Current paradigms in the management of water: Resulting information needs

Leandro del Moral, Maria Fernanda Pita, Belén Pedregal, Nuria Hernández-Mora, and Natalia Limones
Department of Human Geography, University of Seville, Spain

Water management goals, methodologies, conceptual approaches and institutional frameworks have evolved significantly over the past 30 years. These transformations have been stimulated by the promotion of the Integrated Water Resources Management (IWRM) paradigm by experts, academics, managers and international institutions. However, the application of IWRM faces resistance from defenders of the previously dominating infrastructural and resource-oriented hydraulic paradigm. It is also challenged by the contradictions and limitations that emerge from the practical experiences in its implementation at different scales. From a general perspective, criticism against the hydraulic paradigm and the emergence and consolidation of IWRM can be understood as being a part, in the water policy arena, of the historical shift from the post-war Keynesian regulation model to the current neo-liberal globalization system or, in more specific terms, from the "administrative rationalism" stage to the current "neo-privatization" trend. Increasing attention is being paid to the potential interconnections between the encouragement of water governance, a central focus of the IWRM approach, with wider global socio-economic processes that challenge existing democratic institutions. The wider hegemonic economic thought in which IWRM prescriptions are integrated, particularly the commodification processes and monetary reductionism of natural resources and the preeminence of the river basin as the natural scale for water resources management, is also coming under scrutiny.

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

1. Introduction

Water management goals, methodologies, conceptual approaches and institutional frameworks (actors involved, legal contexts) have evolved significantly over the past 30 years. These transformations have been stimulated by the promotion of the Integrated Water Resources Management (IWRM) paradigm by experts, academics, managers and international lending institutions, since the approval of the Dublin Statement on Water and Sustainable Development (Dublin Principles) at the 1992 International Conference on Water and

Environment. This long lasting process of paradigm change and consolidation is the manifestation, in the water resources field, of a wider and deeply contentious transformation in the way we currently understand society-nature interactions and the management of natural resources.

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

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

2. A new paradigm for water resources management

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

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

These are common characteristics of a management approach that is widely known as Integrated Water Resources Management (IWRM), and has received significant attention from academics, managers and international funding institutions. In fact, the Global Water Partnership (GWP) was created in 1996 by the World Bank, the United Nations Development Programme (UNDP), and the Swedish International Development Cooperation Agency (SIDA) as an international network to foster IWRM as a way to achieve sustainable development. The GWP states that 'IWRM is 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, paving the way towards sustainable development, in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000, 22).

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

In the United States, the concept of IWRM is strongly established and even gaining considerable traction now. The United States Army Corps of Engineers (USACE) launched in February 2013 an on-line Federal Support Toolbox to provide Integrated Water Resources Management information[2]. The toolbox responds in part to the publication in 2010 of a National Report entitled *Responding to National Water Resources Challenges*, the result of a nationwide assessment process of water resources issues in the US facilitated by the USACE which established as a goal the need to "promulgate policies, concepts, and clear and consistent definitions that support IWRM" (USACE, 2010). Additionally, the American Water Resources Association (AWRA), a leading association for water managers and researchers in North America, adopted a Policy Statement in 2011 recommending that "water management goals, policies, programs and plans be organized around the concept of IWRM" and has organized two Summer Specialty conferences on this topic (Snowbird, 2011, Reno, June 2014).

IWRM is also the reference used by the SWAN project[3] as the starting point and initial framework for its scientific endeavors. However, building on concrete experiences in different parts of the world, over the past few years a growing debate has emerged questioning the

[2] www.watertoolbox.us

[3] SWAN: Sustainable Water ActioN: building research links between EU and US, FP7-INCO-2011-294947. https://swanproject.arizona.edu/

limitations, contradictions and conflicts that the integrated management paradigm finds in its practical implementation. In its 2011 policy statement, the American Water Resources Association (AWRA) recognized these limitations by stating that: "IWRM suffers from a lack of clear definition, the lack of standard measures to track the success of IWRM plans and projects, and the absence of guidance for those involved in planning and project development". From an applied perspective, for instance, Giordano and Shah (2013) discuss several examples in Asia and Africa where international lending institutions pushed for the approval of water policies aligned with IWRM, with mixed results. From a more theoretical standpoint, Molle (2009) is critical with the status of "nirvana" concept of the IWRM prescriptions, while Pahl-Wostl *et al.* (2012) question the possibility of existing "panaceas".

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

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

In this context, new and complementary management approaches are being proposed that aim to reinforce existing management prescriptions and more explicitly incorporate the concepts of hybridity between the social and the natural (*waterscapes*), complexity and uncertainty that underlie the new water management paradigm. Socio-ecosystem based management, polycentric governance (Ostrom and Cox, 2010), eco-adaptive management (Huitema *et al*., 2009), or the emerging concept of water security (Cook and Bakker, 2012; Staddon and James, 2012; Martínez Cortina *et al.,* 2010) are only some of the new or revised concepts that are gaining traction. Pahl-Wostl *et al.* (2011) argue that water management requires a further evolution along different axis:

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

- From prescriptive solutions to adaptive management approaches that facilitate learning and *adaptation* to a changing reality and to evolving understandings of the problem;
- From separate approaches to discrete environmental problems toward a comprehensive approach that transcends disciplines, geographical and professional boundaries, and areas of expertise.

