs.

A follow up International Conference organized by the SWAN University of Seville team on the same theme is scheduled for June 2014 and will build on the contents of this Deliverable. The output of this conference will serve to further refine the conclusions presented in this report and inform the goals and scientific contents of the Network for Transatlantic Water Dialogue that will be the main scientific and institutional output of SWAN.

2. CURRENT PARADIGMS IN THE MANAGEMENT OF WATER RESOURCES AND HYDROLOGIC RISKS: RESULTING INFORMATION NEEDS

Water management goals, methodologies, conceptual approaches and institutional frameworks (actors involved, legal contexts) have evolved significantly over the past 30 years. These transformations have been stimulated by the promotion of the Integrated Water Resources Management (IWRM) paradigm by experts, academics, managers and international lending institutions, since the approval of the Dublin Statement on Water and Sustainable Development (Dublin Principles) at the 1992 International Conference on Water and Environment. This long lasting process of paradigm change and consolidation is the manifestation, in the water resources field, of a wider and deeply contentious transformation in the way we currently understand society-nature interactions and the management of natural resources.

In practice, the application of IWRM has met significant resistance both from the dominant values and interests of previous management approaches as well as growing criticisms from new theoretical and applied perspectives. The current water management landscape is dynamic and heterogeneous and its evolution cannot be described in a linear way. There is a distinctive hegemony of IWRM principles in programmatic and discursive terms, even in countries like Spain where the hydraulic paradigm has been dominant until very recently. But this hegemonic position of IWRM is challenged by pervasive reminiscences of traditional, infrastructural and resource oriented tendencies, on the one hand, and emergent criticism from new perspectives, rooted in current visions of complexity, risk and insecurity, on the other. In general, the diverse water management institutional frameworks that exist in practice reflect to different degrees elements of these different origins.

In this context of change and transformation it becomes relevant to reflect upon the new information and knowledge requirements for natural resources management in general and water management in particular. These requirements are conditioned by the growing opportunities provided by polycentric and changing loci of data generation; the different avenues for dissemination of existing information in an era of rapidly evolving information technologies; the promotion of public policies and legislation that enhance the dissemination, harmonization and reutilization of publicly produced information; and the growing demands for transparency and knowledge in natural resources management from increasingly demanding and critical social actors.

A new paradigm for water resources management?

The hegemonic water management paradigm during most of the twentieth century in much of the western world emphasized resource development in order to expand supply to meet (while also encouraging) increasing demand, through the public planning and funding of hydraulic infrastructures. This approach, known as the *hydraulic paradigm* or *hydraulic mission* has been well described in different contexts, mainly in bio-geographical regions affected by aridity (see Allan, 1999 and 2006; Faggi, 1996; Feitelson, 1996; Moral and Sauri, 1999; Reisner, 1986; Swyngedouw, 1999; Hutchinson, Varady, and Drake, 2010). It entailed a project for the transformation of arid landscapes, characterised by drought and barrenness, and the resulting socioeconomic under-development and lack of growth. The privileged instrument behind this project for physical and social transformation would be hydraulic works funded with public money, in the all too frequent case that private initiative were not in a position to take on the risks of investment. Under this paradigm, scientific and technical expertise typically supported dominating socio-political structures and cultural values to identify existing problems and propose solutions through rigid management plans with little room for adaptation, uncertainty or public participation. Two basic certainties encompassed in this vision are that Nature can be controlled and that the State, its development agencies, irrigators, power generators, etc., were engaged in essential and appropriate activities of public interest. The uni-functional (‘build’) and uni-disciplinary (‘engineering’) bureaucracy adopted a command-and-control philosophy, seeing users as subjects (and the State the provider) rather than active agents. This project seized both liberal western economies as well as the centrally planned economies of the Soviet Union. The hydraulic mission proved to be readily exportable to the global South in the second half of the 20th century.

As a reaction to this, over the past three decades there has been a substantial shift in the conceptual framework for water resources management, albeit with significant inertias from the past, and strong contradictions and substantial geographical differences in its implementation. The *post-hydraulic paradigm* has at its core the promotion of *demand management* approaches, the introduction of *economic incentives* for rationalization of water management and use, the conservation and restoration of *aquatic ecosystems*, and the *incorporation of stakeholders and the wider public in decision-making processes*.

These are common characteristics of a management approach that is widely known as Integrated Water Resources Management (IWRM), and has received significant attention from academics, managers and international funding institutions. As some of its recent critics argue, IWRM has been promoted as the "panacea" to resolve water management problems worldwide, and inspired national water resources legislation in different parts of the world—the South African National Water Act (NWA) of 1998, the 2000 Water Framework Directive (WFD) in the European Union or the 2004 Australian Intergovernmental Agreement on a National Water Initiative (NWI), to name just a few. From a general perspective, criticism against the hydraulic paradigm and the emergence and consolidation of IWRM can be understood as being a part, inside the particular water policy arena, of a whole historical shift from the post-war Keynesian regulation model to the current neo-liberal globalization system (Raco, 2013) or, in more specific terms, from the “administrative rationalism” stage to the current “neo-privatization” trend (Castro, 2011, Swyngedouw, 2007).

In the US, the concept of IWRM is strongly established and even gaining considerable traction. The United States Army Corps of Engineers (USACE) launched in February 2013 an on-line Federal Support Toolbox to provide Integrated Water Resources Management information (www.watertoolbox.us). The toolbox responds in part to the publication in 2010 of a National Report entitled *Responding to National Water Resources Challenges*, the result of a nationwide assessment process of water resources issues in the US facilitated by the USACE which established as a goal the need to "Promulgate policies, concepts, and clear and consistent definitions that support IWRM" (USACE, 2010). Additionally, the American Water Resources Association (AWRA), a leading association for water managers and researchers in North America, adopted a Policy Statement in 2011 recommending that "water management goals, policies, programs and plans be organized around the concept of IWRM" and has organized two Summer Specialty conferences on this topic (Snowbird, 2011 and Reno, June 2014).

IWRM is also the reference used by the SWAN project as the starting point and initial framework for its scientific endeavors. However, building on concrete experiences in different parts of the world, over the past few years a growing debate has emerged questioning the limitations, contradictions and conflicts that the integrated management paradigm finds in its practical implementation. In its 2011 policy statement, the American Water Resources Association (AWRA) recognized these limitations by stating that: "IWRM suffers from a lack of clear definition, the lack of standard measures to track the success of IWRM plans and projects, and the absence of guidance for those involved in planning and project development". From an applied perspective, for instance, Giordano and Shah (2013) discuss several examples in Asia and Africa where international lending institutions pushed for the approval of water policies aligned with IWRM, with mixed results. From a more theoretical standpoint, Molle (2009) is critical with the status of "nirvana" concept of the IWRM prescriptions, while Pahl-Wostl *et al.* (2011 and 2012) question the possibility of existing "panaceas" and argue that water management requires a further evolution along different axis:

- From central control to poly-centric governance, where the definition of the problems, the alternatives and the solutions are the result of a *cooperative* process between different actors and management centers;

- From prescriptive solutions to adaptive management approaches that facilitate learning and *adaptation* to a changing reality and to evolving understandings of the problem;

- From separate approaches to discrete environmental problems toward an *integrated* approach that transcends disciplines, geographical and professional boundaries, and areas of expertise.

Some advanced formulations of IWRM, as the European Water Framework Directive (Directive 2000/60/EC), advocate for the incorporation of a wide range of areas of expertise and opinions through the entire decision-making process: from problem identification and development of alternatives, to the implementation of solutions (WFD, 1st consideration). However, from a critical perspective increasing attention is paid to the potential interconnection between the encouragement of *water governance* approaches with wider global socio-economic processes that question current democratic institutions and *devolve* power toward higher (EU, WTO, IMF, etc.) or lower institutional levels (NGOs, municipalities, etc.) (Heynen *et al*., 2007, Swyngendow, 2011).

The preeminence of the river basin as the *natural* scale for water resources management (Mostert *et al.,* 2008), a central focus of the IWRM approach, is also coming under scrutiny. In the context of the complexity of socio-hydrological systems, the debate about *spatial fit* or the definition of adequate physical and institutional boundaries becomes particularly relevant. The delimitation of management boundaries exclusively in physical terms does not sufficiently recognize the existence of the multiple geographies—political, socioeconomic, cultural—of socio-ecological systems (van Meerkeert *et al.,* 2013). Critics acknowledge the undeniable and significant physiographic characteristics of the watershed, but also argue that there is no *natural* hydrologic scale that cannot be technically challenged. Authors such as Budds & Hinojosa (2012); Cohen & Davidson (2011); Del Moral & D'O (2014); Molle (2009), or Moss (2012), point to the diversity, ambiguity and lack of commonality of the different phenomenon that are used to define the watershed: micro and macro-watersheds or river basins, sub-basins, administrative boundaries, overlapping surface and groundwater boundaries, etc. Additionally, their lack of coincidence with existing institutional and socio-cultural boundaries, further complicate the traditional challenges of operational coordination with key sectoral policies such as agriculture, environmental and natural resources policy, or regional and urban land use planning, to name just a few. .

In this context, new and complementary management approaches are being proposed that aim to reinforce existing management prescriptions and more explicitly incorporate the concepts of hybridity between the social and the natural (*waterscapes*), complexity and uncertainty that underlie the new water management paradigm. Socio-ecosystem based management, polycentric governance (Ostrom, 2010), eco-adaptive management (Huitema *et al*., 2009), or the emerging concept of water security (Cook and Bakker, 2012; Staddon and James, 2012; Martinez Cortina *et al.,* 2010) are only some of the new or revised concepts that are gaining traction.

