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Knowledge for water governance: Trends, limits, and challenges

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Current discourse about water governance in Western countries is strongly influenced by approaches such as integrated, adaptive and participatory water management. These approaches put different demands on the production and application of knowledge in water governance processes, but mainly implicitly and without attention for the possible limits and trade-offs between these demands. In this article I explicate the role of knowledge within these various paradigms based upon an initial literature review and find out to what extent these demands are taken into account in two recent Dutch water governance programs with regard to flood safety. This theoretical exploration and empirical illustration results in a critical reflection on the limits and trade-offs between these various demands and suggest some lines for a research agenda about organizing knowledge for water governance which are different from the dominant perspectives currently dominating the literature on adaptive, integrated and participatory water management.

1. Introduction: Normative approaches to water governance and the role of knowledge

There are many normative and prescriptive approaches to water management built upon a set of design principles that outline how to organize processes of policymaking and implementation in the broad field of water management. These principles deal with a variety of questions with regard to issues like the scale of management and policymaking, the inclusion of non-water related issues, the role of public participation, and the application of certain methods and instruments for planning and assessment.

Many of these normative approaches also deal (explicitly or implicitly) with the role of knowledge and expertise in water management and policy processes – and quite rightly, as we consider that water management and governance is a highly knowledge-intensive policy domain. Investments in water management, whether for flood safety, water availability, or water quality, are very expensive and therefore need a firm factual underpinning, as is actually often required by formal procedures or legal requirements in most developed countries. Furthermore, water systems are inherently complex and strongly connected to other physical and social systems, and thus fundamental knowledge is necessary to understand these systems in order to be able to select effective interventions. Finally, the development of water systems is highly dependent upon macro-developments like climate change, economic growth, and spatial developments; this means that scenario-making and long-term planning are not only extremely intricate but also indispensable.

In normative managerial approaches to how to organize decision making in water management, we can find many assumptions with regard to the way in which knowledge is produced, applied, and evaluated (Brunner et al., 2005; Raadgever & Mostert, 2005). These models contain specific requirements about the organization of policy processes and put specific demands on the type of knowledge required, the role of experts, the methods they use, and the status given to different sources of knowledge (cf. Tropp, 2007).

These assumptions regarding the role of knowledge are not always explicit, and often not, or only partly, validated. In this contribution, we answer the question of how three normative approaches to water governance (integrated water management, collaborative water management, and adaptive water management) deal with the issue of knowledge and the limits to applying these demands or criteria in concrete water governance projects.

In Section 2, we briefly introduce the three prominent management paradigms distinguished above. Then, we analyze the assumptions within these models with regard to the role of knowledge for decision making and deduce five issues that summarize the 'demands on knowledge' that these approaches postulate. We reflect critically upon these demands by presenting two empirical water governance practices in the Netherlands that fit these three models. We thus expose the limits of the three approaches in relation to organizing knowledge for water governance. We conclude by outlining some avenues through which to improve the governance of knowledge in the water domain both theoretically and empirically.

2. A short introduction to integrated, adaptive, and collaborative water management

As stated in the introduction, at least three approaches to water management dominate the current debate in both science and practice. First of all, there is a development towards integrated water management (Biswas, 2004; Mitchell, 2005; Rahaman & Varis, 2005; Edelenbos, Bressers, & Scholten, 2012; Gleik, 2000). Secondly, there is a trend towards adaptive water management (Pahl-Wostl, Mostert, & Tàbara, 2008; Huntjens et al., 2011). And third, there is a trend towards collaborative, interactive, or participatory water management (Scholz & Stiftel, 2005; Sabatier et al., 2005; van Buuren et al., 2013; Plummer et al., 2012).

These three trends do not cover exhaustively the developments in thinking about water management, but they cover important and widely spread lines of thinking that are now broadly accepted in water management practices. Therefore we draw on them in this article to characterize present-day water governance and its consequences for the governance of knowledge in the water domain.

These concepts are frequently used in a disorderly and amalgamated way. Some authors conceptualize adaptive and integrated water management as one approach (Dewulf et al., 2007; Pahl-Wostl, Craps et al., 2007) and even talk about adaptive integrated water management (Huntjens, 2010). Ferreyra & Beard (2007) describe cases of collaborative integrated water management,whereas others emphasize the collaboration aspect of adaptive management (using the concept of adaptive co-management for example). Integrated water (resources) management often conceptualizes public participation as a specific form of horizontal integration.

