swan
Sustainable Water ActioN

CAPACITIES

Seventh Framework Program
FP7 Grant Agreement
INCO-20011-7.6

Deliverable 5 (Supplement 1)

Analyzing New Challenges for Water Management: *An outline for a trans-disciplinary approach, based on a review of existing conceptual frameworks*

cnrs

ARIZONA

University of the West of England
UWE BRISTOL

UNIVERSIDAD DE SEVILLA

UNESCO-IHE
Institute for Water Education

Authors: Serrat-Capdevila, A. (CNRS/UoA), Cabello V. (US), Boyanova, K. (NIGGG), Poupeau, F. (iGLOBES, UMI 3157 CNRS/UoA), Rodriguez, D. (USP/UoA), Salmoral, G. (UAM), Segura, S. (US), and Yang, Z. (UoA).

Cover picture captions:

Top picture: SWAN work meetings, Spring 2013, Tucson
Photo: Hoshin Gupta

Bottom picture: SWAN Workshop, April 2013, Tucson
Photo: Hoshin Gupta

Project Title	**Sustainable Water Action Network - SWAN**
Grant Agreement	**294947**
Deliverable title	**Analyzing New Challenges for Water Management:** ***An outline for a trans-disciplinary approach, based on a review of existing conceptual frameworks***
Deliverable name	DEL 5 (Supplement 1)
Authors	Serrat-Capdevila, A. (CNRS/UoA), Cabello V. (US), Boyanova, K. (NIGGG), Poupeau, F. (iGLOBES, UMI 3157 CNRS/UoA), Rodriguez, D. (USP/UoA), Salmoral, G. (UAM), Segura, S. (US), and Yang, Z. (UoA).
Reviewers	Leandro del Moral
Due date of deliverable	This deliverable is new
Actual submission date	May, 2014

Dissemination level

X	PU	Public
	PP	Restricted to other program participants (including the Commission Services)
	RE	Restricted to a group specified by the consortium (including the Commission Services)
	CO	Confidential, only for members of the consortium (including the Commission Services)

Deliverable status version control

Version	**Date**	**Authors**
1.0	June 1st, 2013	Serrat-Capdevila, A. (CNRS/UoA), Cabello V. (US), Boyanova, K. (NIGGG), Poupeau, F. (iGLOBES, UMI 3157 CNRS/UoA), Rodriguez, D. (USP/UoA), Salmoral, G. (UAM), Segura, S. (US), and Yang, Z. (UoA).
2.0	Nov. 30th, 2013	Serrat-Capdevila, A. (CNRS/UoA), Cabello V. (US), Boyanova, K. (NIGGG), Poupeau, F. (iGLOBES, UMI 3157 CNRS/UoA), Rodriguez, D. (USP/UoA), Salmoral, G. (UAM), Segura, S. (US), and Yang, Z (UoA).
Final	March 1st, 2013	Serrat-Capdevila, A. (CNRS/UoA), Cabello V. (US), Boyanova, K. (NIGGG), Poupeau, F. (iGLOBES, UMI 3157 CNRS/UoA), Rodriguez, D. (USP/UoA), Salmoral, G. (UAM), Segura, S. (US), and Yang, Z. (UoA).

TABLE OF CONTENTS

ABSTRACT/CONCEPT NOTE

This paper attempts to provide an innovative and holistic approach of the complex dynamics between society and its physical environment. Drawing from emergent and well established fields of study, it aims at integrating different paradigms looking at how society interacts with nature and at expanding the boundaries of understanding between science and management of water and land resources. The combination of physical science tools such as climate and hydrologic modeling with human-centric approaches such as ecosystem services, societal metabolism, water footprint assessment, institutional analysis of water management or social uses of water, allows for a transdisciplinary approach to water issues. The approach presented in this working paper builds on disciplines and schools of thought that have rarely been all connected and that could address questions to face new challenges derived from climate uncertainty and water crisis, and bridge knowledge gaps across management jurisdictions. In addition, research processes has to be confronted to an increasing demand of participation from stakeholders no only to decision-making but also to the definition of scientific questions. This paper discusses how the integration of different methodologies and analysis frameworks can help inform future management strategies in the ever-evolving relationship of societies with their ecological systems.

1. INTRODUCTION

This methodological paper is developed within the framework of the SWAN project: “Sustainable Water ActioN: Building Research Links between EU and US”. SWAN is a four-year International Cooperation Project granted by the 7th Research Program of the European Commission. It focuses on the creation of a transatlantic dialogue on water, involving five universities and research centers of European Union Member States (Bulgaria, France, Netherlands, Spain, United Kingdom) and the department of hydrology of the University of Arizona. SWAN aims at bridging the gap between science and management by involving decision-makers, stakeholders and the general public in the research processes.

Since the 1960’s, the “world water crisis” has generated many interrogations about the scarcity and quality of water resources confronted to population growth (Hardin, 1968; Report Rome 72 Sustainability). In parallel to the constitution of an “international community of water” supported by several world environmental forums since the 70’s (Stockholm-1972, Club of Rome-*Limits to Growth-1972*; Johannesburg-2002; Dublin-1992; Rio-1992,2012), the notion of sustainability emerged as a paradigm for development and governance. The problems of sustainability of natural resources have been explained as a consequence of their governance models. New trends of research insisted on the study of management issues, norms and rules (Ostrom, 1990). Later on, the notion of sustainability has also been questioned as a technocratic paradigm along with the failure of the role of science as provider of technical solutions to the growing problems that societies face with their environments (Bakker, 2011). The growing concern on non-academic knowledge and democratization of science has been reflected in new institutional approaches to water management as the European Water Framework Directive in the beginning of the 2000’s. But if various critics of the traditional function of expertise and of the links between knowledge and power have been formulated, the consequences on methodological issues haven’t fully been analyzed. On that methodological dimension, studies have focused more on the problems of the relativity of knowledge (construction of scientific objects, critics of the notion of truth) than on the integration of disciplines and of “civil society” (Jasanoff, 2007).

This paper is a statement of intent for future integration of conceptual models as a framework for research. It aligns with the critics formulated to scientific expertise by “post-normal science” theory (Funtowicz & Ravetz, 1991, 1994), suggesting that the complexity of environmental issues requires new paths of knowledge production, incorporating multiple scientific, professional and citizen perspectives. Beyond the debate between fundamental and applied research, the hypothesis of a contribution of "democratic participation" to the scientific process leads to an analysis of the specificity of environmental issues: the complexity of water management necessitates a combination of approaches from physical, environmental and social sciences, opened and validated by civil society. However, using multiple conceptual metaphors does not necessarily lead to a better comprehension of human-environment relationship or decision-making support (Raymond et al 2013): the different methods have at least to frame a common scientific object. Modeling this object can be approached in different ways summarized in Box 1.

Box 1: Cross-disciplinarity (Rosendfeld, 1992)

Multidisciplinarity → Researchers work in parallel or sequentially from disciplinary specific base to address a common problem. The total result of the research effort appears as the sum of the partial efforts with a low level of further integration.

Interdisciplinary → Researchers work jointly but still from disciplinary-specific basis in interactive modes of operation in order to address a common problem. Integration efforts are given care and interest but not to the extent that the "input" competences have lost their specificities.

Transdisciplinarity → Researchers work jointly using shared conceptual frameworks that are specifically designed for the purpose of a particular research endeavor and drawing together disciplinary specific theories, concepts, and approaches to address a common problem.

Interdisciplinarity provides the possibility to keep the strengths of a discipline while enriching it with further perspectives and covering gaps in terminology, approach and methodology. This is why this paper presents an interdisciplinary approach attempting to integrate disciplines such as climatology, hydrology, and sociology with transdisciplinary methods such as Societal Metabolism, Ecosystem services and Water Footprint and Virtual Water, to create a holistic approach attempting to answer transdisciplinary questions that can inform water and land management and planning. Furthermore, the importance of transcending science borders is emphasized using the participation of both stakeholders as fellow researchers and direct users of science products.

This work is based on the hypothesis that the involvement of stakeholders can help bridge the gaps and frontiers between disciplines. As the key scientific challenge of the "Anthropocene" as a time where human activities highly impact natural systems (Revkin 1992, Crutzen & Stroemer 2000) is to analyze the relationship between society and nature (Becker 2010), this paper explores how our proposed holistic approach can go beyond existing frameworks to support water resources management and planning, as well as how it relates to current scientific paradigms.

2. BACKGROUND: MAN, WATER AND NATURE

2.1. Ecological challenges in the "Anthropocene": understanding the relations between societies and their environment

Last centuries witnessed an outstanding growth of human population, agricultural production and energy generation. This growth was feasible thanks to an increasing "control of nature" especially regarding water resources: the parallel anchoring of hydraulic science and engineering systems were able to deeply transform natural hydrologic regimes, buffer natural variability and enhance the social uses of water in space and time. Nonetheless, this has come at a cost where in many settings now "nature talks back" (Savenije et al. 2013). Still, facing the negative "reaction of nature" is not the only reason to realize changes in the management of environment. The technological revolution and the following development were turbulent events in human history, opening unimaginable opportunities, as well as increasing risks. Throughout the years, the knowledge on the environment increased significantly and brought the conclusion that intensive technological approach is a good way to manage environment, but it sometimes leads only to short-term solutions, which doesn't incorporate well with the target of sustainability. The science (and slowly policy) realized that the natural functions of ecosystems and their ability to self-regulate are just as powerful tools as technology in some cases and their combination, together with efficient management, can help us create more sustainable future and still cover the demands of the social system. This is also why conservation and biodiversity have found more broad recognition in policy and management during the last years.

The human interferences on the water cycle pose new challenges to the marriage of science and governance. Currently, about 2,600 km^3/year of freshwater is consumed by humans. The estimated planet boundary for freshwater appropriation is 4,000 km^3 (Rockstrom et al., 2009). Nevertheless, many major river basins (i.e. Nile River or the Colorado River) across the world suffer water stress, thus this threshold ignores the importance of local conditions and the role of management in magnifying or ameliorating problems (Molden, 2009). Agriculture represents 70% of total water withdrawal, used to produce food and feed cattle (FAO, 2011), and also embodies the most important driver of land use changes (Foley et al., 2011). With the current trend in population growth and richer meat dietary changes, some studies predict dissatisfied increases of food requirements. Meeting this future food demand can partly be achieved by strategic agricultural intensification, in terms of elevating yields of existing croplands of underyielding nations as long as not irreversible ecosystem damage is caused (Tilman et al., 2011). Additional land will also need to be converted into agriculture leading to environmental concerns such as biodiversity loss and carbon release (Scherr and McNeely, 2008; Gloor et al., 2012). Nowadays about 4 billion metric tons of food are produced per annum, but it is estimated that 30–50% (or 1.2–2 billion tones) of all food produced never reaches a human stomach due to poor practices in harvesting, storage, transportation and distribution, as well as market and consumer wastage (IMECHE, 2013).