The emergence of the water security concept

In the context of these debates, it is unavoidable to make a specific reference to the notion of water security. As Cook and Bakker (2012) point out, over the last decade the water security concept has emerged from its original niche in studies of international security and hydropolitics to become much more widely used. To some extent it seems even to be supplanting the hegemonic position hitherto occupied by the “sustainable water” concept (Staddon and James, 2012). According to UNESCO (2008), “Water security involves protection of vulnerable water systems, protection against water related hazards such as floods and droughts, sustainable development of water resources and safeguarding access to water functions and services.” The above definition subsumes key ideas of the “sustainable water management” paradigm as constitutive definitional elements whilst also importing the ideas of ecosystem functions and services, the risk of climate-related hydrological hazards, and water as an object of geopolitical security discourse. The idea of water security assumes that people's fundamental interests are in satisfying demands for water-related services such as food, fiber, waste disposal and sanitation. Thus, society's focus is not on the use of water per se but on the services and benefits provided per unit of water used (Martínez Cortina *et al.,* 2011).

Staddon and James (2012) point out that the gradual shift from ‘sustainability’ to ‘security’ implies continuing a course of action understood to be working (i.e. towards sustainable water use), but also incorporating a recognition of a widening and deepening urgency. Water security is counterposed to the implied (and undesirable) outcome of water ***in***security: a state of unreliable supplies of water of acceptable quality. Water security is centrally concerned with the potential risks both in terms of rights to water and threats that exist from external factors (which may be human or non-human) over water. While the sustainability discourse recognizes the possibility of “running out”, it nevertheless tends to constitute itself in terms of the achievement of an ecological balance. The security discourse, by contrast, is based more on threats than opportunities and therefore tends to define the policy options negatively; policies that will prevent sub-optimal outcomes as much as those that will broker optimal ones.

More than a decade ago Ulrich Beck, although from another perspective, had envisioned the general context in which *water security* can be framed. Developing his notion of *global risk society* long before the credit crunch of 2008 and the austerity agendas that have followed, he stated that “collective life patterns, progress and control capacity, full employment and exploitation of nature typical of the *first modernity*, have been undermined by five interrelated processes: globalization, individualization, gender revolution, underemployment and global risks (such as the ecological crisis and the collapse of global financial markets). The real political and theoretical challenge of the *second modernity* is the fact that society must simultaneously meet all these challenges" (Beck, 2002 (1999): 2).

What are the new information requirements in the evolving water management paradigm

Traditional water management focused on the procurement of new water resources to meet demand. Data requirements were therefore limited and focused primarily on quantitative estimates of available resources and consumption, as well as chemical water quality parameters insofar as chemical pollution may affect existing uses. Furthermore, economic information was limited to basic budgetary estimations for planned investments since cost recovery, when it existed, was limited to fairly narrowly defined water use levies and fees.

The increasingly dominating water management paradigm recognizes the complex and multifaceted nature of water and therefore has additional information requirements that can be summarized as follows:

- *Environmental information* and, more specifically, information on biological as well as chemical quality of water resources and associated aquatic ecosystems, in order to respond to new ecosystem-based management goals.

- *Socioeconomic information*, which becomes essential in the transition from a technocratic management approach with centralized and hierarchical decision making processes, where social actors are recipients of management decisions, toward more participative decision processes, a part of a new management culture that incorporates institutional learning and adaptation.

- *Economic information* on the costs of water services and associated prices, but accounting for the multifunctional characteristics of water from which multiple ecosystem services derive. That is, the economic information must take into account not only the financial costs of service provision, but also the ecosystemic implications of these services and the associated costs (environmental and resource costs, in the language of the WFD).

- Development of *synthetic and sustainability indicators*: the wealth of data available makes it necessary to develop indicators that present this information in a manner that is concise, agreed upon and easily understood, in order to facilitate continuous monitoring and evaluation of these complex socio-ecological systems. However, as Garnåsjordet et. al (2012) point out, these indicators comprise not only a selection of facts in some technical sense. The choices involved in the development of the indicators are subjective and respond to underlying "narratives" that are conditioned by societal interests and implicit values embedded in the data-generating processes. Therefore, the development of the data and assessments needs to be deliberated in a political process reaching agreements for political action

In the context of the new requirements, what are the main deficiencies of currently available information for water resources management?

The primary limitations of currently available data and information are those that derive from the need to overcome the *nature-society dualism* that still is at the core of the hydraulic management paradigm. There is a strong need for information on the complexity of *socio-hydrological systems*, which are reflexive, adaptive, non-linear and complex, and have feed-back loops, emerging properties and non-predictable responses to management interventions.

The consideration of water as a socio-ecological patrimony requires linking biophysical and socioeconomic variables, a significant challenge given current knowledge and modeling capabilities. The traditional separation of social and natural sciences has ignored the overlap of both fields of knowledge, which results in the limited theoretical and methodological development for their joint analysis, as well as the paucity of available data for management.

There are significant gaps in knowledge in what refers to the efficacy of the measures implemented to improve the health of aquatic ecosystems. Current research in integrative analysis and inter-disciplinary modeling is producing increasingly robust information and knowledge, but the diversity and complexity of natural ecosystems impose significant restrictions on the transferability of the results from one spatially defined case to another.

These limitations in the understanding of the functioning of biophysical systems and their responses to management interventions also apply to the social dimension of socio-hydrological systems. As a result, attempts to precisely value the components of these systems, their functioning and interrelations do not seem feasible. Information and data need to be presented in a transparent manner, specifying their origin and the limitations and uncertainties they necessarily incorporate.

Nevertheless, scientists work on the development of models that target those gaps. Examples are the so called stress-response models, which are used for the development of indicators for analysis of human-environmental systems. According to Regions for Sustainable Change (RSC) partnership's Low-Carbon Indicators Toolkit, they are four[1]:

- Pressure – State – Response (PSR) model, developed by the Canadian scientist Anthony Fried in the 1970s and adopted by Organization for Economic Co-operation and Development's (OECD) State of the Environment (SOE) group[2].
- Driving force – State - Response (DSR) model is a variation of the PSR model, adopted by the United Nations Commission on Sustainable Development (UNCSD)[3]
- Driving force – Pressures – State – Impact - Response (DPSIR) model, used by European Environment Agency[4,5], Eurostat and European institutions.
- Framework for the Development of Environment Statistics (FDES) which was developed in 1984 and endorsed in 1995 and developed in 2013 by the UN Statistical Commission[6].

According to Burkhard and Müller (2008), the PSR model provides a good basis for the analyses of environmental issues and the DSR model is more focused on the human demand and activities that affect the environment. For overall analyses and description of the components and interrelations in the human-environmental systems, the DPSIR model is considered to be the most applicable and finds the broadest recognition. The purpose of the model is to identify and describe the processes and interactions within the human-environmental systems in a manner that emphasizes the infinite cause-effect chain of relationships in past, future and recent developments (Burkhard and Müller, 2008) (see Figure 1).The United States Environmental Protection Agency (EPA) provides "Tutorials on Systems Thinking using the DPSIR Framework"[7] that includes also examples for the application of the model for different issues, including water management and river basin management.

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[1] http://www.rscproject.org/indicators/index.php?page=what-methodologies-can-be-used-to-develop-indicator-s-or-indicator-set

[2] http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Refer/gd93179.pdf

[3] http://www.un.org/esa/sustdev/csd/csd9_indi_bp3.pdf

[4] http://ia2dec.ew.eea.europa.eu/knowledge_base/Frameworks/doc101182

[5] http://www.eea.europa.eu/publications/TEC25

[6] http://unstats.un.org/unsd/environment/fdes.htm

[7] http://www.epa.gov/ged/tutorial/index.htm

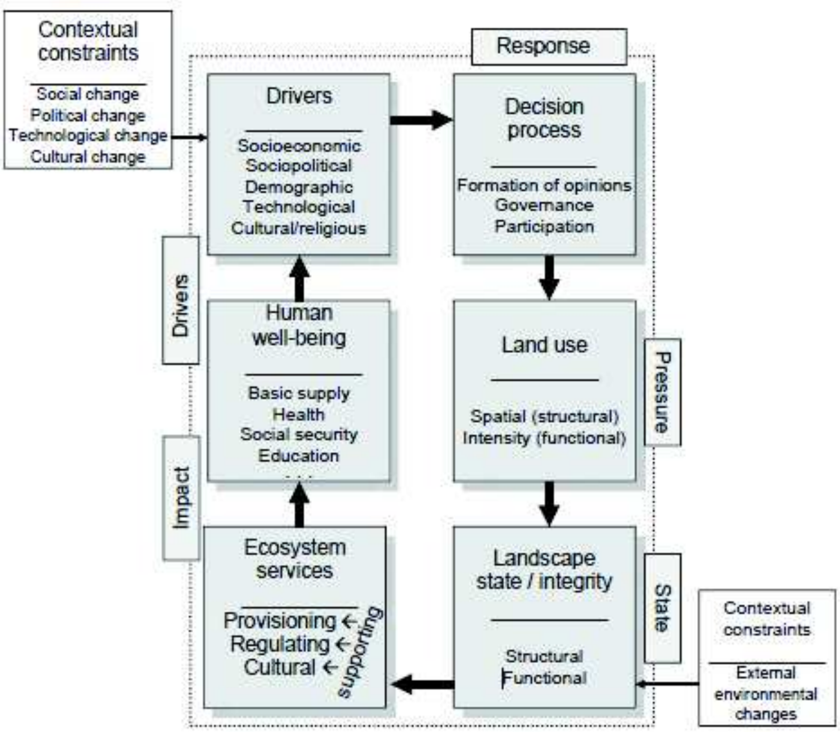

Figure 1. DPSIR-based model of human-environmental systems (Source: Burkhard and Müler, 2008)

How can we manage the uncertainty associated with our understanding of socio-natural processes and its influence on resource availability and hydrological risks?