In the remainder of this section, we describe these three developments in more detail, although we must admit that it is impossible to do justice to all the different insights generated within the context of these rather broad and loosely outlined frameworks.

2.1. Integrated water management (IWM)

An important trend within water governance has been the rise of integrated water management, which has already passed its peak (Biswas, 2004; Butterworth et al., 2010). There are many variations of integrated water management, including: integrated water resources management (IWRM), integrated river basin management, integrated regional water management, and integrated urban water management. In their critical review, Medema, McIntosh, & Jeffrey (2008) repeat the Global Water Partnership's definition as the most widely quoted definition of IWRM: "a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."

IWM entails promoting coordination and integration between actors with different responsibilities and different stakes. The approach is strongly connected to the many accounts of ecosystem-based management, which is also aimed at managing the whole ecosystem in a coherent and coordinated way (Giebels, van Buuren, & Edelenbos, 2013). A strongly related concept is holistic water management, usually defined as a comprehensive approach to water management, contrary to integrated approaches in which the focus is on a set of key variables and relations (Mitchell, 2005).

A common characteristic of these integrated approaches is the ambition to manage the various functions, aspects, and values of water systems in a cohesive way (White, 1998). IWM is seen as a possible solution to the fragmented and compartmentalized strategies emerging in classical bureaucratic administrations. Many authors relate integrated water management to holistic water management: it is aimed at managing the water system as a whole and to do justice to its various functions, recognizing that these functions are mutually connected and influence each other.

In the IWM literature, much attention is given to both institutional and legislative aspects. Less attention is given to the consequences of the integrated management philosophy for the organization of governance processes, and processes of coordination and collaboration in water management.

2.2. *Adaptive water management (AWM)*

The hype around integrated water management seems to have been overtaken by new ideas around adaptive management (Lenton & Muller, 2009). A core characteristic of adaptive water management is the acknowledgment of the complex and dynamic character of physical systems. AWM is aimed at developing management approaches that enable flexibility and adjustments when circumstances change. Because water systems are too complex to determine the consequences of policy actions beforehand, "adaptive management is needed as a systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies" (Pahl-Wostl, Mostert, & Tàbara, 2008).

AWM actions are based, on the one hand, upon long-term scenarios in which a variety of trends are captured and, on the other hand, upon frequent and short feedback cycles in which the impact of steering attempts are monitored and translated into information used to adjust management strategies.

The element of learning is crucial in adaptive approaches: policy is seen as a continuous process of learning by doing, and experiments are important to find out which strategies are effective. At the same time, adaptive management also relies upon extensive attempts to capture the future in scenario and forecast studies. To some extent, both principles are contradictory. Medema, McIntosh, & Jeffrey (2008) state in this respect: "Adaptive management can be seen as a management framework that is both anticipatory and adaptive." By anticipatory, the authors mean the importance of exploring the future and investigating the possible consequences of future developments for current decisions. By adaptive, the authors mean the importance of being flexible in adjusting management actions, and thus they emphasize the provisional character of knowledge.

However, implementing AWM is proving very difficult (Huitema et al., 2009), and the institutional context of water and flood management is only moderately receptive to adaptive approaches (Raadgever et al., 2008).

2.3. *Collaborative water management (CWM)*

The third trend characterizing water management is the trend towards more stakeholder participation, more collaboration, and more interaction (Leach, 2006; Scholz & Stiftel, 2005; Sabatier et al., 2005; Edelenbos, Bressers, & Scholten, 2012). Other authors call this approach participatory water management (Plummer et al., 2012).

There are different traditions within this paradigm in relation to the question of which type of stakeholder is involved. In the Anglo-American literature, much attention is given to collaboration between institutional stakeholders, mainly coming from the public or societal domain. However, there are also many contributions that emphasize the importance of involving citizens or citizen groups, and more specifically involving women or indigenous people engaged in water management in developing countries (Manase, Ndamba, & Makoni, 2003).

Ideas of participatory or collaborative water management acknowledge the societal impact of water management interventions and the plurality of values attached to water systems. The concept also takes into account the increasing desire of citizens and stakeholders to be involved in water governance, because these processes directly impact upon their environment and interests (van Buuren et al., 2013; Warner, 2006).

The frequently used concept of social learning is strongly linked to the adaptive water management paradigm (Dewulf et al., 2007; Von Korff et al., 2012) and the literature about participation (Mostert, 2006). The concept combines ideas relating to stakeholder involvement and collaborative dialogue with ideas inspired by the literature on participatory analysis, joint fact-finding, and post-normal science (Hommes et al., 2009).

