PARADIGMS IN WATER MANAGEMENT

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Executive Summary

Over the past decade a whole range of insights have started to undermine basic assumptions on which traditional water management was based:

- water crises are often crises of governance and not resource or technology problems
- increasing uncertainties due to climate and global change reduce the predictability of the boundary conditions under which water management has to perform
- the polluter-pays-principle and source control are more in line with sustainable water management and have gained increasing support over technical end-of-pipe solutions
- integrated water management has been strongly promoted as being more efficient and effective as guiding principle for water management

Correspondingly more and more voices have advocated the need for a radical change, for a paradigm shift in water management. The arguments put forward differ in detail and emphasis but not in the essential elements of the nature of the needed paradigm shift which are:

- move towards participatory management and collaborative decision making,
- increased integration of issues and sectors,
- management of problem sources not effects,
- decentralized and more flexible management approaches,
- more attention to management of human behaviour by “soft” measures,
- include environment explicitly in management goals,
- open and shared information sources (including linking science and decision making),
- incorporating iterative learning cycles in the overall management approach,
- management as learning rather than control.

The report summarizes major arguments from the perspective of complex systems science and political science that show the need of more distributed and decentralized management and governance styles to cope with complexity and uncertainties in management. However, there persist major gaps between scientific and political rhetoric and the implementation of change at the operational level. This is not too astonishing if one takes into consideration what a paradigm implies:

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

A paradigm shift involves major structural changes in infrastructure and regulatory frameworks. But it involves first of all learning processes which have to start at the level of mental models. It is needed to engage in a critical reflection on innovative management approaches based on sound and unbiased deliberations. To do so requires to realize that paradigms, mental models influence how actors construct a problem domain, the way how they process information and interpret uncertainties and their favoured kind of strategies and problem solutions.

1 Paradigm change in water management

1.1 Why a paradigm shift 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) perspective.

In the past, water resources management focused on well-defined problems that gained urgency with increasing concentration of urban populations and intensification of industrial and agricultural productivity in the 19th and 20th centuries. Hygienic problems within cities and the seemingly insatiable demand for more water drove major efforts in urban water management. Eutrophication problems in lakes and coastal seas triggered more involved research and legislation. Rivers were controlled to protect cities and dryland agriculture from flooding. Technological fixes proved to be very efficient in the short run in solving a number of these urgent environmental problems, e.g. the increasing sophistication of wastewater treatment plants addressing hygienic and pollution problems. However, in general these problems were dealt with in isolation, and potentially undesirable long-term consequences were not taken into consideration. The system paradigm on which traditional water management has been based can be characterized as a "predict-and-control" approach. System design was typically targeted at high predictability and controllability.

A whole range of insights/changes in perspective have started to undermine basic assumptions on which traditional water management was based:

- water crises are often crises of governance and not resource or technology problems
- increasing uncertainties due to climate and global change reduce the predictability of the boundary conditions under which water management has to perform
- the polluter-pays-principle and source control are more in line with sustainable water management and have gained increasing support over technical end-of-pipe solutions
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Before elaborating in more detail on the different voices suggesting a paradigm shift in water management, the general meaning of the term paradigm is discussed below as well as the question whether it is appropriate to use this term to describe what happens in water management.

1.2 Definitions of paradigm and paradigm shift

Driven by Kuhn's seminal work on scientific revolutions, the word paradigm has been used to refer to a thought pattern in any scientific discipline. In a broader context, paradigm can be used to characterize a way of thinking shared by any epistemic community. An epistemic community may consist of those who accept one version of a story, or one version of validating a story. In the philosophy of science and systems science the process of forming a self-maintaining epistemic community is sometimes called developing a mindset. One can argue that the water management community is such an epistemic community comprising researchers, water management practitioners, regulators, technology manufacturers etc. This community is characterized by a paradigm or mindset of how water management should be undertaken codified in practices, laws, technologies, nature of discourse etc.

In his work on the structure of scientific revolutions Kuhn defined a scientific paradigm as consensus on:

- What is to be observed and scrutinized
- The kind of questions that are supposed to be asked and probed for answers in relation to this subject
- How these questions are to be structured
- How the results of scientific investigations should be interpreted

Kuhn's work 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 theretofore 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.

Based on this understanding of paradigms it seems to be justified to use the notion of paradigm to describe and analyse the different control approaches in water management. As pointed out by Pahl-Wostl (2007) one may talk of a social construction of simplicity that has characterized environmental resources management in the past decades. Complexity has been reduced by focusing on issues in isolation and problems could be solved by technical means by focusing on a narrowly defined domain.

Working definition of a water management paradigm:

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

1.3 Some voices advocating a paradigm shift in water management

The following section gives an overview of several arguments from a selection of papers advocating a paradigm shift in natural resources management more generally, and water management in particular. The discussion started as early as 1994 and is still ongoing as documented by more recent publications.

As early as 1994 **Cortner and Moote**[1] identified the emergence of a paradigm shift in land and water resources management. They are the only authors who define what they mean by paradigm shift and refer to the literature on scientific revolutions.

> Cortner and Moote (1994, p 167) summarize their approach as: *"The classical model of a paradigm shift is used to explore changes that are occurring in public lands and water resources management. Recent policy developments suggest that the traditional paradigm, which is characterized by sustained yield, is in the process of being invalidated. While no new paradigm has been fully accepted, the emerging paradigm does appear to be based on two principles: ecosystem management and collaborative decision making. Implementation of these two principles is likely to require extensive revision of traditional management practices and*

1 Cortner,H.J. and Moote,M.A. (1994). Trends and Issues in Land and Water Resources Management: Setting the Agenda for Change. Environmental Management, 18: 167-173.

institutions. Failure to address these issues could result in adoption of the rhetoric of change without any lasting shift in management practices or professional attitudes."

Integrated Watershed Management - A New Paradigm for Water Management?[2]

Ward (1995, p2) highlighted in his forward to a special issue on "Integrated Watershed Management – A New Paradigm for Water Management" the need for change: *"Water management, as it has a number of times in the past, is undergoing considerable change in the 1990s. Past efforts to break down water management activities into highly specialized subject areas (eg flood control, water supply, recreation, irrigation, and waste water treatment) have resulted in the creation of large institutions that today are increasingly being questioned relative to their ability to meet the needs of the 21st century. Universities have organized themselves to meet the staffing, research and outreach needs of many of these institutions.*

Calls to "integrate" water management activities into a more holistic approach are increasingly heard. The goal appears to be to find a more effective way to meet the constantly evolving water-related needs of society.

The terms being used to describe this new approach to water management vary. "Integrated Resource Protection", "Integrated Watershed Management", and "Ecosystem Management" are but a few of the terms. To some, these words elicit a sigh of, "Here we go again!" While to others, the words reflect a major paradigm shift in water management. To still others, the terms imply a threat to "take" water from existing uses and give it to other uses."

Gleick (2000, p. 127)[3] talks of a 'changing water paradigm':

"This 'changing water paradigm' has many components, including a shift away from sole, or even primary, reliance on finding new sources of supply to address perceived new demands, a growing emphasis on incorporating 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. A reliance on physical solutions continues to dominate traditional planning approaches, but these solutions are facing increasing opposition. At the same time, new methods are being developed to meet the demands of growing populations without requiring major new construction or new large-scale water transfers from one region to another. More and more water suppliers and planning agencies are beginning to explore efficiency improvements, implement options for managing demand, and reallocating water among users to reduce projected gaps and meet future needs. The connections between water and food are receiving increasing attention as the concerns of food experts begin to encompass the realities of water availability. These shifts have not come easily; they have met strong internal opposition. They are still not universally accepted, and they may not be permanent. Nevertheless, these changes represent a real shift in the way humans think about water use."

US Army Corps of Engineers on Adaptive Management[4]:

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[2] Ward, R.C. (1995). Special Issue on „Integrated Watershed Management – A New Paradigm for Water Management? Journal of Contemporary Water Research and Education, vol, 100.

[3] Gleick,P.H. (2000). The Changing Water Paradigm: A Look at Twenty-first Century Water Resources Development. Water International, 25, 127-138.