The concept of uncertainty can be understood under three different perspectives (Wynne, 1992):

- *Technical* (or conventional) *uncertainty* which refers to the unavailability of data and, more generally, information and knowledge. In this case the problem is related to the lack of reliability or thoroughness of the historical data, a frequent situation in hydrology. In order to overcome this problem scientists develop models, thus simplifying complexity. Some of the uncertainties related to the hydrological inverse methods (hydrological modeling) are those associated with: (1) model parameter estimates and (2) model parameter resolution (see Vasco et al., 1997) or, more importantly, (3) model structural uncertainty (completeness/adequacy) (Gupta and Nearing, 2014; Gupta *et al*., 2012, and Gupta *et al*., 2008).

- Uncertainty in terms of *indetermination.* In these situations the system parameters and their interrelationships are unknown, since they are so complex, and consequently the model results become completely unreliable.
- Uncertainty in terms of *ignorance,* which occurs when 'we ignore what we do not know'.

In the context of the evolving paradigm for water management these knowledge limitations are of vital importance: we recognize that uncertainty is inevitable when dealing with socio-ecological systems. We must therefore strive to understand its relevance in the system we are studying and, to the extent possible, identify the potential fluctuations and their repercussions on the rest of the system being modeled. The need to adequately manage uncertainty in complex systems is the most relevant factor, in an epistemological sense, which demands multi-disciplinary approaches and the participation of a diversity of actors and interests in decision-making processes.

3. ECONOMIC CONSIDERATIONS IN EVOLVING WATER MANAGEMENT DEBATES

The paradigm of IWRM incorporates two basic economic principles: cost recovery and the polluter-pays principle. However, under current ecosystem-based approaches to water resources management, the goal is no longer only to attain good chemical quality. Rather the goal is to preserve and restore adequate ecosystem form and function or, under Water Framework Directive (WFD) terminology, good status (chemical and ecological for surface waters, and chemical and quantitative for groundwater). In broader terms, the goal has become to protect and enhance the services provided to society by the good functioning of aquatic ecosystems, that is, to use an ecosystem approach (Wallis *et al*., 2011; SCBD, 2004) for resource management. It would therefore be appropriate to substitute the term of polluter pays for the more ambitious concept of payment for the deterioration of ecological function of water ecosystems or, more broadly, for loss of ecosystem services.

The WFD, perhaps the most ambitious legal initiative to incorporate economic considerations into water management practice, uses this broader approach and establishes that the cost of water services should incorporate both *environmental* and *resource costs*, in addition to the *financial costs* associated with the provision of these services, and requires adapting the water pricing system accordingly (Art. 9, WFD). It also requires that the Program of Measures that is adopted in each River Basin Management Plan to achieve good status objectives (Art. 11, WFD) is designed so that the combination of measures selected is the most cost-effective in relation to the established goals (Annex IIIb of WFD and European Commission, 2003). However, the practical implementation of these requirements has been challenging, in spite of concerted efforts on the part of the Commission to establish common guidelines (see for instance European Commission, 2003), and the reports from the DG Eco 2 Working Group)[8]. The evaluation of the experience of the first hydrographic districts' planning cycle (2009-2015) shows that significant amount of work still needs to be done to adequately define environmental and resource costs and establish agreed upon methodologies for their calculation (European Commission, 2012). From the perspective of the economic assessment of water policy

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[8] European Drafting Group (DG Eco 2) was set up in September 2003 under the Common Implementation Strategy (CIS) Working Group ‘Integrated River Basin Management’ (WG 2B).1 WG 2B asked the DG Eco 2 to prepare a non-binding information sheet on the definition and assessment of environmental and resource costs in the context of the implementation of the WFD and to present practical examples for the calculation of ERC from the Member States (Görlach and Interwies, 2004).

measures, more work is also necessary to develop a common methodological approach for the calculation of cost-effectiveness of the measures (Tremolet Consulting, 2006; Berbel *et al.* 2011).

Different reasons can help explain these challenges. According to Naredo (2013 and 2006), they result from a reductionist approach to water management: on one hand the continuing dominance of the hydraulic paradigm that treats water exclusively as a productive (economic) resource and, on the other, a standard economic approach to cost recovery that considers water as an input for economic activities and therefore valued exclusively in monetary terms. These limited perspectives fail to account for the complex reality of water and its associated ecosystems, particularly since many of the social benefits or ecosystem services provided by well-functioning aquatic ecosystems, are not exchanged in the marketplace and therefore cannot be valued in monetary terms. La Roca (2013 and 2011) also points out that, in addition to clear methodological challenges to estimate financial and environmental costs of water services, there has been a significant resistance to incorporate economic criteria into water resources management from traditional water users that have strived to maintain their historic privileges, obtaining private benefits from the use of cheap water resources while externalizing the costs or impacts of this use.

The persistence of the traditional hydraulic paradigm and standard economic perspectives therefore limit our ability to rigorously and comprehensively calculate costs that are outside their standard analytical and accounting frameworks. Different approaches are being proposed to overcome these limitations. Over the past few years there has been an increasing amount of academic and practical work developed that advocates the use of an ecosystem approach to incorporate the wide range of services and benefits provided by aquatic ecosystems (Wallis *et al., 2011;* Vlachopoulou *et al.* 2013; Spray and Blackstock, 2013) while at the same time warning of the potential risks involved in using this approach too narrowly (La Roca, 2013). Naredo (2013) proposes a broader eco-integrative approach to adequately account for the complex, multifaceted nature of water resources and the costs associated with its use.

What are the new information and data requirements to estimate the cost of water services? A proposal from the perspective of eco-integrative economics

Multiple official guidelines, reports and academic papers have been published over the past several years in the context of the WFD implementation process that propose traditional (neoclassical) economic approaches to estimate the environmental and resource costs associated with water services (Martín-Ortega *et al*., 2011; Görlach & Interwies, 2004; or Brower *et al.* 2009; to name just a few that refer to the broader international scientific literature). The traditional economic approach attempts to estimate the so-called *total economic value* of environmental resources, that is the sum of the use and non-use value of these resources (Wright, 2007). The *non-use value* cannot be easily expressed in monetary terms since they are not exchanged in the marketplace. Neoclassical economics attempts to estimate their monetary value through indirect methods such as the stated preference methods (contingent valuation, choice modeling, etc.). The results of these studies are specific to a region and moment in time, since they are highly subjective. Given the limited resources available to carry out these estimations, a benefit transfer approach is often used to apply the environmental monetary values obtained in a specific study site to a different policy area (Brower, 2000). However, this benefit transfer approach entails its own risks, mainly due to the site specificity of the cases and the limited homogeneity between them (USEPA, 2009).

In the case of the implementation of article 9 of the WFD, the scientific literature (and the official guidelines that have been developed in different countries and by the EC), proposes considering the financial costs of water services, and the environmental and resource costs associated to these services, as discrete entities that can be added up (see Figure 2). The logic behind this approach is that the financial cost can be calculated through the accounts of the economic agents that provide water services. Once this amount is known the environmental and resource costs need to be estimated in monetary terms and added to the financial cost in order to obtain the *full cost* (or total economic value) of water services that the WFD requires. The goal is then to adapt the water pricing system to the resulting cost structure, with the possibility of applying adequately justified exceptions.

Given the conceptual and methodological challenges of calculating environmental and resource costs in precise physical units and even more so, in monetary terms, Naredo (2007) proposes an *eco-integrative economic* approach, in which these three components of the *total economic value* are seen as interrelated. This approach focuses exclusively in the hydrological cycle due to the complexity of extending economic analysis to water associated ecosystems and landscapes. Using this approach, water managers must conjunctively analyze these components in order to adequately and effectively account for all of them and design economic instruments and reasonable water tariffs.

Naredo (2013) suggests that the study of the natural and artificial flows of water in a specific region from a systemic or physical balance perspective is the most effective method to identify the costs associated with the provision of water services and the conservation of qualitative and ecological status. It is also an ideal approach to understand to what extent water flows (and their associated costs) are independent from each other, thus avoiding double accounting. From this perspective Naredo suggests the simultaneous use of three types of water accounts: quantity, quality and cost accounting (see also Valero *et al.*, 2006).

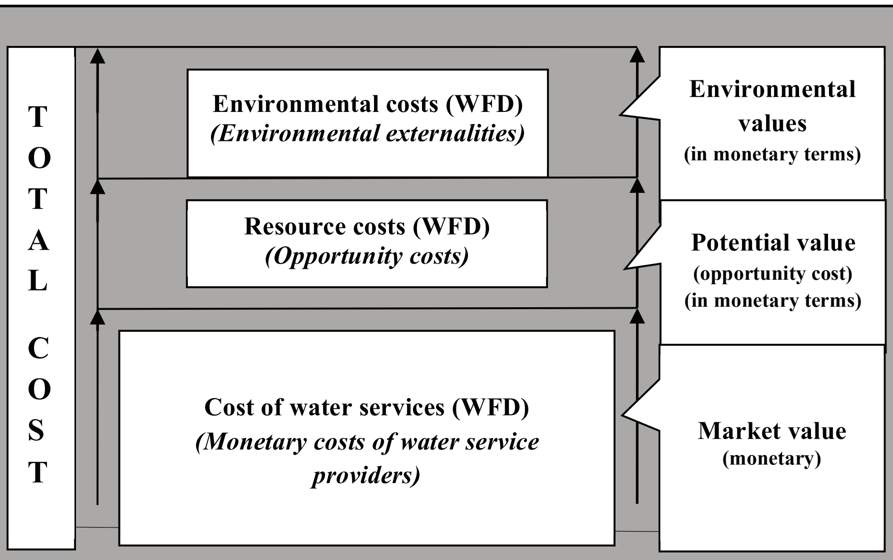

Figure 2. Total cost of water services estimated through the traditional economic approach applied to the requirements of the Water Framework Directive (Source: Naredo, 2013)

The *quantitative water accounts* refer to the hydrologic balance in the geographical region being analyzed (river basin district, watershed or other chosen boundary): the balance between precipitation and inflows from other regions or systems, natural outflows, abstractions for different uses and return flows, determine water availability. Accurate quantitative water accounts are essential to assign costs and prices according to water availability and use and the costs associated with the maintenance of the socio-natural hydrologic cycle under different scenarios.