3. The emergence of the water security concept

In the context of these debates, it is unavoidable to make a specific reference to the notion of water security. As Cook and Bakker (2012) point out, over the last decade the water security concept has emerged from its original niche in studies of international security and hydropolitics to become much more widely used. To some extent it seems even to be supplanting the hegemonic position hitherto occupied by the "sustainable water" concept (Staddon and James, 2012). According to these authors, UNESCO defines water security as a concept that "involves protection of vulnerable water systems, protection against water related hazards such as floods and droughts, sustainable development of water resources and safeguarding access to water functions and services" (Staddon and James, 2012, 2). The above definition subsumes key ideas of the "sustainable water management" paradigm as constitutive definitional elements whilst also importing the ideas of ecosystem functions and services, the risk of climate-related hydrological hazards, and water as an object of geopolitical security discourse. The idea of water security assumes that people's fundamental interests are in satisfying demands for water-related services such as food, fibre, waste disposal and sanitation. Thus, society's focus is not on the use of water per se but on the services and benefits provided per unit of water used (Martínez Cortina *et al.,* 2011).

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

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

4. What are the new information requirements in the evolving water management paradigm?

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

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

- *Environmental information* and, more specifically, information on biological as well as chemical quality of water resources and associated aquatic ecosystems, in order to respond to new ecosystem-based management goals.
- *Socioeconomic information*, which becomes essential in the transition from a technocratic management approach with centralized and hierarchical decision making processes, where social actors are recipients of management decisions, toward more participative decision processes, a part of a new management culture that incorporates institutional learning and adaptation.
- *Economic information* on the costs of water services and associated prices, but accounting for the multifunctional characteristics of water from which multiple ecosystem services derive. That is, the economic information must take into account not only the financial costs of service provision, but also the ecosystemic implications of these services and the associated costs (environmental and resource costs, in the language of the WFD).
- Development of *synthetic and sustainability indicators*: the wealth of data available makes it necessary to develop indicators that present this information in a manner that is concise, agreed upon and easily understood, in order to facilitate continuous monitoring and evaluation of these complex socio-ecological systems. However, as Garnåsjordet et. al (2012) point out, these indicators comprise not only a selection of facts in some technical sense. The choices involved in the development of the indicators are subjective and respond to underlying "narratives" that are conditioned by societal interests and implicit values embedded in the data-generating processes. Therefore, the development of the data and assessments needs to be deliberated in a political process reaching agreements for political action.

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

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

The consideration of water as a socio-ecological patrimony requires linking biophysical and socioeconomic variables, a significant challenge given current knowledge and modeling capabilities. The traditional separation of social and natural sciences has ignored the overlap of

both fields of knowledge, which results in the limited theoretical and methodological development for their joint analysis, as well as the paucity of available data for management.

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

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

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

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

- *Technical* (or conventional) *uncertainty* which refers to the unavailability of data and, more generally, information and knowledge. In this case the problem is related to the lack of reliability or thoroughness of the historical data, a frequent situation in hydrology. In order to overcome this problem scientists develop models, thus simplifying complexity. Some of the uncertainties related to the hydrological inverse methods (hydrological modeling) are those associated with: (1) model parameter estimates and (2) model parameter resolution (see Vasco *et al.*, 1997) or, more importantly, (3) model structural uncertainty (completeness / adequacy) (Gupta and Nearing, 2014; Gupta *et al*., 2012, and Gupta *et al*., 2008).
- Uncertainty in terms of *indetermination.* In these situations the system parameters and their interrelationships are unknown, since they are so complex, and consequently the model results become completely unreliable.
- Uncertainty in terms of *ignorance,* which occurs when 'we ignore what we do not know'.

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

7. Some final remarks and questions for further discussion

(1) IWRM is the dominating paradigm for sustainable water management today. The Water Framework Directive represents perhaps the most ambitious and complex legal effort to put the principles of IWRM into practice in the EU's member states. Other national legislations

also incorporate IWRM prescriptions. However, this model faces resistance from the previously dominating hydraulic paradigm, as well as the contradictions that emerge from the practical experiences in its implementation at different scales (from regional to global). The criticisms that it has received in the recent past focus on the following main aspects:

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

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

- Information versus data;
- Information needed to improve management versus information dissemination to improve transparency and facilitate public participation;
- Real versus modelled data;
- Quantitative versus qualitative data;
- Real time versus delayed data;
- Physical versus socioeconomic data;
- Conventional network versus new networks (remote sensing, etc.) data.

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

- Estimating the costs associated with ecosystem restoration is infinitely more complex than calculating the costs associated with water flows, since these can be simplified through the balance of the hydrologic cycle.
- The valuation of ecosystem services requires using metrics other than monetary valuation, as well as site-specific studies. The methodologies and information necessary for these valuations are still under development.
- The incorporation of the social dimension brings with it elements of complexity and uncertainty in addition to those inherent to natural systems. Therefore the understanding, representation and management of water as an eco-social patrimony poses new challenges that require information that is still being developed.

(4) The selection of the scale for water management has direct implications for information and data availability and requirements: local versus global scale for information gathering;

central planning (models) versus local planning (real network data). Related to this issue the next questions arise:

- What are the possibilities and real potential of different alternatives for information generation and what are the difficulties and challenges inherent to each choice?
- What are the institutional conditions for its implementation?
- Are public information systems organized to facilitate the knowledge generation and information exchanges or are there still important imbalances between the potential of the new ICTs and the individualistic behaviour that still dominates information management?

(5) Currently dominating water management models are also challenged by the use of fixed horizons and time scales. As with spatial scale, the problems and challenges in water management do not meet defined time limits. The elements of the hydro-social system, and thus the uncertainties, are temporarily changing and they entail problems with water risks and water resources that are non-stationary and that cannot be studied under a single temporal pattern. The availability of data and information on the system is also variable and the adaptation to this dynamic is imperative. In addition, water management necessarily requires the handling of a temporal dimension on which incomplete information is available: the future. It is necessary to develop dynamic scenarios without limiting the study to the already known system conditions.

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

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