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Maturing the New Water Management Paradigm: Progressing from Aspiration to Practice

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Abstract Over the past decade a series of major revisions to the generation and use of knowledge in the context of natural resources management has started to undermine basic assumptions on which traditional approaches to water management were based. Limits to our ability to predict and control water systems have become evident and both complexity and human dimensions are receiving more prominent consideration. Many voices in science and policy have advocated a paradigm shift in water management—both from a normative (it should happen) and a descriptive (it happens, and how) perspective. This paper summarizes the major arguments that have been put forward to support the need for a paradigm shift and the direction it might take. Evidence from the fields of science, policy, and management is used to demonstrate a lacuna in the translation of political rhetoric into change at the operational level. We subsequently argue that learning processes and critical reflection on innovative management approaches is a central feature of paradigm change and that contributions from psychology which emphasise the roles of frames and mental models can be usefully applied to paradigm change processes. The paper concludes with recommendations to facilitate debate and test alternative approaches to scientific inquiry and water management practice leading to critical reflection and analysis.

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1 Paradigm Change in Water Management

In recent years there has been increased discussion and debate about a paradigm shift in water management—both from a normative (it should happen) and a descriptive (it happens, and how) perspective. Historically, water resources management focused on technical solutions to well-defined problems, which gained urgency with the increasing concentration of urban populations and the intensification of industrial and agricultural productivity in the nineteenth and twentieth centuries. Health and hygiene problems within cities and the seemingly insatiable demand for more water drove major efforts in urban water management to improve water quality and ensure reliable supply. Rivers were controlled to protect cities and dryland agriculture from flooding. Technological fixes proved to be very efficient in the short run in solving many of these pressing problems in terms of both water quality and quantity. However, interventions which have worked in the past seem to not be appropriate to deal with the challenges of the present and the future. Indeed some have argued that the extent of innovation required to successfully address contemporary water management challenges requires a paradigm shift. The evidence for such a shift together with an argument for a more formal approach to effecting it are the major concerns of this contribution. In it we summarize the major arguments that have been put forward to support the need for a paradigm shift in water management and the direction it might take. We argue that although the beginnings of such a shift are evident, substantive changes have been confined to problem reframing rather than significant transformation of water management principles and practice. In presenting these arguments, the paper elaborates on the kind of learning processes required to move from a discourse about a paradigm shift to its implementation in scientific and water management practice.

1.1 Why a Paradigm Shift in Water Management

The methods and tools used by industrialized societies to manage water supply, wastewater, and stormwater were established in broad outline over a hundred years ago. These methods were highly successful in addressing development and sanitation objectives, but today their functional and economic effectiveness in fulfilling environmental, quality of life, and other objectives is often questioned (Gleick 2000; Larsen and Gujer 1997). Conventional methods such as physical, biological and chemical treatment are evolving in new directions. At the same time, new technologies, and old ones in newly refined forms, are emerging, presenting new options for water systems design and management (e.g. small footprint and decentralised systems). Novel institutional and managerial approaches are similarly emerging at a rapid rate. Indeed, a whole range of insights and changes in perspective have started to undermine the basic assumptions on which traditional water management has been based. For example, (1) water crises are now recognised as often being crises of governance and not of resources or technological problems (Bucknall 2006), (2) increasing uncertainties due to climate and global change reduce the predictability of the boundary conditions under which water management has to perform (Milly et al. 2008), (3) the polluter-pays-principle and source control options are more commensurate with sustainable water management ambitions and have gained increasing support over technical end-of-pipe solutions (Larsen and Gujer 1997), and (4) Integrated Water Resources Management has been vigorously promoted as a more efficient and effective response to multi-criteria resource management problems (GWP-TEC 2000).

But does the deep and fundamental change prompted by these developments herald a new paradigm for the management of water systems? Before elaborating on the different voices which have advocated and outlined a paradigm shift in water management it's appropriate to discuss the general meaning of the term as well as the question of whether its use is appropriate to describe what is happening in water management. Such considerations also provide a base from which to reflect on how the scientific, management and operational processes which underpin society's interactions with water can be transformed to conform with a new paradigm.

1.2 What are Paradigms and what is Shifting

Driven by Thomas Kuhn's seminal work on scientific revolutions (Kuhn 1962), the term 'paradigm' is now widely used to refer to the set of ontological and epistemological assumptions which provide a starting point for scientific enquiry. A paradigm is therefore an agreed way of thinking about the world and an agreed set of valid approaches to investigating that world shared by any epistemic community. In his work on the structure of scientific revolutions Kuhn defined a scientific paradigm as consensus on (1) what is to be observed and scrutinized, (2) the kind of questions that are supposed to be asked and answers probed for in relation to this subject, (3) how these questions are to be structured, and (4) how the results of scientific investigations should be interpreted. Kuhn's contribution is based on the assumption that scientific revolutions occur when scientists encounter anomalies which cannot be explained by the universally accepted paradigm within which scientific progress has previously been made. The paradigm is not simply the current theory but the entire worldview in which it exists and all of the implications which come with it. Importantly, paradigms circumscribe not just acceptable modes of enquiry (consensus on the types of scientific endeavour which are legitimised by a paradigm) but also what are considered workable modes of enquiry (consensus on the types of evidence which would corroborate or contradict a paradigm). A paradigm is thereby an influential precursor of problem formulation, theory, hypothesis, model, interpretation, description, and explanation. However, at a certain level of abstraction, paradigms are also theories in their own right (and thereby also models), though less formal and perhaps not set down as systematic logical propositions; although they are, interestingly, subject to testing and review in the same way that theories are.