In 2007, half of the world's population lived in cities, and this number is projected to be three out of five in 2030 (United Nations, 2007). The level of urbanization is expected to be approximately 70% by 2050 with the percentage increasing from 75 to 86% in developed countries and 45 to 66% in developing countries (UNPD, 2010). In the meantime, anthropogenic emissions altering global atmospheric composition reinforce regional mesoclimate regulation disturbances. Extreme climatic events are expected to be more dramatic under such changing environment (NRC, 2011). Huge urban areas characterized with high density of population and infrastructures usually serve as social, economic and political hubs. Consequently, this poses huge pressure on decision makers as urban areas are vulnerable to storms, urban floods, airborne diseases. In fact, in the past 30 years many of the major weather disasters have been in urban areas and cost billion dollars (NRC, 2012).

Urban expansion poses serious competition on already constrained freshwater resources and available land for agriculture. Intensification of agriculture and production of new water resources (wastewater reuse and desalination) as win-win solutions for this competition are so far only viable under cheap fossil fuels conditions. The transition from an energy system based on fossils stocks, with high power densities, to one based on renewable sources, with low power densities, sits a new competitor on the table (Schneidel and Sorman, 2012). Water and land for energy, for people, for food and for the environment; multiple stakes on finite resources.

In order to understand current and future environmental challenges, it is necessary to first understand the key drivers of the relationship of societies with their environment. The influence of available technology in the dynamics of human livelihood and the evolution of carrying capacities and sustainability of socio-ecological systems is at the center of the Malthusian and neo-Malthusian debates. Indeed, a number of technological revolutions have progressively transformed the ways in which the environment is regulated. As new technology influences the way that society interacts with the environment and new socio-economic structures evolve, new tools and perspectives may be needed to understand and assess human-natural interactions.

This discussion leads to the classical question: how much can global population grow until reaching critical biophysical limits? Concepts like planetary boundaries point at the necessity of quantifying these limits in relation to specific consumption and living standards patterns, and current technology. *Limits to Growth* - based on a system dynamics simulation of the earth's population growth and resource use (Meadows et al. 1972) – and *The First Global Revolution* (King and Schneider 1991) are some of the first modern efforts to understand this question. Nilsson and Persson (2012) argue that global boundary values would need to be reviewed and downscaled in order to gain the necessary degree of "*scientific certainty and political legitimacy*". As sustainability and resilience are site-specific concepts for local and regional scales, the analysis focuses where ecosystems hybridize with societal evolution and complex socio-ecological interactions take place. Given the existing technology, knowledge and practices, the specific socio-ecological systems – such as flood-recession agriculture in Senegal, or the complex engineered landscape of rice-farming in Bali – have their sustainable level of resource use, food production, and productivity. These are likely to change as the socio-ecological system evolves with new technologies, knowledge and social organization.

Thus, beyond the classical question of what are the "limits to growth", how much further can the malthusian vs cornucopian debate be carried forward? For how long will Simon-Ehrlich type of wagers lean in favor of Simon and the power of technological innovations? For how long will technological advances keep pushing the boundary of sustainability? Do socioeconomic dynamics truly depend on the environment, and under which time scales and spatial differentiations? And more importantly: How to analyze – while planning for the future – the current sustainability of resource use versus the influence of new technological advances and new knowledge?

It is necessary to reconcile past debates on the relationship between technology, economic development, social inequality and environmental impacts. An integrative perspective of the role of technology in water management is needed; from utopian and dystopian perspectives on technology as a driver of social progress or distress; through the evolution of constructivism and determinism debates since the industrial revolution; to the promises of "cyberfetichism" for social change and green growth economies as drivers of environmental preservation.

2.2. Water science for water management: scientific expertise questioned by democratic participation

One of the earliest forms of farming is flood recession agriculture, where valley bottoms are planted and cultivated as flood waters recede. The need to regulate access to a variable resource – the area of flooded, thus fertile, land – gave rise to the first complex social structures (Manning 2002; Lafont 2009), which provided mechanisms to ensure some sort of access to land for a range of social groups, given the extent of each year's annual flood and the consequent portfolio of fertile lands available for cultivation. This is one of the early contexts in which the concept of "management" emerged. Flood recession agriculture progressively permitted the existence of large urban centers and Empires in West Africa, Mesopotamia, ancient Egypt and China, as well as transcontinental trade routes (Palerm & Wolf, 1955). It has been argued that the socio-economic structures that developed with flood recession agriculture represent the emergence of social stratification at the institutional level, which led to the highly hierarchical societies and modern nation states in which we live (Park, 1977). The intense specialization of labor enabled by agricultural surpluses allowed for scientific advances that ultimately culminated in technological advances allowing a faster diffusion of knowledge (the printing press, 11th century in China, 15th century in Europe) and the industrial revolution in the late 18th century. The relationship with the environment was again dramatically changed.

Within this last technological revolution, the discovery of reinforced concrete and electricity allowed man to intervene the hydrological cycle in unprecedented ways. Since 10,000 years ago and the appearance of agriculture, only limited flows could be diverted with gravity diversion canals. Now, while dams, canals and pumps intercepted and re-distributed large surface flows within and across basins, rural electrification – a world-wide phenomenon in the mid 20th century – enabled aquifer pumping and the onset of what has turned out to be massive groundwater depletions. This newfound availability of water volumes allowed great economic and social development (growth of irrigated area and agricultural production, drought protection), but environmental impacts and ecological disasters also occurred. Associated chemical advances in pesticide and fertilizer products also led to the Green Revolution, mentioned earlier, which in some cases was a failure due to ecological collapses due to the lack of understanding of complex dynamics of socio-ecological systems (Lansing, 2012).

Since the 19th century, water resources projects and planning have been mostly based on economic impact evaluations. For example, the 1936 Flood Control Act required only that the benefit–cost analysis be positive for a plan to be deemed feasible, and subsequent documents consolidated the concept of "contribution to national income" as the preeminent water resources planning objective (Loucks et al, 1981). Consequently, economic objectives – measured through benefit-cost analysis – have dominated water resources planning in the United States, during much of the past century (from Serrat-Capdevila et al, 2014).

Addressing the need to regulate the intervening power humans on the hydrologic cycle, different paradigms such as Integrated Water Resources Management (IWRM), Resilience of socio-ecological systems and Water Security have emerged, shifted and evolved in the last few decades. These concepts represent ways of assessing how societies are embedded, thrive from, and interact with their natural environment or their ecological contexts. These paradigms originated within specific professional (researcher-practitioner) circles and may reflect their own sector specific perspectives, also obeying to social constraints and trends of the time.

Integrated Water Resources Management (IWRM) emerged as a new paradigm for decision-making in relation to water. This approach adopts the basin scale as the natural unit enabling water issues to be considered both in their broader context and through the more focused lenses of economic efficiency, social equity and environmental sustainability. IWRM can be defined as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). In general terms, IWRM aims at a management based on economic efficiency, environmental sustainability and social equity, with or through public participation. IWRM and its participatory planning approaches can be seen as the nuts and bolts of how to implement the concept of sustainability in water resources management at the basin level (ref. UNESCO IWRM Guidelines at Basin Level).

The Resilience or socio-ecological systems approach – arising from the new-ecology movement (Holling, 2011) – has been a rapidly expanding field in academia but its impact and its uses by management practitioners may not have kept the same pace. Even the more broadly used and appropriated term of adaptation and adaptive management is quite clear in its principles but its real-world applications seem to be discretionary and at the practitioner's best guess. Acknowledging that human and natural systems are linked and coevolve together, and that ecosystem response to human use is rarely linear, predictable, or controllable, there are three main characteristics of the “new ecology” movement: (1) the acknowledgement of uncertainty, dynamics, and complexity; (2) the exploration of nonlinear interactions across different-scale systems (and a more global approach to recognizing spatial patterns); (3) and a historical memory of systems and their temporal dynamics (Scoones, 1999). “Resilience” alludes to the capacity of a system to maintain its functionality, to recover and reorganize after a disturbance, and to adapt to change (Holling 2001). The term “adaptive capacity” can be interchangeable with “Resilience”. Building resilient systems involves learning, the flexibility to experiment and adopt new solutions, and the ability to respond broadly to challenges (Serrat-Capdevila et al 2014).

Overarching these frameworks is the epistemology of how new information, research findings and understanding are generated, incorporated and operationalized within the structures and mechanisms of control that manage a system in order to “improve” the way that resources are extracted, processed, exchanged and allocated. Even paradigms can come with its owner (a professional or academic sector). What is considered “knowledge” and who does it legitimize? Sustainability and water security for whom and at which cost?

The critics of “normal science” have risen in a context of disenchantment with environmental management institutions, especially with the failure of climate change negotiations and the emergence of global markets as regulators overtaking national policies for environment. Throughout the last decades, the paradigm of “post-normal science” has been developed as an epistemological frame to cope with science limitations to deal with complex problems: "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz and Ravetz, 1991). In science for governance, higher the uncertainty, more important is to separate descriptive and normative sides of scientific assessment: scientist are not the only ones with legitimacy to decide what is sustainable and what is not. Assuming the implications of complexity means assuming new ways of building knowledge and legitimizing narratives: scientists’ role is to generate adequate information of sufficient quality to set the table for extended peer-community discussion (Giampietro et al 2006). Science as “truth” creator is challenged by voices of open and participatory science (Holm et al 2013).

These discourses have been translated in western science into practices of integrated assessment (REF) and social multi-criteria evaluation (Munda, 1995). On a different context, Participatory Action Research (Packham and Sriskandarajah, 2005) was developed in Latin American countries routed in community development and rural studies. Recent TICs innovations are also setting a new stage of participation in science through collaborative generation of data and information through social networking.

3. MANAGING WATER IN SOCIO-ECOLOGICAL SYSTEMS: TOOLS ON THE TABLE

The mission of water resources management and planning is to sustainably reconcile multiple demands and water supplies, which can be limited and variable in time and space. In many instances, management has focused on the supply side, with the development of new water sources to cover increasing demands. A few decades ago, demand management started taking an equally important focus in water resources management, with the development of mechanisms and incentives to cover the same necessities with less water. Water resources are also influenced by decisions in many other sectors to which management is intrinsically linked, such as land use planning and land cover change.

The notion of how much water supply can be used, and the natural ecosystems altered, without causing the environment to change or lose its existing functionality is at the core of the water management question. However, once we have taken the water out of the environment, we must also understand how we combine it with labor, energy and other resources to produce goods for well-being, and how we trade and consume these goods that have a specific water footprint. By the same rule, these goods also have an ecological footprint (botanic, biotic, biodiversity footprints as well as an ecosystem services footprint), a land cover footprint and thus a climate footprint. This section presents different disciplines and fields of study relevant to water management that can be interconnected together to provide a more meaningful and multi-faceted analysis to inform water resources management, policy, planning and use.

3.1. Physical sciences

3.1.1. Climate models

Climate models are essentially combinations of mathematical equations that represent different nature processes in the climate system. These processes include radiation on the earth surface, cloud physics, atmospheric and oceanic circulation, chemical cycles, growth of vegetation, etc. Atmospheric models with different resolution have different representation of these aforementioned processes, which in principle aim to reduce the complexity of the computation while ensuring the accurate representation. Initially climate models are built to study the physics of the nature and later on they have been used to generate projections showing consequences of different scenarios, for example, different CO2 concentration or radiation scheme which are likely the consequences of public policy making. Climate models are capable to predict weather only few days ahead of time, but their ability to make reasonable predictions of statistics of weather, i.e. climate prediction, is retained. Thus, climate prediction involves running climate models at least for several seasons and commonly for several years.