[4] Panel on Adaptive Management for Resource Stewardship, Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning, National Research Council (2004). **Adaptive Management for Water Resources Project Planning.**

In the executive summary of their report on the role of Adaptive Water Management for Water Resources Planning the U.S. Army Corps of Engineers (2004) highlights the need for a paradigm shift: "The *U.S. Army Corps of Engineers has constructed much of the nation's inland navigation, flood management, port and harbor, and coastal protection infrastructure. For much of the Corps' history, the objectives of its civil works program for water resources development have been to construct and maintain channels and ports for commercial navigation, reduce flood damages, protect beaches against erosion, and produce hydroelectric power (and more recently, to promote ecosystem restoration). There have always been criticisms of Corps analytical methods and decision making, but the agency's engineering and planning expertise was long held in high regard by many observers. But the setting of U.S. water resources management changed in the latter part of the twentieth century. There were environmental consequences of previous economic development projects, laws were passed to protect the environment and endangered species, new concepts of ecosystem science and water management were developed, and there was increased recognition of longterm risks and uncertainties within water resources management. In addition, challenges to the Corps' analytical abilities became widespread and many well-informed interest groups and citizens demanded a greater voice in project design and decision making. The U.S. Congress also gave the Corps a specific ecosystem restoration mission in the 1990s. Furthermore, biological and ecological scientists increasingly noted that hydrologic variability and extremes—which the Corps had been traditionally expected to reduce and control—are often essential to the health of aquatic and coastal ecosystems. These scientific and social changes, along with inadequacies of traditional water management frameworks and approaches, prompted the search for water management and ecosystem restoration strategies that can better respond to new knowledge and to shifting social and economic preferences.*

The concept of "adaptive management" has gained attention as having the potential to help address these types of changes and challenges. Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a "trial and error" process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.

The foundations of adaptive management rest in many fields, but its initial presentation as a natural resources management paradigm was in the 1970s, when it was offered as a way to help managers take action in the face of uncertainties, to reduce uncertainties, and to craft management strategies capable of responding to unanticipated events. Adaptive management is not a "one size fits all" or a "cookbook" process, as experience with the concept and its related procedures to date is limited and evolving. There are multiple views and definitions regarding adaptive management, but elements that have been identified in theory and in practice are: management objectives that are regularly revisited and accordingly revised, a model(s) of the system being managed, a range of management options, monitoring and evaluating outcomes of management actions, mechanisms for incorporating learning into future decisions, and a collaborative structure for stakeholder participation and learning. These elements have been traditionally viewed and promoted, to varying degrees, as essential to sound water resources management; adaptive management offers a framework for their integration. Implementation of adaptive management also provides the potential to respond in *a timely manner to changing conditions, social objectives, and new knowledge. It can therefore help avoid costly or irreparable mistakes and unintended consequences."*

The Rocky Mountain Institute – On a paradigm shift for water management

The following text is a direct quite from homepage of the Rocky-Mountains Institute: http://www.rmi.org/sitepages/pid279.php.

> *"Methods used by industrialized societies to manage water supply, wastewater, and stormwater were essentially established in broad outline a hundred or more 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. Conventional methods are evolving in new directions. At the same time, new technologies, and old ones in newly refined forms, are emerging that present new options for water systems. Institutional and managerial innovations are likewise emerging at a rapid rate. It appears that development of a new paradigm for water systems is both necessary and likely.*
>
> *The old paradigm and the emerging paradigm are broadly characterized below. These are simplifications of course, and many systems are in transition, but the rough differences in approach are instructive."*

Table 1: Old & emerging paradigm

The Old Paradigm	The Emerging Paradigm
Human waste is a nuisance. It is to be disposed of after the minimum required treatment to reduce its harmful properties.	**Human waste is a resource.** It should be captured and processed effectively, and put to use nourishing land and crops.
Stormwater is a nuisance. Convey stormwater away from developed areas as rapidly as possible.	**Stormwater is a resource.** Harvest stormwater as a water supply, and retain or infiltrate it to support aquifers, waterways, and vegetation.
Build to demand. It is necessary to build more capacity as demand increases.	**Manage demand.** Demand management opportunities are real and increasing. Take advantage of all cost-effective options before increasing infrastructure capacity.
Demand is a matter of quantity. The amount of water required or produced by water end-users is the only end-use parameter relevant to infrastructure choices. Treat all supply-side water to potable standards, and collect all wastewater for treatment in one system.	**Demand is multi-faceted.** Infrastructure choices should match the varying characteristics of water required or produced by different end-users: quantity, quality (biological, chemical, physical), level of reliability, etc.
One use (throughput). Water follows a one-way path from supply, to a single use, to treatment and disposal to the environment.	**Reuse and reclamation.** Water can be used multiple times, by cascading it from higher to lower-quality needs (e.g., using household graywater for irrigation or toilet flushing), and by

	reclamation treatment for return to the supply side of the infrastructure.
Gray infrastructure. The only things we call infrastructure are made of concrete, metal and plastic.	**Green infrastructure.** Besides pipes and treatment plants, infrastructure includes the natural capacities of soil and vegetation to absorb and treat water.
Bigger/centralized is better. Larger systems, especially treatment plants, attain economies of scale.	**Small/decentralized is possible, often desirable.** Small scale systems are effective and can be economic, especially when diseconomies of scale in conventional distribution/collection networks are considered.
Limit complexity: employ standard solutions. A small number of technologies, well-know by water professionals, defines the range of responsible infrastructure choices.	**Allow diverse solutions.** A multiplicity of situation-tuned solutions is required in increasingly complex and resource-limited human environments, and enabled by new management technologies and strategies.
Integration by accident. Water supply, stormwater, and wastewater systems may be managed by the same agency as a matter of local historic happenstance. Physically, however, the systems should be separated.	**Physical and institutional integration by design.** Important linkages can and should be made between physical infrastructures for water supply, stormwater, and wastewater management. Realizing the benefits of integration requires highly coordinated management.
Collaboration = public relations. *Approach other agencies and the public when approval of pre-chosen solutions is required.*	***Collaboration = engagement.*** *Enlist other agencies and the public in the search for effective, multi-benefit solutions.*

NeWater – on a paradigm shift in water management:

For the past two decades, new, more integrated approaches to water management have been developed and are being implemented to address perceived shortcomings in earlier approaches. During the last decade, the principle of Integrated Water Resources Management (IWRM) has, for example, been used as a framework for the implementation of such integrated approaches to water management (GWP-TEC, 2000). “Integrated” clearly indicates an aspiration to functionally engage a range of perspectives by formally considering a wide range of potential trade-offs at different scales in space and time. Such an approach attempts to overcome the short-comings of technical, end-of-pipe solutions dealing with individual problems in isolation and thus often neglecting unexpected consequences (Pahl-Wostl, 2007a). However, implementation of an integrated resources management approach that fully accounts for the complexity and interdependencies of human-technology-environment systems has yet to be realized. 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; Pahl-Wostl in press; Prato, 2003; Light and Blann, 2000; Committee on Grand Canyon Monitoring and Research, 1999). Such complex adaptive systems 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). Control is distributed rather than central (Allen & McGlade, 1985; Pahl-Wostl, 1995). Rather than trying to change the structure of complex, adaptive systems to make them controllable by external intervention, innovative management approaches aim at making use of the self-organizing properties of the systems to be managed.

This implies a paradigm shift in water management from a prediction and control to a management as learning approach. The change towards adaptive management could be defined as "learning to manage by managing to learn". Such change aims at increasing the adaptive capacity of river basins at different scales. Some structural requirements for a system to be adaptive have been summarized in the following table. Two different regimes are contrasted as the extreme, opposing ends of six axes.

Table 2: Different regimes and their characteristics

Dimension	Prediction, Control Regime	Integrated, Adaptive Regime
Governance	Centralized, hierarchical, narrow stakeholder participation	Polycentric, horizontal, 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	Transboundary problems emerge when river sub-basins are the exclusive scale of analysis and management	Transboundary issues addressed by multiple scales of analysis and management
Information Management	Understanding fragmented by gaps and lack of integration of information sources that are proprietary	Comprehensive understanding achieved by open, shared information sources that fill gaps and facilitate integration
Infra-structure	Massive, centralized infrastructure, single sources of design, power delivery	Appropriate scale, decentralized, diverse sources of design, 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

Current approaches to realizing integrated water management build on the heritage of a predict-and-control paradigm that has been dominating the water management community for decades. Failure to implement integrated approaches may not be related to the principle of integration itself but rather to the mental models that frame the process of its implementation.

The characteristics of integrated adaptive regimes are to be regarded as working hypotheses since the change towards more adaptive regimes is yet slow and empirical data and practical experience thus limited. One possible reason for this lack of innovation is the strong interdependence of the factors stabilizing current management regimes. One cannot, for example, move easily from top-down to participatory management practices without changing the whole approach to information and risk management. Hence, research is urgently needed to better understand the interdependence of key elements of water management regimes and the dynamics of transition processes in order to be able to compare and evaluate alternative management regimes and to implement and support transition processes if required.

