Towards adaptive and integrated management paradigms to meet the challenges of water governance

J. Halbe, C. Pahl-Wostl, J. Sendzimir and J. Adamowski

ABSTRACT

Integrated Water Resource Management (IWRM) aims at finding practical and sustainable solutions to water resource issues. Research and practice have shown that innovative methods and tools are not sufficient to implement IWRM – the concept needs to also be integrated in prevailing management paradigms and institutions. Water governance science addresses this human dimension by focusing on the analysis of regulatory processes that influence the behavior of actors in water management systems. This paper proposes a new methodology for the integrated analysis of water resources management and governance systems in order to elicit and analyze case-specific management paradigms. It builds on the Management and Transition Framework (MTF) that allows for the examination of structures and processes underlying water management and governance. The new methodology presented in this paper combines participatory modeling and analysis of the governance system by using the MTF to investigate case-specific management paradigms. The linking of participatory modeling and research on complex management and governance systems allows for the transfer of knowledge between scientific, policy, engineering and local communities. In this way, the proposed methodology facilitates assessment and implementation of transformation processes towards IWRM that require also the adoption of adaptive management principles. A case study on flood management in the Tisza River Basin in Hungary is provided to illustrate the application of the proposed methodology.

Key words | IWRM, management and transition framework (MTF), management paradigms, participatory modeling, water governance, water management

J. Halbe (corresponding author)
C. Pahl-Wostl
Institute of Environmental Systems Research,
University of Osnabrück,
Barbarastr. 12,
49076 Osnabrück,
Germany
E-mail: *jhalbe@uos.de*

J. Sendzimir
International Institute for Applied Systems Analysis (IIASA),
Schlossplatz 1,
A-2361 Laxenburg,
Austria

J. Adamowski
Department of Bioresource Engineering,
McGill University,
21 111 Lakeshore,
H9X 3V9,
Ste Anne de Bellevue,
Quebec,
Canada

INTRODUCTION

The persistence of water issues in many parts of the world has given rise to innovative concepts that advocate an integrated approach to address complexity and uncertainty. Integrated Water Resource Management (IWRM) is the most prominent of such concepts that stresses the importance of integrated and participatory management processes and reform of water governance systems (Medema *et al*. 2008). The term 'management' refers to operational activities including the operation, monitoring, strategic planning and implementation of measures, whereas the term 'governance' comprises the rules under which a management system operates and different actors and networks help develop and implement water policies (cf., Pahl-Wostl 2009). However, theories and methods for sustainable water resource management and governance are still in the developmental phase and continuous experiments in application are required to determine effective approaches for research and practice (cf., Galaz 2007; Medema *et al*. 2008). Methodologies are needed that deal with real-world complexity in order to find effective solution strategies, and facilitate knowledge transfer between science, policy, engineering and local communities. Even though IWRM is a concept widely aspired to, it is often still rooted in a traditional 'predict and control paradigm' despite its linkage to the idea of adaptive management (cf., Jeffrey & Gearey 2006). The need for the integration of adaptive approaches like policy experimentation and learning into IWRM is increasingly acknowledged in order to effectively realize the concept of IWRM (Galaz 2007).

Management paradigms are appropriate concepts to systematically and comprehensively analyze the interlinkages between a resource system (e.g., groundwater resources),

doi: 10.2166/wst.2013.146

water management system (e.g., infrastructure) and water governance system (i.e., regulatory structures and processes). A specific analysis of the multiplicity of elements of water resource management paradigms has been discussed by Pahl-Wostl *et al.* (2011). They define a management paradigm as 'a set of basic assumptions about the nature of the system to be managed, the goals of managing the system and the ways in which these goals can be achieved' (Pahl-Wostl *et al.* 2011). By being explicit about underlying paradigms, inconsistencies in water management and governance systems become apparent (as discussed by Jeffrey & Gearey (2006)). For instance, public participation can be applied in a 'predict and control water management paradigm' (i.e., stakeholders are only informed and consulted), as well as in a 'community involvement paradigm' (i.e., co-management of stakeholders). The ignorance of underlying paradigms can lead to miscommunication and subsequent management problems (e.g., stakeholders expect active involvement but can become frustrated due to missing opportunities for engagement).

This paper presents a methodology for the participatory analysis of management and governance systems that supports the design and implementation of transformation processes towards sustainable water management. In this methodology, participatory model building is applied to elicit case specific water management paradigms held by stakeholders. This information is then used to comprehensively analyze the management and governance system through the application of the Management and Transition Framework (MTF) developed by Pahl-Wostl *et al.* (2007, 2010). Based on such an analysis of the status quo, the methodology allows for the participatory envisioning and design of pathways towards sustainable water management and governance. In this way, the proposed methodology facilitates the development, assessment and implementation of strategies towards sustainable water resources governance and management.

The methodology builds upon the management paradigm concept developed by Pahl-Wostl *et al.* (2011) and the use of group model building for the analysis of paradigms (cf., Sendzimir *et al.* 2007). Innovative elements of the methodology proposed in this paper are the conceptualization of sub-system and overall-system paradigms, and the delineation of a structured action research process including elicitation, analysis and assessment of paradigms. Another innovative element of the proposed methodology is the application of the MTF for the design of pathways towards implementation of integrated and adaptive water management. The approach presented in this paper goes beyond theoretical explanations of institutional and policy change (cf., Cashman 2009) by allowing for participatory analysis and active governance of transformation processes.

