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Uncertainty management strategies: Lessons from the regional implementation of the Water Framework Directive in the Netherlands

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A B S T R A C T

Environmental managers have to deal with many uncertainties in carrying out their jobs. Literature describes several strategies that can be employed to manage these uncertainties, but this is done in a fragmented way. Therefore, this article aims to develop a comprehensive, coherent and empirically sound classification of uncertainty management strategies. The strategies mentioned in literature can be classified into four categories: ignoring uncertainty; knowledge generation; interaction and coping. A case study of the implementation of the Water Framework Directive (WFD) by Dutch water boards was conducted to test whether the identified strategies are employed in practice. The WFD presents the water boards with uncertainties resulting from the requirements to improve water quality and ecology on one hand, while leaving room to adapt those requirements to regional interests, practices and institutions on the other. The case study confirms the empirical soundness of the classification by revealing that many of the uncertainty management strategies in literature are applied in practice as well. However, further research to test the empirical soundness of the classification in other fields of environmental management is required.

1. Introduction

Uncertainty refers to "a situation in which there is not a unique and complete understanding of the system to be managed" (Brugnach et al., 2008, p. 4). In traditional environmental management literature uncertainty used to be equated with a lack of scientific knowledge. It was believed that science could ultimately provide absolute certainty, for example, by developing ever more complex and detailed simulation models. In recent decades, however, the conception of uncertainty has been broadened. The traditional conception has been challenged by the fundamental and permanent nature of some uncertainties and the parallel existence of multiple framings of the same issue by different actors (Van der Sluijs, 2010). This new notion of uncertainty includes not only epistemic uncertainty (lack of knowledge), but also ontological uncertainty (unpredictability) and ambiguity (the existence of multiple framings) (Brugnach et al., 2008; Isendahl et al., 2009; van der Keur et al., 2008). The new notion of uncertainty also concerns the object of uncertainty. It is increasingly recognised that uncertainties related to the social system are at least as policy-relevant as those related to the natural and technical systems and that these three subsystems are strongly interdependent (Ascough II et al., 2008; Pahl-Wostl, 2004).

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Recent changes in the conception of uncertainty have resulted in the emergence of new uncertainty management strategies, which are among others discussed in the literature mentioned before. Yet, the literature does not discuss all possible strategies for dealing with uncertainty in a comprehensive and coherent way. Moreover, relatively few researchers have collected empirical data about uncertainty management in environmental management practice (cf. Isendahl et al., 2009). Isendahl et al. (2009) analysed which uncertainties were experienced by water managers in the Rhine, Elbe and Guadiana river basins. van der Keur et al. (2008) studied how uncertainties were managed in integrated water resources management in the Rhine basin. Furthermore, Turnpenny et al. (2009) analysed the responses to uncertainties in the Canadian regulatory review of health products and food, the European Union (EU) environmental thematic strategies and the United Kingdom's energy and climate policies.

In order to address the above mentioned gaps in the literature, this article aims to develop a comprehensive, coherent and empirically sound classification of uncertainty management strategies. A side goal of the article is to obtain better insights into the types of uncertainty that occur in environmental management practice. In two steps we try to meet these ambitions. First, we consulted literature in the field of environmental management and governance, in order to develop a classification that structures relevant types of uncertainty and uncertainty management strategies. Relevant literature was obtained by searching in Scopus (http://www.scopus.com/) for different combinations of terms like "uncertainty", "ambiguity", "uncertainty management" and "environmental management", and by searching for further relevant references in the articles found. To limit the scope of this paper, we did not look at more general contributions from, for instance sociology and political sciences. The search resulted in a typology of uncertainties that we adopted. In addition, we developed a classification of uncertainty management strategies by collecting, comparing and classifying the strategies mentioned in literature.

Second, we conducted a case study, in order to test the empirical soundness of both classifications. The case study allowed for in-depth analysis of the range of uncertainties and uncertainty management strategies that occur in regional environmental policy practice. It also allowed for analysing mutual relations between uncertainties and management strategies. The case study concerned the implementation of the European Water Framework Directive (2000/60/EC, abbreviated to WFD) by the Dutch water boards De Dommel and Regge and Dinkel. The WFD introduced a new and challenging way of dealing with water by determining ecological objectives in water management and establishing the river basin as the basic water management unit in all Member States. At the same time, the WFD leaves room to mutually adapt ecological ambitions and regional interests, practices and institutions. The implementation of the WFD is a complex policy issue as it concerns the natural, technical and social subsystems in mutual interaction. We therefore expect to find a broad range of uncertainties and uncertainty management strategies in the case study. Water boards fulfil an important role in the implementation of the WFD in the Netherlands. These regional functional authorities are responsible for the maintenance of dikes and the management of water quantity and quality in regional waters. Water boards are governed by a democratically elected board with legislative authority and tax raising power. The board is supported by a bureaucracy of civil servants, who among propose policies, draft permits and execute operational water management tasks (for more details see Reinhard and Folmer, 2009).