1.4 What unites the voices suggesting a paradigm shift in water management?

All examples in the previous section explicitly use the notion of a paradigm for characterizing water management but only Cortner and Moote define explicitly what they mean by a paradigm shift. Elements that seem to be prominent in these descriptions:

- Participatory management and collaborative decision making
- increased integration of issues and sectors
- management of problem sources not effects
- decentralized and more flexible management approaches
- more attention to management of human behaviour by “soft” measures
- include environment explicitly in management goals
- open and shared information sources (including linking science and decision making)
- incorporating iterative learning cycles

The different sources differ in detail and emphasis but not in the essential elements of the nature of the paradigm shift. The concept of a regime is only used in the NeWater project whereas the other contributions summarize what is named regime in NeWater as paradigm by stating basic assumptions crucial for management related to different regime elements. The paradigm shift in water management 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, 2007).

2 Different approaches to management and control

Management may be defined as the planned and purposeful act or practice of exerting influence on a system, of steering it in a certain direction. In general management aims at achieving certain objectives. As defined in a textbook on mathematical control theory “To *control* an object means to influence its behaviour so as to achieve a desired goal” (Sontag, 1998). Hence the two concepts are clearly related. Management implies to be able to steer the system to be managed to a certain degree. However, there may be quite different views on what steering means and how it can be achieved. It may be useful to devote some considerations on theories of control and if and how they have and can be applied to water management.

The application of control theory and technical management problems has a long tradition in control engineering which aims at the design of controlling devices for dynamic systems using mathematical models to optimize the design. Control engineering has its roots in electrical engineering. The design of controllable electronic circuits laid the foundation for linear control theory where much of the concepts for control have been developed. Control theory has developed into all kinds of directions. Still one guiding principle is the attempt to provide means to understand if and how systems can be controlled and to use such knowledge to design systems that are controllable. Such design is easiest in technical systems where all parts are artificially designed and desirable properties can be chosen.

First and foremost of interest has been central control by a control agent which may be a human being or automated control by a technical device. These technical devices range from Watt's steam engine governor, designed during the English Industrial Revolution, to the sophisticated microprocessor controllers found in consumer items such as CD players and automobiles or in industrial robots and airplane autopilots. Machines like cars or airplanes are designed such that they can be controlled by an individual driver or pilot.

Distributed control has been introduced in systems where a central control agent is not appropriate – e.g. water management, electronic circuits, traffic systems or complex power networks. The controlling devices are not in a central location but are distributed throughout the system with sub-systems being under the control of one or more controllers. The principle approach towards the nature of control of these subsystems does not differ from the centralized control approach. The entire system may be networked for communication and monitoring.

The control approach adopted here is that systems (or sub-systems) are controllable. This implies that all a system’s state can be uniquely characterized by observation and that one can move a system around in its entire configuration space using only certain admissible manipulations.

A more radical deviation from the established control paradigm was introduced with the advent of the concept of complex adaptive systems which may be characterized as:

- A complex, nonlinear, **interactive** system which has the ability to **adapt** to externally imposed and internally generated changes. CAS are characterized by the potential for **self-organization** and **emergence**.

- CAS consists of diverse agents which interact according to certain interaction **rules**. The agents adapt by **changing their rules and, hence, behavior**, as they gain experience.
- Complex, adaptive systems **evolve** historically, meaning their past or history, i.e., their experience, is added onto them and determines their future trajectory.

"Control" is distributed here as well but it resides in the properties of individual agents and the nature of their interaction. Hence this is a very different control approach. Such systems are for example supposed to be more efficient than central control in the allocation of limited resources (e.g. energy, labour, computation time) and dealing with localized information for doing so. Huberman (1988) for example introduced the concept of "computational ecologies" to use the power of the characteristics of ecosystem or markets for the design of computational system that outperformed computing systems with a central control (Huberman and Hog, 1993). Adam Smith (1776) coined some centuries ago the metaphor of the invisible hand for the influence of the market as institution. Without any central control an economic market leads to economically and socially beneficial outcomes despite of individual market participants following their self-interest. We do not want to comment on the normative claims about the efficiency of markets, the problem of governmental intervention and the nature of human behaviour. Of interest is here the early recognition of the fact of distributed control residing in the characteristics of individual agents and the nature of their interaction.

To add another level of complexity one has to acknowledge that in human systems the importance of meaning cannot be ignored in the interaction of 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 not meaningful and by far not sufficient to understand management.

Some mechanistic understanding of human behaviour and control has also been applied to social systems. Similar to the control of technical systems one is using some levers to steer the system in the right direction.

What is now the appropriate approach to understand management and potential and limitations of control approaches in water management? And how can and should water management systems be designed? We argue that water systems as human-technology-environment systems need to be characterized as complex adaptive systems where reflexivity has to be taken into account. Such complex adaptive systems are characterized by self-organization, adaptation, heterogeneity across scales and distributed control. The state space is not closed and predictable but open and evolving. Development may be path and context dependent; the system attempts to escape external pressures by adaptation in changing its internal structure. The system itself is in constant change. Regarding the assumptions of a control paradigm one can note the following differences (see Table 3 below):

Table 3: Different types of systems and their characteristics

Properties of controllable, mechanistic systems	Properties of reflexive complex adaptive systems
A system can exist in a finite set of states and each state can be uniquely characterized by observation	The state of a system depends on history and context, entirely new states can evolve.
Based on a system characterization one can devise a unique set of control measures to move the system from one state to another state	Systems may escape attempts of external control by adaptation and human beings may behave differently than anticipated and change even the rules under which they operate.
Uncertainties in the state transition functions can be quantified by probabilities	For some extreme states it may be impossible to quantify transition probabilities, non-linear developments may render probabilistic judgements exceedingly difficult
Risks are quantified by multiplying the probability of an event with the magnitude of the expected damage	Risk assessments require dialogues since people judge risks differently based on their perception of being able to influence the risk)

Remaining in the language of dynamic systems one can illustrate the difference between the two system paradigms using the metaphor of a fitness landscape where hills refer to desirable states and valleys to states to be avoided. The mechanistic control paradigm is based on finding optimal solutions in a constrained and predictable state space. The control problem is then to find the right levers to move the system to the optimal state and keep it there. The system paradigm based on complex adaptive systems and reflexivity acknowledges that the fitness landscape is dynamic and changes upon any attempt to move towards an optimal state. Hence the "control problem" is then to find methods to support navigation in a fitness landscape that is in continuous change.

The different paradigms can also be found in approaches to characterize strategies in human behaviour. Classical game theory assumes the existence of a rational expectations equilibrium, the so-called Nash equilibrium where each player chooses the best response to the strategies chosen by all other players. In contrast approaches based on inductive reasoning which assume that individual players cannot know the strategies chosen by other players in advance (Arthur,1994). Each player disposes of a wide range of strategies and chooses a strategy based on prior experience. One can talk of an "ecology of strategies" where the fitness of a strategy depends entirely on the continuously changing landscape generated by the other members of the strategy set. By trying to optimize the own strategy a player introduces a change in the system and hence alters the conditions on which optimization was based.

The increased awareness for the complexity of systems and for management as learning rather than control seems to be an overall trend in different fields (Senge, 1990; Pahl-Wostl, 1995, 2004; Levin, 1998; Hartvigsen at al, 1998; Berkes et al, 2002). On one hand the systems to be managed and the problems to be tackled have become indeed more complex. The pace of change in socio-economic conditions and technologies is tremendous. Uncertainties arising from global change in general and climate change in particular pose major challenges for the management of environmental resources. On the other hand the awareness of the need to take the complexity of problems fully into account has increased and the frame of analysis has partly changed. One may talk of socially constructed problem domains. The frame of reference determines how a problem is conceptualized (Shakley at al, 1996; Pahl-Wostl, 2007).

A socially constructed problem domain stabilizes itself by recursive reasoning. Institutions and technologies (artefacts more generally) are developed and implemented based on a shared paradigm. Hence, any transition to a new management regime based on a different paradigm requires collective learning processes, and new methods are required that allow us to analyse the origins and importance of socially constructed problem domains and impediments to change. We adopt here a moderate approach to social constructivism which does not deny the existence of a reality independent of an observer and hence rejects ontological relativism but which clearly acknowledges the context dependence of knowledge and thus accepts epistemological relativism (Milton, 1996; Burningham and Cooper, 1999).

As pointed out by Jones (2002) and Pahl-Wostl (2007) special approaches are needed to communicate across paradigm boundaries and make explicit the implications of different world views.Diverse world views are different interpretations of a common reality and the same base of factual knowledge may be used to derive entirely different meanings and thus conclusions for interacting with the world surrounding us. We need to combine hard and soft system approaches which are summarized in table 4. The hard systems approach in problem solving assumes that objectives are given and that optimal solutions can be found. The soft systems approach takes into account the social construction of meaning of knowledge about the world. A combination of both approaches should improve deliberations using factual knowledge and processes of negotiation where beliefs and values play a major role. Section 4 will elaborate in more detail on the importance of increasing understanding of the role of mental models and framing in conceptualizing control and management approaches.