A paradigm provides an intellectual and operational environment within which scientists 'do' science. It shapes the nature of problems to be addressed as well as the methods to be used and the interpretive lens through which the legitimacy and utility of findings are judged. Paradigm shift has often been credited with driving the birth of new disciplines (see the case of ecohydraulics as reported by Leclerc 2005). Understandably then, calls for radical change in knowledge production processes or knowledge use are often delivered in terms of the need for a 'paradigm shift'. That a paradigm shift has been occurring in water management over the past 50 years of scientific endeavour is, in one sense, irrefutable. The transformation has been driven by the emergence of postmodernism as a prevailing cultural and intellectual mission, increased understanding of complex systems phenomena (in particular the relationships between parts and wholes), and a weakening of the previously privileged role of 'science' in knowledge production. The influence of the postmodernist project can be seen in the status afforded to constructivist epistemologies (Kincheloe 2005), and both descriptive and normative relativism (Hollis and Lukes 1982) in current research methodologies. The second driver noted above tells a very different story about ecosystems and resource management. If the old ecology can be characterized as a science of the parts, the new ecology can be thought of as the science of the integration of the parts (Holling et al. 1998). The roots and intellectual heritage of such a conceptualisation go far back to the work of General Systems Theory (von Bertalanffy 1968) and Systems Ecology (Odum 1983). Thirdly, although the trend towards co-production of knowledge by extended constituencies of stakeholders had its roots in social movements for greater public engagement with planning and decision making, an injection of academic rigour and formal articulation of its benefits was provide by Gibbons et al. (1994). This work has had a huge impact on many areas of science, particularly in 'context driven' areas where research is conducted with problem solving in mind. Research on natural resources management has not been immune from these influences and, as will be shown below, it has been at the forefront of a re-alignment of disciplines, stakeholders, and methods which is reflected in many contemporary epistemic communities.

Within the confines of water management as a set of knowledge challenges, there is arguably a well developed and clearly identifiable epistemic community comprising (*inter alia*) researchers, water management practitioners, regulators, and technology manufacturers which can be characterised by a paradigm or mindset of how water management should be undertaken and which is reflected, and in some cases codified, in practices, laws, technologies, the nature of discourse, etc. In pursuing the ambition of this paper we adopt the following working definition of a management paradigm:

> A management paradigm refers to a set of basic assumptions about the nature of the system to be managed, the goals of managing the system and the ways in which these goals can be achieved. The paradigm is shared by an epistemic community of actors involved in the generation and use of relevant knowledge. The paradigm is manifested in artefacts such as technical infrastructure, planning approaches, regulations, engineering practices, models etc.

This definition highlights that a reigning paradigm is stabilized by a whole range of interdependent structural factors which can be expected to instil inertia where a change in paradigm is threatened. Paradigm shifts typically occur when existing methods and models consistently fail to describe or account for our experiences, or when the interventions we base on them fail to generate anticipated benefits. Recognition of failure generates a collective re-evaluation of how and why we seek understanding and derive value from our knowledge. Catalysts for such re-evaluations often come from outside the belief system, from someone who is either unaware or unaccepting of the current paradigm. Perhaps unsurprisingly, challenges to existing paradigms attract no small measure of resistance as the veracity and standing of large swathes of accepted knowledge is undermined and epistemic communities are returned to a position of ignorance (Barker 1992).The struggle for dominance between competing paradigms often happens over decades or even centuries; a useful and fascinating example of this being the struggle between the theories of biogenesis and spontaneous generation which had its beginnings in the seventeenth century but was not resolved until the nineteenth century through the work of Rudolf Virchow and Louis Pasteur. Paradigm shifts are often disastrous for individual careers and present uncomfortable challenges to institutions and governance systems. Paradigm transition will see fractious and contentious debate as vested interests in the old paradigm are defended and the call of radicalism motivates adherents to the new paradigm. Under these conditions, effective learning and communication across the divide is crucial to ensuring a transition that does not destabilise broader social and knowledge production processes.

1.3 Advocates of Paradigm Shift: Heralds of Failure and Heralds of Promise

Proponents of a paradigm shift in water management represent a range of intellectual traditions and consequently pose both problem and solution in slightly different terms. A strict chronological approach to reviewing associated writings could therefore be unwittingly confounding as, whilst the various contributions have water or natural resources management as a common concern, they are not premised on the same critique or even address the same challenges. In the following paragraphs we illustrate the nature and form of the paradigm shift debate by presenting its major voices—'major' inferring both popularity and influence of the writing but not necessarily legitimacy or authority. Most of the contributions we present report a transition from a past, discredited set of assumptions about the problem and viable solutions, to a (significantly) new and promising way of thinking about the challenge and generating utility. They are, therefore, more appropriately referred to as commentators on, or heralds of, change rather than originators of change.

