(Re-)framing
Uncertainties in Water Management Practice

Dissertation

Nicola Isendahl
Institute of Environmental Systems Research
Faculty of Mathematics/Informatics
University of Osnabrück, Germany
January 2010

supervised by

Prof. Dr. Claudia Pahl-Wostl
Institute of Environmental Systems Research (USF)
University of Osnabrück, Germany

Dr. Art Dewulf
Public Administration and Policy Group (PAP),
Wageningen University, The Netherlands

"*The only thing that is certain is that nothing is certain.*
And not even that is certain."

Ancient paradox

Acknowledgements

This thesis would not have been possible without the support from many sides. I am thankful for all the inputs and support I got from so many people throughout the years of developing this thesis.

Above all, I would like to express my sincere gratitude to my supervisors Prof. Dr. Claudia Pahl-Wostl and Dr. Art Dewulf for their constant support, encouragement and constructive revisions of my work.

I also wish to express my sincere appreciation for getting the opportunity to develop my thesis in the context of the European research project NeWater (New Approaches to Adaptive Management under Uncertainty, contract N° 511179), financially supported by the European Commission.

I greatly thank all colleagues from NeWater whom I met in numerous project and case study meetings, summer schools and training courses and who made the PhD study a very productive, enjoyable and creative time. Particular thanks go to Matt Hare and Christian Stein for inspiring discussions and critical reviews of my work in all phases of the research.

I further wish to thank all colleagues from USF for their support, open discussions, and suggestions, which helped me to improve my research and to have a great working environment. Particularly Britta Kastens, Jens Newig, Georg Holtz, Bettina Blümling and Ilke Borowski I would like to thank for their input and encouragement, both professionally and personally. Special thanks also go to Irene Brink for the management of administrative issues.

I remain highly thankful to all participants in the case studies for their collaboration, provision of information, and insights in countless details, particularly the organizations who hosted my meetings, i.e. the Wupperverband in Wuppertal/ Germany, the Hoogheemraadschap De Stichtse Rijnlanden (HDSR) in Houten/ Netherlands, and the Instituto del Agua de Andalucía (IAA) in Sevilla/ Spain.

I give my sincere thanks to all colleagues who provided help in the case study work, particularly Greet François, Sabine Möllenkamp, and Pablo Fernández Méndez for their untiring help in facilitating the realization of the empirical research.

Special thanks go to Tharsi Taillieu and Claudia Pahl-Wostl for making a six weeks research stay at COPP in Leuven, Belgium, possible.

All my friends and flatmates in both Osnabrück and Berlin I thank for their patience and encouragement throughout the years.

I thank Jutta and Claus, Christina and Marlen Isendahl, Frauke Neumeyer, and Gerd Konschak for always being there and mentally supporting me during these years of elaborating the present thesis.

Summary

Water resource systems are complex systems characterized by multi-level interactions and non-linear changes over space and time. As nowadays in water systems the natural processes are highly influenced by human activities it is appropriate to speak of water resources systems as human-technology-environment systems that function as complex adaptive systems. Uses of water resources often compete with each other, natural conditions such as precipitation patterns or ground water recharge are hard to predict and it is virtually impossible to assess all impacts of the changes and the diverse uses on the system. Thus when intervening in the water system one is likely to meet numerous uncertainties. Constructive dealing with uncertainties in water management gets more and more important as pace and dimension of global changes increase leading to hitherto unknown problems and challenges. The need for addressing uncertainty in the management of water resources is widely recognized by now, yet there is little expertise and experience how to effectively deal with uncertainty in practice. Up to now, approaches to deal with uncertainty in water management have predominantly been developed and applied in the scientific world, in order to assess, structure, quantify and analyze uncertainties in a systematic way. Those methods are developed from a supposedly objective scientific perspective. The framing of the scientists and other experts, such as technical consultants, in the analysis is taken for granted and neutral – whereas it is not – without considering that decision-makers possibly and likely have a different view than scientists. In a nutshell, scientific analysis often clashes with requirements in practice and framing differences are disregarded.

Framing differences are more and more recognized as a major impediment to effective management of natural resources. Thus there is a need for making framing and differences in framing explicit and for constructively dealing with them. With respect to uncertainty so far no approaches have been developed that would address this problem. The present thesis aims to fill this gap. It is based on the argument that in order to develop practice-oriented approaches for dealing with uncertainty it is important to understand how water managers frame uncertainties. The objective is to get insights into framing of uncertainties in water management practice, i.e. how strategies to deal with uncertainty in water management practice can be improved based on an assessment of framing of uncertainty. The thesis presents results and insights from a conceptual and methodological discussion of 'framing' and 'uncertainty' illustrated through empirical work in several river basins.