We performed an in-depth analysis of the implementation of the WFD by the two water boards up until the realisation of draft River Basin Management Plans (RBMPs) in December 2008. By studying relevant documents (e.g., technical reports, minutes of meetings, RBMPs) and conducting interviews with civil servants working at the water boards, we were able to identify perceived uncertainties and employed management strategies. First round of interviews was held in 2009, after the establishment of the draft RBMPs. In order to generalise the findings, we conducted second round of interviews with the coordinators of the WFD implementation process in the water boards Noorderzijlvest, Vallei en Eem, Hollands Noorderkwartier and Zeeuwse Eilanden. By selecting these water boards we could gain insights into the regional implementation processes in each of the seven sub-(river)basins in the Netherlands (see Fig. 1 and Section 3) and were able to account for possible regional variations in the perceived uncertainties and strategies adopted to manage them. We conducted semi-structured face-to-face interviews with a total of 16 key actors. Ten actors were interviewed individually and the other six in pairs. After collecting the empirical data, we analysed the extent to which they reflect the uncertainties and management strategies in literature (see for details Raadgever et al., 2009).

The results of the literature review and the classification of uncertainties and uncertainty management strategies can be found in Section 2. Subsequent sections address the case study, firstly by introducing the WFD and its implementation in the Netherlands in Section 3, to be followed by a presentation of the uncertainties that were encountered by the water boards in Section 4. Section 5 addresses the uncertainty management strategies applied in practice. These strategies will be discussed in Section 6. In the final section we present some suggestions for further research.

2. Classification of uncertainty and uncertainty management strategies

2.1. Uncertainties

After conducting our literature study, we decided to adopt both the definition (see Section 1) and the classification of uncertainties introduced by Brugnach et al. (2008) as this classification has already proved its usefulness for analysing uncertainties in water management practice (cf. Brugnach et al., 2008; Isendahl et al., 2009; van der Keur et al., 2008). Brugnach et al. distinguish two dimensions in their classification of uncertainties. Uncertainties may differ in nature (ontological uncertainty, epistemic uncertainty or ambiguity) and object (the natural, technical or social part of the system to be managed). Examples of the nine resulting classes of

Fig. 1 – Map of sub-basins and analysed water boards.

uncertainty in the field of water management can be found in Table 1.

Ontological uncertainty (also referred to as unpredictability, variability or ontic uncertainty) refers to inherently unknowable or unpredictable understanding. Ontological uncertainty may be related to the randomness of nature, human behavior, social, economic and cultural dynamics or technological surprise (Walker et al., 2003). Epistemic uncertainty (also referred to as informational or cognitive uncertainty) refers to incomplete but knowable understanding. In contrast to ontological uncertainty epistemic uncertainty can be reduced by gathering additional knowledge. Whereas ontological and epistemic uncertainty are related to incomplete system understanding, ambiguity refers to a situation in which there is no unique system understanding possible. Such ambiguity may be caused by normative differences about the goals, values or interests to pursue, or by epistemic differences concerning the way the system to be managed functions. In many cases such normative and epistemic differences are interdependent (Arentsen et al., 2000; Dewulf et al., 2005; Newig et al., 2005; Raadgever et al., 2008).

Brugnach et al. (2008) did not provide a generic definition of the natural system, but from their definition of the technical and the social system we derive that the natural system concerns the natural environment without human interventions. The technical system includes ''the technical elements/artifacts that are deployed to intervene in the natural system, with infrastructure and technologies'' (Brugnach et al., 2008, p. 6). Finally, the social system includes ''economic, cultural, legal, political, administrative, and organizational aspects'' (Brugnach et al., 2008, p. 6).

2.2. *Uncertainty management strategies*

As we could not find a coherent and comprehensive classification of uncertainty management strategies in the literature, we developed our own. We listed all the uncertainty management strategies that we could find, grouped those strategies that we considered to be very similar and classified the (groups of) strategies into four categories.

Table 2 gives the overview of the collected strategies, including a description of and references for each strategy. The literature hardly discusses which types of strategies can be used to manage which types of uncertainty.

A first category of uncertainty management strategies is ignorance, by not taking any action to manage them. Actors may not know that particular uncertainties exist or that they can be managed, or they may purposefully choose not to manage certain uncertainties (for the time being at least). A second category of strategies deals with the generation of

Table 1 – Types of uncertainty including examples (integrally copied from Brugnach et al. (2008)).