Downscaling is a method for obtaining high resolution data from relatively coarse resolution global climate data. Typically, downscaling involves statistical downscaling or dynamical downscaling. Statistical downscaling derives relationship between the small scale variables and the large scale variable using statistical methods, e.g. analogue methods, regression analysis, and so on. Dynamical downscaling using regional climate model process the coarse resolution reanalysis data in more physical way. It is an appropriate way to simulate climate conditions in the future. Reanalysis data refers to the coarse resolution climate data that could be extended even a century into future: it is a combination of observation and model data through data assimilation procedure that is usually done by large climate centers. Furthermore, with the evolution of urban expansion and other land use change, studying their effect also requires the use of regional climate model.

Obviously, the most relevant atmospheric variable in the context of water is precipitation. Extreme precipitation is projected to be more frequent in the future (Dominguez et al., 2013 D.1.1). This might lead to flash floods which will serious damage urban infrastructure and cost people’s lives. Moreover, in many other regions, precipitation serves as important source of water. It is important to understand the trend and pattern of precipitation in the future as well. Standing on a physical level of this integrated approach, regional climate model mainly provides the atmospheric conditions that later will serve as input to the following procedures; namely, precipitation, soil moisture data to hydrologic model for atmospheric and land water partitioning, extreme precipitation data as input to ecosystem service for flood regulation.

3.1.2. Hydrology

Climatic and meteorological data can be used, among other things, as input forcing to drive hydrologic models that simulate the partitioning of water through the physical system with a set of state variables (i.e. snow storage, soil moisture, aquifer storage) connected by flows (i.e. rainfall, evapotranspiration, infiltration, runoff, interflow, recharge, streamflow, baseflow, groundwater flow). As any models, hydrologic models reflect a limited understanding of the physical system; however, they can vary from being very simple to being very complex, they can be either spatially distributed or aggregated, and can be conceptual or physically based. Different sub-disciplines study different aspects of hydrology (physical hydrology, ground and surface water, vadose-zone, water quality, stochastic hydrology, etc.) and linkages with other disciplines and systems, such as for example eco-hydrology.

An integrative modeling approach, using models of different resolution and complexity that serve different purposes but inform each other through feedbacks (Liu et al 2008; Brookshire and Gupta, 2011; Brookshire, Gupta and Mathews 2012) can be used to help understand the feedbacks between hydrology, water management and other human interventions (such as land use change). Spatially distributed high-resolution models are adequate when it is necessary to accommodate in detail the processes in the physical environment such as the land-atmosphere partitioning of water and energy, the role of vegetation, the interactions between surface and groundwater hydrology, and the provision of ecosystem services. Medium and coarse-resolution models are typically better suited to modeling human interventions on the environment such as land use management, engineering infrastructure and its operation in terms of intercepting and moving water within the basin and across different uses. Medium-resolution models allow representing water allocation and re-distribution within the system, while coarse-resolution models can be used to describe socio-economic and institutional aspects of water management over the natural and engineered system, with a resolution at the scale of the sub-watershed (Liu et al 2008).

In addition to providing an efficient way to represent the coupled natural-human system, a major benefit of multiple-resolution modeling is that information and findings can be readily transferred across models and used for model refinement. Information regarding natural processes, climate change impacts and feedbacks in the natural system can be up-scaled to higher level models, while behavioral and policy feedbacks from the socio-economic and institutional models can be used to drive lower resolution models and to assess impacts on the natural system. The integrated modeling approach can also be the basis for Decision Support Systems, simplifying complex systems to maintain the key overall processes and feedbacks, allowing numerous scenarios to be investigated in an efficient manner to inform specific management questions (Serrat-Capdevila et al. 2009, 2013b).

3.2. Disciplines centered on planning and governance analysis

3.2.1. Spatial and water planning

Spatial planning has been defined in different ways among countries in Europe, but it can generally be referred to physical land use planning. The European Environmental Agency (EEA, 2012) defines it as the systematic assessment of land and water potential, alternative patterns of land use and other physical, social and economic conditions, for the purpose of selecting and adopting land-use options which are most beneficial to land users without degrading the resources or the environment, together with the selection of measures most likely to encourage such land uses. Land use planning may be at broad levels such as international, national, district (project, catchment) or large urban agglomerations, and at local level such as villages. It includes participation of land users, planners and decision-makers and covers educational, legal, fiscal and financial measures (FAO/UNEP, 1998).

Experience in recent years in Europe shows that without the integration of water management measures into the process of land management and management of settlements development, both sustainable and efficient use of water and flood prevention cannot be achieved. European Water Framework Directive (WFD) tries to reinforce links between Spatial Planning and River Basin Management Plans (RBMP) but these connections are still weak (Woltjer, Al, 2007, EEA, 2012). Spatial planning can help to deliver River Basin Management Plan objectives by checking that proposed development does not cause deterioration of water bodies, ensuring that the scope of Sustainability Appraisal/Strategic Environmental Assessment for spatial plans includes impacts on water bodies, respecting the limits of the water environment when generating development options, and adopting spatial plan policies that will help to achieve ‘good status’ in water bodies.

In the United States of America Spatial, Planning is recognized as Comprehensive Planning. Accordingly with state laws (Arizona) and American Planning Association (2002), a Comprehensive Planning (local\regional) means the adopted official statement of a legislative body of a government (local\regional) that sets forth (in words, maps, illustrations, and/or tables) goals, policies, and guidelines intended to direct the present and future physical, social, and economic development that occurs within its planning jurisdiction and that includes an unified physical design for the public and private development of land and water. Sometimes comprehensive plans are known by other names including master plan, general plan, regional area plan and local government plan. For most of the places in the United States, it is the only planning document that considers multiple programs and that accounts for activities on all land located within the planning area (whether that property is public or private) (Kelly, 2010). In order to integrate Water and Comprehensive Spatial Planning, one needs to take into account the big diversity of the river basins in the European countries and in the United States.

Spatial planning has an important role to provide future scenarios as well as historical, institutional and territorial context to our methodological integrative effort. Coordination between water and spatial comprehensive planning can be the basis for the integration with all sectors planning. A Territorial Comprehensive Model and its strategic visions and goals can provide new scenarios in which to contextualize water management. More effort is needed to link spatial and water planning, and an integrative approach could provide a foundation for evaluation of the plans progress towards its desired objectives as well as monitoring territorial and social changes. Carter (2007) and the EEA Technical Report (2012) present a significant review of case studies and highlight potential synergies and obstacles for the integration of Spatial Planning and River Basin Management Plans in Europe.

On one hand, potential synergies include long term strategic focus and large areas, influences on a broad range of economic sectors that affect water consumption, pollution and impacts on water bodies, influences on the type and the location of new polluting or water use activities. Spatial Planning can incorporate water management goals, for example efficiency improvement measures in new housing developments at the local scale. Some dimensions of spatial planning are intrinsically linked to water, such as environmental assessments, flood risk management (2007 European Commission Floods Directive) and drought planning. On the other hand, potential obstacles in most European countries come from different focus on water, such as efficiency and restrictions in spatial planning versus requirements for the health of water bodies and the environment. Separated institutions, different administrative structures, and management traditions, are historical conditionings for a lack of connectivity. The differences between the boundaries of spatial planning (administrative) and river basins and aquifers, as well as the different timescales of planning horizons, the lack of shared knowledge and sufficient resources are all obstacles to integration.

Hartfield et al (2014) present an interesting collaborative academic-practitioner perspective of the dynamics of water supply and sanitation infrastructure and urban growth using spatial analysis from remote sensing observations and information from water utilities. Using advanced classification techniques, they create a multi-temporal (1984-2010) view of land cover change along the Tucson – Phoenix rapidly growing urban corridor. These classifications created multi-temporal maps of changing urban residential, urban commercial/industrial, agriculture, roads, bare ground, natural desert cover, riparian, and water. These data were then integrated into an ongoing analysis of changing urban and water policy and allocation within the region which provided an enhanced ability to evaluate the correlation of water availability and use, socio-economic drivers, and the direction and magnitude of land use/cover change.

3.2.2. Socio-technical systems and water governance

The study of water networks has been mainly focused on urban areas, following first studies on large socio-technical systems (Mayntz, Hughes, 1985) such as electricity (Hughes, 1985), transportation or gas (Tarr, Dupuy, 1988) in differentiated societies. These works produce an approach of territories which presupposes a static state of natural resources (watershed), and which is focused on the development and the management of the utilities (contracts, costs, urban governance, etc.). This approach consists in case studies of regional areas or, more frequently, city concessions: in a context of globalization, the research study the local markets of water, the consequences of privatization of the services (as part of a larger reform of the states), and urban management of the networks (Barraqué, 1995; Jaglin, 2001; Meublat, 2001; Schneier-Madanes, 2003). The urban monographs are mostly related to the impacts of national public policies (Barraqué, 2005), but they also describe the mobilizations of users to get back to public services. This approach of water networks permits to build the notion of socio-technical services that reveals to be very useful to understand the problems of water networks in urban areas.

Since the 1990’s, this approach has focused on the processes of privatization of water services. The implementation of contracts based on European (and mainly French) models has been used to study the emergence of a “global governance” of water that should have brought technical and economical solutions to the needs of developing countries. However, the many social conflicts that led to remunicipalization of water utilities have also become a growing source of interest since the 2000’s and the rise of international protests against the power of private companies. They have limited the studies on the legal dimension of the contracts, without giving sufficient attention to the social contexts of their application.

3.3. Frames of analysis of the interactions between ecosystems and society

3.3.1. Ostrom approach to Social-Ecological Systems

Social sciences have studied environmental issues from several perspectives: the perception of environmental problems, the analysis of decision making, the emergence of environmental justice or the construction of energetic and hydrologic networks. However, they have not paid much attention to the way social structures interact with ecosystems, and they have tended to develop simple theoretical models instead of taking into account the relational dynamics of human and natural worlds. Moreover, most of social science studies about water are focused on the way that socio-technical systems are built, on their management and their failures (with an important literature on the conflicts against privatization of water). One of the main challenges for social sciences is thus to bridge the gap with the natural/ecological conditions of water management (Martinez Allier, 2008).

An attempt to integrate natural/environmental sciences and social sciences has been developed by Elinor Ostrom (2009) in her writings about the sustainability of “Social-Ecological Systems” (SESs). SESs are composed of multiple subsystems (Figure 1) and internal variables within these subsystems at multiple levels. She shows that the “core challenge in diagnosing why some SESs are sustainable whereas others collapse is the identification and analysis of relationships among multiple levels of these complex systems at different spatial and temporal scales”. The analysis of SESs requires knowledge about specific variables and the relations between their component parts, which may be the separate objects of different disciplines, with different frameworks and models used to analyze their parts of the complex multilevel whole. A common, classificatory framework is thus needed to facilitate multidisciplinary efforts toward a better understanding of complex SESs.