In order to develop *water quality accounts* Naredo suggests using a balance of differences of *physical and chemical potentials* of water. Under natural conditions water flows into a system at high altitudes and with good quality conditions. Therefore there are two fundamental concepts that allow for the quantification of the potential differential associated with water quality: the *physical potential*, which is related to elevation, and the *chemical potential*, which is related to its salt and contaminant load. From this perspective, environmental costs can be estimated as the units of energy that would be necessary to return water to its starting physical (elevation) and chemical conditions, assigning a market price to these energy units in order to translate costs to monetary terms.

The *cost accounting* derives from the other two type of accounts combined with information on energy prices and energy requirements for each change in potential (both physical and chemical). It is also necessary to have information on available technologies (water treatment, pumping, etc.), their applicability to the specific region being analyzed and their implementation and operational costs.

How can monetary and physical magnitudes be combined?

In addition to the implementation of the full cost recovery and the polluter pays principles, the WFD requires taking into account cost-effective criteria when selecting the most adequate combination of measures to achieve planning goals (Annex III, WFD). However, attempts to perform a cost-effective analysis of alternative measures to achieve ecological goals or to value the contribution of natural ecosystems to human welfare meet with the limitations of knowledge and information both within disciplines (economics, ecology, hydrology, etc.) as well as in the use of trans-disciplinary approaches. In the field of economics, for instance, we find that classic valuation approaches based on monetary prices are insufficient to adequately handle goods and services for which there are no markets, and that are not easily reduced to market logics.

In order to overcome these limitations, Naredo (2007, 2013) proposes assigning market prices to the energy necessary to obtain the resources and restore them to their original state (altitude and chemical potential), which will be added to the costs of providing water services. Energy costs are calculated as the sum of the actions necessary to maintain the hydrological cycle (water quantity and quality) in the best possible health (status, in WFD terminology) while supplying the population and economic activities with the necessary water resources. Naredo does not estimate the costs associated with ecosystem restoration because the complexity of defining the initial and final state is much greater than the complexity associated with the flows of water, which can be simplified through the inflows and outflows of the hydrological cycle. Such complexity would require geographically-specific detailed analysis to be developed.

Attempting to value environmental costs or the contribution of natural ecosystems to human welfare, in other words, valuing ecosystem services, requires different metrics, they cannot be expressed exclusively in energy and monetary terms. The information and knowledge necessary for this valuation is still being developed (La-Roca, 2013).

What are the main obstacles to internalize the environmental costs associated with water services and what progress has been made toward their evaluation?

Under standard economic practice, environmental considerations are externalities outside the system, impacts that result from the use and consumption of water but are not compensated through the water pricing system. The main obstacle to overcome this scenario is the difficulty of precisely quantifying or valuing the degradation of complex natural ecosystems that result from human actions. It is difficult to translate that degradation into replacement costs and determine the price to pay by those that have caused it.

Naredo (2007, 2013, Valero et al. 2006) proposes overcoming this limitation by relating the *environmental degradation* resulting from economic and human activity with the *exergy loss*—or energy required—associated with all the materials that take part in the productive process. The negative balance or thermodynamic irreversibilities that are associated with the economic metabolism thus becomes a powerful and synthetic quantitative indicator of the direct environmental damages that result from economic activities, that then spread out and affect ecosystems and their associated natural spaces in different ways. The replacement cost of these direct losses is an equally powerful synthetic quantitative indicator of what we could consider their *direct environmental costs.*

If instead of considering all materials and substances that are mobilized in the global economic metabolism we focus only on one, water, the complexities that derive from the previous reasoning are obviously simplified. According to Naredo, as above mentioned, in the case of water it would be necessary to distinguish between two levels: *dimensions*, which refer to water as an element; and *systems*, which are related with the organisms, ecosystems and landscapes that are dependent on water and its territorial support. In terms of dimensions, water is understood in the conceptual framework of the hydrologic cycle, which operates according to generally accepted laws and norms, thus facilitating the delimitation and quantification of the environmental and resource costs that derive from its possible and effective replacement. However, in the systemic level, which is the object of study of ecology, there is a significant leap in complexity and a greater amount of irreversibility of some processes. It is thus much harder to quantify precisely replacement costs.

The establishment of a common cost estimation methodology is complicated by the variety and complexity of conservation and restoration costs. This results from the challenges of undertaking ecosystem restoration processes and the great diversity of water-dependant organisms, ecosystems and landscapes. The WFD attempts to systematize the diversity through the concept of *reference conditions* for each type of water body in different river basins. This approach recognizes that, in the systemic level identified above, the calculation of the conservation or restoration costs are linked to the specific measures that are identified for each geographic-specific situation, which vary depending on the type of ecosystem and level of degradation of each *water body*.

The availability of enough good quality water in the first *dimension* level is a prerequisite for the conservation of ecosystem integrity in the more complex systemic level. Therefore understanding the necessary measures and associated costs for the maintenance of water quality and quantity in a water body is a necessary first step for the conservation of the associated organisms, ecosystems and landscapes.

How can we value the ecosystem services that derive from more sustainable water use patterns?

The identification and valuation of environmental services provided by water-dependant ecosystems is an integral part of more advanced water management approaches. The concept dates back to the 1990s with the introduction of the Ecosystem Approach by the 1992 Convention on Biological Diversity and the resulting efforts to value ecosystem services (see for instance Constanza *et al.*'s 1997 seminal article in *Nature*). However the valuation of ecosystem services as a methodological approach became institutionalized by the 2005 Millennium Ecosystem Assessment, which attempts to assess the consequences of ecosystem change for human welfare (see table 1).

Table 1. A classification of water-dependent ecosystem services according to the categories identified by the Millennium Ecosystem Assessment

Categories	**Examples**
Provisioning	Provision of primary goods (food, fibers, wood)
	Biophysical support of fishing (continental and marine waters), hunting and grazing
	Water supply
	Contribution to energy production
Regulating	Coastal protection
	Water purification
	Carbon sequestration
	Climate regulation
	Flood control
	Biological control
	Waste decomposition
Cultural	Tourism, recreation, landscape and aesthetic quality
	Spiritual and religious benefits
	Education and research
Supporting	Contribution to primary production (for instance, fish banks)
	Seed dissemination through water currents
	Sediment formation and circulation
	Erosion control

Source: Millennium Ecosystem Assessment (2005)

Since then the concept finds broad acknowledgement in science and management. These are some of the platforms facilitating information sharing and networking on the topic of ecosystem services: the Ecosystem Assessment Platform[9] of the Biodiversity Information System for Europe (BISE)[10]; the Ecosystem Service Partnership (ESP)[11] that also provides the interactive ESP Visualization tool[12]; and the Intergovernmental Platform on Biodiversity and Ecosystem

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[9] http://biodiversity.europa.eu/ecosystem-assessments
[10] http://biodiversity.europa.eu/
[11] http://www.es-partnership.org/esp
[12] http://esp-mapping.net/Home/

Services (IPBES)[13]. There are also a significant number of initiatives at the European and global level. USA initiatives in the area of ecosystem services include: the ecosystem service research center of the United States Environmental Protection Agency (EPA)[14] which includes EnviroAtlas[15], a web-based tool that combines maps, graphs, analysis tools, and interpretive information for the United States; the National Ecosystem Services Partnership (NESP)[16]; the United States Department of Agriculture (USDA) Forest Service initiative "Valuing Ecosystem Services"[17]; and the Global Observatory for Ecosystem Services (GOES)[18].

The classification typologies of ecosystem services also evolve through time (for a review see Haines-Young and Potschin, 2009). The state of the art for the different categories excludes Supporting services from the list. A project undertaken by the European Environmental Agency (EEA) developed a Common International Classification of Ecosystem Services (CICES). The classification and the report can be found on the website: http://cices.eu/ The concept of ecosystem services finds broad acknowledgement in the European Union legislation, for instance in the EU Biodiversity Strategy to 2020[19], the Environment Action Programme to 2020[20], or the Blueprint to Safeguard Europe's Waters[21].

The difficulty of identifying and valuing ecosystem services derives from the diversity of dimensions that are encompassed by the concept (productive, ecological, cultural, etc.). Furthermore, ecosystem services often result from interrelations between different ecosystem components, thus adding complexity to any systematization and evaluation attempt. Even the classification of ecosystem services in non-overlapping categories is problematic. However, a strict partition of the set of ecosystems services, in exhaustive and mutually exclusive classes, is a necessary condition wherever an arithmetic approach is envisaged (for instance for avoiding double accounts) (La Roca, 2014, personal communication).

In terms of costs, Naredo (2013) highlights the difficulty of valuing environmental factors that are not directly associated with the quantity or quality (physical and chemical potentials) of water as

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[13] http://www.ipbes.net/
[14] http://www.epa.gov/research/ecoscience/eco-services.htm
[15] http://enviroatlas.epa.gov/enviroatlas/index.html
[16] http://nicholasinstitute.duke.edu/initiatives/national-ecosystem-services-partnership#.UuEyouXZCc_
[17] http://www.fs.fed.us/ecosystemservices/index.shtml
[18] http://www.goes.msu.edu/index.cfm
[19] http://ec.europa.eu/environment/nature/biodiversity/comm2006/2020.htm
[20] http://ec.europa.eu/environment/newprg/
[21] http://ec.europa.eu/environment/water/blueprint/pdf/COM-2012-673final_EN_ACT-cov.pdf

a resource, that is, factors that support life or provide ecosystem services. The methodology he proposes for valuing the environmental costs of water services can be temporally and spatially adapted, but the calculation of the ecosystem costs cannot be adapted to such precise approaches. Impacts on water related ecosystems have greater irreversibilities than the balance of the hydrologic cycle, thus complicating the estimation of replacement costs. The greatest challenge derives from the transition from inert materials (water) to the living world (water-dependant ecosystems), which also responds to physical and chemical laws, but cannot be explained exclusively through them.