This paper is structured in two parts. First, the underlying concepts and methods upon which the proposed methodology is built are presented. Following this, a case study on flood management in the Tisza River Basin in Hungary is provided to illustrate the application of the proposed methodology.

METHODS

The proposed methodology combines an analysis of the overall water management and governance system (using the MTF) with an investigation of embedded management paradigms applying the systems thinking method in a participatory modeling process. Participatory modeling supports the analysis of case-specific elements of resource management and governance systems, while the MTF analysis allows for a broader perspective by integrating the detected elements found via participatory modeling into an overall system perspective.

Participatory model building

Different participatory modeling approaches exist that follow different objectives and apply a range of methods (cf., Jonsson *et al.* 2007; Renger *et al.* 2008; Voinov & Bousquet 2010). In this paper, the method of participatory model building using systems thinking and system dynamics methods is proposed for analyzing the perceptions of stakeholders on the management and governance system. Systems thinking is a method for the qualitative analysis of systems and their dynamic behavior through time. System dynamics modeling is based on this qualitative analysis and comprises the quantitative simulation of systems to discover their inherent dynamics as well as allowing for the testing of strategies.

Causal Loop Diagrams (CLDs) are powerful tools of the systems thinking method for the qualitative analysis of systems. They help to depict the system's structure, and mark time delays and feedback processes that are often responsible for difficulties in controlling the inherent dynamics of the management system. In these diagrams, elements of the system are connected by arrows having positive and negative polarities. A positive link indicates the parallel behavior of variables: in the case of an increase in the 'cause' variable, the variable that is affected also increases, while a decrease in the ‘cause’ variable implies a decrease in the affected one. A negative link indicates an inverse linkage between variables (see Figure 1 as an example of a CLD).

Despite the fact that expert models often offer comprehensive and scientifically validated results, missing ownership and understanding of the model by decision-makers and other stakeholders often impedes the implementation of model-based recommendations. This has led to the development of system dynamics applications that involve stakeholders in quantitative model building. Group model building processes (also called mediated modeling) for collaborative management of complex human-environment problem situations have begun to be applied more frequently over the course of the last decade (e.g., Costanza & Ruth 1998; van den Belt 2004; Tidwell et al. 2004; Metcalf et al. 2010; Halbe et al. accepted).

Management and transition framework (MTF)

Understanding processes of change towards sustainable resource management and governance requires an analytical approach that allows for the analysis of the interdependence between structural context and process characteristics. The MTF developed by Pahl-Wostl et al. (2010) supports such analyses of water governance regimes and transition processes towards more adaptive and sustainable systems. The MTF builds upon the three conceptual pillars of adaptive management (cf., Holling 1978), social learning and transformation processes (cf., Pahl-Wostl et al. 2007), as well as the Institutional Analysis and Development Framework (which is aimed at the analysis of the role of institutions in collective choice processes, cf., Ostrom (2005)). Specific emphasis is given to the analysis of adaptive capacity and multi-level learning processes. However, the MTF is not constrained to one specific theory; instead it provides a flexible language that can be tailored to specific research questions (for examples of applications of the MTF, see Schlüter et al. (2010); Sendzimir et al. (2010)).

The MTF helps to formalize structural elements of a water system (which are denoted as ‘classes’) as well as policy and learning processes (cf., Pahl-Wostl et al. 2010). Central classes in the MTF are as follows. An ‘Action Situation’ refers to formal or informal social