Object	Nature		
	Unpredictability (unpredictable system behavior)	Incomplete knowledge - Lack of information - Unreliable information - Lack of theoretical understanding - Ignorance	Multiple knowledge frames - Different and/or conflicting ways of understanding the system - Different values and beliefs - Different judgement about the seriousness of the situation, growth potential of problems, priority of actions or interventions
Natural system - Climate impacts - Water quantity - Water quality - Ecosystem	Unpredictable behavior of the natural system, e.g., How will climate change affect weather extremes?	Incomplete knowledge about the natural system, e.g., What are reliable measurements of water levels?	Multiple knowledge frames about the natural system, e.g., Is the main problem in this basin the water quantity or ecosystem status?
Technical system - Infrastructure - Technologies - Innovations	Unpredictable behavior of the technical system, e.g., What will be the sideeffects of technology X?	Incomplete knowledge about the technical system, e.g., To what water level will this dike resist?	Multiple knowledge frames about the technical system, e.g., Should dikes be built or flood plains created?
Social system - Organisational context - Actors - Economic aspects - Political aspects - Legal aspects	Unpredictable behavior of the social system, e.g., How strong will actors' reactions be at the next flood?	Incomplete knowledge about the social system, e.g., What are the economic impacts of a flood for the different actors?	Multiple knowledge frames about the social system, e.g., Should water markets be introduced to deal with water scarcity or negotiation platforms?

knowledge. Knowledge generation may be aimed at assessing uncertainties or at reducing epistemic uncertainties. A specific form of knowledge generation is to perform a scenario study, in order to explore visions of possible futures. The third category of uncertainty management strategies is labelled interaction. Communication, the first strategy in this category specifically aims at transferring knowledge about uncertainties from one (group of) actor(s) to another. Persuasive communication, dialogical learning, negotiation or oppositional modes of action aim to reduce ambiguity about the system to be managed. Finally, coping strategies, acknowledge that some uncertainties cannot be reduced and instead aim to mitigate their negative consequences and/or stimulate their positive consequences. This includes preparing for the worst, adopting robust solutions, developing resilience and adopting flexible solutions.

3. The WFD and its implementation in the Netherlands

3.1. *The WFD*

The WFD aims to protect and improve the quality of surface water and groundwater and to promote the sustainable use of water in EU Member States (MSs). The WFD and related guidance documents prescribe the methodology that the MSs have to adopt, but at the same time leave a lot of room for interpretation by (sub)national actors. The WFD obliges collaboration between the competent authorities in a river basin (Art. 3) and the organisation of active involvement of all interested parties (Art. 14). An important milestone in the implementation process was the realisation of the draft RBMPs in December 2008. The final RBMPs are due in December 2009.

A central concept in the RBMPs is the water body (WB). In this article we discuss surface WBs only, since the Dutch water boards were at that time not involved in the definition of groundwater bodies and related goals and measures. MSs had to specify and characterise or classify the WBs in their country. For this purpose, they had to develop a typology for the WBs (according to Annex II of the WFD). Under specified conditions, MSs could qualify their WBs as artificial water bodies (AWBs) or heavily modified water bodies (HMWBs), instead of 'natural' WBs. AWBs are WBs created by human activities, while HMWBs are WBs with significant long-term hydro morphological alterations caused by human activities which prevent the achievement of certain environmental objectives (Art. 2).

By 2015, MSs are to achieve at least a good chemical status and a good ecological status in each WB (Art. 4). A good chemical status means that the concentrations of pollutants in the WB do not exceed environmental quality standards. Ecological status is assessed against type-specific reference conditions, which refer to natural conditions (undisturbed by human influence) in terms of hydro morphological, physico–chemical and biological quality elements (REFCOND, 2004). These ideal reference conditions do not have to be realised: the norm is to reach the slightly less ambitious good status. Reference conditions and norms for AWBs and HMWBs deviate more strongly from natural conditions. According to the WFD goals have to be achieved by 2015. However, under specified conditions, this deadline may be extended to 2021 or 2027 (Art. 4.4) or MSs may decide to apply less stringent objectives (Art. 4.5).

In their RBMPs, MSs had to report on the actual status of their WBs. They had to express the status of each ecological quality element in quantitative ecological quality ratios (EQRs) and related qualitative classes. Where possible, the actual status had to be defined on the basis of monitoring data. To

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Table 2 – Classification of uncertainty management strategies collected from literature.