The interrelationships between living organisms, human society and the geographical spaces where they occur can be expressed in terms of the provision or reception of ecosystem services. The complexity and multiple ramifications of these interrelations make their systematic evaluation difficult. The attempt is further complicated by the difficulty of segregating the aquatic component of environmental costs from other costs of conserving and restoring organisms, ecosystems and landscapes within the geographical space being analyzed, since they are closely intertwined. Progress therefore needs to be made in the understanding of socio-ecological systems and the effects of these interrelationships.

Many of the knowledge limitations discussed in this section are to some extent insurmountable, inherent to the complexity of socio-natural systems. Institutional arrangements are necessary to deal with these uncertainties (in the sense of ignorance) and the need to manage water resources and associated ecosystems in this uncertain and partially understood context. It may therefore be necessary to shift the emphasis from the quantification and deterministic approach to valuating trade-offs and management alternatives, toward a more deliberative approach, where interested actors can jointly discuss values, preferences, risks and alternative outcomes (La Roca, 2013). In this sense the dynamic modeling approach discussed below can be seen as a step in this direction.

In spite of the limitations discussed in this section, there are initiatives that are attempting to provide guidelines for valuing ecosystem services, such as the Economics of Ecosystems and Biodiversity (TEEB)[22]. Based on its work, the EC issued the report “A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB”[23]. This report,

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[22] http://www.teebweb.org/

[23] http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/EU%20Valuation.pdf

together with the Mapping and Assessment of Ecosystems and their Services in Europe (MAES)[24] discussion paper, are key documents aiming to support EU Member States in addressing one of the main actions of the EU Biodiversity Strategy[25], Target 2, Action 5. This Action aims to map and assess the state of ecosystems and their services in the national territories of EU Member States by 2014, assess their economic value, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020.

Other platforms that integrate information on different initiatives, tools and practices for the valuation of ecosystem services for decision-making are the Nature Valuation and Financing Network[26] and Ecosystem Valuation[27]. The appropriate choice of indicators is a key step in the process of measuring ecosystem services for environmental needs, and these platforms provide a set of possible indicators for each service. Staub *et al*. (2011) also suggest a set of indicators for ecosystem services. The EEA published a Core Set of Indicators (CSI) Guide[28] addressing environmental issues, though it is not focused on the ecosystem service analysis.

All these resources can supplement a research on water related ecosystem services, after the services of importance and interest are recognized.

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[24] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf
[25] http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/1_EN_ACT_part1_v7%5B1%5D.pdf
[26] http://www.fsd.nl/naturevaluation
[27] http://www.ecosystemvaluation.org/uses.htm
[28] http://www.eea.europa.eu/publications/technical_report_2005_1

4. NEW INFORMATION TECHNOLOGIES AND WATER RESOURCES MANAGEMENT: NEW OPPORTUNITIES AND DEMANDS RESULTING FROM THEIR AVAILABILITY

The proliferation of information and communication technologies (ICT) has caused profound changes in the availability of information about our planet (remote sensing, GPS, spatial climate sensors, etc.); in its storage and processing capabilities (database management, geographic information systems, cloud computing, etc.); and in its distribution and dissemination (internet, web services, web-based applications, mapping technologies, mobile applications, etc.). These processes obviously also pertain to water resources information, so that the availability of key data for sustainable water management will evolve in relation with the development of the ICTs.

ICTs have changed society. The continuous increase in computing power and the growth of the Internet have changed the way in which society manages information. New technologies like faster computers, broadband internet, huge storage and cloud computing create new environment of data and information sharing.

The Internet provides communication infrastructure for countless networks associating human beings and the environment. Internet connection allows remote management of the monitoring systems of sensors observing factors such as soil moisture, crop water retention and weather information. Information sharing about natural and man-made systems on a global scale is crucial for solving critical problems (*Location matters: Spatial standards for the Internet of Things, September, 2013, http://www.itu.int/techwatch)*. Observation and management systems (sensors, imaging and geospatial processing) were created by different professional communities to solve different kinds of problems.

A set of specialized ICT are the Geographic Information Technologies (GIT), which help to collect, manage, and analyze data about the resources, landscape features, and socio-economic characteristics of an area in space and time. Their capability to visualize spatial information is an important feature for communication, dissemination and knowledge sharing. GITs include the ICT tools as Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS) and Web-based tools. GITs are increasingly used in combination. The strength of each technology is applied to deal with integrated approaches. Web-based tools provide new ways of information sharing and real-time data visualization, Remote Sensing (RS) provides Earth's surface images, and the development of web GIS can be regarded as a major advancement opening many new opportunities, such as real-time maps, frequent data updates and sharing of spatial information by users all over the world. Through GIS overlay functions, knowledge from different disciplines is brought together, enabling spatial modeling of processes and dynamics of local human-ecosystem inter-linkages (*http://www.inforesources.ch/pdf/focus07_3_s.pdf*).

The effect of wireless technologies on society is tremendous and profound. Wireless communications between devices can be provided by the cell phone infrastructure. Other physical networking technologies such as RFID (*Radio-frequency identification*), WLAN (*Wireless Local Area Network*) and Bluetooth are better suited to communication between sensors and mechanical systems. Wireless networks are incredibly valuable in emergencies and disasters.

The explosive growth of mobile communications provides a wide range of opportunities. A mobile phone can also be thought of as a sensor. Smartphones typically include a gyroscope, accelerometers, GPS, Wi-Fi, Bluetooth, sound, light, time, near-field communications (NFC), compass, camera etc.

New ICT also with tremendous potential are Ubiquitous Sensor Networks (USN), networks of intelligent sensor nodes that could be deployed “anywhere, anytime, by anyone”. USN could generate applications in a wide range of fields, including environment and habitat monitoring, disaster management, security, intelligent transport systems etc. The main components of a USN are Sensor Network, Network Infrastructure and Access, and Middleware. USN can be used in three broad categories: detection, tracking and monitoring (e.g. detect temperatures exceeding a particular threshold, track workers in dangerous work-environments, monitor inhospitable environments, behaviour of animals in their indigenous habitat etc.).

Currently, the telecommunications industry is undergoing a revolution as it migrates from today’s separate networks (for voice, mobile, data etc.) to a single, unified IP-based next-generation network (NGN).

The new computing paradigms of Cloud and Grid computing also offer more opportunities for data and information management through provision of new services as SaaS (Software as a Service), IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SOA (Service-Oriented Architecture). This distributed computing contributes to enhance features such as ubiquitous access, reliability, scalability, virtualization, exchangeability, location independence, cost-effectiveness etc. The resources that can be shared in grids and clouds could be physical (computational power, storage devices, communication capacity) and virtual (software, applications, services).

Advances in technologies allows us to collect increasing amount of scientific data (in experiments, observations, simulations etc.), which respectively leads to a leap forward in the development of data storage, processing, handling and analysis. The progress determines the development of new areas of knowledge such as data mining, scalability, artificial intelligence (AI) and many others.

In the field of IWRM the propagation of Smart Water Management (SWM) in agriculture, domestic and industrial water use sectors, as well as the wider aspects of socioeconomic development is associated with many public benefits. For example Smart metering technologies play an important role in real time measuring of water consumption, leak identification at the consumer level and may contribute to change consumers' awareness about their water use. Smart water-metering technology can enable water utility companies to track usage more accurately at the consumer level and implement water-pricing plans to encourage water conservation[29]. Water use in manufacturing plants can also be managed more efficiently using ICT. Another example of SWM is the use of SCADA (*Supervisory Control And Data Acquisition*) in water and sewage systems in big cities to gauge and control flows, which provides monitoring and analysis tools for water managers. These systems can be integrated into Web-based architectures.

The use of Earth Observation (EO) technologies such as satellite based monitoring can be very useful as it can provide a cost-effective alternative or complement to field data collection. The main advantage of EO data is that it provides coverage over large and remote areas with systematic, repetitive data captures. For example, flood risk studies use LiDAR (*Light Detection and Ranging*) technology to create highly accurate Digital Elevation Models (DEMs) for improved floodplain mapping. EO products range from simple satellite images to more complex remote sensing applications such as climate change detection, mapping of land cover and land

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[29] http://www.itu.int/net/itunews/issues/2011/01/36.aspx

use, snow cover maps, wetland and water quality monitoring, pollution source detection, and other project-specific monitoring, and analysis services[30].

Weather forecasting and climate monitoring has also benefited greatly from ICT development. The World Weather Watch system for observation includes three core components[31]: Global Observing System (GOS), Global Telecommunication System (GTS) and Global Data Processing and Forecasting System.

Satellite imagery and aerial photography provide visual information assisting water managers in more accurate distribution of available water resources. The UAVs (*Unmanned Aerial Vehicles*) can be used in wetland mapping, river hydraulic modeling, soil moisture monitoring etc.

ICT use can play a crucial role in environmental protection, mitigation of local effects of climate change, energy efficiency, disaster management, water utility business and a wide range of many other fields interconnected with IWRM.

What are the challenges and opportunities of the new sources of information that are provided by ICTs?

ICTs open a wide array of possibilities to obtain, process and disseminate information for water resources management. The latter is particularly relevant in a context of a growing social and political support for open government and open data standards. In fact it could be argued that the information innovations that derive from the evolution of new information technologies will give way to a new and more efficient public administration.