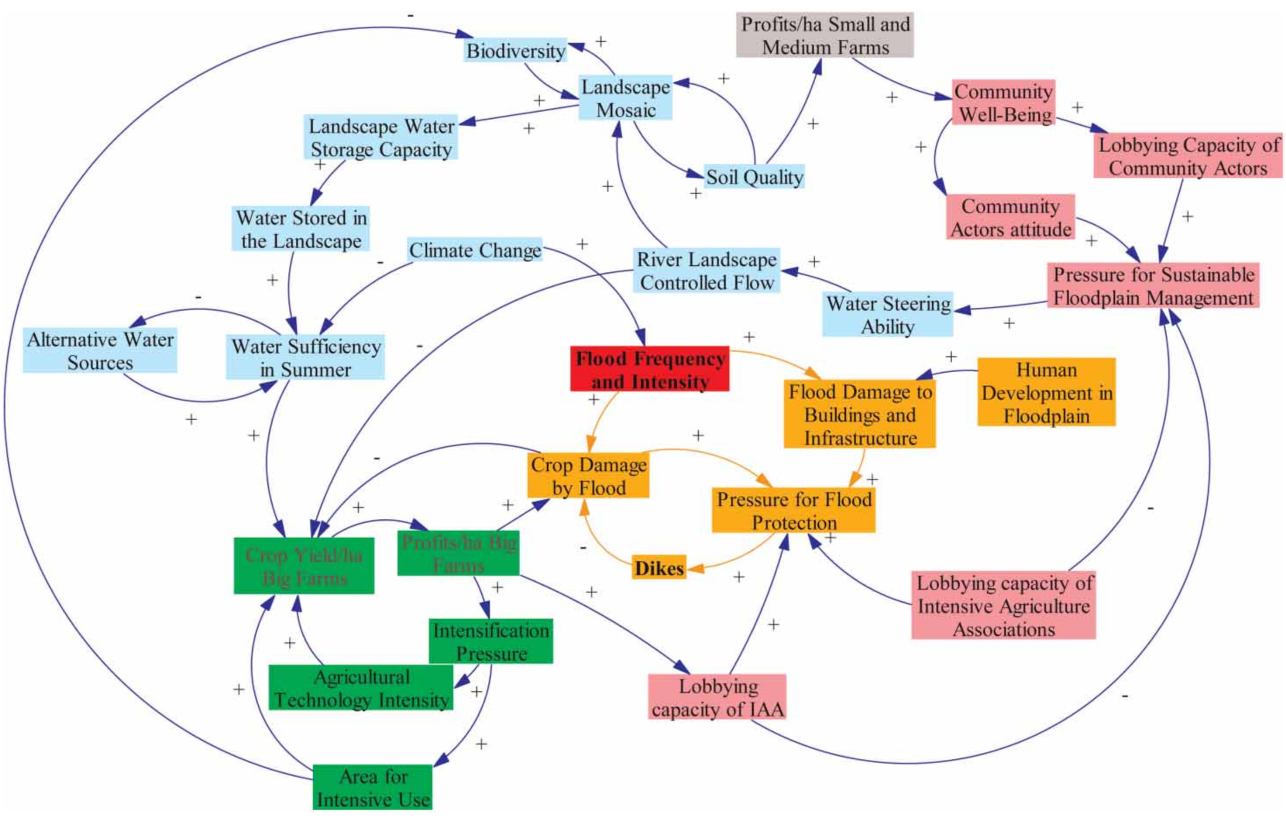

Figure 1 | Causal Loop Diagram regarding the flooding problem in the Tisza River Basin (extended from Sendzimir et al. (2007)). The colors reflect the sub-system paradigms: ‘Adapt to Floods’ paradigm (blue); ‘Control Floods’ paradigm (orange); ‘Economies of Scale’ paradigm (green); ‘Tradition’ paradigm (grey); ‘Community Involvement’ paradigm (pink). The problem variable is highlighted in red. Please refer to the online version of this paper to see this figure in color: http://www.iwaponline.com/wst/toc.htm.

processes that lead to relevant outcomes for water management. Results can be 'Institutions' (e.g., a new water legislation), 'Knowledge' (e.g., increased understanding of stakeholder problem perspectives) or 'Operational Outcomes' (i.e., direct physical interventions in the system such as the implementation of infrastructure or distribution of water to different uses). The 'Action Arena' class sets the context for the management of a specific water-related problem such as flood management, and is characterized by 'Strategic Management Goals', 'Actors' and a number of 'Action Situations'. In this way, the MTF provides a common language to analyze and discuss complex management and governance systems in research and practice. Relational databases are used to support formalization and standardization of data collection and analysis protocols (cf., Knieper *et al.* 2010). A graphical interface allows for the straightforward presentation and discussion of analyses (http://www.yworks.com/en/products_yed_about.html).

A management process can be depicted as a temporal sequence of action situations that are linked by institutions, knowledge or operational outcomes (see example in Figure 3) and represent different phases in an overall policy cycle (e.g., policy formulation or implementation). Another approach to analyze a management and governance system is the interpretation of action situations as governance and management functions (e.g., water purification or allocation or conflict resolution). While temporal analysis is more suitable to examine the evolution of management issues over time, functional analysis allows for the comprehensive analysis of the status quo of management and governance systems at specific points in time.

RESULTS AND DISCUSSION

In this section, the proposed methodology is described in more detail and its application is illustrated with an example of flood management in the Tisza Basin, Hungary. The Tisza is a transboundary river and extends from the Ukrainian Carpathian mountains along the Romanian border, flows across the great Hungarian plain and enters the Danube in the Serbian Republic. It is the largest tributary of the Danube with a total catchment area of 157,200 km^2. In the Hungarian reach of the Tisza Basin, a centralized water management regime has existed since the 19th century, with a focus on engineered flood protection through the large-scale construction of dikes in order to allow for intensive agriculture and to protect residential and industrial areas. Rising flood intensities and frequencies have resulted in significant challenges for the existing water management paradigm over the past decade. A bottom-up learning process was formed by activists and academics that brought innovative ideas into the flood policy debate. However, a transition towards alternative paradigms has stalled due to weak linkages between the informal learning process and the formal institutions (Sendzimir *et al.* 2010). To address issues such as this, the methodology proposed in this paper supports a structured action research process of water management and governance systems, comprising three steps: (1) elicitation of management paradigms at the sub-system level; (2) analysis of the status quo in management and governance regimes; (3) design of pathways to overcome detected barriers towards sustainable water management.

Methodology

A management paradigm is defined by a specific 'system perspective' regarding the management problem, chosen 'solution strategies', as well as 'risk and uncertainty management strategies' (cf., Pahl-Wostl *et al.* 2011). The proposed methodology differentiates between paradigms linked to the sub-system level (e.g., the social, environmental, or technical system) and the overall system level (i.e., comprising the complete management and governance system). The former are called 'sub-system paradigms' and the latter 'overall-system paradigms'.