Ostrom presented a multilevel framework for qualitative analysis of outcomes achieved in SESs: four interrelated first-level core subsystems of an SES that affect each other as well as linked social, economic, and political settings and related ecosystems (Cf. box 1). The subsystems are: (i) resource systems (e.g., a designated protected park encompassing a specified territory containing forested areas, wildlife, and water systems); (ii) resource units (e.g., trees, shrubs, and plants contained in the park, types of wildlife, and amount and flow of water); (iii) governance systems (e.g., the government and other organizations that manage the park, the specific rules related to the use of the park, and how these rules are made); (iv) users (e.g., individuals who use the park in diverse ways for sustenance, recreation, or commercial purposes). Each core subsystem is made up of multiple second-level variables (e.g., size of a resource system, mobility of a resource unit, level of governance, users' knowledge of the resource system), which are further composed of deeper-level variables.

A FRAMEWORK FOR SESs, BY ELINOR OSTROM

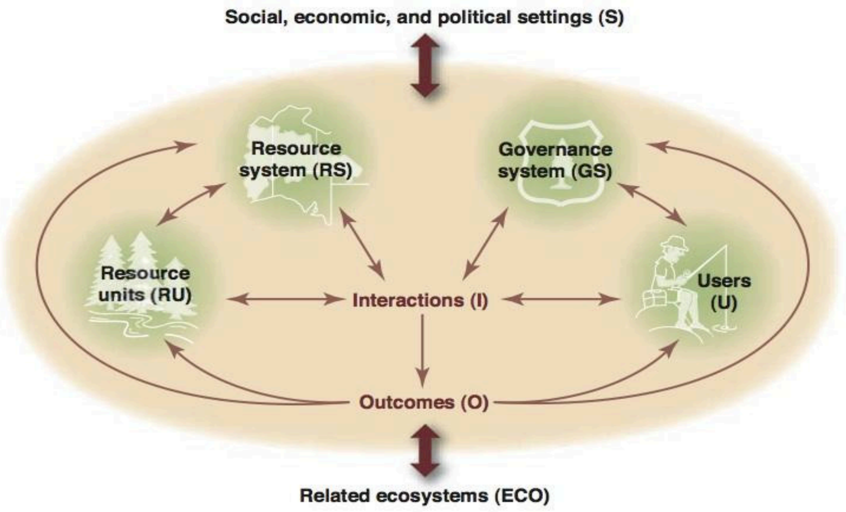

Figure 1. The core sub-systems of Elinor Ostrom's framework for social-ecological systems analysis (Ostrom, 2009)

This framework is useful in cumulating knowledge from various areas of research, and providing a common set of potentially relevant variables in order to collect data, conduct fieldwork or analyzing findings of various SESs. This model implies measuring variables and their interaction in order to study the relevant problem. It goes beyond an institutional analysis, by showing that the inequalities of access to utilities are not linked to "natural" demographic tendencies or to scarcity of natural resources, but to the effective management of natural resources and the economic models of their distribution. It allows the development of a sociological approach integrating the socially differentiated uses of water, in function of local contexts, urbanization trends and community lifestyles in relation with the structure of economic activities and of residential demands, etc.

However, the SESs model does not pay much attention to other important dimensions of social contexts and practices, especially to the neighborhood mobilizations for utilities, and to the socio-environmental conflicts they might generate. Many laws and norms promulgated to regulate water services are the product of conflictive processes where different lobbies act to reinforce their interests and legitimate them on a legal level (a dimension ignored by the SES model). The many environmental conflicts that have taken place in the Americas since the 19th century have been the object of numerous studies (Watson, 1993; Espeland, 1998). Water Wars in the West of USA, constitute a key field of research in terms of understanding the social conditions of water management, and especially the relations of power and the imposition of a vision of the world and of the good ways of administrating it, in conformity with the interests and way of life of dominant classes or groups of interest. As demonstrated by research published by Cronon, Worster (1985) or Riesner (1986), the West of the United States can be analyzed as a hydrological society fashioned by power relations and how hydrological imperatives have structured natural and human spaces. Pincetl (2011) shows as well that the appropriation of natural resources and their transformation into material goods (water to drink, food, etc.) is effectuated through institutional arrangements organized in certain patterns; each regime of accumulation entails a mode of nature appropriation that produces a dynamic resource landscape. The example of water projects in California highlights the difficulties to produce water sustainability, due to potential impacts of climate change on the hydrologic cycle, and to intensive urbanization (80% used by agriculture and demographic pressure to re-allocate water to urban areas).

One of the tasks of social sciences is to identify the different levels of regulation of water management: if in the American West, water is regulated by federal institutions since the 1902 Reclamation Act (water is considered as common good but agriculture is for the privileged user), one has to take into account the relations between federal regulation and the management local water districts. The water wheeling from Colorado River to San Diego County in California, for example, illustrates the transfer of the resource to urban areas by the commercialization of water, initiated not by the market but by the state. This process of “re-regulation of the social metabolism of nature is highly contingent of local variables” (Pincetl, 2011), especially of the local conflicts between the rural users and the urban water wholesalers, and of the power of local economic entities.

3.3.2. Ecosystem services

The topic of ecosystem services (ES) has attracted significant attention in the last decades. There are several national and international ongoing research initiatives in the field of ES such as MA (Millennium Ecosystem Assessment), TEEB (The Economics of Ecosystems and Biodiversity), IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services), RUBICODE (Rationalising Biodiversity Conservation in Dynamic Ecosystems), etc. (Burkard et al., 2012a, de Groot et al., 2010). The definition of ecosystem services to which we refer in this paper is from the 'Salzau Message' on Sustaining Ecosystem Services and Natural Capital (2010): "ecosystem services are the contributions of ecosystem structure and function - in combination with other inputs - to human well-being", where the "combination with other inputs" refers to the anthropogenic inputs in the natural systems which nowadays have increased considerably due to the technological development of humanity. The point is that ecosystems, ecosystem functioning, and ecosystem services are being threatened and degraded by human activities, and the situation will be exaggerated by climate change and biodiversity loss (Burkhard et al., 2012a).

Ecosystem services concept is an approach that integrates analysis of the ecosystems' functions and the benefits people derive from them. It studies the human-environmental systems in a manner that provides qualitative and quantitative data that is crucial for the better understanding of the consequences of human activities on nature and humanity. Its analysis methods develop in a way that provides more efficient and comprehensive data on the interactions between these systems. The approach gives the opportunity for identification, quantification and assessment of the ecological and socio-economic trade-offs and synergies on which decision-making should be based (Burkhard et al., 2012a, 'Salzau Message').

The classification of ecosystem services is structured in three main groups: provisioning, regulating and cultural. Some of them, such as water flow regulation (regulating) – maintaining of water cycle features such as water storage and buffer, natural drainage, flood regulation, irrigation and drought prevention,, water purification (regulating) - the capacity of ecosystems to purify water from sediments pesticides, disease-causing microbes, and freshwater (provisioning) - used freshwater for drinking, domestic use, irrigation, industry, etc. (Kandziora et al., 2013), are directly related to the water resources - water-related. Those are the services that contribute to water quantity and quality in certain time and location. Watersheds' borders are accepted to provide an appropriate spatial scale for analysis with focus on the water cycle, being functional entities. Furthermore, there is a big list of other services that are directly dependent on water resources, such as for example food and energy provision, local and global climate regulation, recreation. The trade-off analysis on different services for a certain area may be useful tool for decision-making.

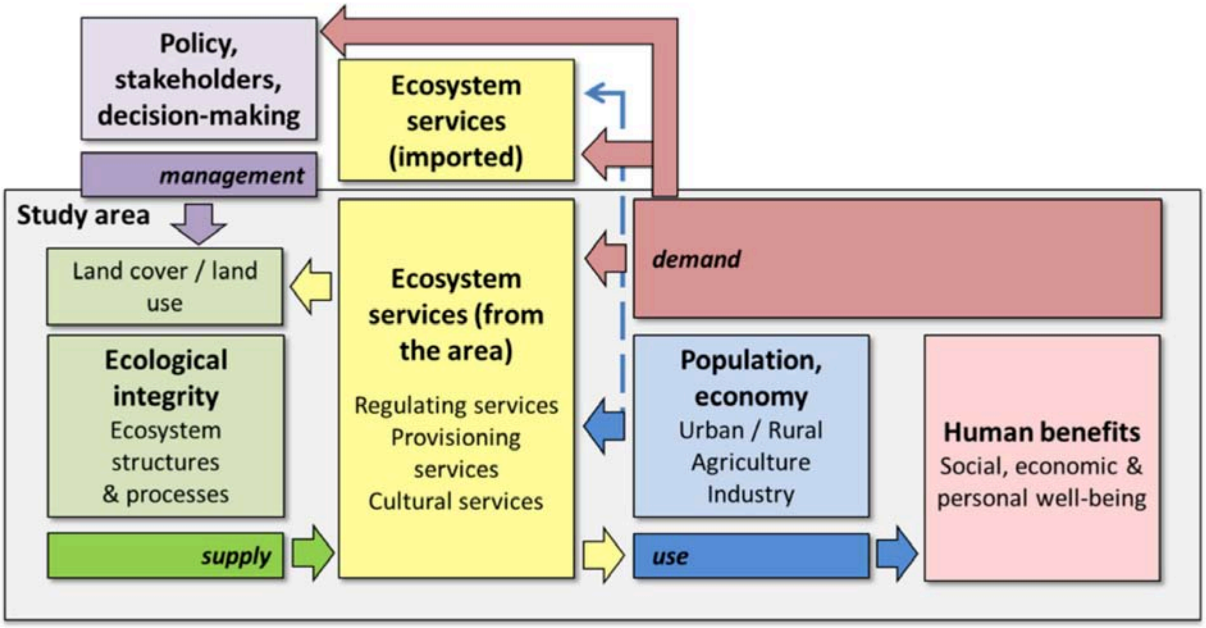

Figure 2. Conceptual framework linking ecosystem integrity, ecosystem services and human well-being as supply, use and demand sides in human–environmental systems. Adapted after Burkhard et al., 2012b.

The *supply* of ecosystem goods and services is assessed on regional level and it refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services (Figure 2). The *capacity* is the actually used set of natural resources and services that is generated in the area. Therefore, an ES supply map for a certain region visualizes only the provided goods and services that are generated within the borders of the same region – the flow of service within the ecosystem. For the provisioning services there is very often also flow of services from outside the ecosystem (e.g. food provision), while many regulating services on regional level cannot be transported, thus ES providing and benefitting areas have to be physically connected (e.g. flood regulation). The supply is directly determined by the regional ecological integrity of the ecosystem and the structures and processes within it, which are strongly influenced by human actions and decisions such as land cover change, land use and technical progress. Because of this, land cover/land use classifications provide appropriate reference unit for ecosystem service assessment and application in decision-making. The *used* services are the one that are currently consumed in a particular area, but not necessarily supplied by it. Human well-being depends on the benefits derived from the actual use of ecosystem goods and services (Burkhard et al., 2012b). The *demand* for ES is the requirement for optimum realization of a specific activity.

For example, in the case of freshwater provision service, *used* water is the total volume of water that an activity, sector, consumer, etc. receives. The transportation water losses should be excluded: use = abstraction - transportation water losses. The *supply* of freshwater ecosystem service is the volume of used water that comes from the region. The demand for freshwater service refers to the requirement for optimum realization of a specific activity, sector, consumer, etc. (for instance water requirements for crops). The quantitative assessment and mapping of supply, use and demand for a certain area provides visualization and quantitative measure of ES flows (through supply and use maps for an area), critical areas (where demand exceeds use indicating lack of services) and dissipate areas (where use exceeds demand, indicating overconsumption).