Category	Strategy	Description	References
Ignoring	Ignoring uncertainty	Implicitly or explicitly ignoring uncertainty for the time being. This wait and see approach may be complemented with thinking up and implementing strategies in the timeframe of an unfolding potentially damaging event.	(Brugnach et al., 2008)
Knowledge generation	Uncertainty assessment	Strategy used, often in academic world, to get a better grip on uncertainty, e.g., by: - Uncertainty identification; - Uncertainty classification; - Uncertainty quantification; - Uncertainty propagation in models - Uncertainty prioritisation Can provide a basis for uncertainty communication and efficient, target-oriented uncertainty management.	(Arentsen et al., 2000; Ascough II et al., 2008; Brugnach et al., 2008; Rotmans and Van Asselt, 2001; Walker et al., 2003)
	Reduction of epistemic uncertainty	Strategy used to reduce epistemic uncertainty, e.g., by: - Develop indicators and monitor; - Data gathering; - Experimentation; - Quantitative simulation modelling; - Qualitative assessment; - Integrated assessment (tools) - Use of expert opinions	(Arentsen et al., 2000; Brugnach et al., 2008; Jakeman and Letcher, 2003; van der Keur et al., 2008; Walker et al., 2003)
	Scenario study	The performance of alternative strategies is tested under several consistent and plausible pictures of how the future may unfold.	(Börjeson et al., 2006; Brugnach et al., 2008; van der Keur et al., 2008)
Interaction	Communicating uncertainties	Communicating uncertainties from scientists to other actors in a policy debate allows the other actors to co-assess the quality of technical expertise and co-produce the relevant evidence. Communication may also be aimed at raising awareness among actors.	(Funtowicz and Ravetz, 1993; van der Keur et al., 2008; Van der Sluijs, 2010; Wardekker et al., 2008; Wynne, 1992)
	Persuasive communication	Convince others by presenting your perspective as attractive and worthwhile.	(Bouwen et al., 2006 in Brugnach et al., 2008; Bouwen and Fry, 1991 in Brugnach et al., 2008)
	Dialogical learning	Understanding one another's perspectives better through open dialog and by encouraging learning on all sides. Several authors advocate forms of dialogical learning as a good strategy to reduce ambiguity, as it may lead to mutual understanding, trust and support for management actions, or at least reduce resistance against actions. It may require a well-founded process design and the involvement of facilitators and mediators.	(Arentsen et al., 2000; Argyris and Schön, 1978; Bouwen et al., 2006 in Brugnach et al., 2008; Hanssen et al., 2009; Koppenjan and Klijn, 2004; Newig et al., 2005; Van Bueren et al., 2003; van der Keur et al., 2008)
	Negotiation	Reaching a mutually beneficial and integrative agreement that makes sense from multiple perspectives;	(Bouwen et al., 2006 in Brugnach et al., 2008; Leeuwis, 2000)
	Oppositional modes of action	Distancing and avoiding each other or trying to impose your perspective upon others by force	(Bouwen et al., 2006 in Brugnach et al., 2008; Gray, 2003)
Coping strategies	Preparing for the worst	Limiting potential negative consequences (controlling damage) of the worst case scenario (i.e., being conservative or precautionary)	(Brugnach et al., 2008; Klinke and Renn, 2002; Wynne, 1992)

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Table 2 (*Continued*)

Category	Strategy	Description	References
	Adopting robust solutions	Adopt strategies that perform well under multiple scenarios. This may mean adopting multiple measures (diversifying solutions) to ensure that one or more will be effective under each of the possible scenarios.	(Brugnach et al., 2008; Lempert et al., 2006; Pahl-Wostl, 2007)
	Developing resilience	Developing "the capacity of a system to absorb recurrent disturbances, such as natural disasters, so as to retain essential structures, processes and feedbacks" (Berkes, 2007, p. 283).	(Berkes, 2007)
	Adopting flexible solutions	Choosing flexible management strategies, which can be adapted to future changes. This may include adopting measures that are feasible within the timeframe of an unfolding potentially damaging event and that prevent or mitigate damage.	(Brugnach et al., 2008; Walker et al., 2003)

obtain relevant data, MSs had to set up monitoring programmes. They also had to plan how they would monitor the effects of specific measures (Art. 8 and Annex V). A last major component of each RBMP was the programme of measures, which was designed to bridge the gap between the actual situation and the environmental objectives (Art. 11. See also Uitenboogaart et al., 2009; Van Rijswick, 2009).

3.2. *The implementation of the WFD in the Netherlands*

The Ministries of Transport, Public Works and Water Management (TPW), of Agriculture, Nature and Food Quality (ANF) and Housing, Spatial Planning and the Environment (HSPE), 12 provinces, 26 water boards and over 400 municipalities are involved with the implementation of the WFD. The Ministry of TPW is formally designated as competent authority for the four Dutch river basins and reports to the European Commission. It coordinated the implementation process, issued guidelines and finally approved the draft RBMPs for the Dutch parts of the Rhine, Meuse, Ems and Scheldt basins (major features of these basins are presented in Table 3). The Public Works Department, the executive organisation of the Ministry of TPW, took the lead in the implementation of the WFD in large rivers, lakes and seas, while provinces had a leading role concerning groundwater bodies. They also had to approve the input from the water boards that took the lead in defining regional surface WBs and related goals and measures. Municipalities, responsible for urban water management and sewerage, collaborated with the water boards in defining goals and measures for regional surface WBs. Draft water management plans of the national government, the provinces and water boards formed the basis for the draft RBMPs (Mostert, 2008; Uitenboogaart et al., 2009; Van Rijswick, 2009).