Management paradigms can co-exist at the sub-system level, either by being complementary (i.e., reinforcing each other) or competing (i.e., balancing each other). The proposed methodology builds on the notion that a concerted set of paradigms is usually needed, each tailored to the specific sub-system, to find effective and sustainable solutions. For instance, technical sub-systems (e.g., infrastructure) can be managed by a 'control paradigm' that aims at controlling the behavior of the sub-system (different paradigms are presented in detail below, cf., Table 1). Selected social issues (e.g., an allocation system) can be governed by a 'community paradigm' that builds upon the self-organization capacity of stakeholders (e.g., installing irrigation associations). Several paradigms can also belong to the same sub-system by complementing each other. For instance, water pricing can be implemented by applying a 'market paradigm' (i.e., prices are set by demand and supply) as well as a 'control paradigm' (i.e., the range of prices is predetermined). Alternative sub-system paradigms can also

Table 1 | Management paradigms elicited in Figure 1

	Name				
Dimension	**'Economies of Scale' Paradigm**	**'Control Floods' Paradigm**	**'Adapt to Floods' Paradigm**	**'Community Involvement' Paradigm**	**'Tradition' Paradigm**
System Perspective	Big farms	River and protected values	Floodplain landscape	Flood prone communities	Small farms
Solution Strategies	Economies of scale; rationalization	Build dikes	River-landscape controlled flows	Community involvement	Traditional farming methods
Risk and Uncertainty Management	Reduce flooding risk and uncertainties	Reduction of uncertainty	Accept flood risk; adaptive management (through experimentation)	Uncertainty dialogue	Build on experience from the past

co-exist by being linked to different locations. For example, an 'adapt to floods paradigm' can be applied in rural areas where retention areas are available, while a 'control floods paradigm' might be more likely to be implemented in urban areas due to fewer adaptation options.

An encompassing 'overall-system paradigm' is linked to the overall resource system and can emerge from the sub-system level (e.g., through the supersession of other sub-system paradigms), or can be purposefully implemented by a higher-level institution (e.g., a ministry for water). In the case of a 'control paradigm' at the overall system level, heterogeneity of sub-system paradigms is constrained as only a limited number of paradigms are compatible with this overall-system paradigm. However, an 'integrated and adaptive overall-system paradigm' (cf., Pahl-Wostl *et al.* 2011) allows for the coordination of various sub-system paradigms and increases the adaptive capacity of the overall management system.

The proposed methodology that allows for the elicitation of management paradigms at the sub-system level (Step 1) and overall system level (Step 2), as well as the visioning of pathways towards sustainable water management (Step 3) is presented in the following sections.

Step 1: 'Elicitation of sub-system specific management paradigms'

Participatory model building using systems thinking can support the elicitation of sub-system specific management paradigms from individual participants or groups. The interviewee/group is asked to include the causes and consequences of the particular problem (i.e., the 'system perspective'), as well as preferred 'solution strategies' (e.g., technical approaches like building dams or socio-economic aspects like stakeholder involvement). The resulting CLDs will comprise elements of the resource system (e.g., variables like 'precipitation' or 'vegetation type'), the management system (e.g., 'dams' or 'retention areas'), and the governance system (e.g., 'public participation' or 'water legislation'). Further information about the 'risk or uncertainty management' strategies is needed to derive management paradigms from CLDs. Uncertainties are commonly typified in ontological and epistemological uncertainties. While the former denotes complex phenomena whose behavior cannot be predicted, the latter refers to incomplete knowledge or information about a system that can be attained through scientific research (Walker *et al.* 2003). Relational uncertainties are a third type of uncertainty and acknowledge subjective perceptions of actors. People perceive objects differently depending on personal values, roles, and interests (Brugnach *et al.* 2008). Based on this categorization, possible strategies for the handling of uncertainties and risks comprise the following (cf., Brugnach *et al.* 2008):

- Acceptance of uncertainty since *ontological uncertainties* imply that predictions cannot be made.
- Reduction of uncertainty since *epistemological uncertainties* can be minimized through purposeful research.
- Uncertainty dialogue since relational uncertainties requires a dialogue between stakeholders. For instance, the method of participatory model building facilitates the learning of groups and the revision of mental models and frames of participants. The goal of this reframing process is not to determine a 'true' frame – rather, the process aims at widening individual frames to one that considers multiple values and interests of stakeholders.

Figure 1 shows a CLD that was developed via a group model building processes in the Tisza River Basin (see Sendzimir *et al.* 2007). The CLD contains case-specific elements of the resource (e.g., soil quality), management (e.g., dikes), and governance system (e.g., lobbying capacity of community actors).

The group model in Figure 1 integrates different aspects of the flooding problem in the Tisza Basin that were mentioned by stakeholders including government representatives, local activists, and scientists. The CLD shows two different paradigms that are directly related to the flooding problem (represented by the problem variable 'Flood Frequency and Intensity'), namely the 'Adapt to Floods' paradigm (related elements are marked in blue in Figure 1) and the 'Control Floods' paradigm (marked in orange). For the specific attributes of paradigms, see Table 1. Further paradigms are indirectly related to flooding, including the 'Economies of Scale' paradigm (marked in green) of the intensive agriculture sector, and the 'Tradition' paradigm (marked in grey) that is more applicable to small farms. In addition, there are societal processes that demand more of a 'Community Involvement' paradigm (marked in pink) that relies on dialogue between actors.

The group model presents the interplay of different paradigms held by stakeholders related to the flooding problem in the Hungarian reaches of the Tisza Basin. The model clarifies the specific system elements that are related to paradigms. Thus, the CLD can support a purposeful discussion and handling of management paradigms.

Step 2: 'Analysis of management paradigms embedded in the overall management and governance system'

Management paradigms cannot only belong to the sub-system level but also belong to the overall system. Management paradigms of the overall system can be considered as a general 'mindset' that dominates in the management and governance system. Such overall-system paradigms are not only represented in the way of governing water resources, but are also manifested in infrastructure, information management, and finance, amongst others (cf., Pahl-Wostl *et al.* 2011).