However, there remain significant challenges to take full advantage of the opportunities offered by the constantly evolving ICTs, challenges that derive from the inertias of existing models of information generation and management and that limit the potential of these new technologies to transform information into knowledge. Some examples serve to illustrate the magnitude of these inertias (Moreira, 2013):

- Only small percentage of the WWW contents (4% out of about 8 billion web pages, according to the person in charge of the Spatial Information System of Andalusia regional

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[30] http://www.eurac.edu/en/research/receivingstation/default.html

[31] http://www.itu.int/net/itunews/issues/2011/01/36.aspx

government) are available through publicly available search engines such as Google. Therefore about 96% of digital information is protected by access codes (the so-called deep WEB) (Moreira, 2013).

- Public administrations use a wide array of programs and applications that request personal information from the public. However, too often these applications are independent of one another and do not take advantage of potential synergies or develop "one-stop" government procedures. These would be possible if governments changed their data management approach.
- The information used for water resources management is often exclusively local, in spite of the availability of global information that would allow for different management scales.

What are the primary limitations to a fluent exchange of information among different public administrations?

Inertias from the past and a high level of mistrust between different administrations result in the coexistence of different systems of organization, control and dissemination of information for each institution. While existing technology allows for the existence of a single information system, information generation and dissemination continues to be poly-nuclear and disperse. Each information provider, either individually or collectively, generates its own information structure and expects others to adapt to it, instead of working collectively to integrate information within a common system.

In the European Union there have been several initiatives that attempt to harmonize existing public information systems, limit duplicities and redundancies and improve public access to information. The INSPIRE Directive (Directive 2007/2/EC establishing an infrastructure for spatial information within the EU); existing legislation on the right to public access of environmental information (Law of Access to Public Information 55/2000, Directive 2003/4/CE and their various national transpositions; and the Directive on the re-use of public sector information, Directive 2003/98/EC, known as the 'PSI Directive') are landmark steps in this direction. However, public administrations are still reluctant to accept the public right to access environmental information and an individualistic approach continues to dominate information management. Public administrations have still largely not reorganized their information management procedures and systems in order to facilitate knowledge generation and information integration. On the contrary, they maintain traditional procedures but rely on information technologies to carry them out. This results in a significant contradiction between the great potential of the ICTs and the individualistic approach to information generation and management that continues to predominate.

Another dimension of this issue deals with the lack of attention to the new experiences of distributed and collaborative data generation advocated by the ICT. It is necessary to pay attention to and enhance the different platforms of social exchange and collaboration that allow forging social learning and knowledge on water. The pending issue of water policy in the field of information is to ensure that information gives rise to knowledge truly useful for participatory planning and management. This implies the need to facilitate the conditions in which knowledge produced through collaborative methods is disseminated and shared in an open, free and easy way, in accordance with the characteristics and potentialities of the new networked society. The collaborative generation of information has, surely, institutional implications concerning changes in the geometries of power, that is, potential changes in the identity of the agents that control information and, as a result, the decision-making processes.

From a technical point of view, the integration of various data types from different sources in common data standards is a problem that has to be solved by the joint efforts of many international organizations for standardization. The standards enable management interoperability among multi-user systems, tools and solutions within the heterogeneous environment. The standards and specifications intend to achieve consistent management of interconnected elements. Several organizations are working on standardization issues: the Open Geospatial Consortium (OGC), the World Wide Web Consortium (W3C), TeleManagement Forum (TMF), Globus Alliance, Open Grid Forum (OGF) and many others. The OGC collaborates with over twenty different Standard Development Organizations.

Geospatial standards must meet many interoperability requirements and the OGC has begun work on GIS-related interoperability issues since 1994 and has tackled Earth imaging, Web Mapping, and GML. For example KML (Keyhole Markup Language) is an encoding standard enabling users' unique spatial data to be displayed on the map provided by Earth browsers (Google Earth, Bing Maps or WebGL Earth). Existing Internet standards, such as HTTP, XML, SSL/TLS, developed at W3C, IETF, etc., a range of different wireless standards such as 2G (e.g., GSM), 2.5G (e.g., GPRS) 3G/WiMAX (e.g., IMT), play an important role in the IT communication.

GML is a joint OGC/ISO standard that defines an XML grammar for encoding and exchanging geospatial content. GML is a part of the interoperability platform enabling a single software program to control and access data from multiple Earth-imaging devices on satellites or aerial platforms. GML is embedded in international encoding standards for domains such as weather, aviation, hydrology, geology, emergency response etc.

Standards' harmonization is critical to ensure interoperability, ease of implementation and networks operations. As there are still many standardization gaps, the investments in developing and implementing open spatial standards could bring additional socioeconomic value.

Data quality control and its implications for water planning

The quality of hydrologic data highly conditions water planning processes and outcomes. There are different possible reasons for the poor quality of hydrologic data:

- In many instances, hydrologic information used is not sufficiently precise because centralized planning institutions are removed from (and not coordinated with) local sources of knowledge and information. In the recently completed WFD planning cycle, some European countries such as Spain, found that river basin plans relied on vast amounts of information generated by large River Basin Agencies. This information was often not locally validated and was sometimes inaccurate. Decentralized and cooperative network planning institutional arrangements could serve to overcome these limitations by informing and complementing centrally produced models and plans with local knowledge and expertise, thus providing for robust data quality control mechanisms. Network planning would allow for the multiplication of resources (staff, technologies, integration and cooperation) and increase the trust both in the information being generated as well as between players in the planning process.

- In the European Union, the WFD planning process has resulted in a significant improvement in the quantity, quality and availability of water resources information (hydrological, chemical, biological, etc.). However, the significant budgetary restrictions that are resulting from the economic crisis that started in 2007-8 are limiting the development and consolidation of these improvements. Furthermore, some experts argue that the information necessary for water management under the traditional hydraulic paradigm (primarily hydrologic and chemical quality information) is deteriorating while the new information gathering networks (remote sensing, biological indicator networks, etc.) are not yet consolidated.

- A similar problematic transition is perceived with respect to information generation technologies. For instance, conventional meteorological and hydrological manual measuring stations are being replaced by automatic measuring stations and remote sensing tools (for instance the SAIH network - *Sistema Automático de Información Hidológica* or Automatic Hydrologic Information System in the case of Spain). While the traditional manual measuring network is deteriorating, the territorial coverage of the new automatic measuring systems is still incomplete.
- Data quality, data gathering and quality control processes are key components of the metadata that must always accompany information systems developed with new technologies. Unfortunately this is seldom the case, although some efforts are underway to harmonize data and metadata and guarantee the traceability of the information.

What are the uncertainties associated with climate change scenarios and their relation to the uncertainties in water resources data and information?

The three types of uncertainty discussed in Section 3 above (*technical uncertainty, indetermination* and *ignorance*), can also be applied to the climate change debate. However, when dealing with the challenge of climate change it is the second type of uncertainty that is currently most relevant. It is an uncertainty characteristic of the new environmental risks that will likely dominate the XXIst century and have been well categorized and characterized by Ulrich Beck (1992).

Uncertainty in terms of indetermination is an integral part of climate change scientific work, where equally probable potential future scenarios are presented to policy makers not as certain information on future climate, but as possible future situations that will need to be managed. This explicit recognition of uncertainty on the part of scientists and experts, together with other factors such as the existence of powerful interest groups, have probably contributed to the popular perception of climate change science as the main source of uncertainty in the environmental field, and particularly in water resources and risk management. A clarification and identification of traditional and new sources of uncertainty with respect to environmental risk, and their relative importance is still needed.

5. MODELING HYDRO-SOCIAL SYSTEMS: REFLECTIONS ABOUT KEY INFORMATION AND DATA REQUIREMENTS

A water management perspective adapted to the current challenges requires a systemic approach to water resources, overcoming the simple, reductionist and static approaches that still persist (Ostrom y Cox, 2010). The development and use of dynamic modeling techniques can help us move in the right direction, since they provide simplified but effective representations of the evolution of the whole study area at different spatial scales and from different viewpoints, but always under an integrative perspective (Fagan *et al.*, 2010). Building dynamic models is a laborious process since it requires going beyond the requirements of traditional hydrologic model building (Hannerz and Langaas, 2007; UNESCO, 2008). Dynamic models incorporate the views and perspectives of managers, politicians and stakeholders in the characterization and diagnostic phases as well as in the definition of objectives and management alternatives. This approach enables the combination of the skills and technical expertise of the analyst with the range of incommensurable perspectives that affect socio-ecological systems (Martínez Fernández and Esteve Selma, 2004).

The combination within the same model of natural and social parameters—the essence of hydro-social models—, implies such level of complexity that the models can only hope to represent specific geographic and hydro-social realities (Martínez Fernández *et al.*, 2013). Their results can therefore not be extrapolated to other settings, at least not entirely. The development of dynamic models also requires the combination of new kinds of information with the physical parameters that are necessary for traditional modeling approaches (George *et al.*, 2011). It therefore requires a new socio-political and technical framework to deal with water resources management challenges in order to overcome current limitations to the involvement of the public and stakeholders in the definition of management alternatives. In essence, then, dynamic modeling is the necessary approach within the current water management context.

To what extent does the availability of information limit the development of hydro-social models? What kind of information is necessary to improve their simulation capacities?

The lack of good quality information is the most significant limiting factor for a successful modeling exercise, particularly when dealing with complex hydro-social realities. It is important to differentiate between the lack of information about the system prior to the design of the models, which limits their correct definition (conceptualization); and the lack of information about each of the processes once they have been identified and defined, that is, once the model has been conceptualized. The greatest limitations derive not so much from the identification of the parameters to be analyzed or modeled, but rather from the lack of data or experience in modeling the behavior of these parameters or in gathering information for modeling (De Lange *et al*., 2010). Models are thus often limited by the uncertainty and conflicts that result from trying to estimate the parameters and components since their behavior is unknown.