Social learning occurs when actors adjust their frames and problem perceptions as a result of information sharing, dialogue, and interaction. The literature on the question of how to organize social learning, and how important it is, is strongly dominated by authors like Pahl-Wostl (2006, 2007) who conceptualize the idea of social learning rather broadly, as based upon the edge of processes of joint fact-finding, reframing, and negotiation. Most of this literature is rather optimistic about the possibilities for social learning and the impact of various methods to realize it, and there is a tendency to neglect the political and hegemonic dimensions of water governance (Wegerich & Warner, 2010). The same holds true for the question of whether there is real participation and collaboration, or whether it is mainly superficial and restricted to the small matters.

3. Consequences for knowledge for water governance

The three trends described above pose various demands on the way knowledge is dealt with. Several of them are more or less comparable. In all three trends, there is a focus on including stakeholder knowledge in addition to expert knowledge and on involving stakeholders in the research process. Furthermore, interdisciplinary knowledge is seen as crucial for both adaptive and integrated water management (Dewulf et al., 2007; Medema, McIntosh, & Jeffrey, 2008) and is also seen as a cornerstone of collaborative management. However, for the purpose of this paper,we reconstruct the specific demands on knowledge that are unique to these three distinct frameworks.

3.1. Knowledge for integrated water management

Gupta and van der Zaag (2008) summarize the demands on knowledge for IWM with a call for sound science, which in their view can adequately identify uncertainty and risk and gaps in knowledge when all possible alternatives have been considered. These authors thus stress the issue of certainty, which of course is not specific to the issue of integration.

Other authors make this demand more specific and focus upon the question of how knowledge can contribute to integration. Medema, McIntosh, & Jeffrey (2008) summarize the demands on knowledge production in the context of integrated water resources management by formulating five elements:

- Knowledge processes should be coordinated across water and land resources;
- They should involve multiple stakeholders (those responsible for, and affected by, management intervention);
- They should integrate across spatial and temporal scales;
- They should integrate disciplinary perspectives; and
- They must be holistic in character.

In other words, knowledge for integrated water management has to be vertically and horizontally integrated. Vertically integrated means that knowledge is collected at different scales and translated appropriately to the scale at which it has to be applied. Knowledge about the whole water system is deemed necessary, as well as knowledge about the concrete places for which interventions are intended. Such knowledge enables the weighing up of interventions at specific locations against their effects on the whole system, and vice versa. Horizontal integration entails interdisciplinary collaboration: integration between various knowledge disciplines and other types of (nonscientific) knowledge (Ferreyra & Beard, 2007).

Many methods and techniques are suggested to meet these challenges. Kolkman, Kok, & van der Veen (2005) suggest mental model mapping as a way to arrive at a construction of knowledge between actors with different ways of knowing and frames, and to communicate and transfer knowledge. Many other authors have described methods for integrated impact assessments, integrative decision support tools, and dynamic system simulations and models.

3.2. Knowledge for adaptive water management

Within the AWM literature, the role of knowledge is explicitly recognized. In the words of Walters (1997):

> Adaptive management should begin with a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies. This modeling step is intended to serve three functions: (1) problem clarification and enhanced communication among scientists, managers, and other stakeholders; (2) policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and (3) identification of key knowledge gaps that make model predictions suspect (...). The design of management experiments then becomes a key second step in the process of adaptive management, and a whole new set of management issues arises about how to deal with the costs and risks of large-scale experimentation.

However, the same author has to admit: "Unfortunately, adaptive-management planning has seldom proceeded beyond the initial stage of model development, to actual field experimentation." He attributes this to the risky and costly character of the approach, which is politically difficult to sell.

Medema, McIntosh, & Jeffrey (2008) summarize the requirements for knowledge in AWM as follows. Knowledge production has to:

- make causal understanding explicit as hypotheses;
- anticipate the effects of management action;
- actively experiment by treating management action as tests of these hypotheses;
- keep a record of causal understanding and the outcomes of management action;
- compare the outcomes of management action with causal understanding to learn and to adapt management action; and
- integrate disciplinary knowledge.

The core of AWM is about enabling the continuous adjustment of policies and actions on the basis of a steady stream of information about the evolution of the physical system and about the effects of policy interventions (Walters, 1997). Long-term monitoring trajectories based upon appropriate time scales are thus important. These forms of monitoring enable the continuous (gradual) improvement of policy and management. However, decisions have also to be based upon accurate exploration of possible futures. Scenario studies are deemed necessary to find strategies "that perform well under different possible but initially uncertain future developments" (Pahl-Wostl, Sendzimir et al., 2007: 30).