Overall-system paradigms can influence paradigms at the sub-system level. For instance, a 'Control' overall-system paradigm might only be compatible with the 'Economies of Scale' sub-system paradigm due to a similar uncertainty and risk strategy (cf., Figure 1 and Table 1) but usually hampers the functioning of other paradigms at the sub-system level. However, an overall 'Adaptive and Integrated' paradigm, as conceived by Pahl-Wostl *et al.* (2011), allows for the functioning of all paradigms at the sub-system level due to its integrative nature. This permits diversity in management approaches, which increases the resilience of the social-ecological system (cf., Folke 2006).

Management paradigms pertain to both structural as well as process characteristics of management and governance systems. In the MTF, sub-system paradigms are considered as a type of cultural-cognitive institution and can therefore be an input or output of action situations (i.e., sub-system paradigms are social rules that can influence water management processes). Each action situation is characterized by at least one paradigm. The designation of paradigms to an action situation depends, first, on participating stakeholders who include their perspectives, and second, on input factors (e.g., knowledge, institutions, operational outcomes).

Overall-system management paradigms have a more general influence on the water system and are therefore linked to the Action Arena. As mentioned above, an 'Integrated and Adaptive' paradigm can function as such an overall-system paradigm. However, a 'Predict and Control' paradigm might be the most prevalent current overall-system paradigm, which hampers the application of most of the paradigms at the sub-system level (and thereby limits diversity). Figure 2 shows a graphical representation of the management and governance system in the Tisza Basin comprising action situations as management functions (boxes), institutions (circles), knowledge (trapezes), and operational outcomes (octagons).

On the left hand side of Figure 2, the 'status quo' of the management and governance regime in the Hungarian Tisza Basin is depicted. It is characterized by the dominance of a 'predict and control' paradigm at the overall-system and sub-system level that hampers solution strategies other than 'flood protection'. Intensive agriculture is tightly linked to this kind of management and governance system (Sendzimir *et al.* 2007). On the right hand side, a future vision of an alternative system is presented, which is based on the combination of paradigms included in the group model (see Figure 1). In this future system, an 'integrated and adaptive' flood management paradigm has emerged at the overall-system level, which allows for a diversity of paradigms at the sub-system level (cf., Grabs *et al.* 2006). A 'stakeholder platform' coordinates the 'Flood Control' and 'Flood Adaptation' management functions. Small-scale and intensive agriculture are exogenous elements that are linked to this Action Arena.