The research follows the relational concept of uncertainty (as opposed to purely objective or subjective concepts). That means that uncertainties do not exist per se and can be described objectively but depend on the involved actor and object or issue. This concept is instructive for the purpose of the present research as it connects well with the concept of framing. Framing relates to how we make sense of the world. Due to inherent limitations of the human mind and according to the personal, professional and cultural backgrounds everybody has a specific and restricted view on the world. That means one cannot and does not consider all details and information relevant to a specific situation but observes selectively according to his or her interest and concern. In terms of dealing with uncertainty, framing means that different actors in water management are likely to have differing views on uncertainties and hence frame them differently. The aim then for uncertainty assessment is not to identify how an uncertainty really is and get to a universally valid description of it, but understand how actors relate to it, how they

frame it and what changes in that relationship entail for dealing with uncertainty. Framings may change over time and influence the direction of decision-making processes. On the one hand, how somebody frames a problem or an uncertainty influences the way that uncertainty is dealt with. On the other hand, diverging framings may lead to conflicts.

It is difficult is to make the concept of framing workable for assessment in practice. Framing processes are complex and to fully assess mental models is virtually impossible. In order to obtain practicable and meaningful results of analysis the present thesis aimed at developing parameters that are influential in the process of framing uncertainty in water resources management. Parameters are considered a promising means to operationalise the concept of framing and mental models as they are a straightforward means for structuring and are relatively easy to assess and display. The assumption is that by help of parameters the framing of the uncertainties can be made more explicit than currently is the case in water management practice. Moreover, they provide a basis to develop more systematic and structured approaches for dealing with uncertainty in water management practice which eventually enables better informed decision-making.

The research for this thesis has been closely linked to the EU research project NeWater (New Approaches to Adaptive Water Management under Uncertainty) (2005-2009). The empirical work concentrated on three European river basins: the German Wupper and the Dutch Kromme Rijn, both sub basins of the river Rhine, and the Doñana region located in the Guadalquivir Estuary in Spain. It draws on practical experiences of water managers at local and regional level in river basin management. For the assessment of framing of uncertainty two different methods were developed and applied in the three river basins. Both aim at identifying parameters of importance in the process of framing uncertainty in order to understand how uncertainties get framed. For the first approach, framing parameters (FP) were identified through an ex-post analysis of narratives of water managers on their dealing with uncertainties. The resulting set of parameters was used for assessing uncertainty framings in the Wupper and Kromme Rijn along selected uncertainty situations. A second alternative approach was developed for two reasons. On the one hand a method was searched to reduce the limitations of direct verbal communication. On the other hand an approach was looked for that would minimize distortion of actors' framings in consequence of scientific intervention. Thus, as an alternative a participant-structured approach was developed and applied in the Doñana region where participants developed parameters themselves with help of a method of contrived knowledge elicitation, i.e. card sorting.

The empirical research confirmed that indeed water managers are faced with a range of uncertainties and that so far no systematic approaches are applied for dealing with those in management practice. The participants in the case studies were eager to learn how to better deal with uncertainties. The results in the case studies suggest that there are no universal findings as to how actors frame uncertainties but rather that framings are dependent on the respective uncertainty situation, on roles (e.g. project leader, public administration, scientist etc.), and most often on personal traits.

The two approaches applied in the case studies proved to be practicable and useful for the participants. The alternative participant-structured approach rendered participatory framing parameters (PFP) that were mostly different from the FP of the ex-post analytic approach. The case study findings suggest that there are no universally valid parameters of influence in the framing of uncertainties. Neither could a clear superiority of one approach over the other be discerned. Nonetheless, the parameters of framing of uncertainty proved to be a supportive tool

for preparing and structuring decision-making in the case studies and developing improvement options for dealing with uncertainty.

From the results in the Wupper and Kromme Rijn a checklist was developed to be used by water managers in practice when confronted with situations marked by uncertainty. The checklist contains of a set of overall strategies according to the FP each of which is specified by concrete action options. Those were synthesized from the case study findings of the Wupper and the Kromme Rijn. By using the checklist uncertainties can be addressed in an explicit and structured way and sound decision-making is enabled. In the Doñana case suggestions were made how to use the PFP for improvement of decision-making under uncertainty.

Beyond the results of the development of approaches for the assessment of framing of uncertainty in water management practice, processes of communication and learning turned out to be of major importance. Making framings of uncertainties explicit by help of parameters of framing proved to be useful in the case studies for revealing different points of views on the uncertainties and with regard to the strategies to deal with them. This is a first step in enabling dialogue among opposed framers and an important precondition for reframing and learning which is crucial for the long-term performance in management of natural resources.

Through my research, I hope to have captured important features in the framing of uncertainties. Although for effective use in practice it may be necessary to modify and complement the proposed lists of parameters according to the needs of the applicants, the presented work constitutes a step forward in the search of adequate ways for dealing with uncertainty in water management practice. Based on the obtained results different options for extension and combination of the two methods are outlined that may be addressed in future research:

1. The two elaborated lists of parameters may be combined into a joint list for a more comprehensive approach to assessing and dealing with framing of uncertainty. The usefulness of combining the two lists would have to be tested in practice.