Moreover, ecosystem services analysis can help clarifying modeling or other kind of quantitative data, making them more accessible and understandable for practitioners and policy makers. Quantifying, modeling and mapping ecosystem services have become major issues for the ecosystem service concept's application. Mapping is a good tool for representing spatial data, as maps are perceivable and intuitive. The European Union's new Biodiversity Strategy to 2020 puts the task on its member states to map and assess ecosystem services on national levels until 2014. The resulting data will be used for assessing the economic values of ecosystem services and their integration into the European Union's and national accounting and reporting systems by 2020. This is a big challenge for scientists and decision makers.

Methods for quantification of water-related ecosystem services are many and diverse. The assessment can be based on results from hydrological modeling (Nedkov & Burkhard, 2012) or other quantitative methods (Kroll et al., 2012), ecosystem services modeling – InVEST, ARIES, etc. (look: Vigerstol & Aukema, 2011), analysis of spatial and statistical data (Kroll et. all, 2012), expert valuation (Burkhard et al., 2012b, Burkhard et al., 2009), participatory approaches – interviews, participatory mapping, etc.

3.3.3. Societal Metabolism

Grounded in complex systems theory, the societal metabolism concept refers to the processes of appropriation, transformation and disposal of energy and materials in order to sustain a given identity of a socio-ecological system (Martinez-Alier and Schlüpmann, 1987, Giampietro et al 2011). These are considered as hierarchical systems (Ahl and Allen 1996) operating at multiple levels of organization and thus multiple spatial and temporal scales. Societal levels perform at shorter temporal scales framed by wider ecological context. Ecosystems pose the external constraints to societal metabolism, since certain thresholds of ecological integrity cannot be surpassed if the whole system is to be maintained (Madrid et al 2013). Institutional and political organization pose the internal constraints, since they express the desirability of specific metabolic patterns (behavioral patterns of the systems in terms of resources use to maintain their structure and functioning). These constraints show themselves as non-linear interactions along multiple scales. In the case of water, several hierarchical levels need to be considered for a holistic analysis of water metabolism: the water cycle, the ecosystems, the society and the interface between them, the social management of water availability.

The Multiscale Integrated Analysis of Societal and Ecosystems Metabolism (MuSIASEM) has been developed (Giampietro and Mayumi 2000; Giampietro et al 2009, 2011) as a multicriteria quantitative analysis of metabolic patterns for wider integrated assessment of sustainability (Giampietro, Mayumi and Munda, 2006). Based on the flow-fund model (Georgescu-Roegen, 1971), it moves forwards in the conceptualization of natural resources as stock and flows, introducing the concept of funds as variables representing the identity of the system and thus having to be maintained by the use of flows. Fund variables (those remaining the same in the representation) describe the structure and size of the system while flow variables (those changing in the representation) describe its functioning. The combination of these two dimensions generates metabolic indicators (flow/fund intensity ratios of resources use). These variables are quantified from lower levels (individuals, specific economic activities) until the whole social system that interacts with wider levels indicators of ecological performance. Water is considered a flow for social systems, because it provides services to multiple activities, and a fund for ecosystems, because it is the pattern of water availability on earth what shapes ecosystems distribution and if ecosystems identity is to be maintained this pattern has to be stable.

The relevance of MuSIASEM is the capacity to integrate information coming from non-equivalent descriptive domains (different models from different scientific disciplines at different scales) regarding a variety of context-specific relevant variables: energy, water, land use, economic performance, and to check the feasibility of policy scenarios in terms of internal and external constraints. If MuSIASEM was originally designed to analyze agroecosystems (Giampietro, 2003), many applications have been developed for rural systems and poverty analysis (Serrano and Giampietro 2009, Arizpe, Giampietro and Ramos-Martin, 2011, Scheidel, 2013). A second chief line is energy use analysis at macroscale (Ramos-Martín et al. 2009, Giampietro et al 2012, Diaz-Maurin and Giampietro 2013, Sorman and Giampietro 2013). Its application to water use (Figure 3) is a more recent branch (Madrid and Cabello 2012). Current studies are being undertaken at local (urban), regional (river basin) and national (economy-wide) levels. For these purposes, specific integrated sets of indicators have been developed including Water Use Rate (WUR m^3/hour of human activity), Water Use Density (WUD m^3/ha of land used), Water Monetary Productivity (WMP €/m^3 of water supplied), Water Energy Intensity (WEI Kwh/m^3 of water supplied), Ecosystems Water Requirements (EWR ha of land/m^3 of water or million m^3/year for aquatic ecosystems).

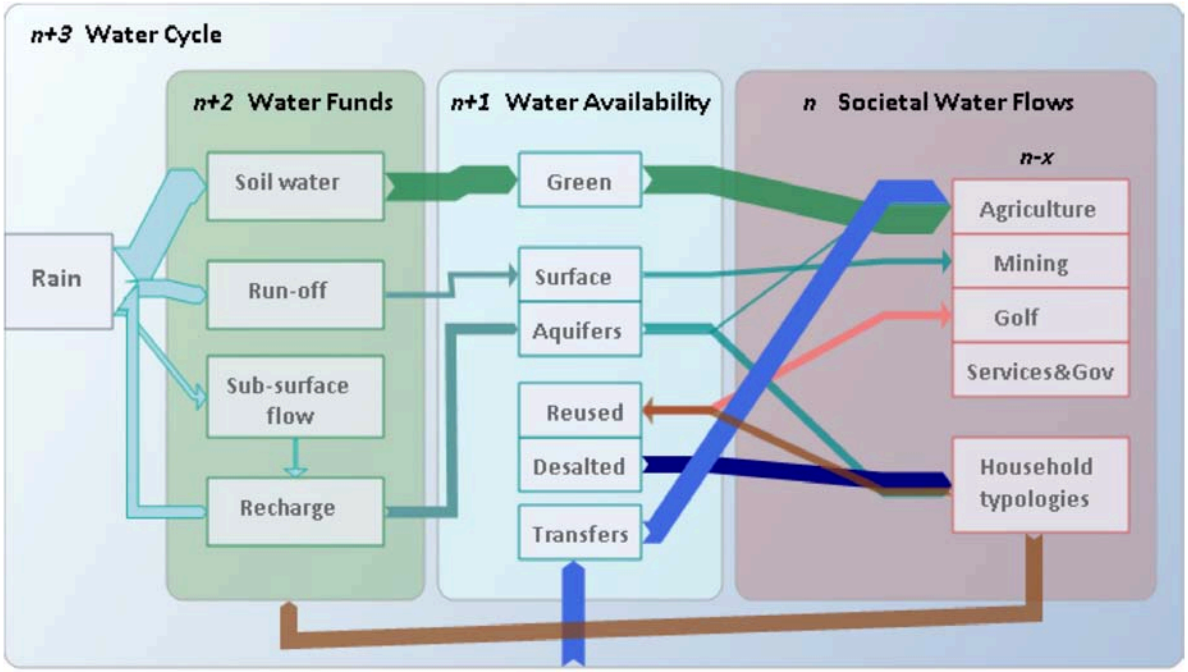

Figure 3. Framework for multi-scale analysis of societal and ecosystems metabolism of water.

3.3.4. The Water Footprint and Virtual Water Trade

The virtual water is defined as the water embedded in agricultural products, which generates a "virtual" flow of water through trade of these products (Allan 1997; 1999). Virtual water trade is seen as a new perspective to achieve an integrated water resource management, particularly for water scarce regions. Authors have claimed that drought effects can be mitigated (Allan, 1999) and the unequal spatial distribution of global water resources can be compensated (Islam *et al.*, 2007) by virtual water trade. Nevertheless, the virtual water trade cannot be used alone as a criterion for selecting optimal trading strategies (Wichelns, 2010). Some authors vindicate that the discourse promoting both the concept of VW and the methodologies used to estimate VW flows is structured according to some underlying ideas that are framed within market logic and the rationality of international trade (Velazquez et al. 2011).

Related to the concept of virtual water, the water footprint (WF) analyses the appropriation of water resources by human societies and computes only the consumptive, or non-reusable, water associated with a specific use or process (Hoekstra et al., 2011). The main strength of this tool is to show the weight of consumption patterns and global dimensions in water governance, although it also requires to be complemented with additional analysis or indicators in order to achieve integrated policy options (Vanham and Bidoglio, 2013). Studies have addressed the WF of a variety of crops and food products such as olive oil (Salmoral et al., 2011a) and sugar-containing water beverages (Ercin et al., 2010), populations within nations (Chapagain and Hoekstra, 2004; van Oel et al., 2009) or other geographical areas such as watershed level (Dummont et al., 2013).

Three water color components are distinguished in the WF assessment: 1) the blue water (surface and groundwater) , 2) the green water (rainwater stored as soil moisture), and 3) the grey water footprint that refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. Traditional water planning has been focused on blue water although it has been argued that this conventional approach is incomplete towards more integrated water and land policies (Falkenmark et al., 2006), since green water comprises a critical role in food production and support for terrestrial ecosystems. Beyond water accounting, other authors (Garrido et al., 2010; Salmoral et al., 2011b) provide an "extended" WF calculation including economic indicators for irrigation water (€/m^3) and agricultural land productivity (€/ha), which are in the same line as indicators used in MuSIASEM methodology.

The WF of a delimited geographic area (i.e. catchment area) can be studied from different perspectives. The *WF of consumers* in the catchment comprises the internal water consumption from products and services generated in the catchment, plus imported virtual water. Looking only at the imported virtual water, one can determine how dependent on imports a region is, particularly for food, and highlight environmental and economic implications at the production site. The *WF within the catchment* includes the internal water footprint plus related virtual water exports. The analysis can be done with a top-down approach, based on production and trade data, or bottom-up approach according to direct consumption data. A further overview is the integration of the *WF within the catchment* in hydrological modeling (Salmoral, 2011). This procedure allows for distinguishing water storage and consumption with spatial and temporal resolution. An example of summarized results of the WF within the hydrological cycle are shown in Figure 4.

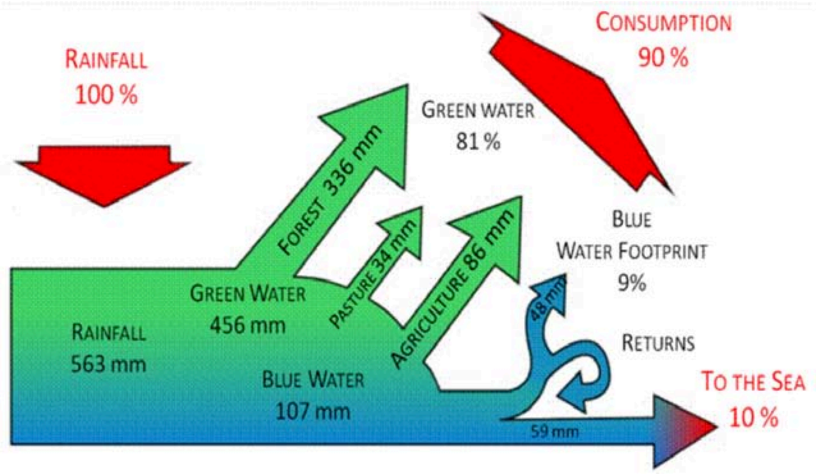

Figure 4. The WF within the hydrologic cycle (inspired by Falkenmark, 2009). Values correspond for a normal climatic year. Source: Salmoral et al. (2011).