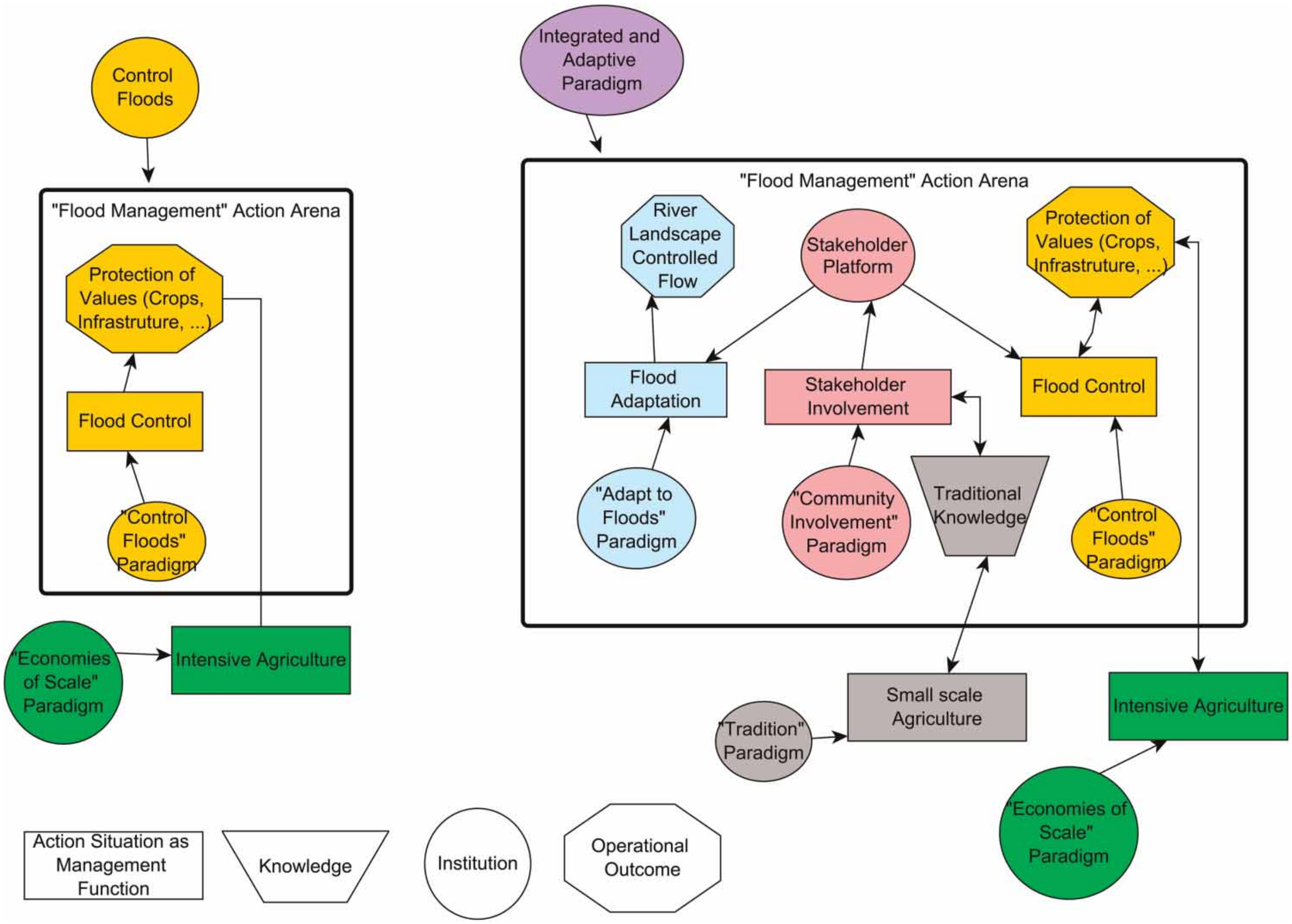

Figure 2 | Functional analysis of the management and governance system (purple colored variables reflect the new 'integrated and adaptive paradigm'; other colors refer to sub-system paradigms, cf., Figure 1). Please refer to the online version of this paper to see this figure in color: http://www.iwaponline.com/wst/toc.htm.

Step 3: 'Visioning of pathways towards sustainable water management'

Based on the functional diagnosis of the status quo and the desired future of the management and governance system (cf., Step 2), necessary measures through time are defined in Step 3 to achieve the desired changes. The transformation towards sustainable water management and governance usually requires substantial investments of resources and reform of institutions. The MTF can be applied to explore these required changes in a holistic manner, and specify a temporal succession of action situations in order to achieve the desired future. The outcome from this task is the design of a concrete pathway towards a sustainable water management and governance system. The resulting pathways include requirements for institutional change, dissemination or production of knowledge, physical interventions (i.e., 'operational outcomes'), as well as participation of actors.

Figure 3 shows an example pathway towards an integrated and adaptive flood management system for the Hungarian reaches of the Tisza River Basin that was developed based on literature review and expert opinion. The pathway starts from a present action situation comprising the reinterpretation of a flood management policy called VTT2 (in Hungarian: 'Vásárhelyi TervTovábbfejlesztése') (cf., Sendzimir *et al.* 2010), which reflects the mindset of the dominating 'Control Floods' paradigm. The transformation process ends with an 'Integrated and Adaptive Flood Management' action situation that delivers the outcome of 'integrated and adaptive flood-land-agriculture management' (see Figure 3). In the example pathway depicted in Figure 3, two action situations are envisioned to lead to the desired outcome. First, a round table is advised under participation of the Ministry of Environment and Water, responsible engineers and water managers, and representatives of the 'Living Tisza Alliance', which is formed of local activists,