The lack of precise information about the various subsystems or components of hydro-social realities (hydrological, economic, social, etc.) greatly limit the development of hydro-social models. This is particularly true if they require information with sufficient spatial or temporal resolution to accurately simulate the behavior of a system. As a result, too often only "Black Box" models are developed—made up of simple regressions or empirical relationships between the different components—, which greatly limit the understanding of the system being modeled, and the transparency of the information or rationale that leads to a public policy decision.

In order to improve modeling capacities and to overcome the limitations of opaque descriptive models, good quality complete data would be required, with wide spatial and temporal coverage, and relating to all the elements, processes and flows that are included in the model (Kirchner, 2006). However the inverse is often the case, where the lack of data conditions or limits the design of the model.

Scale aspects of knowledge bases are also very important, particularly in order to better understand how to consolidate information gathered at different spatial scales. Bridging scales enable better integration of local knowledge into global models and data sets, i.e. integration of scientific and indigenous knowledge, which may strengthen the accuracy and contribute to its translation into effective policy strategies addressing global environmental changes.

The challenges in bridging scales are particularly significant in terms of understanding cross-scale interactions. Databases are scale-specific and most environmental analyses focus on a particular scale of interest rather than on cross-scale linkages (Reid *et al.*, 2006). Consistency in data form and quality is essential for data analysis.

Scaling is often considered together with Data Mining (extraction of implicit, previously unknown and potentially useful information from data). Data Mining uses semi-automatic discovery of patterns, associations, changes, anomalies, rules, and statistically significant structures and events in data (Gupta G. K, 2011). For instance, data processing uses various approaches of reduction of Large Datasets such as data aggregation, dimensional reduction, compression, discretization etc. The aim is to increase the speed of processing and to fit the data in a suitable way. Accordingly, complex algorithms, specialized hardware, parallelism and effective visualization are used in order to improve data analysis and to increase the understanding of the results.

Where are the greatest information deficiencies, in the natural or the socioeconomic subsystems?

It is challenging to attain a global understanding of the social subsystem and of its component variables. Socioeconomic information is diverse and heterogeneous: it can cover different geographical, and sometimes non-comparable, dimensions (for instance local agricultural information versus national agricultural trade magnitudes); quantitative and qualitative information; static data versus temporal time-series, etc. (Halpern *et al.*, 2013). Furthermore, socioeconomic variables are very site-specific and not easily transferable to other systems, as opposed to natural variables that respond to universal physical laws (hydrology, climatic variables, digital elevation models, etc.).

Dynamic hydro-social models give significant weight to qualitative socioeconomic data, information that has not traditionally been a part of model building efforts. This requires clearly defining the necessary level of precision of the information, data sources, accessibility, the methodologies employed to obtain this information, data treatment approaches, etc. Qualitative information is typically very robust, because it is obtained from expert knowledge (understanding expert knowledge in the least technocratic and most open sense of the term), but is not very precise and thus is challenging to incorporate into quantitative models (University of Ljubljana, 2012). Some argue that it may be an error to try to introduce “human” factors “inside pre-existing hydrologic models" but, on the contrary, that we might try to “translate” the “natural” factors in order to include them into social science modeling (Tom Evans, 3rd SWAN Progress meeting, Tucson October-November 2013)[32].

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[32] Available at: http://swanproject.webhost.uits.arizona.edu/

In addition to the challenges of complexity and dispersion of data, hydro-social models have to deal with a basic lack of information. A clear example is the lack of comprehensive information about water demands and use, since there are often no up-to-date and precise registries of some water sources (mainly groundwater) and sectors (specially, irrigation). Nevertheless, the assessment of information accurateness and accessibility has to be refined taking into account different national or regional traditions and institutional regimes.

In terms of the available information on the natural subsystem, the deterioration of traditional hydrologic and climatic information records mentioned before presents an additional difficulty that needs to be overcome. Willaarts *et al.,* (2012) also point to challenges resulting from the necessary identification and interpretation of the interrelationships between the flows of water, as a substance with different quantities, chemical characteristics and potential, and the associated ecosystems and landscapes. This challenge, as commented in section 3 above, has not yet been fully resolved.

Finally, the interrelationships and flows between the different system components, particularly between physical and social subsystems, are not sufficiently understood. Significant efforts are needed to better understand these relationships, such as the territorial dimension of water and the services it provides.

What are the most appropriate scales for social and hydrological modeling?

The definition of the physical and temporal scale for the analysis and management of water resources is a key decision that determines the nature of the problem, the identification of the actors involved, and their relative position in the decision-making process. It therefore clearly affects the power balance within the system.

In general, dynamic modeling efforts use the river basin as the territorial scale for analysis since it reveals processes and interrelationships that are not apparent at smaller (more detailed) scales and, in general, is able to provide an integrated and holistic view of the natural water flow patterns (Pedraza, 2007). The river basin is also the territorial unit that is proposed in the context of the IWRM paradigm. However, the selection of this scale is not undisputable (Blöschl and Sivapalan, 1995) since socio-political networks and interconnections often transcend the boundaries established by the physical division of the river basin. Institutional and administrative boundaries, commercial flows, socio-cultural identities rarely coincide with physical boundaries.

The dominance of the physical characteristics as the defining factor for management and analysis is currently being questioned, as was discussed in section 3 above.

In what pertains to the water-territory relationships, changes in scale profoundly affect the design, behavior and outcome of the models that represent them. Very often modelers only have access to information on a small part of the space-time continuum in which processes take place, thus conditioning the understanding of reality and, therefore, model conceptualization, establishment of parameter values and calibration.

In terms of the temporal dimension, it is clear that complex systems can present distortions over time or imperceptible flows in short time-frames. Modelers therefore favor working with long time-series for input and calibration data.

Are there effective ways of modeling and incorporating information on abstract variables such as changes in behavior?

Some models already incorporate this kind of information—changes in water consumption patterns by irrigators or water use changes as a result of expected inflows of new sources of water such as desalinated or transferred resources—in their own internal structure as well as in the generation of possible scenarios (Hurlimann *et al.*, 2009). The key to model these variables is to carefully describe the determining factors, what sets them off, how they operate and how they affect other variables. Therefore, the correct conceptualization of the model is essential and in turn requires a significant amount of information about the socioeconomic components. The main challenge is that these variables do not respond to straightforward rules or laws like those that govern physical processes. They are complex behaviors and phenomenon, random, uncertain and highly reflexive that evolve in time and space and are rarely documented in a systemic fashion. These limitations make their incorporation as variables in a model difficult and challenging (Alvisi *et al.*, 2007).

In order to calibrate and establish the parameter values of model variables for which there are no empirical data series it is necessary to thoroughly review existing information about similar systems in order to adapt this information to the reality being simulated. At the same time, it is important to rely on local and stakeholder expertise, a key input to limit uncertainty.

Depending on the goal of the modeling exercise, the abundance and level of detail of the variables being used can vary from their identification as an element or magnitude to consider, to the inclusion of time-series or estimative functions developed from consultations with experts or bibliographical review. However it is important to keep in mind that sometimes simple models can provide very good results if carefully defined and calibrated. An excess of information and detail is not always required.

6. TRANSPARENCY AND PUBLIC PARTICIPATION AS KEY COMPONENTS OF THE NEW WATER GOVERNANCE: RESULTING INFORMATION NEEDS

Traditional transparency and public participation efforts have focused on the need to disseminate information to the public rather than on collaborative generation of information for water planning and management. This has been the dominant *rational comprehensive planning* approach, where public participation is not *inherent* to the planning process, but rather *instrumental* to improve knowledge in the diagnostic phase. In the context of this approach public participation is not seen as a means for the common identification of objectives, strategies and alternatives, or for decision making.

The most advanced versions of the IWRM paradigm such as the WFD, draw upon this experience and incorporate public participation as an act of *governance* where, starting from a participated identification of problems, possible alternative solutions are jointly identified. This revised approach implies that problems, goals and objectives should be identified together with the public and stakeholders, who also participate in the identification of alternative strategies, measures and proposed actions. The growing recognition of the complexity and uncertainty associated with socio-ecological systems necessarily demands this new epistemological approach to public participation.

In this new context, transparency requirements imply that the information that is generated during water planning and management processes must be accessible to the public, both in terms of physical accessibility through internet as well as in terms of information that is understandable by different audiences. Public participation also requires the use of public forums for debate and exchange of information. Public input on problem diagnosis, definition of objectives and alternatives needs to be taken into account and influence management decisions.

In the EU, environmental legislation in general, and water legislation in particular regulate the right of public access to environmental information (Directive 2003/4/CE) or the requirement of public participation processes (art. 14, Directive 2000/60/CE). Transparency, information and public participation requirements are closely interrelated since the latter requires publicly accessible good quality information for decision-making.

The emphasis on public participation mechanisms to legitimize public policy decision-making processes found its theoretical grounding in the deliberative democracy theoretical framework (Cohen, 1989; Fishkin, 1991; Gutman & Thompson, 2004). However, a systematic framework for the evaluation of the outcomes and impact of collaboration in water planning often appears lacking—both in terms of monitoring and evaluating the quality of the collaborative process, and in terms how it may have influenced water management outcomes. The lack of rigor in applying core concepts frequently results in water planners, and their government agency supervisors operating in an environment where terms such as ‘involve’, ‘consult’, ‘collaborate’ and ‘partner’ retain a cultivated ambiguity. Some (see Poh Ling Tan *et al*., 2008) have claimed that the outcomes expected of deliberative forms of collaboration are naïve and unrealistic underscoring limitations to current political and social theories of collaboration, deliberation and social learning. Furthermore, after more than two decades of general acceptance and widespread implementation of this approach, there is a growing body of work that is critically questioning the limits of the *participatory governance* approach to natural resources management and its true impact on final decisions (Ranciére, 2006, and Swyngedouw, 2011). This critical work is framed within the debates of *post-politics* or *post-democracy* in the context of the global neoliberal globalization processes.