A second characteristic of knowledge for AWM has to do with access and availability. To support continuing processes of management and decision making, knowledge has to be available at any given time. Furthermore, it has to be accessible to everyone involved in management and decision making. This puts high demands upon information systems, databases, and monitoring instruments.

3.3. Knowledge for collaborative water management

Finally, knowledge production in a CWM context has a number of distinct characteristics compared to knowledge production for traditional, top-down, and government-centered water management. In the literature on network governance, knowledge is seen as one of the resources that actors can mobilize to defend their stakes and their interests. Furthermore, it is one of the issues, besides the problem definitions and the ambitions of involved actors, debated in policy processes. Knowledge is not neutral, but mobilized by actors with their own values and preferences. Therefore, from a collaborative governance perspective, it is important to think about provisions to prevent or minimize battles of analysis (van Buuren, 2009). CWM implies that knowledge is generated and then shared and supported by stakeholders, and it can contribute to informed and legitimate decision-making (Raadgever & Mostert, 2007). The social robustness of knowledge is thus equally important as its scientific validity (Petts, 1997).

But most characteristic for dealing with knowledge in the CWM context are the approaches that try to design participatory research processes in which citizens become involved in conducting research (Barreteau, Bots, & Daniell, 2010), often labeled as joint fact-finding (van Buuren & Edelenbos, 2004). Their knowledge is seen as equally important as expert knowledge and is thus one of the sources to clarify the problem and to assess and select policy alternatives.

There are thus two directions with regard to the (implicit) demands on knowledge for CWM. First of all, there is the issue of coproduction: generating knowledge is seen as a process of coproduction between citizens, stakeholders, policymakers, and scientists (Edelenbos, van Buuren, & van Schie, 2011). Secondly, there is the issue of consensus building: knowledge is used as a means to facilitate a dialogue between stakeholders, to differentiate between opposing problem definitions. In order to make knowledge authoritative, stakeholders are consulted about research questions, assumptions, and so forth; and the results are discussed with them.

Summarizing, CWM calls for knowledge that:

- is coproduced in collaboration with stakeholders;
- makes use of and integrates lay people's knowledge (citizen knowledge);
- is accomplished in a dialogue that contributes to frame reflection, learning, and consensus building;
- is accepted by stakeholders and citizens and thus adds to the legitimacy of policy choices;
- incorporates questions and assumptions of other actors and is delivered by trusted and independent scientists.

4. Current water management approaches and the governance of knowledge

As we saw, the various paradigms are often used and described in a rather intermingled way. Current water governance practices often combine various elements of these paradigms and focus both on integrative solutions that are adaptive and flexible and on collaboration and participation. Therefore, in this paper we look at the common denominators within these three approaches as regards the demands that are posed on the governance of knowledge in the water domain.

First of all, the various requirements presuppose that knowledge is approached as essentially provisional and thus subject to continuous adjustment and improvement. Within adaptive water management approaches, this requirement is essential: knowledge is never conclusive, but always 'under construction.' Monitoring is vital as it enables learning and reflection. Water managers need a steady stream of information to enable the flexibility and adaptability of management as required in many accounts of adaptive water management (van der Brugge & van Raak, 2007).

Secondly, knowledge is aimed at facilitating a process of (joint) learning and exploring rather than just supporting a process of generating and selecting policy alternatives. Policy-relevant knowledge is derived by organizing experiments and pilots (Huitema et al., 2009).

Thirdly, the various requirements call for knowledge that deals with long time horizons: knowledge has to be produced to anticipate the possible consequences of future and unknown developments. This also implies a more important role for scenario studies, forecasting, visioning, and long-term planning (van der Brugge & van Raak, 2007).

Fourthly, especially in the context of integrated and adaptive water management, the inclusive character of knowledge is emphasized. Knowledge has to be assembled in interaction with all relevant disciplines, from both the natural and the social sciences (Dewulf et al., 2007). Multidisciplinarity or even transdisciplinarity become the norm for knowledge production. The sources of knowledge deemed relevant are thus diverse and broader than only expert knowledge. Relevant knowledge for water management can be obtained from formal expertise and science as well as from citizens and stakeholders.