4. Uncertainties in the regional implementation of the WFD

During the implementation process the water boards had to deal with several uncertainties. Table 4 gives an overview of the uncertainties encountered by the interviewees. We first describe the uncertainties (unpredictability, incomplete knowledge and ambiguity) related to the natural system, followed by those related to the technical and the social systems.

4.1. *Uncertainties related to the natural system*

The interviewees experienced several uncertainties related to the natural system. Fundamental was the existence of different opinions (ambiguity) about the definition and assessment of a good ecological status. Several ecologists disputed that nature can be quantified to the level as required by the WFD and proposed to develop simpler methods to assess the ecological status. Other uncertainties concerning the assessment of the ecological status were related to flaws in the premature assessment methods, gaps in the available data and a limited monitoring budget.

Table 3 – Major features of the river basins in the Netherlands (based on Willemse (2008) and RBMPs).

	Ems	Meuse	Rhine	Scheldt
Area in the Netherlands (km^2)	2600	7700	28,500	3200
Number of involved provinces	2	4	10	3
Number of involved water boards	2	7	18	3
Number of involved municipalities	22	109	343	16
Number of surface WBs	22	155	490	56
Percentage of natural WBs (%)	9	4	2	3
Percentage of AWBs (%)	55	29	63	63
Percentage of HMWBs (%)	36	67	35	34

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Table 4 – Uncertainties experienced in the regional implementation of the WFD.

	Unpredictability of...	Incomplete knowledge about...	Ambiguity about...
Natural system	- Physical relation between supportive and leading quality elements	- Current ecological status and variation in space and time - Physical relation between supportive and leading quality elements	- The definition and assessment of a good status (within budget) - Adequate norms for supportive quality elements
Technical system	- The effects of certain measures on water quality and ecology	- The effects of certain measures on water quality and ecology	- The usefulness and necessity of certain measures
Social system	- Response by EC and ECJ to RBMPs and their implementation - Implementation process in NL (organisation structure, tasks, responsibilities and deadlines) - Time of delivery and content of (improved versions of) national instructions - Stakeholder support for RBMPs and stakeholder behaviour	- Legal obligations, scope, level of ambition, exemptions, sanctioning, etc. - Dependencies between different concepts in the WFD - The costs of measures, synergy with other goals and impact on actors	- Meaning of WFD and response of EC and ECJ to RBMPs and their implementation - Appropriate level of ambition - Normative principles behind national instructions - How to connect goals and measures - Relevant problems, goals and measures

The WFD prescribes that biological quality elements constitute the most important components in the assessment of the ecological status, and that hydromorphological and physico–chemical quality elements have to support the achievement of biological objectives. However, the interviewees experienced a lack of knowledge about the physical relation between the supportive and the leading quality elements. In particular the influence of nutrients on achieving the biological goals in specific situations was considered uncertain. As a consequence, the actors did not agree on the norms for supportive quality elements.

4.2. *Uncertainties related to the technical system*

The interviewees experienced strong uncertainties related to the technical system (human interventions in the natural system). The WFD reflects the assumption that the effects of potential measures on water quality and ecology are known and that this knowledge can be used to set feasible objectives. In practice, however, insufficient knowledge and natural variability render it (almost) impossible to quantify measure-effect relations. Hydro morphological restoration, for example, can create a suitable habitat for flora and fauna, but whether and when specific species will return can hardly be predicted. As a consequence, there was ambiguity about the usefulness and necessity of certain measures.

4.3. *Uncertainties related to the social system*

Most of the uncertainties experienced by the interviewees were related to the social system. First of all, the status of the obligations resulting from the WFD was not clear to the water boards. The WFD confronted EU MSs with the obligation to develop RBMPs, execute the planned measures and achieve the objectives set. However, for the water boards questions arose about the exact contents of the obligations and the scope and level of the ambition to adopt. Moreover, it was not clear to them which exemptions would be legitimate and who will be accountable for what. The water boards were concerned about the consequences the obligations might have in cases in which the European Commission (EC) is not satisfied with the objectives set and the measures planned in the RBMPs or with the extent to which measures are executed and goals are achieved. In these cases, the EC might start a legal proceeding at the European Court of Justice (ECJ) which might result in a condemnation and eventually even in financial sanctions.