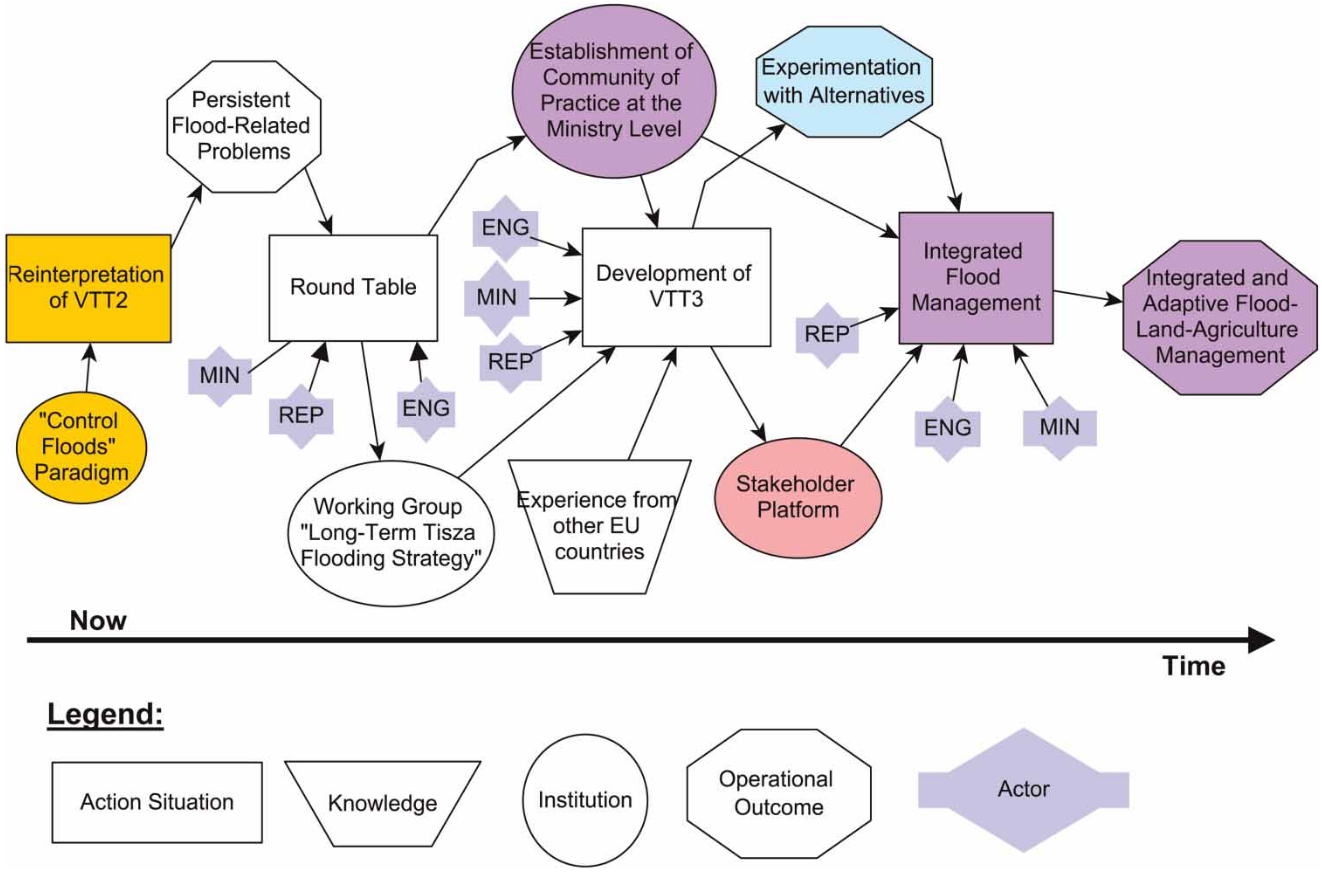

Figure 3 | Example of a possible pathway towards a sustainable water management and governance system in the Tisza River Basin (purple colored variables reflect the new 'integrated and adaptive paradigm'; other colors refer to the respective management paradigm, cf., Figure 1). Abbreviations of actors mean the following: REP = representatives of 'Living Tisza Alliance'; ENG = Responsible Engineers and Water Managers; MIN = Ministry of Environment and Water. Please refer to the online version of this paper to see this figure in color: http://www.iwaponline.com/wst/toc.htm.

national non-governmental organizations and the Village Municipalities Association (cf., Sendzimir *et al.* 2007). This round table sets the rules for a working group for a long-term flood strategy (institution) that includes all participating actors, and facilitates the institutionalization of a community of practice at the ministry level. The community of practice is supposed to link different departments and facilitate a continuous deliberative process on innovative solutions for the flood management problems in the Tisza Basin. In the past, this was temporarily achieved by the leadership of an individual at the ministry level, before his departure from the parliamentary committee stopped this process. A community of practice could lead to a more sustainable network that is less vulnerable to change of personnel. These activities together with experience from other EU countries with innovative flood management could set the basis for the development of a new flood management policy (named VTT3) that could lead to the institutionalization of a stakeholder platform at the local and regional scales as well as more experimentation with alternative approaches (e.g., through pilot studies). The established institutions and the experimental approach would result in the 'Integrated and Adaptive Flood Management' action situation that brings together the ministerial 'community of practice' and the stakeholder platform. This leads to river-landscape controlled flows (operational outcome), which reflects a transformation of the overall management and governance system towards a more 'integrated and adaptive' overall-system paradigm.

The example application of the proposed methodology demonstrates a structured approach to analyze water management and governance systems in an integrated way, and envision transformation processes towards IWRM. Through the use of the proposed methodology, hidden assumptions about the management and governance system, as well as requirements for integrated and adaptive solution strategies, are elicited. This approach can be particularly useful in transboundary river basins as paradigms might vary considerably between international water authorities due to different historical and cultural developments. While the Tisza case was confined to the Hungarian reach of the Tisza, a basin-wide study would be very useful to reveal differences in management paradigms in order to explore opportunities to deal with them constructively. The proposed methodology builds on straightforward methods and is therefore particularly suitable to be applied in collaborative management processes. At the same time, the proposed methodology composed of participatory modeling and the MTF allows for in-depth analysis of the water system. In this way, the linkage of the MTF and participatory modeling allows for the inclusion of scientific insights on water governance into management practice, and vice versa.

In future studies stemming from this research, empirical research will aim to determine concrete sets of management paradigms that facilitate IWRM. In particular, the relationships of overall-system and sub-system management paradigms require additional empirical research to identify which sets of sub-system paradigms are supported or inhibited by overall-system paradigms. In addition, the applicability of the proposed methodology to design concrete pathways towards IWRM will be evaluated through further case-study research in other basins with different socio-economic and hydrological characteristics (especially transboundary basins).

CONCLUSIONS

The analysis of management and governance systems is a complex task. Methods and tools have to deal with this complexity in order to avoid resorting to simplistic solutions or panaceas. In addition, effective science-policy-engineering dialogues need to be initiated to transfer findings between research and policy-making, and facilitate implementation on the ground.

The methodology presented in this paper complies with these requirements by building on participatory model building and the MTF. Participatory model building is a suitable and widely tested method to structure complex problems and elicit different perspectives held by stakeholders. Participatory model building supports the analysis of objective and subjective dimensions of resource issues. The MTF allows for the integration of elicited knowledge into an overall system perspective, and supports subsequent discussions of pathways towards sustainable management and governance systems. The MTF provides a formalization of complex management and governance systems and a 'common language' that can be used in participatory processes.

Management paradigms are proposed in this paper as suitable concepts to analyze the interlinkages between resource, management and governance systems in a comprehensive way. The consideration of sub-system specific management paradigms acknowledges that the effectiveness of paradigms depends on the respective application area or sub-system. However, an overall-system paradigm usually emerges that reflects the common mindset for the overall system. Such an overall-system paradigm can support a variety of management paradigms at the sub-system level (e.g., an adaptive and integrated management paradigm), or hamper variety by being incompatible with other paradigms (e.g., a predict and control paradigm).