In a paper on linking science with environmental decision-making that summarized the conclusions of the 10-year SAHRA[33] research project (scientific starting point for the work of SWAN) its authors conclude with the following statement (Liu *et al.,* 2008): "Finally, although involving the stakeholders and decision-makers in the entire process of model development, implementation, and analysis can help enhance the transparency and credibility of the modeling results, there might still exist additional limitations of decision-makers not selecting a scenario due to political or other concerns/considerations." A similar frustration was expressed by Andalusian water managers in the context of the SWAN Seminar on *New paradigms in water resources and risks management: Key water data and information for sustainability*, held at the University of Seville in January 2013; or by the previous director of the Catalan Water Agency in the final seminar of the PART-DMA[34] research project held in Barcelona in November 2012.

What motivates the *externalization* (del Moral, 2013) of key operational and final decisions following deliberative planning and decision-making processes? Where do the so-called

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[33] See: http://www.sahra.arizona.edu/ for more information.
[34] http://blogs.uab.cat/partdma/

"political" decisions come from? Why don't they fit within the logic of scientific, integrated and participatory decision-making processes that precisely aim to understand, anticipate and drive sustainable decisions? Don't these scientific and policy processes aim to integrate science with environmental decision making or at least understand under what conditions this integration can take place? The following pages offer some preliminary ideas and perspectives on of these questions.

To what extent are EU legal requirements on transparency and public participation fulfilled in hydrologic planning processes under the WDF in Spain?

The Spanish experience with participatory water planning processes in the context of the WFD has had mixed results (Ballester and Parés, 2013; Espluga et al., 2011; Hernández-Mora and Ballester, 2010). Spanish water policy is still largely immersed in the old hydraulic paradigm, where public participation is understood as a means for disseminating information and legitimizing policy decisions that are still taken within the closed traditional water policy community (irrigators, hydroelectric company and large construction companies) quite independent of more open and participatory processes. Furthermore, leaving aside considerations about the formal and substantive quality of the public participation processes undertaken in the different river basin planning districts, too often there has been a *political externalization* of key planning decisions.

It is however important to recognize that some progress has been made in terms of transparency in water planning and management, albeit modest and uneven. The Spanish branch of Transparency International undertakes a periodic comparative analysis of transparency in water planning and management in the different river basin management agencies in Spain (se De Stefano *et al.*, 2012; and Transparencia Internacional-España, 2013). The resulting Index for Transparency in Water Management (INTRAG or *Índice de Transparencia en la Gestión del Agua)* has been applied in 2010, 2011 and 2013, and showed that overall transparency improved from an average of 51.2 in 2010, to 59.6 in 2011 and 62.9 over 100 in 2013. However, results differ significantly for different agencies ranging from 33,5 to 93,5 over 100 in 2013, as well as between the different elements being evaluated[35] (see table

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[35] For more information see:
http://www.transparencia.org.es/INTRAG/INTRAG_A%C3%91OS_ANTERIORES.htm

2), which shows the progress made by some and that there is still significant room for improvement.

Table 2. Components and variables of the 2013 Transparency Index of Water Management

Components	Subcomponents	Number of variables
Information about the river basin management agency	Basic institutional information	5
	Water-related laws and regulations	1
Relations with the public and stakeholders	Public information and attention	12
	Public participation	2
Transparency in the planning processes		16
Transparency in water management and use	Water management	12
	Information on water uses	5
	Compliance with current legislation	5
Economic and financial transparency	Accounting and budgetary information	4
	Transparency on income and expenses	4
Transparency in public contracting and licensing	Public contracting procedures	4
	Relations and operations with purveyors and contractors	8
	Follow up and control of public works	2

Source: www.transparencia.org.es

The INTRAG is a good example of a useful indicator for transparency in water management. Its conceptual approach is comprehensive and flexible enough to be applicable to other countries or regions (in fact, Brazil and Portugal are currently adapting the index to their own institutional settings). It is made up of 6 component or thematic areas which refer to the main areas of activity of the agencies responsible for water management in Spain (Table 2). However, INTRAG only evaluates the information being made available to the public, that is, active transparency. It does not measure the quality of the information or its usability, or the response of the River Basin Agencies to the requests for information from the public, that is, the compliance with the right to information legislation, which is also important legal obligations.

What type of information is particularly relevant to inform public participation processes for water governance?

The information required to inform public participation processes for water governance depends upon the water planning and management goals. In the context and logic of the WFD, fully in line with the IWRM paradigm, the information required must facilitate answering the following planning and management questions:

- How much water do we have, and who uses it?
- What is the current state of our waters (ecological, chemical, quantitative)?
- What is the cost of current and required water services (financial, environmental and resource costs)?
- What are our goals?
- What measures can we implement in order to achieve them and what is the most cost-effective combination of measures?
- How is the implementation of the measures helping us achieve our goals? Do we need to adapt our Program of Measures to better reach our goals?

At the same time, the information provided must meet several requirements: quality and reliability; ease of access (internet); regularly updated; sufficient and adequate to inform planning, participation and management objectives; detailed and traceable; and adapted (accessible in terms of content) to the different publics.

Are there positive experiences that can help us advance along these lines?

Public participation and transparency are essential components of decision-making processes aimed at jointly identifying challenges, alternatives and potential solutions. Public participation must be present at every step of the planning and decision making process: from the collaborative development of information (for instance through the integration of information and knowledge from different institutions and sources, particularly local knowledge); the recognition and incorporation of different interpretations of reality and associated problems (for instance trough different modeling approaches); and the development of poly-centric and shared decision-making mechanisms. Existing water management challenges require public participation processes that are not purely formal but, rather, substantial and politically-binding, that is, moving up the ladder of public participation originally proposed by Arnstein in 1969 (see Table 3).

Table 3. The ladder of public participation in water management

↑	**Support for local initiatives**	Higher levels of participation – delegation of power.
	Joint action	Collaborative efforts (working groups) to deal with and resolve specific problems.
	Co-decision	Joint definition of problems and alternative solutions.
	Public consultation	Selection between predetermined alternatives. Limits input of ideas and does not allow for the joint definition of problems, nor the participated evaluation of the implementation process.
	Information	Necessary but insufficient condition for public participation. Uni-directional.

Source: Adapted from Arnstein (1969)

7. SOME FINAL REMARKS AND QUESTIONS FOR FURTHER DISCUSSION

1. IWRM is the dominating paradigm for sustainable water management today. The Water Framework Directive represents perhaps the most ambitious and complex legal effort to put the principles of IWRM into practice in the EU's member states. Other national legislations also incorporate IWRM prescriptions. However, this model faces resistance from the previously dominating hydraulic paradigm, as well as the contradictions that emerge from the practical experiences in its implementation at different scales (from regional to global). The criticisms that it has received in the recent past focus on the following main aspects:

    - The river basin as the undisputed scale for integrated management and water governance. While it may be the ideal scale of hydrologic characterization, its appropriateness as the ideal scale for governance is under dispute.
    - The larger hegemonic economic thought in which IWRM prescriptions are integrated, particularly the commodification processes and monetary reductionism of natural resources.
    - The weaknesses and failures of public participation processes that have accompanied actual water resources planning and management experiences and that are an integral part of the IWRM theoretical framework.

2. Water management today presents significant information challenges. Information must simultaneously fulfill requirements that are to some degree opposed and antagonistic but also mutually necessary, in close interaction with one another or, as Edgar Morin would say, *dialogically* related (see Morin 1977, 80).

    - Information versus data;
    - Information needed to improve management versus information dissemination to improve transparency and facilitate public participation;
    - Real versus modeled data;
    - Quantitative versus qualitative data;
    - Real time versus delayed data;
    - Physical versus socioeconomic data;

- Conventional network versus new networks (remote sensing, etc.) data.

3. The profound paradigm shift in water management has had important implications for information and data requirements. The transition from the promotion of hydraulic infrastructures as the primary water policy goal to economic and ecosystem-based water management, and the recognition of water as a patrimony has required not only new information, but also new methodologies for gathering and generating this information. Some of the main new debates about the limitations and insufficiencies of the now discursively dominant of IWRM paradigm revolve around the following issues:

    - Estimating the costs associated with ecosystem restoration is infinitely more complex than calculating the costs associated with water flows, since these can be simplified through the balance of the hydrologic cycle.

    - The valuation of ecosystem services requires using metrics other than monetary valuation, as well as site-specific studies. The methodologies and information necessary for these valuations are still under development.

    - The incorporation of the social dimension brings with it elements of complexity and uncertainty in addition to those inherent to natural systems. Therefore the understanding, representation and management of water as an eco-social patrimony poses new challenges that require information that is still being developed.

4. The selection of the scale for water management has direct implications for information and data availability and requirements: local versus global scale for information gathering; central planning (models) versus local planning (real network data). Related to this issue the next questions arise:

    - What are the possibilities and real potential of different alternatives for information generation and what are the difficulties and challenges inherent to each choice?

    - What are the institutional conditions for its implementation?

    - Are public information systems organized to facilitate the knowledge generation and information exchanges or are there still important imbalances between the potential of the new ICTs and the individualistic behavior that still dominates information management?

5. Too often in the final stages of decision making processes there is a *political externalization* of key final operational decisions. Water managers (or politics) impose decisions that are not coherent with scientific, integrated and participatory processes that precisely aim to understand, anticipate and direct sustainable management decisions. There is a lack of understanding about these informal decision making processes. Research about the links between science and politics must incorporate information about the factors that drive and help explain these fundamental mechanisms.

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