At river basin scale, the blue and grey WF components can be called environmentally sustainable when they do not have negative impact on environmental flows and standard water quality of the rivers (Ridoutt and Pfister, 2010; Hoekstra et al., 2011). The Environmental Flow Requirement (EFR), in particular, represents an amount of water that is kept flowing down a river in order to maintain quality, quantity and temporality required for environmental goals, taking into account what local people uses for the river and what river condition is acceptable from them (O'Keefe et al., 2009). This could also be applied on groundwater comparing the actual water abstractions in relation to the natural aquifer recharge. The positive evaluation of the blue WF depends on the reference flows established for the basin or if the blue WF values are less than blue water available for consumptive water use. The assessment of grey WF, in turn, considers the pollution level occasioned by the point/non-point sources, comparing the river dilution capacity, represented by the total river discharge, and the grey WF values estimated for specific water quality standards (Hoekstra et al., 2011).

In this way, spatially and temporally assessment of WF components against environmental indicators allows the identification of hotspots, which refer to a period of the year (e.g. dry period) and a specific sub-basin, when quantitative or qualitative water requirements are violated. Consequently, the hotspots are likely to present problems of water scarcity or conflicts and can be useful for the basin management (Hoekstra et al., 2011, 2012).

4. INITIAL TIPS FOR METHODS INTEGRATION

This section discusses how the effect of human demands can be successively tied to demands on ecosystem services, to water budget components, to hydrologic processes and functions, to climate, and finally to feedbacks between climate and land use cover, which again is strongly influenced by spatial planning and social uses of water. In other words, we describe a potential integration of the previously described approaches in which each methodology poses feedbacks from/to the others, not only between variables and indicators but also between concepts. This integration will help to understand the synergies and overlaps among them. Combining physical and water-centric modeling with social sciences, the goal of a transdisciplinary and integrative methodology the quantitative and qualitative research required for a meta-framework of analysis of water management in socio-ecological systems (Figure 5).

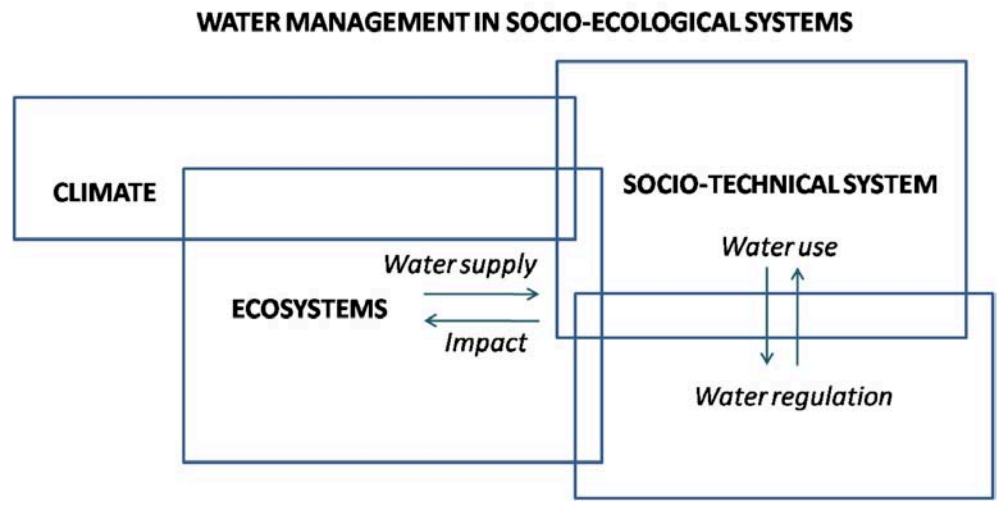

Figure 5. Simplified Conceptual framework for integration of approaches

In this integrative effort, atmospheric and hydrologic modeling provide information regarding the functioning of the physical environment. Atmospheric variables such as precipitation, specific humidity, snow cover, etc. are basic input data to run hydrologic models to generate hydrologic outputs (i.e. actual evapotranspiration, streamflow, groundwater recharge, soil water content). This data is important to relate water availability changes to human well-being. By processing climate change projections through hydrologic models (Rajagopal 2011; Rajagopal et al 2011, Serrat-Capdevila et al. 2007, 2011a, 2013a), future hydrologic states under climate change conditions can be generated. These can be used for water management purposes such as drought planning, development of water supply planning scenarios, connections to agricultural and other use activities, and evaluation of management options that optimize flood protection and water availability.

Hydrological models generate quantitative data with spatial and temporal scale, and in some cases qualitative characteristics of the hydrological attributes and the ability of hydrological systems to supply ecosystem services. Therefore, models can provide detailed hydrological assessments as long as appropriate input data and expertise are available (Vigerstol and Aukema, 2011). The ecosystem services assessment allows managers to have easy access and comprehensive information during decision making about land use and water related services (i.e. visualization of flood control areas by level of flood risk). Comprehensive sets of indicators are needed for integrated assessments, and they need to be selected systematically in order to reflect ecosystem properties, ecosystem functions and ecosystem services, as well as to represent land management as a main driving force for land use change (Burkhard et al., 2012a). Deriving and choosing appropriate indicators from hydrological model results is needed in order to properly quantify water-related ecosystem services. The indicators are chosen depending on the ecosystem services that have been quantified. For example climatic indicators (i.e. precipitation, temperature, albedo, etc.) provide information regarding the ecosystem service *local climate regulation*. Potential indicators for *water flow regulation* are groundwater recharge rate (mm/ha*a), infiltration (mm; m3/km), runoff (mm; m3) and peak flow (mm/hr; m3/s). For *water purification* different water quality indicators: sediment load (g/l), total dissolved solids (mg/l), N (mg/l), P (mg/l), etc. *Provisioning ecosystem service for freshwater* is account with withdrawal of freshwater (l/ha*a, m3/ha*a) (Kandziora et al.,2013).

The approaches for studying the demand for ecosystem services are much less developed than the ones for supply. In this sense, societal metabolism and water footprint assessments provide much better understanding on this side of coupled human-environmental systems. The ecosystem services framework is suitable to connect ecosystems' water-related services to societal metabolic demand of those services. A complete MuSIASEM scheme for water requires the integration of both eco-hydrological and climatic data to describe upper levels of ecosystem metabolism (ecosystems water requirements on the supply side, ecological status of water bodies on the sink side). The different water flows taken from the ecosystems will be followed through the social structure using demographic, labor and economic data in order to assess how these are combined with labor and other resources to produce goods and well being. Water planning scenarios can be used to assess different trade-off solutions for a sustainable balance between human-use and ecosystem health. Institutional configuration of water rights and management plans is essential for a proper definition of the constraints of each scenario.

Green and blue WF figures for agricultural and natural areas will vary based on precipitation and evapotranspiration data gathered from climate models. The water accounting in WF determines the water appropriation of main water users: agriculture, urban, industry and tourism. The assignation of green water for human appropriation is more complicated. In parallel to human activities, land use associated to green water consumption sustains agricultural and natural areas. The repartition between human and ecosystems uses, basis for the WF definition, is even more complex with the ecosystems service concept, since the multiple values for humanity generated by ecosystems could finally be considered also as human appropriation (Dummont et al., 2013). For the integration of the WF analysis in the hydrological cycle, the total available volume of blue water in a watershed comprises the definition of available water resources by the traditional hydrological planning and can be determined as the sum of water yield and deep aquifer recharge. The blue WF accounts for evaporation from reservoirs, irrigation for agriculture and water consumption from urban and industrial areas. Green water storage determines the water availability in soils' root zone, which is a critical component for plant and primary production. The green water storage can be calculated subtracting the blue water from precipitation. The difference between the initial and final soil moisture of each simulated year is considered as the variation of green water storage. The variation of green water and green water storage sums up the total green water consumption of a watershed. This value is equivalent to the evapotranspiration.

Ecosytem Services, Social Metabolism and Water Footprint are three approaches developed to respond to the same scientific challenge: understand how human activities interact with ecosystems, thus have many overlaps. Nevertheless, the conceptual metaphors behind are different and thus each of them highlight some perspectives and objects of analysis while hide others, and their combination and comparison will support their further development as frameworks. While ecosystems services focus on the benefits obtained by society from ecosystems (Raymond et al 2013), societal metabolism is based on systems autopoiesis (Maturana and Varela 1971) (i.e. societal requirements to maintain and reproduce itself and which ecological thresholds can't be surpassed to guarantee this reproduction). Similarly to the ecological and carbon footprints (Rees, 1992; Wiedmann and Minx, 2007), the WF addresses the appropriation of water resources by humanity. It represents an innovative approach introducing the metaphor of virtual water (water embedded in a product) leading to analysis of water equity and food security through virtual water trade, as well as the impacts created on ecosystems by consumers choices.

The institutional analysis of common pool resource management developed by Ostrom can help to understand how human groups organize themselves to face resource management problems and to arrange collective responses (Ostrom 1990, 2009). By studying which are the specific rules of organization, different management systems can be compared towards their success in guaranteeing a sustainable resource exploitation. The conflict dimension is a transversal one to the institutional issues, emphasizing how these magnify/ameliorate inequalities in resources access/conservation and which are society's responses to them. Water and land planning integration are a further institutional analysis at a higher scale of organization, which feeds from all the approaches and at the same time constitutes their normative frame, in continuous updating and adaptation. Water management plans provide information regarding management goals, future scenarios of water use, measures to meet new water demands etc. Land planning is the main driver of land use change, core feedback for the rest of the quantitative approaches. Therefore, building realistic scenarios and assessing their social viability and their biophysical feasibility requires detailed analysis of both water and land planning.

In order to further embed the scientific process within the broader exercise of water management, proper participatory processes should be arranged with decision-makers of the issues being researched. There are many participatory planning and research approaches that can provide guidance to define and structure the problems to be analyzed, to identify relevant stakeholders to engage, and to establish a collaborative process for a fruitful post-normal science practice. Scientific questions should be validated by a stakeholder community from the very beginning and continuous dialogue and feedbacks maintained until the final assessment of scientific results.

5. CONCLUSIONS

This paper proposes an integration of human-centric approaches that look at human water demand, use and impact, with physico-centric approaches that provide understanding of climate, hydrologic and environmental processes. The presented approach provides: i)a new way of assessing feedbacks and linkages between fields of research that have been disconnected until now , ii) a comprehensive planning and, iii) water governance processes. In summary, we presented a meta-framework that can relate (a) human behavior and the way water is used, governed and organized with (b) specific water budget components and footprints, ecosystem functions, environmental impacts, climate, land use change, and social parameters.