Second, for a long time it remained unclear how the WFD would be implemented in the Netherlands, who would be responsible for what tasks and which deadlines would be set. In 2005, five years after the WFD entered into force, this uncertainty was reduced when the national government presented its process design. Still, the interviewees experienced uncertainties related to national memorandums, guidelines and standardized reporting forms. In national memorandums the national government introduced guiding principles for the implementation such as pragmatism, feasibility and affordability (Parliamentary Papers, 2004). The principles were developed out of fear for (the possible significant) damage to the Dutch economy and out of fear that the legal obligations of the WFD could not be complied with. Some of the interviewees experienced a discrepancy between these principles, which were adopted in regional politics, and their own strong ecological ambitions. In national working groups guidelines in the form of handbooks with typologies and classification scales for natural WBs and AWBs (i.e., Evers et al., 2007; Van der Molen and Pot, 2007) and instructions for monitoring and assessing the ecological status were developed which must be used by the water boards. Furthermore, the national government developed several standardized, internet-based forms that had to be filled in by the regional authorities in order to process their input into the RBMPs. However, during the implementation process it was uncertain when the memorandums, guidelines and forms would be issued, what their content would be, and what their status would be (when issued). Sometimes improved versions of these documents were issued at a later stage. Consequently, the water boards continuously feared that they would have to revise their original work.

A third uncertainty that was brought up in the interviews was the lack of knowledge about (or unpredictability of) the implications of decisions that had to be made in the early stages of the implementation process. The different elements of the RBMPs were strongly related, but in an indistinct, complex manner. The number and intensity of monitoring and reporting obligations depend for instance on the number of WBs. The type and status of WBs had strong impacts on the definition of environmental objectives for that WB.

Finally, ambiguity was caused as regional actors had partly different perspectives on the relevant problems, goals and measures. A strong contrast manifests itself between ecological ambitions of nature organisations and economic interests of the agricultural sector. The latter did not support very ambitious ecological objectives. Stakeholder support is very important for the implementation of the RBMPs. Water boards can for instance only implement spatial measures, such as a remeandering of rivers, in (good) cooperation with landowners or with provinces and municipalities, which in theory have the mandate to expropriate landowners.

5. Uncertainty management strategies in the regional implementation of the WFD

The interviewees also explained the strategies they employed to manage the uncertainties described in the previous section. In Table 5 we organised these strategies using the classification of uncertainty management strategies previously developed. Below we describe the adopted strategies (per category) in more detail.

5.1. *Ignoring uncertainties*

Some uncertainties were currently being ignored. One strategy that the water boards adopted was to wait until another actor made a decision, instead of proactively trying to manage the uncertainty themselves. Some water boards for instance waited until the state had issued its process design or waited until errors were removed from national instructions. By doing this the water boards were able to limit their workload. A related strategy was to ignore some of the interdependencies in the implementation process. Some water boards did not take full account of the relation between the current ecological status, the measures to be implemented and the expected fulfilment of ecological objectives. Another related strategy employed was to make decisions whilst system understanding was far from complete and clear. The latter was often required due to time pressure from the tight planning schedule of the implementation process. Often such decisions were based on one of the coping strategies described in Section 5.4.

5.2. *Knowledge generation*

Knowledge generation predominantly took place by monitoring and expert judgment. Most water boards let their specialists determine the WBs, their type, environmental objectives, monitoring strategy and current status. In most cases the water boards altered their approach, where appropriate, after the issuing or revision of national instructions, for example, on monitoring and assessment of ecological status. They also adapted national instructions to local specificities (where necessary). Some boards for instance tried to derive specific norms for supporting quality elements for their own HMWBs. By participating in technical working groups at the national or sub-basin level regional officials also contributed to knowledge development. Furthermore, water boards acquired legal knowledge by consulting legal experts about the scope of the WFD obligations.

Specialists at the water boards reduced uncertainties about the effectiveness of measures by making estimations. They also assessed the costs, synergy with other objectives, technical feasibility and regional support for measures. The effects of the measures that will be implemented up until 2015 will be monitored, in order to gain a better understanding of the effectiveness of specific types of measures. Such an experimentation approach is also meant to reduce natural and technical uncertainties.

5.3. *Interaction*

In our case no researchers were involved in communicating uncertainties to other actors. Other actors, however, frequently communicated about the uncertainties they had to face. Some of the interviewees articulated uncertainties in the assessment of current environmental status and in determining the effectiveness of measures.