A useful starting point is provided by those writers who have advanced an historical account of paradigm change. Foremost amongst these is Tony Allan who has offered a particularly rich understanding of the influence of paradigms on water management, describing five dominant water management paradigms relevant to the history of water-scarce economies. Allan (1998, 2005) uses a critical historical perspective to argue the benefits of critiques rooted in an appreciation of political economy. His commentary starts with Premodern Thinking and takes in Industrial Modernity (characterised by the 'hydraulic mission') on its way to Reflexive Modernity which is represented by a dominant mindset of uncertainty resulting in emphases on the environment, the economy, and institutional structures. In suggesting that a focus on water *per se* is a misleading theoretical point of departure, Allan highlights the role of discursive hydro-politics as having explanatory power and narrative benefits. Hence, social adaptive capacity is seen to be the primary process through which effective responses to water scarcity are secured. Allan's objective is to inform and support the delivery of what he terms the fifth paradigm (Reflexive Modernity) by providing a perspective which helps identify appropriate modes of enquiry and intervention tools. A complementary perspective to this critique is provided by Turton (1999) who also posits several phases in the history of water management as a way of illustrating how 'adaptive capacity' is needed to realign population-induced demand with the maximum level of sustainable supply. Labelling the four phases 'Getting More', 'End-use Efficiency', 'Allocative Efficiency', and 'Adapting to Absolute Scarcity' Turton delivers a compelling narrative on the history of thinking in the water resources management sector.

An alternative historicist interpretation of the development of dominant water management paradigms comes from Laakkonen and Laurila (2007) who, focusing on the case of Helsinki since 1850, suggest that urban water management challenges have been framed by (chronologically) Miasmatic, Sanitary, Bacteriological, Phosphorus and Nitrogen paradigms. Such studies are instructive because they exemplify how the shaping of hydrological systems in the service of human communities can be determined by local context, immediate challenges, and rather parochial but nonetheless meaningful concerns. Whilst it may be tempting to disregard the difference between two chemical elements as mere variation within a dominant framework of pollution control, the argument within Laakkonen and Laurila's contribution draws attention to the way in which paradigms embrace political communities as well as scientific ones, creating professional environments within which consensus about the meaning of the challenge, appropriate methods for understanding the challenge, and validated solution sets are forged.

Whereas some contributions tackle questions of ontology or epistemology (i.e. what is the system and how do we gain useful knowledge of it), others ask what functions water resources serve and how we can best manage them for the benefit of humans. In his introduction to a Special Issue of the Journal of Contemporary Water Research and Education, Robert Ward (1995) commented that past efforts to break down water management activities into highly specialized subject areas (e.g. flood control, water supply, recreation, irrigation, and waste water treatment) resulted in the creation of large organizations that are increasingly being questioned about their ability to meet the needs of the twenty-first century. Ward also conjectured that appeals for a more holistic approach to water management might frustrate and enthuse in equal measure. The distinction here would be between those who perhaps have (negative?) experiences of integrative approaches or perhaps have vested interests in existing networks of power and value, and those who would welcome a fundamental change to the way we think about the problem set which goes beyond joining up the various components of the water management challenge.

There is also a set of contributions which seek to illustrate an 'emerging paradigm'. Writing in the broader context of land and water management, Cortner and Moote (1994), who are amongst the few authors who actually define what they mean by paradigm shift, characterise the current paradigm as one that is focused on sustained yield. They characterise the emerging paradigm as founded on two principles: ecosystem management and collaborative decision making. They also point out that implementation of these two principles is likely to require extensive revision of traditional management practices and institutions with failure to address these issues resulting in the adoption of the rhetoric of change without any lasting shift in management practices or professional attitudes. A similar vein of analysis is provided by Peter Gleick (2000) who offers a concise characterisation of the changing temper in approaches to water resources management, describing a shift away from reliance on finding new sources of supply to address perceived new demands, an emerging emphasis on embedding ecological values into water policy, a re-emphasis on meeting basic human needs for water services, and "a conscious breaking of the ties between economic growth and water use". The fact that the desired paradigm shift identified by earlier writers had yet to be realised is reflected in Gleick's observation that a reliance on physical solutions continues to dominate traditional planning approaches. His perspective is, however, broadly optimistic, as he highlights that despite strong internal resistance (although 'internal' is left undefined) and patchy adoption, new ways of thinking about the relationship between water and communities are becoming influential.

Even traditionally conservative state-run organizations have recognised the shifting intellectual landscape, resulting in some spirited statements about the need for new thinking on water resources planning and management. For example, in defending the case for the use of Adaptive Management approaches, the U.S. Army Corps of Engineers (2004) recognises that new knowledge about the relationships between hydrological regimes and habitat functions and demands for a more broadly based decision taking and resource management constituency significantly changed the setting of U.S. water resources management in the latter part of the twentieth century. It sees Adaptive Management as providing a unifying thesis within which several well recognised desirable features of sustainable water management can be incorporated.

However, perhaps the most succinct illustration of the difference between the 'old' and the 'emerging' paradigm has been provided by Richard Pinkham of the Rocky Mountain Institute. Pinkham (2002) contrasts the old and new paradigms by exploring both how the system and processes are viewed and what form of management is deemed appropriate. He notes how, in the emerging paradigm (or 'soft path'), stormwater and human waste are transformed from nuisance to resource; how single pass flows become multi-pass loops or cascades utilising green rather than grey infrastructure; how large, centralised systems are replaced by smaller decentralised ones; how demand is discretised to provide opportunities for more nuanced consumption management approaches which reflect considerations of quality as well as quantity; how collaboration transforms from public relations to meaningful engagement, and how diversity and complexity play significant roles in understanding system dynamics.

2 What Unites the Voices Describing a Paradigm Shift in Water Management?

A dominant theme in many of the contributions reviewed above is the need to develop understandings of water resources and their management as a complex system. The increasing awareness of the complexity of environmental problems and of human–technology–environment systems has encouraged the development of new management approaches based on the insight that the systems to be managed are, in broad terms, complex, non-predictable and characterized by unexpected responses to intervention (Pahl-Wostl 2002; Prato 2003; Light and Blann 2000). Such Complex Adaptive Systems (CAS) are characterized as hierarchies of components interacting within and across scales with emergent properties that cannot be predicted by knowing the components alone (Lansing 2003). Rather than trying to change the structure of complex, adaptive systems to make them controllable by external intervention, innovative management approaches aim to make use of the self-organizing properties of the systems to be managed.