This integrated approach is a first step that provides theoretical outlines for a new integrated framework. A second step would consist in defining not only relations between disciplines or paradigms but also key questions and specific methodologies. Furthermore, this transdisciplinary approach should be articulated with case studies and collaborations with stakeholders. To this end, it will be necessary to define new scientific practices on water issues, as the debates initiated by post-normal science have encouraged them. The added value of such a framework might be constituted by another way of understanding and practicing water management beside today's top-down decision-making processes and the current institutionalized but somewhat limited "participation" in water management and planning. It would be a way to provide the bottom-up feedbacks from changes in the way people decide to change their water footprint, their imposed needs on ecosystem services and functions, their needs on water resources and their influence in climatic feedbacks through their choices on land and energy use.

While technology has pushed societies forward in terms of extracting resources, processing and combining them to produce wealth, the same science that enabled such technology has constantly struggled to advance our understanding of how new technological tools would impact relationships with the environment and how to manage such interaction. Acknowledging the need for an evolving science with new schools of thought to analyze environmental issues, this paper is an effort to provide an integrative analysis to keep up with observed growing levels of complexity in social-ecological dynamics. More effective strategies are needed to deal with present and soon to come ecological problems.

6. REFERENCES

AhValerl Ie, Allen T. F. H. (1996) *Hierarchy Theory: A Vision, Vocabulary, and Epistemology*. Columbia University Press.

Allan, T., 1997. Virtual water: a long term solution for water short Middle East economies? British Association Festival of Science. In: water and development session, University of Leeds, United Kingdom.

Allan, J. A. (1999). Global systems ameliorate local droughts: water, food and trade. Occasional Paper No. 10, Water Issues Study Group, School of Oriental and African Studies, University of London, UK.

American Planning Association (2002) *Growing Smart Legislative Guidebook 3: Model Statutes for Planning and the Management of Change.* (S. Meck, Ed.). American Planning Association Planners Press.

Arizpe N., Giampietro M., Ramos-Martin J. (2011) Food Security and Fossil Energy Dependence: An International Comparison of the Use of Fossil Energy in Agriculture (1991-2003). *Critical Reviews in Plant Sciences*, 30 (1-2): 45-63. doi:10.1080/07352689.2011.554352.

Bakker K. (2011) *Privatizing Water. Governance Failure and the World's Urban Water Crisis*, Ithacca and London, Cornell University Press.

Brookshire D, Gupta H., Matthews P. (Eds) (2012), *Improving New Mexico Water Policy And Management by Coupling Science, Modeling and Institutions*, RFF Press, Resources for the Future Book Series: Issues in Water Resources Policy Series.

Burkhard B., Groot R. de, Costanza R., Seppelt S. E., Potschin M., (2012a) Solutions for sustaining natural capital and ecosystem services. *Ecological Indicators* 21: 1-6.

Burkhard B., Kroll F., Nedkov S., Müller F. (2012b) Mapping of ecosystem service supply, demand and budgets. *Ecological Indicators* 21: 17-29.

Burkhard B., Kroll F., Müller F., Windhorst W., 2009. Landscapes capacities to provide ecosystem services – a concept for land-cover based assessments. *Landscape Online* 15: 1–22.

Carter, J. G. (2007) Spatial planning, water and the Water Framework Directive: insights from theory and practice. *Geographical Journal*, 173(4): 330–342. doi:10.1111/j.1475-4959.2007.00257.x

Changnon S.A., Semonin R.G., Auer A.H., Braham R.R., Hales J., 1981. *METROMEX: A review and summary*. Meteor. Monogr. 40, Amer. Meteor. Soc., 81 pp.

Chapagain A. K., Hoekstra A. Y. (2004). *Water Footprints of Nations*. Vol. 1. (Value of W.). UNESCO-IHE.

Chapagain A.K., Hoekstra A.Y., Savenije H.H.G. (2006) Water saving through international trade of agricultural products. *Hydrol Earth Syst Sci* 10, 455-468.

Crutzen Paul J., Stoermer, Eugene F., (2000) « The “Anthropocene” », *Global Change, NewsLetter*, n° 41, p. 17-18.

Groot R. S. de, Alkemade, R., Braat, L., Hein, L., Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7: 260-272.

Diaz-Maurin F., Giampietro M. (2013) A “Grammar” for assessing the performance of power-supply systems: Comparing nuclear energy to fossil energy. *Energy* 49: 162-177. doi:10.1016/j.energy.2012.11.014.

Diem J. E., Brown D.P. (2003). Anthropogenic impacts on summer precipitation in central Arizona, U.S.A., *Prof. Geogr*. 55: 343–355.

Dumont, A., Salmoral, G., & Llamas, M. R. (2013). The water footprint of a river basin with a special focus on groundwater: The case of Guadalquivir basin (Spain). Water Resources and Industry, 1-2, 60–76. doi:10.1016/j.wri.2013.04.001

Ercin A.E., Aldaya M.M., Hoekstra A.Y. (2010) Corporate Water Footprint Accounting and Impact Assessment: The Case of the Water Footprint of a Sugar-Containing Carbonated Beverage. *Water Resources Management*. 25: 721–741.

Espeland W. N. (1998) *The Struggle for Water. Politics, Rationality and Identity in the American Southwest*, Chicago & London, University of Chicago Press.

Environment Agency, *Spatial planning and the Water Framework Directive* http://www.environment-agency.gov.uk/research/planning/40195.aspx

European Environment Agency (EEA) (2012): *Territorial cohesion and water management in Europe: the spatial perspective.* Luxemburgo: Publications Office of the European Union. Retrieved from: http://www.eea.europa.eu/publications/territorial-cohesion-and-water-management

Falkenmark, M., Rockström, J. (2006) The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management. *Journal of Water Resources Planning and Management* 132: 129–132.

Falkenmark M. (2009) Water for a Starving world: time to grasp the 1977 war-ning. Presentación 4º Seminario de Aguas: Seguridad hídrica y alimentaria. Seminarios internacionales del Observatorio del agua de la FMB.

FAO/UNEP: Choudhury K., Jansen J.M. (Eds.). (1998) *Terminology for integrated resources planning and management.* Food and Agriculture Organization of the United Nations.

FAO (2009). How to Feed the World in 2050. FAO.

FAO (2011). *The state of the world´s land and water resources for food and agriculture (SOLAW) - Managing systems at risks*. Food and Agriculture Organization of the United Nations, Rome and Earthscan. London.

Foley J.A., Ramankutty N., Brauman K.A., Cassidy E.S., Gerber J.S., Johnston M., Mueller N.D., O'Connell C., Ray D.K., West P.C., Balzer C., Bennett E.M., Carpenter S.R., Hill J., Monfreda C., Polasky S., Rockström J., Sheehan J., Siebert S., Tilman G.D., Zaks D.P.M., 2011. Solutions for a cultivated planet. *Nature* 478, 337–342

Funtowicz, S.O. and Ravetz, J.R. (1991). "A New Scientific Methodology for Global Environmental Issues." In *Ecological Economics: The Science and Management of Sustainability*. Ed. Robert Costanza. New York: Columbia University Press: 137–152.

Funtowicz, S. O., and Ravetz, J. R. (1993). Uncertainty and quality in science for policy, Dordrecht: Kluwer.

Funtowicz, S., Ravetz, J.R. (1994) The worth of a songbird: ecological economicsas a post-normal science. Ecological Economics 10 (1994) 197-207

Garrido A., Llamas M. R., Varela-Ortega C., Novo P., Rodríguez-Casado R., Aldaya M. M. (2010) *Water Footprint and Virtual Water Trade in Spain*, Springer.

Georgescu-Roegen N. (1971) The Entropy Law and the Economic Process. in Giampietro, M. (2003) *Multi-Scale Integrated Analysis of Agroecosystems*. 1.a ed. CRC Press.

Giampietro M., Mayumi K., (2000) Multiple-scale integrated assessment of societal metabolism: Introducing the approach. *Population and Environment* 22 (2): 109-153.

Giampietro, M., Mayumi K., Munda G. (2006) Integrated assessment and energy analysis: Quality assurance in multi-criteria analysis of sustainability. *Energy* 31 (1): 59-86. doi:doi: DOI: 10.1016/j.energy.2005.03.005.

Giampietro M., Mayumi K., Ramos-Martin J. (2009). Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy* 34 (3): 313-322. doi:doi: DOI: 10.1016/j.energy.2008.07.020.

Giampietro M., Mayumi K. Sorman A. (2011) *The Metabolic Pattern of Societies: Where Economists Fall Short*. Routledge.

Giampietro M., Mayumi K., Sorman A. (2013) *Energy Analysis for a Sustainable Future: Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism*. (1st Edition) Routledge.

Gloor M. *et al.* (2012). The carbon balance of South America: a review of the status, decadal trends and main determinants. *Biogeosciences*, 9 (12), 5407–5430.

Grossman-Clarke S. *et al*., (2010) Contribution of Land Use Changes to Near-Surface Air Temperatures during Recent Summer Extreme Heat Events in the Phoenix Metropolitan *Area. Journal Of Applied Meteorology And Climatology* V: 49, I: 8: 1649-1664. DOI: 10.1175/2010JAMC2362.1

Global Water Partnership (2000) Towards Water Security: A Framework for Action. Stockholm, Sweden and London, United Kingdom. ISBN 91-630-9202-6.

(http://www.gwp.org/Global/ToolBox/References/Towards water security. A framework for action. Mobilising political will to act (GWP, 2000).pdf)

Hartfield, K., Schneier-Madanes, G., Marsh, S., Curley, E. (2014) Remote Sensing of Urban Change: Water and Urban Growth in the Sun Corridor of the US Southwest. Sustainable Water ActioN (SWAN) Report - Working Paper.

Hoekstra A.Y., Chapagain A.K., 2008. Globalization of water: sharing the planet's freshwater resources. Blackwell Publ, Oxford, UK.

Hoekstra A. *et al.* (2011). *The Water Footprint Assessment Manual: setting the global standard*, London: Earthscan.

Hoekstra A. Y., Mekonnen M. M., Chapagain A. K., Mathews R. E., Richter B. D. (2012), Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability, *PLoS ONE* 7(2), e32688, doi:10.1371/journal.pone.0032688.

Hughes Th., 1985. *Networks of Power. Electrification in Western Society (1880-1930)*. Baltimore and London, Johns Hopkins University Press.

IMECHE (2013). *Global food waste not, want not*. Institution of Mechanical Engineering. London, UK.

Islam M.D., Oki T., Kanae S., Hanasaki N., Agata Y., Yoshimura K. (2007) A grid-based assessment of global water scarcity including virtual water trading. *Water Resources Management* 21, 19-33.

Jasanoff S. (2007) *Designs on Nature. Science and Democracy in Europe and the United States*, Princeton & Oxford, Princeton University Press.

Kandziora M., Burkhard B., Müller F. (2013). Interaction of ecosystem properties, ecosystem integrity and ecosystem service indicators – A theoretical matrix exercise. *Ecological Indicators* 38: 54-78.

Kelly E.D. (2010) *Community Planning: An Introduction to the Comprehensive Plan.* 2nd Edition. Island Press.

Kroll F., Müllera F., Haaseb D., Fohrera N. (2012). Rural–urban gradient analysis of ecosystem services supply and demand dynamics. *Land Use Policy* 29: 521– 535.