Finally, the quest for stakeholder involvement in processes of knowledge production also means that the acceptance and authority of knowledge no longer depends only upon its scientific quality, but also upon what citizens and stakeholders reflect. The quality of knowledge is thus to be assessed not only by scientific peer review, but also by extended forms of stakeholder review (Funtowicz & Ravetz, 1993). The inclusion of citizens' knowledge (Bäckstrand, 2003) is important to enhance the legitimacy but also the quality of policy-relevant knowledge. The focus is on mode 2 science (Nowotny, Scott, & Gibbons, 2002) and on post-normal knowledge (Funtowicz & Ravetz, 1993). This also means that the way in which knowledge is produced has to be changed. For consensual knowledge to be realized, it has to be produced in a process of interaction and dialogue that enables frame reflection and joint learning (van Buuren, Edelenbos, & Klijn, 2007).

These generalized demands on the governance of knowledge for water management are summarized in Table 1.

Table 1
New demands on knowledge for water governance.

	Conceptualization in 'modern' approaches	Reflects a demand for	Originates especially from the paradigm of
Content of knowledge	Focus on provisional knowledge that can be easily adjusted based on a steady stream of new information.	monitoring and continuous adjustment	AWM
Function of knowledge	Knowledge has to be a source of learning based upon careful evaluation of policy experiments.	learning, simulation, and experimenting	AWM
Horizon of knowledge	Knowledge about long-term developments and their related uncertainties is necessary for anticipatory policy action.	forecasting and scenario tools	AWM
Span of knowledge	There is a need for multi- or even transdisciplinary knowledge when we acknowledge the interconnectedness of water issues. Knowledge from different sources is deemed relevant.	holistic or transdisciplinary knowledge	IWM
Status of knowledge	Focus on consensual knowledge that is accepted by stakeholders with diverging views and values (joint fact-finding) and comprising both scientific and non-scientific knowledge sources.	negotiated knowledge	CWM

Compiled by the author.

5. Doing the proof: The role of knowledge in current water governance practices

In this section, we present two major water programs in the Netherlands to illustrate how current water governance practices (deemed to fit the main principles of adaptive, integrated, and collaborative water management) deal with knowledge. These cases are the Space for the River Program aimed at realizing a comprehensive program of measures to enlarge the discharge capacity of the main Dutch rivers (consisting of 39 projects), and the Dutch Delta Program aimed at realizing national policy strategies to deal with the long-term climate change consequences for flood risk safety and freshwater availability (consisting of six regional and three thematic subprograms).

Although these programs comprise a huge variety of different projects or subprograms, we try to analyze them at the program level to present a more generic analysis of how they manage knowledge. We try to avoid reliance on project-specific characteristics.

5.1. Space for the River program

The Dutch Space for the River program was started after the near flooding of the Dutch main rivers in 1993 and 1995. The program was aimed at realizing a certain discharge capacity for the main river system by 2015 (but the deadline has been extended to 2017). The program starts from the explicit ambition to combine flood safety and spatial quality (nature development, recreational provisions, landscape quality). Furthermore, it was organized in such a way that regional governments had an important say in the selection and fine-tuning of the various projects. A central program organization worked together with regional project organizations comprised of various public authorities and societal stakeholders.

In 2012, 39 projects,which together have to deliver the ambition of the program, were defined and most of them were under construction. Some of these projects are rather classical in scope, like deepening the river channel. Others are more innovative (in the Dutch context) and comprise river widening, retention areas, high water channels, and so on, in combination with housing, recreation, nature development, and infrastructure.

For the water-related aspects, there was a significant investment in a modeling tool (a modular system called *Blokkendoos*) that visualizes the impact of specific measures on the level of the river basin. All the projects were subject to various knowledge procedures such as impact assessments and cost-benefit analysis.

The various projects differ significantly in the extent to which they apply elements of joint fact-finding. Some projects are characterized by intense ‘fact fights,’ whereas others show remarkable success in realizing negotiated knowledge (Warner, van Buuren, & Edelenbos, 2012).

5.2. Delta Program

The Dutch Delta Program is a major policy program aimed at safeguarding the long-term climate robustness of the Dutch water system. It was started after the influential report of the Dutch State Advisory Commission on the Delta (Deltacommissie, 2008), which advocated paying structural attention to the consequences of extreme climate change scenarios for flood risk management and freshwater availability. The Delta Program was subsequently elaborated into six regional subprograms and three thematic subprograms.

The aim of the program is to prepare important system-wide decisions (Delta Decisions) to be taken in 2014, comprising new flood safety norms, the organization of freshwater supply, the organization of river discharges in the long run, and the way in which spatial planning and flood risk safety should be synchronized.