Examples of each of the other interactive strategies were found in practice as well. In order to promote an intensive debate between society, administrators and politicians, informal horizontal and vertical consultation structures were set up in the Netherlands (Ligtvoet et al., 2006). Provinces, water boards, municipalities and regional directorates of the Public Works Department collaborated in seven regional sub-basins: Ems, Meuse, Rhine-North, Rhine-Middle, Rhine-East, Rhine-West and Scheldt (see Fig. 1). The regional actors attended meetings on the political and expert level, and set up technical working groups. In addition, they established sounding boards, in which the most relevant non-governmental actors met regularly in order to express their perspectives on the implementation (Mostert, 2008; Uitenboogaart et al., 2009; Van Rijswick, 2009). All the water boards interviewed participated in these sub-basin meetings. Moreover, they organised meetings with local municipalities, drinking water companies and agricultural and environmental NGOs in order to inform them about the WFD and to consult with them. Moreover, water boards actively tried to influence national decision-making and national instructions. Water board de Dommel for instance organised a strong lobby against the draft legal transposition of the WFD.

Often, interactions were primarily oriented at mutual learning through dialogue and collaboration. In the more political meetings, the water boards defended their interests and negotiated with other actors, for example, about the appropriate ambition levels. Our interviewees have not reported truly oppositional modes of action, but stated that sometimes water boards distanced themselves from other actors and processes, either by simply ignoring them or by expressing their viewpoints or counterarguments. Some water boards for instance refused to deliver data on the status of their WBs as they felt these data were too uncertain to be used in specifying official reference conditions. In practice, several interactive strategies were employed at the same time. During sub-basin meetings a mix of persuasion, negotiation, learning and opposition occurred.

Table 5 – Uncertainty management strategies adopted in the regional implementation of the WFD.

Category	Strategy	Specific application in the case study
Ignoring	Ignoring uncertainty	- Wait for national implementation process design and adopt it - Wait for errors to be removed from national instructions - Ignore interdependence between decisions
Knowledge generation	Uncertainty assessment	n/a
	Reduction of epistemic uncertainty	- Develop and apply WFD-conform methods to define WBs, water types and goals - Monitor and assess the status, based on existing methods, guidance documents and expert judgement - Asses the influence of supportive quality elements based on expert judgement - Assess the effectiveness of measures based on expert judgement - Include research measures in RBMP (plan research) - Consult legal experts about the correct interpretation of the WFD - Asses the costs of measures, the synergy with other goals and impact on actors
	Scenario study	n/a
Interaction	Communicating uncertainties	- Articulate uncertainties in the assessment of the current environmental status and in determining the effectiveness of measures to other actors
	Persuasive communication	- Actively influence national implementation process - Influence national instructions (e.g., lobby)
	Dialogical learning	- Participate in national and regional working groups about the assessment of ecological status and the influence of supportive quality elements - Participate in national and regional working groups about measures and their effects - Organise meetings with municipalities and NGOs and consultation
	Negotiation	- Discuss about appropriate level of ambition in several fora - Participate in sub basin deliberation
	Oppositional modes of action	- Refuse to deliver uncertain data or make reservations
Coping strategies	Preparing for the worst	- Designate large WBs to limit monitoring and reporting - Design an affordable and feasible programme of measures - Adopt national principles, norms and instructions (limit accountability) - Determine feasible objectives and a feasible programme of measures with a phased execution
	Adopting robust solutions	- Plan cost-effective, synergetic measures that can be executed independent of other parties and that do not significantly harm other parties
	Developing resilience	n/a
	Adopting flexible solutions	- Maintain flexibility to change RBMPs

5.4. *Coping strategies*

By preparing for the worst, adopting robust solutions and adopting flexible solutions water boards tried to cope with uncertainties. This was particularly stimulated by the politicians in the board. In order to manage uncertainty about the legal obligations, the water boards did not promise more than necessary in the RBMPs. In this way, they reduced potential negative effects that might occur in case they were not able to significantly improve the status of their WBs. First, the water boards decided not to designate smaller waters as WBs, in order to limit the reporting and monitoring obligations. Second, the water boards proposed the provinces to designate most WBs as AWBs or HMWBs, which offered them the opportunity to develop realistic, feasible objectives. Third, to limit implementation costs, the programmes of measures included mainly measures that had already been planned. They will be executed in phases (up until 2027). The water boards did not select measures that would cause significant damage to existing land use functions. Measures like the expropriation of agricultural land were not specified. Instead the boards decided that acquisition could only be done on a voluntary basis. These strategies clearly reflect the national principles of pragmatism, feasibility and affordability. By adopting the national principles the water boards shifted some responsibility and accountability for the content of the RBMPs to the state. This further reduced potential negative consequences for the water boards.

An example of a robust solution was the search for cost-effective, innovative and synergetic ‘‘no-regret’’ measures. Measures such as the realisation of nature friendly embankments were popular, as they potentially contribute not only to achieving the objectives of the WFD, but also to improved flood management and spatial planning.