The next section will now elaborate in more detail on the efficiency of different control strategies (centralised versus de-centralised) for water management under different circumstances highlighting what is quite robust knowledge and where there is room for interpretation and normative judgements. .

Table 4 illustrates the differences between hard and soft system approaches in systems science (after Checkland, 1989).

	Hard	**Soft**
objective	given	problematic
focus	reality how to do it	perceptions what and how
models	of X relevant to Y	of pure purpose to structure a debate
paradigm	optimising goal seeking	learning
expert	external expert	participative (facilitator)
system	exist in the world	in the process of inquiry

3 Centralised versus decentralised water management

3.1 Centralisation and decentralisation: an overview

In prehistoric times society was organised in small communities that made all decisions concerning people and their environment themselves. The rise of chiefdoms and later nation states started to change this. More and more power became centralised in one location (whether it be geographically or politically). What eventually in mediaeval times arose were absolutist monarchic states. Within these states political power was centralised, but especially in rural areas individuals retained a certain degree of autonomy and even cities enjoyed some self-government (Wollmann, 2006).

In the 19th century further centralisation took place. Technological advances made mass production possible, resulting in large centrally organised infrastructure (such as water and sanitation supply). Standardisation became increasingly important, not only allowing economies of scale but also issues as safe guarding public health. However, the centralised welfare state ideal was not to last. By the late 1960s the management of national economies was shaken when it became clear that stagflation could occur (Manor, 1991). Unemployment and inflation, later combined with the oil crises of the 1970s, made people realise that centralisation might not be the answer to solve the world's economy forever.

Decentralisation slowly became of interest to politicians and other leaders. It is not possible to point at just one cause for this move. It happened at different times in different countries under different circumstances due to different reasons. Central groups were unable to meet demands from organised interests, over-centralised power diminished the autonomy, resources, effectiveness and responsiveness of ruling parties and formal institutions, small enterprises in many sectors were able to compete with large enterprises due to advances in technology, their greater flexibility and greater adaptive capacity. Decentralisation was seen as a means to link political demands for services with a requirement that beneficiaries pay for them. Decentralisation was also seen as a means to delegate responsibilities from national governments to lower levels of government, and as a means to cut expenditure.

Sustainability has started to play an increasingly larger role in the move towards decentralisation. Resources are not infinite and which has become especially apparent in natural resources management. In the 1980s and 1990s sustainability awareness led to the abandonment of large investments in water and other natural resources infrastructure in favour of smaller more decentralised projects. Climate change is the latest actor in the field of decentralisation. Decentralisation is seen by many as the solution to inefficiency, bad management, corruption, inequity and other undesirable factors in governance. But is it really the cure for all evils?

The terms 'centralised' and 'decentralised' have been used by many authors with a variety of meanings in a variety of contexts. It is therefore important to make clear what the definition of both is as used in this document. A general common-sense definition of centralisation *is to concentrate by placing power and authority in a centre, while to decentralise is to disperse or distribute power from the centre* (Wolman, 1990). Rondinelli et al. (1981), adapted by Faguet (1997) gave the following more developed general definition of decentralisation: *the transfer of responsibility for planning, management, and resource-raising and allocation from the central government to (a) field units of central government ministries or agencies; (b) subordinate units or levels of* *government; (c) semi-autonomous public authorities or corporations; (d) area-wide regional or functional authorities; or (e) non-governmental organisations, private voluntary organisations and private firms*.

Centralisation and decentralisation happens in different areas of influence. Wolman (1990) distinguishes three types: political, administrative and economic. Political refers to the centralisation or decentralisation of political decision-making, that is decision regarding policy issues, revenues required and allocation of those revenues. Administrative is not always easy to separate from political centralisation/decentralisation. It relates to delegation of administrative decision making as opposed to decisions about the nature of a policy. Economic centralisation/decentralisation relates to the location of economic decision-making (Bardhan, 2002).

These three types of decentralisation all can occur in water resources management. In water management however, there sometimes is a fourth area where the term decentralisation is used, that to describe the physical system. Water works infrastructure can be at a national level (for instance a national grid for domestic water supply) or local (a single well or borehole). Whether the physical situation is centralised or decentralised says little about the political, administrative or economic decision making of that system. A state company may own and operate a series of physically separate wells and still be considered as a centralised system. Similarly a national grid can be operated by a large number of companies and considered decentralised.

3.2 The theory behind decentralisation

The literature on the theory of decentralisation has been applied to many different situations and circumstances, one of them is water resources management. In 1956 Tiebout developed an economic model of the local public sector. According to this model individuals and companies will optimise their preferences for levels of services and amenities and willingness to pay tax for these (Bardhan, 2002). Those willing to pay more will tend to move to areas with like-minded people and similarly so for people who are less interested in extra amenities (Wolpert, 1990). In Tiebout's model local governments compete to attract individuals thus achieving allocative efficiency at a greater degree than a central government would be able to do.

Tiebout's model has been the most influential economic model driving decentralisation processes around the world, including those in water resources management, for a long time. There are however some essential problems with this model. Tiebout's model assumes perfectly informed actors that are mobile and a fixed public service. In reality it is often the opposite, individuals are largely static and it is the government that changes (Faguet, 1997). Another assumption of Tiebout's model is that revenues raised by a given subnational level of government come from individuals living within the area of that level of government and will be used by that government. But in many countries this is not necessarily the case and revenues from one area may be used to benefit another area (Prud'homme, 1990). there is also an assumption that taxes and expenditures are joined, but this assumption is not realistic in many countries.

Wolman (1990) argued that there are three sets of important values that can be improved or hindered by decentralised as opposed to centralised systems. These sets consist of efficiency, governance and distributive values. Efficiency is given by Wolman (1990) as the maximisation of social welfare. To achieve this, individual preferences must be expressed. Because there is a difference in individual preferences for public goods, some divergence between individual preferences and the tax and service package will take place reflecting the aggregated preferences of the community as a whole. The average divergence is likely to be smaller in smaller communities of similar individuals than in larger more heterogeneous areas. A highly centralised government is therefore more likely to result in a greater than average divergence and a highly decentralised government is more likely to result in a smaller divergence. Allocative efficiency is thus more likely to be achieved in decentralised political structures.

Wolman's second set of values is that of governance. This can be subdivided into a number of categories: (a) responsiveness and accountability, (b) diversity, (c) political participation, education and leadership, (d) countervailing power, (e) national interests and (f) equality. By placing the government closer to the people, decentralisation encourages greater responsiveness of policy-makers to what people want. This is not only because policy makers are more knowledgeable about local needs but also decentralisation allows them to be held directly accountable through local elections. In more decentralised societies there will be a larger variety in public services, allowing individuals to choice their preferred option. Diversity is also argued to encourage local experimentation and innovation. Devolving real decision making to lower levels of government is thought to result in higher levels of interest and participation. Decentralisation also encourages political education and debates, prerequisites for the effective functioning of democracy. Decentralised structures are sometimes proposed as a way of protecting democracy through assuring countervailing centres of influence and power. There are governance value arguments for both centralisation and decentralisation when it comes to national interests. It is possible that local level policy choices are different from those at national level. This can be acceptable when they are not conflicting, but this is not always the case. Some governments may wish to impose certain national policies on local level, for instance to guarantee a minimum level of welfare or to ensure certain standards are met. The final governance value is that of equality. Decentralisation will lead to different levels of public services and taxation. These differences may be extreme. If this is undesirable centralisation may be more appropriate than decentralisation (Wolman, 1990).

Political decision-making is not policy-neutral. Certain interests have more influence at a national level than locally and vice versa. Changes in centralisation or decentralisation will therefore bring changes in public policies. According to Wolman (1990) these changes are reflected in a third set of values, that of distributive values.

3.3 Decentralisation in water management: its promises and requirements

Water management is characterised by so-called 'wicked' problems (Rittel and Webber, 1973). Wicked problems are groups of related problems, with high levels of uncertainty and a range of competing values and decision stakes. Due to their complexity and far reaching consequences wicked problems cannot be solved by one single organisation, but require cooperation, as a solution for one group involved can actually result in problems for others (Waalewijn et al., 2005). Competing perceptions and values often involve differences in power and as a result wicked problems enter into the world of politics. A central problem in water management lies in finding ways to deal with the uncertainty and complexity of the wicked problem (Rogers et al., 2000). Collaboration of all involved parties is stimulated in a decentralised approach and it is not strange that decentralisation is more and more seen as the way forward. However, traditional legal structures usually favour centralised administration and decision making. Stakeholder involvement and public participation are important tools to achieve the goals and objective set out by water management reforms towards decentralisation, but the main question remains, does decentralisation work?