Within the various subprograms, the teams work along the same lines. The first phase was devoted to problem analysis. The second explored possible policy strategies. In the third phase, likely strategies have to be further elaborated. The fourth and final phase is devoted to formulating the various Delta Decisions based upon preferred strategies. Within the various subprograms, involved actors make extensively use of so-called delta scenarios, an integrated delta model, and design ateliers to consider how different interventions in the water system can be optimized in relation to spatial ambitions and pressures. The Delta Program is now at the half-way stage and is busy formulating potential or likely strategies.

5.3. Similarities and differences of the two programs

Both programs fit more or less the paradigms of integrated, adaptive, and collaborative water management. With regard to integration, we can observe that the program Space for the River is aimed at combining flood risk reduction with spatial development and landscape quality. In many projects, these goals are combined Warner, van Buuren, & Edelenbos (2012). However, as noted in one evaluation study, the knowledge generated for these projects was mainly derived from different 'silos' and was only combined at the design table and in the various assessment studies (impact assessments, cost-benefit analysis). The Delta Program is (in theory) also aimed at combining flood safety and freshwater availability with other functions, but in practice we can observe a strong focus on water issues and thus a strong involvement of traditional knowledge institutions from the water domain, as demonstrated by the central position of the mainly hydrological-oriented delta model. This focus is reinforced by political pressure to focus the Delta Program on national interests (defined as flood risk safety and freshwater availability) only.

With regard to adaptability, the program Space for the River is much more driven by a project logic (with specific targets regarding content, scope, and budget)than the Delta Program, although the latter is mainly driven by an administrative target: to prepare the various Delta Decisions before the deadline of 1 January 2014. This means that the Delta Program invests much more in analyzing possible adaptation pathways, whereas the Space for the River program is more oriented towards deciding which projects are most efficient in realizing the overarching objective within the conditions formulated *a priori*.

Finally, in the Space for the River program there are many more provisions for stakeholder participation than in the Delta Program. However, stakeholder involvement focuses mainly upon the process of negotiation and fine-tuning the final proposals rather than participation in the research and assessment process. The focus of the Space for the River program is more suitable for stakeholder involvement than the Delta Program, because of the long-term horizon and abstract character of the latter. In both programs, joint fact-finding and participatory research remain limited.

6. Analysis: How these cases accommodate the various knowledge demands

Table 2 summarizes how and to what extent the several demands are applied in these two policy programs. This analysis is based upon a variety of empirical sources – most notably several case studies conducted for other purposes, observations at several

Table 2
Knowledge for water governance: Two Dutch practices.

Element	Space for the River program	Delta Program
Provisional knowledge	Because of strong project orientation, the program is based upon one decisive target (16,000 cubic meters per second river discharge capacity by 2016). New climate scenarios are only taken into account to assess the comprehensiveness of measures.	Stimulated by the concept of adaptive delta management, the Delta Program tries to develop ways of working that fit the complex, evolving character of climate change, and thus provisions are developed to do justice to the provisional character of science.
Knowledge to learn	Knowledge to learn mainly in exploration phase. Knowledge to legitimate mainly in decision and implementation phase.	Mainly knowledge to learn (because of long-term orientation and explorative phase of strategy development).
Long-term knowledge	Yes, but only in phase of defining the program scope (Kors & Alberts, 2002). After that initial phase, knowledge was mainly aimed at finding out the extent to which concrete measures contribute to this target.	Much emphasis is given to exploring the next 100 years with scenarios and to thinking about adaptation strategies that fit various scenarios.
Multidisciplinary knowledge	Knowledge is mainly collected around specific aspects and brought together (but not merged).	Most knowledge relates to water issues. Strong emphasis on whole delta system (higher-scale level), but not on connections with other systems.
Negotiated knowledge	Strong reliance on expert knowledge, paying attention to modern interfaces (*Blokkendoos*) to enable communication with stakeholders. Within many projects intensive processes of deliberation and joint fact-finding (joint design sessions), but also intense clashes between competing knowledge coalitions of experts and bureaucrats versus stakeholders and scientists.	Strong reliance on expert knowledge and expert model building (delta model) within the water domain (Deltaprogramma, 2011). Not much interaction with citizens and local stakeholders. Informed stakeholders are involved in knowledge process and in design ateliers.

expert meetings, and expert interviews with people involved in these programs conducted in the context of various case studies and evaluation studies (Warner, van Buuren, & Edelenbos, 2012). Furthermore, our conclusions are informed by the analysis of various documents, such as evaluation reports for the Space for the River program (van Twist et al., 2011; Ecorys, 2011) and the scientific evaluation of other scholars (Wesselink, de Vriend, & Krol, 2008; Schut, Leeuwis, & van Paassen, 2010), some letters and memos in relation to the Delta Program describing its structure, approach, and functioning (Deltaprogramma, 2012, 2013), as well as some first evaluative notes (BMC, 2011).