Finally, the water boards made definitive decisions about the formulation of the RBMPs as late as possible. They built in reservations (to their reporting) about the actual status of WBs and the objectives set. By doing this, they maintained the flexibility to change their activities as a consequence of political discussions, national instructions and/or advancing insights.

6. Discussion

To focus our study, we concentrated on the debate in environmental management and governance literature. In other disciplines, such as environmental sociology and political sciences, uncertainty is addressed in slightly different matter. These disciplines appear to provide a more extended discussion of differences in the perception of uncertainty among groups of stakeholders and implications for decision-making. The types of uncertainty and uncertainty management strategies discussed, however, appear similar to those discussed in this article.

Our case study results confirm the practical relevance of the uncertainty classification of Brugnach et al. (2008), as the water boards were confronted with unpredictability, incomplete knowledge and ambiguity related to the natural, technical and social system. Most uncertainties experienced by the water boards were related to the social system. This indicates that the traditional focus in environmental management on uncertainties related to the natural and technical system has its limitations as it provides an incomplete view of the uncertainties that have to be faced in practice. In practice, uncertainties related to the social system appear to be dominant (cf. Ascough II et al., 2008) and ask for careful management.

At the same time, strong mutual relations between the different categories of uncertainty appeared to exist which makes them (sometimes) difficult to separate (cf. Pahl-Wostl, 2004; van der Keur et al., 2008). For example, incomplete knowledge about the current ecological status and unpredictability about the effects of measures on ecology aggravated ambiguity about the level of ambition that should be reflected in the ecological objectives.

The uncertainty management strategies found in the case study fitted well into the categories of the classification developed. Ignoring uncertainty, knowledge generation, interaction and coping strategies could be discerned in practice. This confirms the empirical soundness of the classification. The water boards employed strategies that formed a rich combination of almost all uncertainty management strategies identified in literature. So far, the water boards have abstained from strategies as uncertainty assessment, drafting of scenario studies and the development of resilience.

During the interviews several water board officials expressed their views on the effectiveness and efficiency of the employed uncertainty management strategies. Although knowledge generation resulted in some reduction of epistemic uncertainty, several interviewees put forward that not enough knowledge was generated. Although intensive interaction appeared to have resulted in a significant reduction of ambiguity, in particular among public actors, both interviews and official stakeholder reactions to the draft RBMPs demonstrated that fundamental differences in perspectives between for example nature conservation and farmers' organisations still exist. Moreover, the effects of the coping strategy to adopt the principles of pragmatism, feasibility and affordability are still uncertain. The strategy may have decreased the risk that in the longer term legal obligations cannot be met, but at the same time increased the risk that the EC will not be satisfied with the RBMPs in the short term.

Furthermore, interviewees were critical about the efficiency of the sometimes fragmented and ad hoc application of uncertainty management strategies. The interviews revealed that it was not always clear who would employ which activity, when (intermediate) results were due and how different results were to be combined and utilised. This resulted in some duplicate work, and some competition and tension between the strategies and the actors that applied them.

7. Conclusion

The main aim of this article was to develop a comprehensive, coherent and empirically sound classification of uncertainty management strategies. For this purpose we developed a classification of uncertainty management strategies which we confronted with the results of a case study. A side goal was to obtain better insight in the types of uncertainty that occur, by testing the empirical value of the classification of uncertainties of Brugnach et al. (2008). The case study results demonstrate that both classifications are empirically sound; at least as far as the water issue is concerned.

We conclude this article by suggesting three directions for further research. First, further empirical research could be aimed at testing the classifications of uncertainty and uncertainty management in other fields of environmental management. Second, more research is needed to investigate how mutual adjustment of uncertainty management strategies can be improved. We agree with authors like (e.g., Isendahl et al., 2009; Walker et al., 2003; Wardekker et al., 2008) that an explicit, structured and integrated assessment (identification, evaluation and prioritisation) of uncertainties is an essential preparatory step in uncertainty management (cf. Isendahl et al., 2009; Walker et al., 2003; Wardekker et al., 2008). To enable assessment of all relevant uncertainties and to facilitate all possible management strategies, a broad range of actors should be involved (cf. Pahl-Wostl, 2009; Raadgever et al., 2008; Van der Sluijs, 2010). The results of a thorough uncertainty assessment may be helpful information in deciding which strategies will be employed, by whom, and how uncertainty management strategies can be arranged in a synergetic way. Yet, these hypotheses need to be tested in practice. Finally an evaluation of factors/components which constitute effective, efficient and legitimate uncertainty management in practice could be conducted. Such an evaluation would require the careful development of a normative framework with criteria to specify effectiveness, efficiency and legitimacy (such as in Hedelin, 2008) and more longitudinal research to be able to meet the challenge of finding causal links.

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