Decentralisation in the past few years has been seen as the cure to many problems. Aiyar et al. (1996) named a number of areas where decentralisation shows considerable promise: Reversing neglect of local institutional development, improving development projects and making them more sustainable, enhancing government responsiveness, increasing information flows between governments and citizens, promoting greater participation and associational activity, enhancing transparency, enhancing accountability, integrating society with the state and reinforcing and reinvigorating democracy at national level. Moderate promise is shown in the following areas: reinforcing central government commitment to rural development, broadening project focus beyond agriculture, reducing absenteeism among government employees, promoting cooperation between NGOs and government, reducing regional disparities, tackling the problem of complexity and coordination, paying greater attention to socio-cultural factors, empowering women, tailoring development to local conditions, facilitating scaling up of successful pilot projects and reducing corruption. On the other hand, very little promise is shown in the following areas: alleviating poverty within localities, accelerating economic growth, reducing overall government spending, enhancing macro-economic policy coordination and stabilisation, easing the problem of excessive agricultural taxation, mobilising local taxes, promoting planning from below and promoting mass community participation in projects (Aiyar et al., 1996).

There are many factors that influence successful decentralisation. The factors mostly concern actors involved in the process. These actors are the stakeholders (including the general public), local governments and higher levels of government (state, national and even international). Starting with the local government, the factors can be divided into three main categories, organisational, relationships and accountability (see Table 5 below):

Table 5: Factors for successful decentralisation – local government

ORGANIZATIONAL
▪ Sufficient administrative capacity (Aiyar etal.,1996) ▪ Strong governmental institutions which produce high quality outputs can lead to participative and responsive governance (Faguet, 2003) ▪ Institutional mechanisms can help to meet stakeholders' demands (Henocque, 2001) ▪ Development of appropriate policy instruments (Baril et al., 2006) ▪ Sufficient funds to achieve tasks (Aiyar et al., 1996) ▪ Clearly defined spatial and jurisdictional boundaries (Latham, 2002)
RELATIONSHIP
▪ Bottom up approach from within the local government supported by higher levels of government (Lemos and Oliveira, 2004) ▪ Local governments should have a firm grounding in the local economy, politics and civil society (Faguet, 2003) ▪ Local governments should be part of an open and fair political system, with transparency in local politics and economy (Faguet, 1997) ▪ Local governments should have the power to influence the political system (Aiyar et al., 1996) ▪ Local governments can gain access to valuable local knowledge through involvement of NGOs (Brannstromm et al., 2004) ▪ Local governments should treat all stakeholders as equal partners, (Brannstrom et al., 2004) ▪ It is important that all officials within the local government support the decentralisation process

(Lemos and Oliveira, 2004; Vári, 2004)
ACCOUNTABILITY
▪ Local governments should be accountable, not only upward to higher levels of government, but more importantly also downward to stakeholders and lateral to other local governments (Branstromm et al., 2004; Latham, 2002) ▪ Local governments should have public accountability (Faguet, 2003) ▪ Local governments should have accountability mechanisms (Aiyar, 1996) ▪ Local governments should demonstrate procedural and distributive justice (Syme and Nancarrow, 2006)

Like certain factors affecting local governments have an influence on the success of decentralisation, factors affecting stakeholders also have an influence. These factors mostly lie in the areas of organisation and relationships (see Table 6 below).

Table 6: Factors for successful decentralisation – stakeholders

ORGANIZATIONAL
▪ stakeholders have a greater chance of influencing the decentralisation process if they are part of a legal frame work (Brannstom, 2004) ▪ stakeholder organisations have a greater chance of influencing the decentralisation process if they have a legal basis (Vári, 2004; Latham, 2002) ▪ stakeholders should not only be able to make decisions but also to enforce them (Latham, 2002) ▪ stakeholders should be able to make modifications to plans (Sumberg and Okali, 2006) ▪ stakeholders need resources for capacity building (Latham, 2002) ▪ stakeholders should have a shared vision and perceptions (Henocque, 2001; Latham, 2002) ▪ stakeholder organisations should have social cohesion and organisation (Faguet, 1997)
RELATIONSHIP
▪ stakeholders should support local government officials (Lemos and Oliveira, 2004) ▪ stakeholder organisations should be recognised by all sectors involved in the process (Lemos and Oliveira, 2004) ▪ a sense of ownership and participation of stakeholders are beneficial for good stewardship and political good will (Henocque, 2001) ▪ cooperation between all groups involved is essential (Henocque, 2001) ▪ trust is an essential ingredient for all actors involved, but even more so for stakeholders (Vári, 2004) ▪ activity levels and professionalism of stake holder organisations will influence the process (Vári, 2004) ▪ stakeholders need a complete understanding of all actors in the system (Lemos and Oliviera, 2004)

Higher levels of government, be it state, national or even international, also can have a beneficial influence on decentralisation:

- by working as a neutral administrator and referee (Faguet, 1997);
- through commitment to the decentralisation process (Latham, 2002);

- by providing financial resources required for decentralisation (Rondinelli, 1983);
- by keeping interference and intervention to a minimum (Latham, 2002);
- through (financial) support from international agencies and donors (Vári, 2004; Lemor and Oliveira, 2004), as long as this is not continued indefinitely (Rondinelli, 1983).

Finally there is a number of factors which influence the decentralisation process at one or more of the levels mentioned before, or do not fit into any category:

- The use of technology can support democratic decision making (Lemos and Oliveira, 2004);
- Conflicts, such as severe water scarcity, can act as a catalyst for decentralisation (Lemos and Oliveira, 2004);
- Water management can not be seen as a separate issue from land management (Dube and Swatuk, 2002);
- Smaller units of management increase the chances of success (Latham, 2002);
- Methodological support is important as is the social learning process (Vári, 2004);
- Teaching and training are important aspects of a decentralisation process (Rondinelli, 1983);
- Long term planning is essential (Rondinelli, 1983);
- Planning small and increasing incrementally to increase the chances for success (Rondinelli, 1983);
- (financial) incentives can be used as tools to develop plans (Lesouëf, 1996; Hunt, 1989).

It should be emphasized that even where decentralisation is a useful tool, the state does not loose its legitimacy. It can play an active role in the mobilisation of people in local processes, it can aid in neutralising local oligarchs, can provide funds for local initiatives, provide technical and professional services to help local capacity building, guarantee quality standards, invest in larger infrastructure and coordinate in externalities that span more that one local government (Bardhan, 2002).

To conclude this section, it can be stated that decentralisation can work. As discussed above, there are some advantages to decentralisation, but at the same time there can be draw backs as well. These advantages and disadvantages may not always be clear at the beginning. What is clear is that decentralisation is not a straight forward solution to water management problems. It is also true that some problem areas lend themselves more to decentralisation that others. Local solutions to local problems such as water allocation within a small river basin will likely be found more easily under a decentralised system, but there will probably always be the need for a certain degree of centralisation, for instance in the area of transboundary problems and the setting of standards.

Related concepts used in NeWater: POLYCENTRIC GOVERNANCE

Discussing the aspect of decentralisation in a broad approach, it has to be mentioned that other concepts exist in that field and have some overlapping parts with the decentralisation concept. One important concept from the governance-sphere is the concept of polycentric governance, which also is mentioned in connection with further related concepts such as “multi-level governance” and "multiple spheres of authority" (Ostrom, 2005: 255; Marks and Hooghe, 2004; Rosenau, 2004). According to Ostrom (2001: 2) "*polycentric systems are the organization of small-, medium-, and large-scale democratic units that each may exercise considerable independence to make and enforce rules within a circumscribed scope of authority for a specific geographical area*". Adaptive management suggests that there should not be one single centre of power, but a system dividing power to multiple centers, or a polycentric governance system. This coincides with the decentralisation concept described above. The concept of polycentric governance plays an important role in the NeWater project as it is considered as one important element of adaptive regimes.

A scientific paper by Huitema et al. on adaptive governance was written within the NeWater project and recently submitted. In this paper the topic of polycentric governance within adaptive management is discussed in depth. The following lines are extracted from this article and show the similarities with the concept of decentralisation that was discussed above. Both concepts are currently used in parallel.

Compared to monocentric systems – which can be similar to the centralised systems mentioned above – a polycentric governance system has more capacity to cope with external shocks, is more robust, and possesses considerable redundancy. (Otrom 2001) Polycentric systems are supposed to be less vulnerable and – when failing to adapt – expected to induce only small-scale disasters, which may then be compensated by the successful reaction of other units in the system (Ostrom, 2001: 2).