A case study in the Tisza River Basin, Hungary, demonstrated the application of the proposed methodology. Further empirical research will be conducted in the future to evaluate the applicability and effectiveness of the proposed methodology in different water management contexts. In addition, concrete sets of management paradigms will be examined that support integrated and adaptive water resources management.

REFERENCES

Brugnach, M., Dewulf, A., Pahl-Wostl, C. & Taillieu, T. 2008 Toward a relational concept of uncertainty: About knowing too little, knowing too differently, and accepting not to know. *Ecology and Society* **13** (2), 30.

Cashman 2009 Alternative manifestations of actor responses to urban flooding: Case studies from Bradford and Glasgow. *Water Science and Technology* **60** (1), 77–85.

Costanza, R. & Ruth, M. 1998 Using dynamic modeling to scope environmental problems and build consensus. *Environmental Management* **22** (2), 183–195.

Folke, C. 2006 Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* **16**, 253–267.

Galaz, V. 2007 Water governance, resilience and global environmental change – a reassessment of integrated water resources management (IWRM). *Water Science and Technology* **56** (4), 1–9.

Grabs, W., Tyagi, A. C. & Hyodo, M. 2006 Integrated flood management. *Water Science and Technology* **56** (4), 97–103.

Halbe, J., Pahl-Wostl, C. & Adamowski, J. (accepted) A framework to support the initiation, planning, and institutionalization of participatory modeling processes in water resources management. *Water Resources Research*.

Holling, C. S. 1978 *Adaptive Environmental Assessment and Management*. Wiley, Chichester, UK.

Jeffrey, P. & Gearey, M. 2006 Integrated water resources management: Lost on the road from ambition to realisation? *Water Science and Technology* **53** (1), 1–8.

Jonsson, A., Andersson, L., Alkan-Olsson, J. & Arheimer, B. 2007 How participatory can participatory modeling be? Degrees of influence of stakeholder and expert perspectives in six dimensions of participatory modeling. *Water Science and Technology* **56** (1), 207–214.

Knieper, C., Holtz, G., Kastens, B. & Pahl-Wostl, C. 2010 Analysing water governance in heterogeneous case studies – experiences with a database approach. *Environmental Science and Policy* **13** (7), 592–603.

Medema, W., McIntosh, B. S. & Jeffrey, P. J. 2008 From premise to practice: A critical assessment of integrated water resources management and adaptive management approaches in the water sector. *Ecology and Society* **13** (2), 29.

Metcalf, S. S., Wheeler, E., BenDor, T., Lubinski, K. S. & Hannon, B. M. 2010 Sharing the floodplain: Mediated modeling for environmental management. *Environmental Modelling and Software* **25** (11), 1282–1290.

Ostrom, E. 2005 *Understanding Institutional Diversity*. Princeton University Press, New Jersey, USA.

Pahl-Wostl, C. 2007 Transitions towards adaptive management of water facing climate and global change. *Water Resources Management* **21**, 49–62.

Pahl-Wostl, C. 2009 A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* **19**, 354–365.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D. & Taillieu, T. 2007 Social learning and water resources management. *Ecology and Society* **12** (2), 5.

Pahl-Wostl, C., Holtz, G., Kastens, B. & Knieper, C. 2010 Analysing complex water governance regimes: The management and transition framework. *Environmental Science and Policy* **13** (7), 571–581.

Pahl-Wostl, C., Jeffrey, P., Isendahl, N. & Brugnach, M. 2011 Maturing the new water management paradigm: Progressing from aspiration to practice. *Water Resources Management* **25** (3), 837–856.

Renger, M., Kolfschoten, G. L. & de Vreede, G.-J. 2008 Challenges in collaborative modeling: A literature review. *International Journal of Simulation, and Process Modelling* **4**, 248–263.

Schlüter, M., Hirsch, D. & Pahl-Wostl, C. 2010 Coping with change: Responses of the Uzbek water management regime to socio-economic transition and global change. *Environmental Science and Policy* **13** (7), 620–636.

Sendzimir, J., Flachner, Z., Pahl-Wostl, C. & Knieper, C. 2010 Stalled regime transition in the upper Tisza river basin: The dynamics of linked action situations. *Environmental Science and Policy* **13** (7), 604–619.

Sendzimir, J., Magnuszewski, P., Flachner, Z., Balogh, P., Molnar, G., Sarvari, A. & Nagy, Z. 2007 Assessing the resilience of a river management regime: Informal learning in a shadow network in the Tisza River Basin. *Ecology and Society* **13** (1), 11.

Tidwell, V. C., Passell, H. D., Conrad, S. H. & Thomas, R. P. 2004 System dynamics modeling for community-based water planning: Application to the Middle Rio Grande. *Aquatic Science* **66** (4), 357–372.

van den Belt, M. 2004 *Mediated Modeling – A System Dynamics Approach to Environmental Consensus Building*. Island Press, Washington.

Voinov, A. & Bousquet, F. 2010 Modelling with stakeholders. *Environmental Modelling and Software* **25**, 1268–1281.

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluis, J. P., van Asselt, M. B. A., Janssen, P. & Krayer von Kraus, M. P. 2003 Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment* **4** (1), 5–17.

First received 28 September 2012; accepted in revised form 6 February 2013