All the examples reported above explicitly use the notion of a paradigm for characterizing the underlying thinking behind approaches to water management. The examples differ in detail and emphasis but not in the essential elements of the nature of the proposed or anticipated paradigm shift. The shift may be interpreted as a sign of an increased awareness of complexity and a fundamental change in understanding what management implies which is not only limited to the field of natural resources and water (Pahl-Wostl 2007b). This leads to a quite different agenda for understanding the function of management and how it can best be practiced. If the change in thinking about how we generate useful knowledge to respond to the challenge of water management is deep enough to be classed as a paradigm shift, then there are substantive and significant implications for how we act to better manage water resources.

Management can be defined as the planned and purposeful act or practice of exerting influence on a system and steering it in a certain direction. The now fading water management paradigm was characterised by a command and control approach. Such strategies seek to influence system behaviour so as to achieve a desired goal (Sontag 1998). Typically, control is exerted centrally, adhering to rigid and detailed plans for the fulfilment of established goals. Command and control infers that management interventions can be optimised and their impact, in principle, be fully calculated. This is facilitated by segregation of the system to be controlled into separable individual elements. Uncertainties are either ignored or assessed quantitatively and dealt with by the establishment of norms. Such measures are acceptably effective for a roughly stable system with reliably recurring phenomena. They fall short, however, for adequately dealing with the types of non-linear change and unexpected system behaviour which characterises many river basins. Influencing CAS trajectories requires a looser management approach: one which does not aspire to comprehensive prediction and control but rather nurtures a capacity to steer the system to be managed to a certain degree. Such an approach is consequently less rigid and may contain a set of basic rules, set a general direction for the achievement of certain goals, but allow greater freedom in the interventions deemed appropriate to achieve those goals.

Another level of challenge for managing CAS is provided by the fact that, in systems with human components, the importance of meaning cannot be ignored in interactions between individual agents and in their desire to achieve goals (or rather their interpretation of goals). The existence of externally defined and measurable system goals is insufficient to understand the management project. The extent to which we can talk of the ‘management’ of complex adaptive systems is therefore also questionable. Control is arguably replaced by influence, and imperative by meaningful engagement. Claims about the legitimacy of intervention and change no longer reside exclusively in the realms of authority and privileged knowledge. Legitimacy now depends on shared visions of both problem and equitable solution set. Management (as directed change to increase utility) is thereby reliant on the reliability and constancy of how understanding and opinion influence action. The evolution in water management discourses from speaking of “government” to speaking of “governance” evidences this radical change in thinking. The notion of government as the single decision-making authority, where state authorities exert sovereign control over the people and groups making up civil society, has been enriched by the notion of multi-level, polycentric governance where many actors in different institutional settings contribute to policy development and implementation

(Mayntz 1998). The notion of political steering as promoted by the concepts of polycentric and multi-level governance embraces complexity and diversity. In particular the concept of reflexive and adaptive governance emphasizes the role of learning and self-organization in such processes (Pahl-Wostl et al. 2007).

We are currently poorly served by concepts and methodologies which can provide bridges to new ways of thinking under conditions where paradigm shifts challenge management norms. As pointed out by Jones (2002) and Pahl-Wostl (2007b) context specific and carefully formed approaches are needed to communicate across paradigm boundaries and make explicit the implications of different world views. Diverse world views generate varying interpretations of a common physical reality and the same base of factual knowledge may be used by different actors to derive entirely different but equally plausible meanings and thus conclusions for interacting with the world surrounding them. Interestingly, the facility for entirely different but equally plausible meanings to be legitimated was used by Kuhn as an argument for not associating paradigms with the 'soft' sciences—a conclusion that may hold specific challenges for any new water management paradigm. In terms of planning intervention therefore, the new paradigm implies a change from "command and control" to a more systemic approach rooted in the co-production of knowledge and acceptance of uncertainty. The change towards such integrative, adaptive management seeks a more holistic understanding and promotes adaptive capacity as the central mechanism of change. The distinction between the two approaches is summarized in Table 1 where they are contrasted as the extreme, opposing ends of seven characteristic dimensions.

The new paradigm in water management has spawned many re-evaluations of how the problems should be stated, how knowledge of the system is best obtained, and what constitutes an appropriate management approach. However, two approaches have been particularly influential in providing alternative intervention strategies: Integrated Water Resources Management (IWRM), and Adaptive Management (AM). Both IWRM and AM have multi-decade histories of development and application—IWRM from the first UNESCO International Conference on Water in 1977, and AM from the early work of Carl Walters (Walters and Hilborn 1978). IWRM is particularly concerned with pursuing what might be termed an integrationist agenda; the integrated and co-ordinated management of water and land as a means of balancing resource protection whilst meeting social and ecological needs and promoting economic development (Odendaal 2002). AM stems from the recognition that even though interactions between people and ecosystems are inherently unpredictable (Gunderson et al. 1995) there is a need to take management action (Johnson 1999). Contrastingly, AM is a process to cope with uncertainty in understanding centred on a learning model where natural resource 'management actions are taken not only to manage, but also explicitly to learn about the processes governing the system' (Shea et al. 1998). Both IWRM and AM make claims about how best to organise knowledge production for sustainability in natural resource use where the utility bearing system can be classified as complex—IWRM focussing on integration and co-ordination, AM focussing on handling uncertainty. However, both frameworks have been criticised for struggling to live up to their ambitions (Jeffrey and Gearey 2006), and in suffering from problems in translation from research to practice. For example, Biswas (2004) has argued that the kind of institutional and organisational integration demanded by IWRM may not be possible, whilst Walters (1997) noted that many AM initiatives have either 'vanished with no visible product'