Also similarly to the decentralisation process, one of the main challenges in a polycentric system is the need to co-ordinate the different units of governance. Here, the importance of individuals connecting scales and sectors is of utmost importance. If the units pursue only their individual interests without any coordination, polycentric governance may become detrimental to sustainable water governance. "Boundary spanners"- individuals or collectives who connect centers, levels and sectors- and boundary objects – artifacts with sufficient ambiguity to appeal to multiple audiences- are essential to co-ordinate the different units (see e.g. Star and Griesemer, 1989 Sullivan and Skelcher, 2002). Boundary spanners facilitate and steer the knowledge debate, but they also use knowledge to span boundaries between different jurisdictions and policy sectors.

Collaboration across existing boundaries is thus crucial to make sure that the potential advantages are realized and potential disadvantages are avoided in a polycentric system. One of the major decisions in a polycentric system is also to determine which question is being dealt with at which level. In practice, these decisions are highly political. Adaptive management suggests that these decisions should remain flexible and subject to re-evaluation.

An important task of the research in the NeWater project will be to integrate the different concepts on governance which deal with similar themes but slightly different emphasis and which reflect the discourse in different scientific communities.

4 Role of mental models and framing in conceptualizing management and control

There are numerous factors that influence how people make sense of the world. Since this is a very complex issue involving subconscious processes it is impossible to reconstruct this sense making process. In this section different approaches will be presented that conceptualize social constructions of meaning and help to understand the role of paradigms in this process. As pointed out previously, we adopt here a moderate approach to social constructivism which does not deny the existence of a reality independent of an observer and hence rejects ontological relativism but which clearly acknowledges the context dependence of knowledge and thus accepts epistemological relativism (Milton, 1996; Burningham and Cooper, 1999).

In a first step it is useful to introduce the concepts of mental models and frames.

4.1 Role of mental models and socially constructed realities in general

Different scientific disciplines highlight different aspects of this making sense of the world using various terms in different constellations. Among those are mental models, frames, worldview, perspective and also paradigms; Craps et al. in press). There are no common definitions of any of these terms. What they seem to have in common is to offer a coherent (based on some internal logic) interpretation of reality that can be activated from fragmented evidence. The different approaches differ in the importance they attribute to the (re)negotiation of meaning in a social context and in the emphasis given to shared versus individual representations.

In the current paper the following distinction between mental models and framing is made:

> **Mental Model**
>
> *A mental model is a relatively enduring internal abstraction of an external system (reality) (after Doyle and Ford 1998: 17) to aid and govern activity. It is not static but may undergo changes over time. This definition of mental models is in line with Dewulf et al.'s (2005) "structure of expectation". (Structure)*
>
> **Framing**
>
> *Framing is the way mental models are applied to a certain (action) situation. OR: Framing is the way the meaning of external systems is (socially, interactively) constructed in a specific action situation. This definition of framing is in line with Dewulf et al.'s (2005) "alignments negotiated in interaction". (Process)*

The definition of framing refers to rather external though not necessarily completely conscious processes. As for the non-interactive process the term "adopting a frame" would be more adequate (cf. Kaufmann & Smith http://urban.csuohio.edu/~sanda/papers/frames98.htm#s1).

The definition of framing refers to action situations, a term which is derived from the IAD (Institutional Analysis and Development) framework[5] (Ostrom, 2005). Ostrom (2005) elaborated on the role of mental models as part of the IAD framework based on an institutional economics approach: Mental models influence what one perceives of a certain situation and how, and can change based on new experience. Mental models are assumed to store knowledge of relevance to act in collective choice problems which are the focus of the IAD framework. They store action-outcome linkages and allow actors to compare different actions, their anticipated outcomes to make a choice between alternatives. Mental models can be influenced by culture (or paradigms) which represents shared beliefs and shared (parts of several mental) models about the world

Figure 1 shows the relation between mental models, frames and paradigms. A paradigm is defined as an ideal-typical institutional pattern linked to a specific set of mental models. Going back to our original definition of water management paradigm in section 1 these include basic assumptions about the nature of the system to be managed, the goals of management and the ways in which these management goals can be achieved.

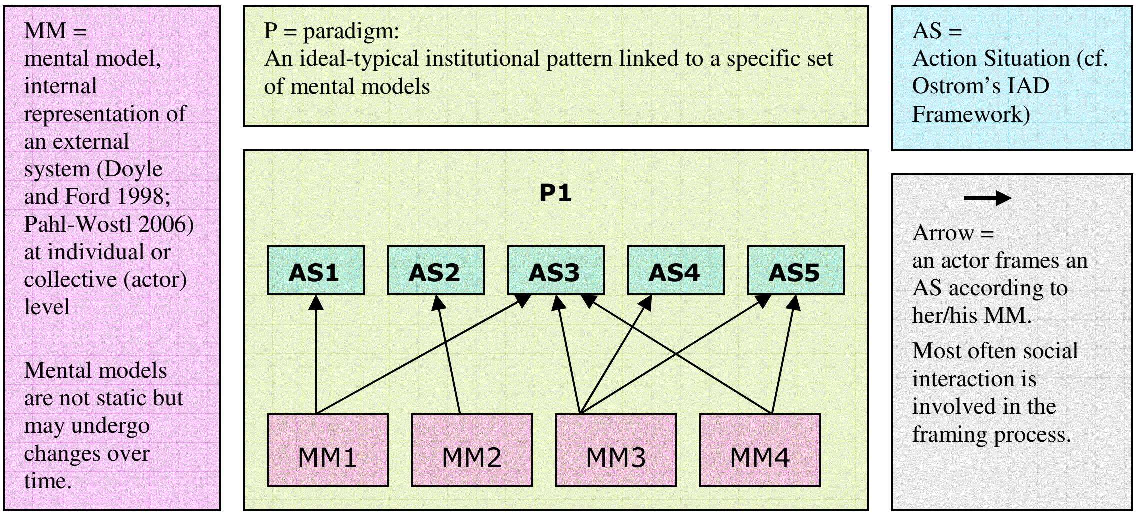


Figure 1: Relation between mental models and paradigms[6]

Within one paradigm numerous different mental models may exist but which all share a basic conviction with regard to the paradigm. These mental models have different relations to certain action situations. The arrows in the graph representing processes of framing (more precisely "issue framing" according to Dewulf et al. (2005)) show two relations: on the one hand a person can apply his individual mental model to different action situations and on the other different persons with their individual mental models frame situations differently.

Differences in framing are one of the key reasons for problems in communication among actors. Two people may engage in a conversation with their mental models, holding different interests, beliefs, cultural background etc. They will interpret each others arguments very differently and hold

[5] See also deliverable 1.7.1 on the MTF (Management and Transition Framework) for a more detailed explanation of the IAD framework.

[6] From Nicola Isendahl (2006). Re-framing Uncertainties in Water Management – On the way to Adaptive Water Management. PhD proposal, unpublished.

contradicting expectations about each others behaviour. People make judgements about motives other actors hold. Hence the framing of the goal of a negotiation process – the role of different actors, their position, their views on what is at stake are key factors and determine entirely the outcome of a process. The nature of framing may be based on prior experience or cultural beliefs/paradigms. Figure 2 summarizes the role of mental models in processing and filtering information. It highlights the role of individual cognitive limitations and the influence of factors stemming from the social environment.

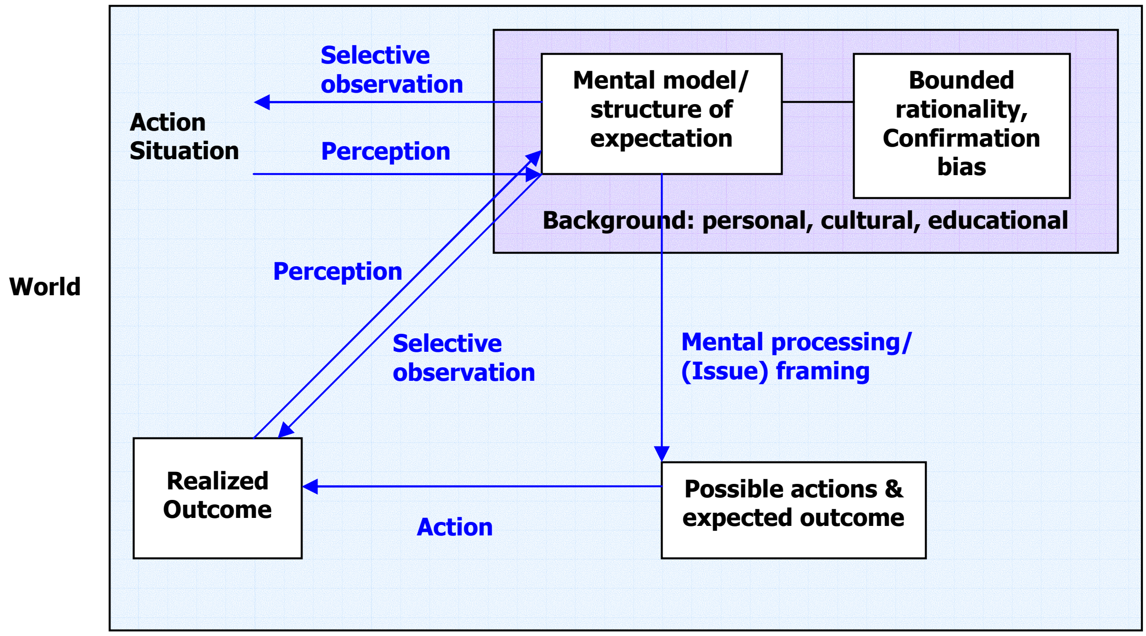


Figure 2 The role of mental models in the selective processing of information

People hold internal representations, mental models of an external system. These mental models may be shaped by the role of actors in a social system, their previous experience and cognitive biases that result from heuristics that allow human beings to survive and act in a very complex and partly unpredictable world. Mental models determine the processing of information which is selective. Experience may help to construct a context from few pieces of information, to draw analogies to previous situations and select a type of response and behaviour that is deemed to be appropriate based on previous experience. Sometimes selective information processing may prevent learning and the adaptation to a changing environment – this applies for individuals, for enterprises or for scientific organizations.