Our first impression of both programs is that most of the demands are only partly fulfilled. Therefore, we have further analyzed the various barriers to implementing the various requirements emanating from the three approaches of adaptive, integrated, and collaborative water management. In Table 3, we present the various limitations encountered in the two programs in relation to the various requirements.

Table 3
Limits of new knowledge demands.

Element	Limits
Provisional knowledge	Politicians want to take and implement authoritative decisions (with regard to issues like a specific river discharge capacity)within a reasonable timeframe. They therefore need knowledge enabling them to formulate decisive strategies focused upon a set time horizon. This focus is less strong in the Delta Program, although even in such a long-term program the focus is on taking guiding decisions (Delta Decisions) at a specific juncture (2015).
Knowledge to learn	Opportunities to experiment and adjust policies are often restricted due to administrative, procedural, and political constraints. Major policy interventions like Delta Decisions or Space for the River cannot be simulated or based upon experiments. When there are links with experiments, these connections are often weak and informal.
Long-term knowledge	For a more project-oriented policy program like Space for the River, long-term knowledge is of limited value, because this program has to realize measures with a relatively short-term horizon. For more explorative programs like the Delta Program, long-term knowledge is a crucial ingredient. Methods for generating knowledge for the long term and investigating uncertainties have made much progress, but remain limited due to fundamental ignorance and uncertainty.
Multi-disciplinary knowledge	Knowledge infrastructures are essentially discipline oriented; interdisciplinary cooperation is not rewarded. Knowledge production remains (due to institutional and organizational boundaries) mainly separated and disconnected. Additional investments in knowledge development (Delta Program) mainly result in more interdisciplinary sophistication. Knowledge assemblage depends mainly upon simplifying tools for assessing and ranking options based on knowledge from different sources (integrated assessment frameworks).
Knowledge coproduction	Strong focus on expert knowledge hinders the input of stakeholder knowledge. Stakeholder dialogue about knowledge used is mainly reserved for the implementation phase and less common in the strategy phase (and thus only limitedly applied in the Delta Program). In the Space for the River program, joint fact-finding could not prevent fierce controversies about facts and ambitions.

Most of the limits presented in Table 3 concern the day-to-day complexities of water governance that hinder or even impede the application of the principles of integrated, adaptive, or collaborative water management.

First of all, policy-makers and especially politicians are focused upon taking decisions with are based upon the best available knowledge which hinders their openness to future developments and their uncertain consequences. The Space for the River program is a nice example of this; and even the Delta Program is bound by the ambition to take the so-called Delta Decisions in 2015. Mobilizing and applying provisional knowledge is theoretically attractive, but takes on a much more pragmatic interpretation in the context of real-life policy processes aimed at facilitating political decision making. Much emphasis is putted on reducing uncertainty (or at least unraveling it) to gain political legitimacy, rather than to emphasize what is uncertain or unknown.

Secondly, although much has been written about the added value of pilots and experiments, about learning-by-doing, and so forth, the actual opportunity to make use of them in concrete policy programs and implementation projects is rather small. The relation between experiments and 'normal' policy processes is generally thin and weak. Practical restrictions due to time pressure, procedural constraints, and budgetary limits often hinder serious investment in piloting and experimentation as a basis for designing new policy approaches and strategies.

Thirdly, the possibility of doing justice to long-term knowledge is heavily dependent upon the scope and ambition of the policy program in question. Within the Delta Program, much work has been done to develop delta scenarios, and strategies are explicitly assessed with regard to their long-term robustness. Within the Space for the River program, much attention is also given to assessing the long-term durability of the proposed measures, but at the same time there is a strong focus on realizing the short-term ambition with regard to the river discharge capacity (in relation to other spatial ambitions), which has to be realized within a relatively short timeframe, and thus gives rise to a certain degree of pragmatism and reserve in relation to long-term challenges.

Fourthly, within the water domain there is still a strong focus on water-centered knowledge domains (hydrology, civil engineering). The position of other knowledge domains has become stronger during the last decades, but they are still less dominant compared to the traditional knowledge domains Wesselink, de Vriend, & Krol (2008), thus putting serious limits on the realization of integrated knowledge. It also hinders the accomplishment of post-normal knowledge, because of the privileged position of scientific expertise Edelenbos, van Buuren, & van Schie (2011). Any attempt to deal with knowledge for water governance thus has to include the recognition that some knowledge sources are perceived as more important than others and possess an institutionally embedded position as preferred supplier.