Table 1 Two water management paradigms and their manifestation in characteristics of the water management regime (Pahl-Wostl 2007a)

Dimension	Prediction, control paradigm	Integrated, adaptive paradigm
Governance style	Centralized, hierarchical, narrow stakeholder participation	Polycentric, balance between bottom-up and top-down processes, broad stakeholder participation
Sectoral integration	Sectors separately analysed resulting in policy conflicts and emergent chronic problems	Cross-sectoral analysis identifies emergent problems and integrates policy implementation
Scale of analysis and operation	Trans-boundary problems emerge when river sub-basins are the exclusive scale of analysis and management	Trans-boundary issues addressed by multiple scales of analysis and management
Information management	Understanding fragmented by gaps and lack of integration of proprietary information sources	Comprehensive understanding achieved by open, shared information sources that fill gaps and facilitate integration
Infrastructure	Massive, centralized infrastructure, single sources of design and power delivery	Appropriate combination centralized and decentralized, diverse sources of design and power delivery
Finances and risk	Financial resources concentrated in structural protection (sunk costs)	Financial resources diversified using a broad set of private and public financial instruments
Dealing with uncertainties	Uncertainties perceived as undesirable sign of incomplete knowledge. Emphasis on reducing uncertainties Influence of different perspectives largely ignored	Irreducible uncertainties accepted. Emphasis on how to deal with uncertainties and robust strategies Influence of different perspectives explicitly acknowledged

or become ‘trapped in an apparently endless process of model development and refinement’.

We agree with these commentaries and argue that contemporary research and practice in water management is precariously balanced on a cusp midway between the two paradigms illustrated in Table 1. The sector is in transition with theory way ahead of practice and even further ahead of the capacities (skills, knowledge sets, competencies etc.) required to effect integrated adaptive regimes. Failure (or reticence) to implement integrated and adaptive approaches may not be related to the principle of integration itself but rather to a natural but constraining adolescence in the mental models that frame the implementation process. Bormann et al. (1993) note that “Adaptive management is learning to manage by managing to learn”. This insightful statement is not only applicable to the process of adaptive management itself but also to the paradigm shift required to get there.

3 Water Management—Quo Vadis?

We have already provided evidence from scientific literature for an ongoing discourse on the need for a paradigm shift in water management. To assess if and to what extent such a paradigm shift is already taking place we make an exploratory analysis of relevant indicators within the scientific, policy and practitioner communities over the past decade. We use a bibliometric analysis to identify change within the scientific community, national and regional case studies to explore transformations in the policy making community, and case studies from European river basins to seek evidence for change amongst water managers.

3.1 Evidence for a Paradigm Shift within the Scientific Community?

As noted above, the advocated new water management paradigm emphasises the importance of the human and governance dimensions that were largely neglected in the previous technically dominated approach. If the scientific community was taking up this challenge we would expect more research to be published on water governance issues and interdisciplinary approaches integrating the natural, engineering and social sciences to prosper. To assess the current state of development in this direction we conducted a bibliometric analysis of publications using the SCOPUS data base, applying different combinations of key words to define search terms. The resulting data set records the number of publications in peer reviewed journals in the search space "articles and reviews" that included the defined search term in the abstract, title or key words (Table 2).

Table 2 highlights the continued dominance of technical over social perspectives in scientific writings on water management. Publications in water-related science exhibit a decisive emphasis on technology over governance. This, despite overwhelming recognition that many water related problems have their origin in governance failure! However, one must also acknowledge the increase in publications with a social science focus over the past decade from virtually no publications on water management and governance in 1999 to over 70 publications in 2009. The data also evidences that over the past 5 years research on governance related water

Table 2 Development of research in water management (cell values indicate number of papers matching each search term in each year)

	Year										
Search term	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Governance AND water	12	18	36	19	39	59	58	86	107	148	193
"Water" AND "policy"	482	588	643	712	754	865	901	976	1,116	1,283	1,354
Water AND stakeholder	58	59	98	94	113	145	164	201	232	263	266
"Water management" AND "governance"	2	4	10	5	24	35	26	28	43	66	82
"Water management" AND "policy"	130	127	125	141	204	233	211	200	294	347	369
"Water management" AND adaptive	5	8	11	8	20	16	23	17	30	36	63
"Water management" AND integrated	96	88	104	112	126	155	188	193	267	284	322
"Water management" AND technology	81	151	127	135	172	213	234	263	324	344	365
Water AND technology	1,517	1,713	1,780	1,890	2,304	2,656	3,081	3,403	4,090	4,213	4,494

management issues has experienced a non-linear change in the rate and increases now at a faster rate than other fields. One may argue that it has crossed a critical threshold as the social science community starts to get involved in water related research. Another indication of that is that about 50% of the papers on "Water Management AND Governance" and 60% of the papers on "Water AND Governance" are published in Social Science classified sources (e.g. Social Sciences, Economics, Econometrics, Finance, Business, Management, Accounting, Decision Sciences, Arts, Humanities, Psychology). The corresponding percentage of papers on "Water Management AND Policy" or "Water and Policy" is only 25%.