Human beings have a confirmation bias – they search for and process selectively information confirming their beliefs (Evans, 1990). Sometimes beliefs may be proven to be wrong by factual knowledge that is provided by empirical analyses or modelling exercises. If mental models are based on these factually wrong beliefs they should be corrected. This requires an agreement among actors on the soundness of the factual knowledge. Mental models may be linked to normative assumptions, values and preferences which determine the interpretation of knowledge. In this case a change of mental models requires processes of reflection and negotiation.

Sometimes beliefs about the social environment may support the construction of social reality and influence it (e.g. expectations about the behaviour of others). If one believes for example that other actors in a negotiation process are not willing to cooperate one is full of distrust which may trigger a corresponding behaviour from the other side.

This situation is exacerbated by the role of paradigms. Since paradigms are shared by what can be called an epistemic community of the actors and since they are manifested in artefacts such as technical infrastructure, planning approaches, regulations, engineering practices, models, paradigms introduce a strong bias to process information supporting a paradigm's basic assumptions rather than questioning them (Kuhn, 1962; Pahl-Wostl, 2007).

4.2 The significant role of interfaces between individual interpretations

Many of the activities of water management involve attempts to bridge or integrate knowledge, experience and opinion across scientific, societal and governance communities (e.g. the preparation of basin management plans, the deployment of new technologies, and the allocation / distribution of water resources). Far from being simply notional boundaries between sets of actors in society, these interfaces are characterised by significant discontinuities. Specifically, human interaction at an interface is likely to involve disagreement concerning;

- sources of credible information and plausible knowledge on which to base action;
- the value and valuation of products and processes;
- acceptable risks;
- temporal and spatial relevance of knowledge;
- notions of efficiency and effectiveness.

Although inter-personal interactions are goal directed, they will also be characterised by one or more of the following;

- dispute the (nature, meaning, ownership etc.) of the problem;
- debate about the reality of the problem for different actors;
- negotiation of possible solutions and what constitutes a 'better outcome';
- anticipation of the impacts of solutions;
- planning changes to steer our communities along better development paths.

Interfaces are clearly scenes of dialogue, analysis, deliberation and debate (Guimãres Pereira et. al., 2003). In particular, they host negotiations between differing interpretations of problem diagnosis and resolution. They are arenas where personal, social, and professional ambitions clash, and where competing models of 'what is' and 'what should be and 'what should be done' are articulated.

To take one example of the type of interface we are interested in, let us consider that between science and politics. Most scientists are concerned about single issues or phenomena and, correspondingly, the idea of "solutions" to "well-defined problems". The policy world, on the other hand, exists in a multiple-issue and multiple-constituency world where the agenda is constantly changing and where an environmental issue is only one of many competing for attention. Environmental issues are linked to other topical themes of major concern. Linkages between issues may lead to unexpected windows of opportunities where suddenly changes become possible (Olsson et al, 2006; Nooteboom, 2006). .

There is an additional problem of diagnosis. Scientists and other environmental specialists (water companies, technical professionals in local or regional government and so on) simplify from complex situations in a way that enables them to apply their knowledge. We have come across numerous situations where the interpretation of the symptoms of an environmental disorder have been specified as very different "problems" by politicians and specialists and between specialists themselves. A simple example is a situation where more water is being consumed than can be sustained in a local environment: in one domain, the problem may be perceived as excessive water use, but in another, it may be perceived as insufficient supply. The policy implications of the two perceptions are dramatically different, in that the first would result in a policy instrument to reduce water consumption, whereas the second would result in a technical solution that would increase water supply.

This mismatch of agendas and "problem" identifications can result in inappropriate research, perhaps because it is not at a suitable scale or cannot easily be connected to decision issues. Conversely, relevant research may just not be important to people who consider many other issues to be more significant at that time.

Water Management can be characterized as a 'wicked' problem' (Rittel and Weber, 1973; Pahl-Wostl, 2002), being both complicated (many elements interacting in many ways at different spatial and temporal scales) and complex (as above but with the added dimension that the rules or laws by which interaction takes place are also changing … so any specification of the relationship between phenomena 'A' and phenomena 'B' will change through time). In attempting to design and implement water management strategies, society is faced with the challenge of negotiating and operating across many types of institutional and knowledge interface. It is negotiation (at the various interfaces) of different ways of understanding the problem and modes of intervention that eventually determines policies and outcomes. Uncertainties play a key role in such processes – the larger the uncertainties the more opportunities exist for valid and legitimate interpretations of problem situations and solution spaces.

4.3 Uncertainty as a relational property between system and observer

Uncertainty issues can be looked at in numerous ways. In order to address the role of uncertainties in policy processes it is important to adequately take into account socially constructed realities. The concept of uncertainty as a relational property is shared by numerous scientists (cf. e.g. Pahl-Wostl et al, 1998; van Asselt and Rotmans 2002; Klauer and Brown 2004; Dewulf, Craps et al. 2005). It means that uncertainty is not an attribute of an object but has a subjective connotation. It clearly relates to certain values or interests of the one who states the uncertainty. In other words, uncertainties are framed according to one's interpretation and perception of world in which one is embedded.

Uncertainty depends to considerable extent on the context, i.e. the situation in question and the person who perceives and formulates the uncertainty (Brugnach, Dewulf et al. 2006). Klauer and Brown define an uncertainty situation as follows: "*A person is uncertain if they lack confidence about the specific outcomes of an event or action*" (2004: 126). Uncertainty may be, in theory, constructed independently (from actor and action) but is then irrelevant for dealing with uncertainty in practice since it lacks relevance.

Edna Einsiedel states that there are many different forms and degrees of uncertainty and it is critical to understand what it is, how it is framed and what people do with it (in Friedman, Dunwoody et al. 1999: 44). So, in order to assess uncertainty (& its meaning) in collective choice situations as they typically occur in water management it may be useful to locate uncertainty to the relation between an actor and an action situation (AS) (Ostrom 1999).

Figure 3: Uncertainty as relational property using the concepts of the IAD framework

A prerequisite for the occurrence of an uncertainty is an actor's awareness and subsequent attention or worry about an action situation. In case the actor is aware of a situation but attention or importance is zero, obviously uncertainty does not play a role in that situation for that specific actor, but it may play a role for another actor.

For representing this relational uncertainty objects or issues, e.g. flooding, are not really appropriate since their properties do not constitute an uncertainty of interest per se, but rather action related formulations or questions related to the situation out of which the uncertainty evolves, e.g. uncertainty about "how region XY can be prevented from flooding". This way of eliciting and addressing uncertainties implies the involvement of a certain actor to whom the uncertainty is of importance.

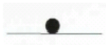
According to Friedman, Dunwoody et al. there are two influencing factors that shape perceptions of uncertainty: individual and social-structural (1999: 47). The individual factor refers to personal skills, motivations etc.; the social-structural to externally controlled access to information (technology, laws, etc.) but also to shared models and cultural beliefs.

4.4 Stereotypes – Cultural Theory

It is by no means a straightforward task to analyse the influence of cultural factors on individual perceptions. A possible albeit controversial approach is the use of cultural stereotypes as introduced in cultural theory. Cultural Theory (CT) provides a typology of human perspectives of seeing and approaching the world. It arose out of the work of the anthropologist Mary Douglas who observed that differences in people's reactions correlated with differences in their social structure. She proposed a functionalist explanation: social structures (which she called "ways of life") generate attitudes toward the world (which she called "cultural biases") that serve to uphold the social structure. Later, Douglas argued that social structures differ along two principal axes: grid and group. Grid refers to the degree to which individuals' choices are circumscribed by their position in society. Group refers to the degree of solidarity among members of the society.