Finally, processes of water governance frequently deal with controversial issues that touch upon a variety of societal values and interests. Many potential controversies can be prevented or mitigated by collaborative approaches, but ultimately painful consequences cannot be entirely avoided, especially not when projects enter the implementation phase. This also means that water issues remain controversial, whereby stakeholders evaluate knowledge for water governance as biased and partial. Joint fact-finding and other methods to involve stakeholders in conducting science are thus only suitable for issues that are only moderately wicked and controversial. Many projects in the Space for the River program are too controversial to be depoliticized by means of participation and dialogue (Warner & van Buuren, 2011).

7. The governance of knowledge: Recommendations for theory and practice

The analysis presented above of how the various demands work out in practice makes clear that it is necessary to reconsider the way in which knowledge is dealt with in current water management paradigms.

First of all, it seems necessary to reconsider the generic character of the various approaches in general, and with regard to the governance of knowledge in particular, and to elaborate on the building blocks for a more contextual approach to apply them. They are frequently formulated in a one-size-fits-all way, but, once we acknowledge the complexity of water governance processes, we also have to recognize their context-specific characteristics by thinking about how to organize knowledge. The exact constellation of stakeholders involved, the spatial functions at stake, and the ambitions of actors involved can make huge differences for the knowledge that is deemed relevant and the way it should be generated. From our two cases, we can also learn that there are clear differences between governance practices aimed at preparing adaptation measures and practices aimed at refurbishing the current system, reflecting differences between practices aimed at strategy formulation and project implementation.

This also means that organizing knowledge for water governance can sometimes be mainly a matter of conducting a stakeholder dialogue and a small-scale experiment to get more insight into local-level problems, whereas in other situations scenario building in combination with multidisciplinary model building is necessary to develop nationwide flood risk strategies. It is thus important to shed more light upon the question of the relevant context characteristics that determine the extent to which there is a need for adaptability, integration, and collaboration. As we saw, the two Dutch water governance programs differ significantly in their aim and scope, and this has important consequences for the perceived need for adaptability, integration, and collaboration.

Secondly, the various management approaches seem to underestimate the political and value-laden character of water management and knowledge. The literature on adaptive, integrated, and collaborative water management is strongly dominated by a rather rationalistic and technocratic idea that management frameworks, tools, and methods are sufficient to structure decision-making processes and to guarantee that principles and heuristics from these paradigms are applied in a correct manner. This tendency can also be witnessed in relation to the question of how to organize knowledge for water governance. However, it is questionable whether this depoliticized and managerial view of water is realistic. Water governance is about the interaction of actors with different values, power positions, and resources, rather than a technocratic, expert-driven issue of rational choice. Governance is much more than management because it is about power play, controversies, fact-fighting, and so on (Turnhout, Hisschemöller, & Eijsackers, 2008).

These political aspects put constraints on the application of integrated, adaptive, and collaborative water management, as we can see most clearly in the case of Space for the River, and requires more realistic approaches to organizing knowledge for water governance. Knowledge is not neutral and is used as an instrument to defend interests and to influence policy choices (Sarewitz, 2004; Pielke, 2007). Governance of knowledge can only be legitimate when its political function is taken into account. This also means that organizing consensus about knowledge is a crucial precondition before the other functions of knowledge (in terms of learning, reflexivity, and experimentation) can be realized. At the same time, it is important to stress that water management is essentially about value conflicts. Joint fact-finding and other methods are not sufficient to eliminate value conflicts, but can help to reduce their impact.

Finally, it is necessary to reconsider the position of knowledge within the various water management paradigms. It is striking that, in the three approaches dealt with in this article, policy and management ideas are dominant,and the knowledge domain is seen from a functionalistic logic as merely providing the necessary knowledge. An engineering idea of knowledge and expertise seems to dominate the debate. This idea presupposes that science is always able to produce 'usable' knowledge that reduces uncertainty. To better understand the role and added value of knowledge in complex governance processes,it is necessary to gain more insight into how knowledge is produced, how the fragmented institutional context of knowledge production functions, and how processes of knowledge production and policymaking co-evolve. More preciseness is necessary in thinking about how to organize knowledge for water governance, and the idea that knowledge is just a tool ready to solve all complex decision-making problems must be abandoned.

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