An integrated approach taking into account the complexity of social–ecological systems might also be expected to generate manuscripts on human–environment interactions. Table 3 summarizes search results focusing on this kind of research and indicates a tenfold increase in work on ecosystem services over the past decade—an increase similar to governance related work. This is much higher than the increase in work on environmental flows reflecting an interest in the environmental dimension only. 'Ecosystem services' is a bridging concept that supports integration of environmental and human dimensions. Hence the increase in scientific outputs on this topic can be judged a promising development. However, Table 3 also highlights the complete absence of research that relates environmental flows or services to governance processes. Such research would be needed to address the implications of different governance regimes on environmental flows and ecosystem services and thus to understand the complexity of human–environment interactions. The complete absence of this kind of research is a clear indication that the corresponding communities in the social and environmental sciences have not yet engaged in productive cooperation.

Similar conclusions to these were drawn by Braimoth and Craswell (2008) in their quantitative assessment of interdisciplinarity in water science programs. In a meta-analysis of water science projects they showed that water research activities fall into clusters where priorities are set along the lines of certain scientific disciplines. The

Table 3 Development of research on environmental flow and ecosystem service (cell values indicate number of papers matching each search term in each year)

Search term	Year 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
"Environmental flow"	16	17	24	17	40	22	45	47	43	72	69
"Ecosystem service"	32	36	45	64	77	76	122	213	281	389	584
"Ecosystem service" AND water	9	15	15	22	22	26	43	60	90	112	179
"Environmental flow" AND governance	0	0	0	0	0	0	3	0	0	0	1
"Environmental flow" AND adaptation	0	0	0	0	0	0	0	0	0	1	1
"Ecosystem service" AND water AND governance	1	1	0	0	0	0	1	1	1	0	4

integration between these research clusters was found to be low. They conclude that the persistence of a disciplinary perspective hinders science from effectively informing policy for integrated water resources management and argue for new partnerships and collaborations.

3.2 Evidence for a Paradigm Shift Within the Policy Community?

The ‘policy community’ is used here as a broad term to embrace actors involved in water policy as well as those involved in operational implementation. We also distinguish between the policy development, policy implementation, and operational functions of water management since different kinds of inertia might be expected to be dominants at each level.

Our first port of call is the European Water Framework Directive which came into force in 2000. This policy initiative promotes an integrated approach to achieving "good status" for all European waters (surface waters and groundwater) by prescribing water management at river basin scale. The WFD terminated a phase of increasing fragmentation of water policy in terms of both objectives and of means. The WFD is also the first major European directive to formally prescribe the involvement of stakeholders and the public at large. The official information from the European Commission states the clear need for strong participation of all involved parties for the successful implementation of the WFD. The WFD promotes sectoral integration and encourages trans-boundary cooperation in international river basins. Management plans are to be revised every 15 years, supporting an adaptive approach to developing and implementing measures. More recently, the European Flood Directive (FD) on the assessment and management of flood risks entered into force in November 2007. This Directive was a response to the severe floods in many parts of Europe between 1998 and 2004 including the flood catastrophes in the Danube and Elbe basins in the summer of 2002. The FD requires EU Member States to assess if water courses and coast lines are at risk from flooding, to map flood risk, and to take adequate and coordinated measures to reduce potential impacts. The FD also reinforces the rights of the public to access this information and to participate in the planning process. The implementation process requires harmonization with the WFD.

These two initiatives demonstrate that European water policy has undergone profound changes over the past decade. The WFD and the FD offer opportunities and provide support for a shift from conventional command and control strategies to integrated and adaptive water management and governance. Consequently, one might legitimately talk of a paradigm shift in European water management. Such a paradigm shift is even more pronounced at national scale, for instance in The Netherlands where the government has requested a radical rethink of water management in general, and flood management in particular. The resultant policy stream, initiated through the ‘Room for the River’ (*Ruimte voor de Rivier*) directive (V&W 1996), has strongly influenced other areas of government policy. Greater emphasis is now given to the integration of water management and spatial planning with the regulating services provided by landscapes with natural flooding regimes being highly valued. The increasing awareness of the threats posed by climate change has given a boost to these activities.

Additional evidence for a paradigm shift amongst the policy community comes from Australia where, until the late 1980s, most of the emphasis was on building infrastructure and water supply capacity characteristic of the technology dominated command and control paradigm. In 1994 the Council of Australian Governments agreed to a wide ranging package of reforms that put more emphasis on soft measures including the development of water pricing, allocation, and institutional mechanisms. In 2004 the Council of Australian Governments established an Intergovernmental Agreement on a National Water Initiative (NWI), which provides for: comprehensive planning for surface and groundwater, progress towards addressing the problem of over-allocation (by 2010), the provision of water to meet specific environmental outcomes, secure water access entitlements, an expansion of water trading, best practice water pricing, community partnerships, public consultation and monitoring, reporting and accounting of water use.

Further examples of highly aspirational and significant changes to water management policies can also be found elsewhere. South Africa, for example, has announced transformatory policies in water management. Here, the river systems have traditionally been highly regulated and inter-connected to allow water supply to be controlled to meet diverse water demands (Pollard and du Toit 2009). The South African National Water Act (NWA) that came into force in 1998 is built on IWRM as a guiding principle (RSA 1998). The NWA emphasizes the need for integrated water management and the implementation of participatory processes at all levels. In a similar way to the WFD, it also promotes the management of water at basin scale. In China, water management policies have traditionally privileged large scale infrastructure and engineering solutions; prominent examples being the three gorges dam and the South-North transfer project connecting the Yangtse and the Yellow river basins. However, a major shift in water policy thinking occurred in 1999 when the Ministry of Water Resources introduced the *ziyuanshuili,* or “resource water conservancy,” concept as a major theoretical and methodological departure. (Boxer 2001). This innovation promoted the idea of a water saving society and tightly aligned the further development of water resources with the principle of harmony with nature.