Lafont B. (2009) *Eau, pouvoir et société dans l'Orient ancien : approches théoriques, travaux de terrain et documentation écrite* In : *Stratégies d'acquisition de l'eau et société au Moyen-Orient depuis l'Antiquité*. Beyrouth : Presses de l'Ifpo: http://books.openedition.org/ifpo/1256

Lansing J. S, de Vet, T. (2012) The Functional Role of Balinese Water Temples: A Response to Critics. *Human Ecology*, 40 (3): 453-467

Liu Y., Gupta H., Springer E., Wagener T. (2008). Linking science with environmental decision making: experiences from an integrated modeling approach to supporting sustainable water resources management. *Environmental Modelling & Software* 23 (7): 846-858.

Madrid C., Cabello V. (2011). Re-opening the Black Box in Societal Metabolism: The Application of MuSIASEM to Water. Working Paper. Nov.4. http://www.recercat.net/handle/2072/172087.

Madrid C., Cabello V., Giampietro M. (2013) Water-Use Sustainability in Socioecological Systems: A Multiscale Integrated Approach. *Bioscience* 63 (1): 14-24.

Martinez-Alier, J., Schlüpmann, K. (1987) *Ecological economics: energy, environment, and society*. Basil Blackwell.

Martinez-Alier, J. (2008) Conflictos ecologicos y justicia ambiental, *Papeles*, 103: 11-27. http://www.fuhem.es/media/ecosocial/file/Analisis/enero 2009/Conflictos ecologicos_J. MARTINEZ ALIER.pdf

Koïchiro M. (2007) *Signons la paix avec la Terre*, Paris, Unesco.

Manning J. (2002) Irrigation et État en Égypte antique, *Annales. Histoire, Sciences Sociales* 3: 611-623.

Ministry of Housing, Spatial Planning and the Environment, Ministry of Transport, Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality, and Ministry of Education, Culture and Science (Netherlands) 2009. *Designing on the interface between water and spatial planning. Guide and Examples*. The Hague, Netherlands: The Ministry of Housing, Spatial Planning and the Environment with the Ministry of Transport, Public Works and Water

Management, the Ministry of Agriculture, Nature and Food Quality and the Ministry of Education, Culture and Science. http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2009/02/01/designing-on-the-interface-between-water-and-spatial-planning.html

Munda G. (1995) *Multicriteria Evaluation in a Fuzzy Environment: Theory and Applications in Ecological Economics*, Physical Verlag, Heidelgberg.

Nedkov, S., Burkhard B. (2012) Flood regulating ecosystem services – mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21: 67–79.

Nilsson M., Persson Å. (2012). Can Earth system interactions be governed? Governance functions for linking climate change mitigation with land use, freshwater and biodiversity protection. *Ecological Economics*, 75: 61–71.

NRC (National Research Council) (2011) *Climate stabilization targets*, Washington, DC: The National Academies Press, 286 p.

NRC (National Research Council) (2012) *NRC Report on Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs.* National Academies Press. Authors: Snow, J.T., X. Zeng, P. Klein, S.E. Sarnat, J.M. Shepherd, and E.M. Stanley, Washington, D.C., 190 pp.

O'Keeffe J. (2009), Sustaining river ecosystems: balancing use and protection. *Progress in Physical Geography*, 33(3): 339–357, doi:10.1177/0309133309342645.

Ostrom E. (1990) *Governing the commons. The Evolution of Institutions for Collective Action*, Cambridge, Cambridge University Press.

Ostrom Elinor (2009) A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325: 419-421.

Palerm A. & Wolf E. (1955) El Desarrollo del área clave del imperio texcocano, *Revista Mexicana de Estudios Antropológicos*, 14: 337-349.

Pincetl S. (2011) Urban water conflicts in Western US, in Barraqué Bernard (ed.), *Urban Water Conflicts*, Paris, Unesco.

Rajagopal, S. (2011). Impacts of Climate Change on Water Supply for the City of Phoenix, Arizona, Ph.D Dissertation, University of Arizona.

Rajagopal, S., Gupta H., Dominguez F., Troch P. (2011). Assessing Climate Change Impacts on Water Supply for the City of Phoenix, Arizona, Water Resources Research (in press).

Ramos-Martin, J. (2001) Historical Analysis of Energy Intensity of Spain: From a “Conventional View” to an “Integrated Assessment”. *Population and Environment* 22 (3): 218-313.

Ramos-Martín J., Cañellas-Boltà S., Giampietro M., Gamboa S. (2009) Catalonia’s energy metabolism: Using the MuSIASEM approach at different scales. *Energy Policy* 37 (11): 4658 - 4671. doi:DOI: 10.1016/j.enpol.2009.06.028.

Rees W.E. (1992) Ecological footprints and appropriated carrying capacity: what urban economics leaves out, *Environment and Urbanization* 4: 121–130.

Reisner M. (1986) *Cadillac Desert. The American West and its Disappearing Water*, Penguin Books.

Andrew R. (1992) *Global Warming : Understanding the Forecast*, American Museum of Natural History, Environmental Defense Fund, New York, Abbeville Press.

Riddoutt B. G., Pfister, S. (2010) A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. *Glob. Environ. Change*, v.20, p.113–120.

Rockström J., *et al.* (2009) A safe operating space for humanity. *Nature* 472-475.

Rosenfield, P.L. (1992) The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. Soc Sci Med 1992;35:1343–57.

Salmoral, G. (2011) Green, blue and grey water analysis of the bottom part of the Turia River Basin. Dissertation for the Master in Environmental Technology for Sustainable Agriculture. Technical University of Madrid

Salmoral, G., Aldaya, M. M., Chico, D., Garrido, a., & Llamas, R. (2011). The water footprint of olives and olive oil in Spain. Spanish Journal of Agricultural Research, 9(4). doi:10.5424/http://dx.doi.org/10.5424/sjar/20110904-035-11

Salmoral G., Dumont A., Aldaya M.M., Rodríguez-Casado R., Garrido A., Llamas R. (2011b) Extended Water Footprint Analysis of the Guadalquivir basin. *SHAN nº 1. Observatorio del Agua*. Fundación Marcelino Botín. Available at: http://www.huellahidrica.org

Scheidel A. (2013a) Flows, funds and the complexity of deprivation: Using concepts from ecological economics for the study of poverty. *Ecological Economics* 86: 28-36. doi:10.1016/j.ecolecon.2012.10.019.

Scherr S.J., McNeely J. A. (2008) Biodiversity conservation and agricultural sustainability: towards a new paradigm of “ecoagriculture” landscapes. *Philosophical transactions of the Royal Society of London, Series B, Biological sciences* 363: 477–94.

Serrano T., Giampietro M. (2009) A multi-purpose grammar generating a multi-scale integrated analysis of Laos, *ICTA Working Paper*. http://ddd.uab.cat/pub/estudis/2009/hdl_2072_40519/ICTATechnicalReport_2009-3.pdf

Serrat-Capdevila A., Browning-Aiken A., Lansey K., Finan T., Valdés J.B. (2009) Increasing Socio-Ecological Resilience by placing science at the decision table: The role of the San Pedro Basin Decision Support System Model (Arizona). *Ecology and Society* 14(1): 37.

Serrat-Capdevila A., Dominguez F., Valdes J.B., Rajgopal S., Gupta H. (2013) Characterizing the Droughts of the new century in the US Southwest: A comprehensive assessment from state-of-the-art climate model projections, *International Journal of Water Resources Development*, 29:2, 152-171, http://dx.doi.org/10.1080/07900627.2012.721717

Serrat-Capdevila, A., Scott, R. L., Shuttleworth, W.J. and J.B. Valdés (2011a) Estimating ET under warmer climates: Insights from a semi-arid watershed, *Journal of Hydrology*, 399: 1–11.

Serrat-Capdevila A., Valdes J.B., Gupta H. (2011b) Decision Support Systems in Water Resources Planning and Management: Stakeholder participation and the sustainable path to science-based decision making. In: *Efficient Decision Support Systems: Practice and Challenges – From Current to Future* / Book 1", ISBN 978-953-307-165-7. InTech - Open Access Publisher.

Serrat-Capdevila A., Valdes J.B., Gupta H., Schneier-Madanes, G. (2014) Water Governance Tools: The role of Science, Decision Support Systems and Stakeholder Participation. In Schneier-Madanes, G. (ed.) *Globalized Water*, Springer, ch.17: 241-259. ISBN 978-94-007-7323-3

Serrat-Capdevila A., Valdes J. B., Gonzalez J., Baird K., Mata L.J., Maddock T. (2007) Modeling climate change impacts - and uncertainty - on the hydrology of a riparian system: the San Pedro Basin (Arizona/Sonora), *Journal of Hydrology*, 347: 48-66.

Shepherd J., Pierce H., Negri A. (2002). Rainfall modification by major urban areas: Observations from spaceborne rain radar on the TRMM satellite. *J Appl Meteorol*. 41, 689–701.

Shepherd, J.M. (2005). A review of current investigations of urban-induced rainfall and recommendations for the future. *Earth Interactions*, 9 (12), 1-27.

Sorman A. H., Giampietro M. (2013). The energetic metabolism of societies and the degrowth paradigm: analyzing biophysical constraints and realities. *Journal of Cleaner Production* 38: 80-93. doi:10.1016/j.jclepro.2011.11.059.

Steffen W., Crutzen J., McNeill J.R. (2007). The Anthropocene: are humans now overwhelming the great forces of Nature? *Ambio* 36: 614–21.

Stokols D., Hall K.L., Taylor B.K., Moser R.P. (2008) The science of team science: overview of the field and introduction to the supplement. *Am J Prevent Med*. 35: S77-S89.

Tilman D., Balzer C., Hill J, Befort B.L. (2011) Global food demand and the sustainable Intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 108: 20260-4.

United Nations (2007) World Urbanization Prospects: The 2007 Revision [Available online at http://esa.un.org/unup].

UNPD (United Nations Population Division) (2010). *World urbanization prospects, the 2009 revision*. Available from http://esa.un.org/unpd/wup/doc_highlights.htm. Accessed on 12/26/2011.

Van Oel P.R., Mekonnen M., Hoekstra A. (2009). The external water footprint of the Netherlands: Geographically-explicit quantification and impact assessment, *Ecological Economics* 69: 82–92.

Vanham D., Bidoglio G. (2013). A review on the water footprint indicator for the EU28. *Ecological Indicators* 26: 61-75.

Velázquez E., Madrid C., Beltrán, M. (2011), Rethinking concepts of virtual water and water footprint in relation to the production–consumption binomial and the water–energy nexus. *Water Resources Management* 25: 743-761.

Vigerstol K. L., Aukema J. E. (2011) A comparison of tools for modeling freshwater ecosystem services. *Journal of Environmental Management* 92: 2403-2409.

Wichelns D. (2010) Virtual water: a helpful perspective, but not a sufficient policy criterion. *Water Resources Management* 24: 2203-2219.

Wiedmann T., Minx, J. (2007) *A Definition of Carbon Footprint*, ISA Research & Consulting, Durham, United Kingdom.

Woltjer J., Niels A. (2007) Integrating Water Management and Spatial Planning. *Journal of the American Planning Association*, 73(2): 211-222.

Worster D. (1985), *Rivers of Empire. Water, Aridity and the Growth of the American West*, Oxford, Oxford University Press.

Directives:

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

Directive 2007/60/EC on the assessment and management of flood risks

European Union Biodiversity Strategy to 2020, Target 2, Action 2