Thompson and Widalvsky followed these ideas and developed the Cultural Theory (CT) which defines five major biases or perspectives: Egalitarian, Hierarchical, and Individualist as active perspectives, as well as Fatalist and Hermit (e.g. van Asselt and Rotmans 2000).

Each of these types of CT can be attributed a relation towards nature. This is represented in the structure frames: utility (Individualist), risk (Egalitarian), control (Hierarchical), fate (Fatalist), (and morality) (Thompson, Ellis & Widalvsky 1990 in Listermann 2006).

Relation Man-Nature	Nature can be controlled	Nature is too powerful to control
Separated	**Utility** 	**Risk** 
Integrated	**Control** 	**Fate** 

Additional fifth frame: **Morality**

Figure 4: Structure frames based on CT (Thompson, Ellis & Widalvsky 1990 in Listermann 2006)

The hierarchical perspective and the perception of nature as being controllable can be closely linked to the "control paradigm" in water management. Regarding the alternative of distributed control and management as learning a clear link seems not to be possible. Both the individualistic and the egalitarian perspective include elements of relevance for the suggested alternative management paradigm.

Albeit being controversial cultural stereotypes may be useful as ideal-typical perspectives to illustrate the possibility of coming to different and logically coherent interpretations of a problem situation and possible solutions based on the same body of empirical knowledge (Pahl-Wostl et al, 1998; van Asselt and Rotmans, 1995).

4.5 Historical Memory and Projected Futures

In human-environmental interactions it is often possible to observe a relationship between two or more processes which could result in the collapse of an ecosystem (e.g. the sudden demise of a thriving population, or increased ecological vulnerability in the face of major anthropogenic perturbations). Non-linear or discontinuous changes of this type are inherently problematic to assess and understand through the use of empirical indicators that are rooted within disciplinary boundaries. Non-linear changes may have the characteristics of a time-bomb (Stigliani 1991), where a long-term accumulative process provides the conditions for a short-term trigger to dramatically, and unexpectedly, change the state of the 'system' in question. Such dynamics have been clearly described in a number of contexts (ter Meulen *et. al*., 1992) and models have been developed which indicate the proximity and magnitude of such changes (Oxley, 2000).

But it is not only natural processes which display such non-linear behaviour. Perceptions can also display non-linearities over time with multiple historical memories of environmental change being projected towards expected futures and anticipated responses to those futures (Green and Lemon, 1996). The relationship between environmental processes and human perceptions and responses has been illustrated by Oxley et al., (2003) and is represented schematically in Figure 5. It is the combination of historical knowledge and the current state or trend of natural processes (as reflected by indicators) which enables us to project potential change into the future, and thus adapt our responses to these changes. However, our perceived future may follow a contrasting trajectory to that observed in reality (ie. we may be wrong). This discrepancy may often be accounted for by differences in the perceptions and/or expectations of the observer. Whether a phenomenon is actually perceived as unexpected is dependent upon the 'appreciative system' retained by the individual (Vickers 1983). What is very clear, however, is that when environmental change is apparent, humans can, through inappropriate intervention, turn 'damage' into disaster .

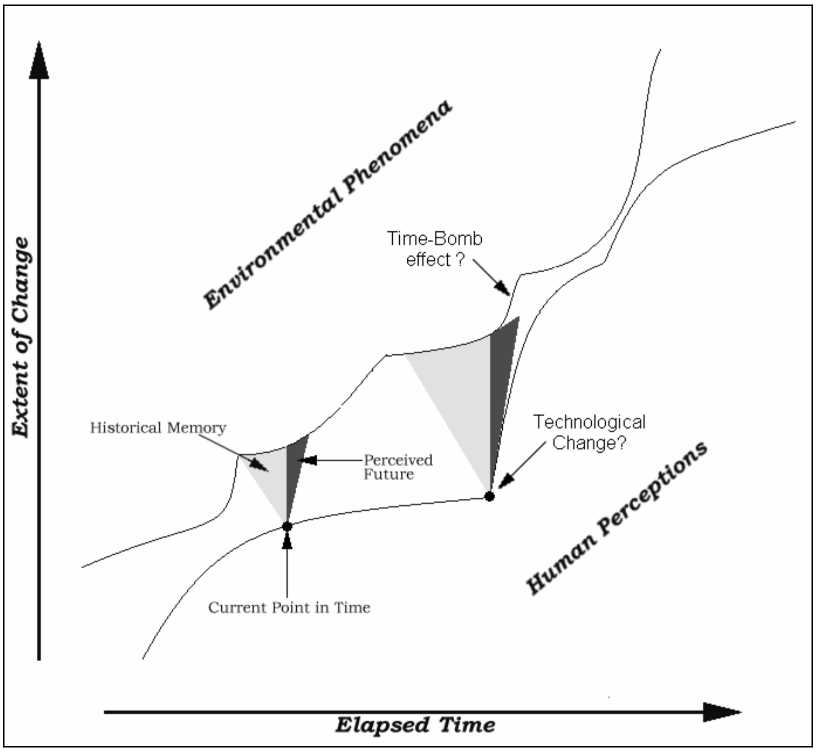


Figure 5: A conceptual view of human perceptions and responses to environmental change based around historical memories and perceived futures. This abstract representation only shows two possible trajectories, whereas in reality there will be multiple perceptions and multiple environmental phenomena; the purpose here is to suggest how such trajectories may converge or diverge, and that our objective, by keeping a tight focus (using indicators), is to keep both perceptions and environmental phenomena following similar trajectories (Source: Oxley *et al.*, 2003).

It is important to highlight the distinctions between changes in the physical environment ('physical emergence'), changes in human knowledge about the environment ('knowledge emergence'), and changes in perceptions ('perceptual emergence') (Hadfield & Seaton, 1999). Our inability to 'know' about emergent phenomena does not preclude us from learning from them and thereby expanding the knowledge base upon which we can draw for dealing with future uncertainty. Indicators may highlight physical emergence, but their context and what we can learn from them relate to perceptual and knowledge emergence, respectively.

Climate change is here a prime example. The knowledge about climate change and the role of humans, about global and regional impacts has over the past decade gradually shifted from highly uncertain hypotheses to quite likely and worrying developments. The response in policy and the awareness in the media has experiences a very non-linear development over the past year and in particular after the latest IPPC report. The dominant global discourse has clearly shifted and this shift occurred in a highly non-linear way.

5 Conclusions and research questions

Paradigms matter because ….

If we accept that our problem set (Water Management) is both complicated and complex, are there any ways of understanding the process that can help us make sense of it? How should we and who should decide if one approach is superior to another? Researchers have, of course, evaluated many different conceptual frameworks and conceptual models in search of a coherent and consistent method for diagnosing water management issues and prescribing beneficial intervention. This has included work on water management itself (Biswas, 1981) but also contributions from Systems Theory (Votruba, 1988), System Dynamics (Stave, 2003) and Adaptive Management (Walters, 1986).

Some utility has been claimed for all these approaches. Although such limited success is welcome from an ontological perspective, within a world of wicked problems, it leaves us with a problem. Put simply, the model or interpretational framework that we use to describe something will influence how we seek to influence its future.

In the case of water; water environments provide multiple functions to multiple communities. Both functions and communities change across space and time. Each community or stakeholder group will have a preference for a set of functions and a preferred interpretive model for describing or diagnosing the system. Each potential use, perspective or way of understanding will have its adherents (disciplines, professions, stakeholders etc). Although theories of change such as systems dynamics or coevolution promise generic or integrated understanding, they still lock us in to a way of managing the resource which is dependent on how we understand it to work.

A main issue here is one of accommodation. Does there need to be agreement about the way the world works or the value of the resource in order for catchment communities to agree on a management scheme? Do we need orthodox ontologies and epistemologies in order to manage the resource for the benefit of all? Until we understand more about the implications of competing claims to understanding and knowledge, we will be unable to respond to such queries.

Based on the characterization of the two paradigms in water management one might conclude that the control paradigm is less open to divergent views. A paradigm that acknowledges the limits of control and accepts change, that emphasizes learning should be more inclusive and develop institutions that allow to deal with multiple perspective. But this remains to be shown.

Important research questions to be addressed in the NeWater project:

- Can one find empirical support for the existence of the two dominant paradigms on water management introduced in this report?
- Can one find indications for changes of a paradigm shift? What are main drivers and what are barriers for change? What are the kind of mental models and framings currently used by actors when they characterize a water management problem and its solutions?
- How can one judge the superiority of one paradigm versus another taking into account the specific historical, political, cultural, economic and environmental context into which water management is embedded.

- Does the explicit recognition of mental models and framing lead to an improved understanding of institutional dynamics? How can it support to improve communication between actors and across the science – policy interface (e.g. about uncertainties)?

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