Despite these clear signs of reframing in water policy and codification of new approaches in legislation, progress in implementing the policy ambitions itemised above is patchy. For example, early experiences with the WFD are not too promising. A recent detailed study reported in Olsson and Galaz (2009) and Galaz (2005) on the transition to adaptive water management in Sweden concludes that despite the opportunities offered by the WFD, current implementation practice does not take into account either resilience or complexity. They conclude that more effort is required to change dominant practices and behaviours and support social learning and active stakeholder involvement. Their findings are particularly instructive in that they identified constraints at the operational level where prevailing practices and institutional inertia are not supportive of change. Similar findings are forthcoming from an Australian study by Allan and Curtis (2005) who report that adaptive management is constrained by deeply entrenched norms and institutional frameworks and that activity, control, comfort and clarity are more highly valued than reflection, learning, and embracing complexity and variability. These conservative tendencies are confirmed by Gunderson and Light (2006) in their study of adaptive management and adaptive governance in the Everglades ecosystem. There appears to be something of a social trap at work in these studies where governance mandates, planning based-paradigms, and vested interests in entrenched actor networks stabilize the "scientific" approach to management favouring engineering and technological solutions over experimentation and learning even when the former have failed.

Vested interests also seem to have stalled the transition to adaptive and integrative flood management in the Tisza basin in Hungary (as reported by Sendzimir et al. 2007). Here, the water governance regime is highly centralized and flood management has historically been dominated by an engineering informed control approach. Despite new flood policies exhibiting more advanced levels of learning and innovation, a full transition to a new flood management paradigm has been derailed by the much needed institutional reform being delayed by a governance system dominated by representatives of the established paradigm with little willingness to change.

3.3 Evidence for a Paradigm Shift Amongst Water Managers?

Recent empirical evidence from studies in several European river basins shows a persistence of the perception of uncertainties as a problem that needs to be eliminated. Research undertaken in the Wupper (Rhine, Germany), the Kromme Rijn (Rhine, The Netherlands) and the Doñana region (Guadalquivir estuary, Southern Spain) from 2006 to 2008 and reported by Isendahl (2009), assessed how water managers, mainly from public administrations at regional and local level, deal with uncertainty in water management practice. In all these case studies, most participants saw uncertainty as something negative to be solved or eliminated. Despite the acknowledgement of the existence of uncertainty and of the illusion of complete knowledge in environmental decision-making (see e.g. Bradshaw and Borchers 2000; Bergkamp et al. 2003; Oreskes 2004; Wardekker et al. 2008), the participants in the researched case studies pursue the ideal of certainty; a mindset still very much in line with the traditional command and control approach. The actors are uncomfortable dealing with uncertainties since they lack the routines in professional life to deal with them. Deliberate and structured approaches to deal with uncertainty were not in use or not known. Most experience, if there was any at all, with regard to uncertainty analysis was scientifically based (e.g. sensitivity analysis or Monte Carlo simulations). The decision makers themselves were observed to base their decisions on experience, intuition, heuristics and norms. Typically, for situations marked by uncertainty the immediate response would be to shift responsibility for a final decision to higher levels, e.g. national level, or to norms that had to be complied with. Alternatively, scientists are called on to provide more and better knowledge and certainty, substantiating the role of scientists as exclusive knowledge providers (Sarewitz 2004). Although water managers in these examples were aware of the drawbacks of traditional management approaches, examples of more innovative and adaptive approaches to handling uncertainty were rather scarce. Perhaps the only useful example being from the Kromme Rijn where decisions are based on intermediate deadlines which may be revised and adapted instead of refraining from action and waiting for certainty provided by timely research and knowledge production.

4 Discussion and Conclusions

Our exploration of paradigm shifts in the field of water management has so far delivered (1) a discussion of the substantive nature of such transformations, (2) a consideration of whether the label 'paradigm shift' is appropriate in the context of contemporary developments in the field, and (3) evidence to demonstrate the extent to which the emerging paradigm shift is influencing practices. Based on our elaborations we conclude that although it is indeed appropriate to talk about a paradigm shift in water management, progress in terms of changes at the operational level of both science and practice is slow. Irrespective of whether this slow progress can be blamed on the inertia of well established management systems or on reservations about the value and benefits of the new paradigm, our analysis suggests that those convinced of the new paradigm's value are faced with a major challenge. Turning the argument for how enquiry and intervention should proceed into evidence and management tools to support and implement policy is a far from trivial activity (see Medema et al. 2008 for an exposition on this in the context of water management). We have argued above that a paradigm shift requires processes of learning and communication across paradigm boundaries. But what tools are at our disposal for supporting these processes? We here detail the role which mental models and different kinds of learning can play in delivering a change in paradigm. Our emphasis is on fleshing out key requirements for change on the ground to make a paradigm change effective which goes beyond identifying the need for a paradigm change and/or conceiving a new paradigm at a more conceptual level.

People make sense of the world in different ways. Individuals cannot and do not pay equal attention or attribute equal value to all information available in a specific situation but observe selectively according to their interest and concern (cf. Fig. 1) (see e.g. Denzau and North 1994; Doyle and Ford 1998). As one consequence they value and make use of only those considerations which are most relevant to them while

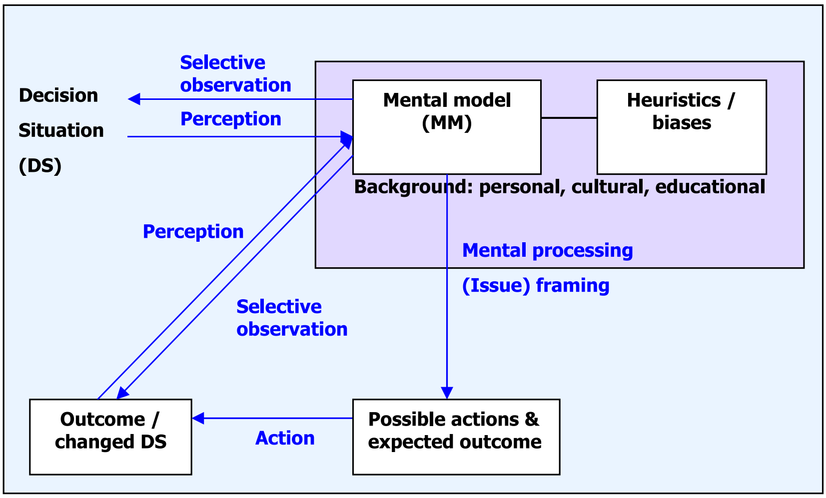

Fig. 1 The role of mental models in the selective processing of information

others remain unrecognized or overlooked. Disciplinary background and experience are major aspects that shape different mental models of an issue, leading to variation in their initial framing. When an engineer analyzes a water stress situation he will most likely detect technical problems such as inefficient use of available technologies whereas a social scientist will perhaps see the problem as rooted in the perceptions of individuals and perhaps in a lack of awareness or concern about declining water resources. Among the multitude of frameworks and concepts posited by science which describe how we make sense of the world we adopt 'mental models' for our analysis of how paradigms influence information processing and communication, and how conversely a change in mental models influences changes in paradigms.

We understand mental models as "*a relatively enduring internal abstraction of an external system to aid and govern activity*" (after Doyle and Ford 1998: 17). They are not static but may undergo changes over time. Mental models may be shaped by the role of actors in a social system, their personal, educational and cultural background as well as their previous experience and biases (cf. Fig. 1). Biases result from heuristics which are shortcuts or simplifications for actions that allow human beings to survive and act in a very complex and partly unpredictable world without deeply analyzing and calculating every detail (Gigerenzer 2000). As such, biases are examples of bounded rationality, meaning that perfectly rational decisions are often not feasible in practice. A very common form of bias is 'confirmation bias', which posits that information confirming one's beliefs is privileged over contradicting evidence. Mental models shape the selective processing of information. Filtered information is translated into strategies to deal with situations (mental processing/issue framing in Fig. 1). Thus, the way people act is influenced by how they frame a certain situation, an issue or relationships with other actors (see Dewulf et al. 2009 for further details). Within a paradigm, actors hold mental models, significant parts of which they share and according to which they frame the situations which they seek to influence and manage. As noted by Denzau and North (1994: 1): "*Individuals with common cultural backgrounds and experiences will share reasonably convergent mental models, ideologies and institutions*". In terms of a water management paradigm, the respective epistemic community of actors possesses a shared mental model with respect to the nature of the system to be managed, the management goals and the way the goals may be achieved.

So what is the significance of these insights in the context of water resources management and paradigm change? A group of actors holding the same management paradigm will most likely reinforce their beliefs through their interactions (confirmation bias). Learning and change will most likely be triggered by being confronted with a crisis or catastrophe ('cognitive variation' in Termeer and Koppenjan 1997) or by communication with actors who hold different mental models ('social variation' in Termeer and Koppenjan (1997)). However, this confrontation is not automatically productive in terms of reframing and learning. In fact, differences in mental models are one of the key reasons for problems in communication among actors (Gray 2003; Pahl-Wostl 2007b). A basic precondition for active reframing is that actors become aware of their own framing, critically reflect on it and acknowledge that there may be other legitimate framings contesting their own (Schön and Rein 1994; Dewulf and Craps 2004). It is hence crucial to find ways of communication and interaction that enables the questioning of one's own framing. As highlighted by Pahl-Wostl et al. (2007) processes of reframing and social learning are most effective in shared experiences and when supported by relational practices (e.g. role playing games, group model building).

The pressures currently shaping our communities' relationship with water resources (climate change, population growth & mobility etc.) may be generating change at such a rate that the design of appropriate responses cannot afford to wait for the generational timescales that are typically associated with a paradigm shift. However, forcing the pace of change in basic assumptions about the nature of the system to be managed, the goals of managing the system and the ways in which these goals can be achieved etc. holds real and immediate dangers. The history of fast-paced radical and revisionist movements in both intellectual and broader social spheres (e.g. politics, religion) suggests that attempts to break orthodox patterns of thought and behaviour have a tendency to generate tension, conflict and the splintering of previously well integrated epistemic communities. This may lead to strong resistance, denial of the need for and any benefits of innovation, ideological debates to replace scientific argument and deliberation. The implication is that if the water community wants to—and we are convinced it should—engage in a serious debate about and test alternative approaches to scientific inquiry and water management practice, a more social (in the sense of shared or collegiate) and paradigm-sensitive form of critical reflection and analysis will be needed.

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