2. Context-specific parameters could be developed newly for each case for the assessment of framing of uncertainty. That way meaningfulness for the actors in the respective cases is ensured.

3. The two approaches explored in the present research could be combined in a sequential order. For the assessment of framing of uncertainty in a certain case study, first a participant-based approach could be followed, concluding in a locally relevant list of criteria. Afterwards, the parameters and intervention options of the researcher-structured approach of the present thesis could be provided to the participants in order to broaden their insights by using criteria that they did not come up with but may consider relevant. The latter approach is also promising regarding the establishment of a sound knowledge base on the framing of uncertainties which would allow deriving more general conclusions on the importance of local factors compared to generally applicable criteria.

All suggested options would require more research involving practitioners in water management. For testing in practice and further development of the parameters extending the range of actors to other sectors and levels is crucial as all relevant framings have to be considered for successful decision-making in the long term. A major challenge and interesting field for future research is how scientific approaches to uncertainty assessment and management and approaches from water management practice to deal with uncertainty can be integrated for mutual benefit.

"*Wir haben soviel Ungeklärtes auf dieser Welt,*
und damit dies so bleibt, haben wir die Wissenschaft."

Otto Waalkes (*1948)
German comedian

Index

List of Tables

List of Figures

List of Abbreviations

AM	Adaptive Management
AWM	Adaptive Water Management
BR	Bezirksregierung (regional government, Germany)
CAS	Complex adaptive systems
CHG	Confederación Hidrográfica del Guadalquivir (water authority, Spain)
DM	Decision-making
DS	Decision situation
EBD	Estación Biológica de Doñana (research station)
END	Espacio Natural de Doñana (nature reserve)
EU	European Union
FP	Framing parameters
HDSR	Hoogheemraadschap De Stichtse Rijnlanden (Kromme Rijn, NL)
MM	Mental model
NGO	Non-governmental organization
NL	the Netherlands
PFP	Participatory framing parameters
RQ	Research question
SES	Socio-ecological systems
SMM	Shared mental model
WFD	Water Framework Directive
WRM	Water Resources Management
U	Uncertainty
UE	Uncertainty about the environment
UM	Uncertainty Matrix
UR	Uncertainty about related decisions
UV	Uncertainty about guiding values

1 Aim and Scope of the Thesis

Constructive dealing with uncertainties in water management gets more and more important as pace and dimension of global changes increase leading to hitherto unknown problems and challenges. It is widely argued in literature that framing differences are an impediment to effective management of natural resources (Friend and Hickling 1997; Ney and Thompson 1999; O'Connor 1999; Pahl-Wostl 2002; Dewulf et al. 2004; Koppenjan and Klijn 2004; Dewulf et al. 2009). With respect to uncertainty, so far no approaches have been developed that would address this problem. The present thesis aims to fill this gap. The assumption is that if strategies to deal with uncertainties in water management practice are to be effective and implementable they need to take into account the actors' framing, i.e. how different actors involved in water management understand and relate to uncertainties. This thesis presents results and insights from a conceptual and methodological discussion of framing and uncertainties illustrated empirically in several river basins.

1.1 Outset

Water systems and uncertainties have an inevitable relation. This is partly due to the characteristics of water as a constantly changing and partly fugitive element (Alaerts 2003) and to the water resources systems as complex adaptive socio-ecological systems (Pahl-Wostl 2006). As a result the likelihood for uncertainties to arise is high, be it with regard to ecological parameters (e.g. temporal or spatial distribution of water) or concerning the anthropogenic consumption, use or pollution of water resources and the consequences resulting from the interplays between the two. The need for addressing uncertainties in the management of water resources is evident. In the light of increasing global changes, in particular climate change, uncertainties are likely to increase. Hence it is necessary to develop robust approaches for dealing with uncertainties, in order to cope with increasing and unpredictable future changes. New approaches such as Adaptive Water Management (AWM) argue for acknowledging uncertainty and for explicitly incorporating uncertainty assessment in water management decisions (Holling 1978; Pahl-Wostl 2007; Pahl-Wostl et al. 2007b). Still, concrete ways and methods to do so are not fully in place yet and actual implementation on the ground is scarce.

One means to make the claims of AWM operational is to incorporate the concept of framing into the development of methods. Framing relates to how people make sense of the world (Kickert, Klijn et al. 1997; Doyle and Ford 1998; Kaufman, Elliot et al. 2003; Lewicki, Gray et al. 2003; Dewulf, Gray et al. 2009). In terms of dealing with uncertainty, framing means that different actors in water management are likely to have differing views on uncertainties and hence frame them differently. These framings may change over time and influence the direction of decision-making processes. On the one hand, how somebody frames a problem or an uncertainty influences the way that uncertainty is dealt with (Bardwell 1991; Sheppard, Blumenfeld-Jones et al. 1994; Kickert, Klijn et al. 1997; Cortner 2000; Koppenjan and Klijn 2004; Dewulf, François et al. 2007). On the other hand, diverging framings may lead to conflicts.

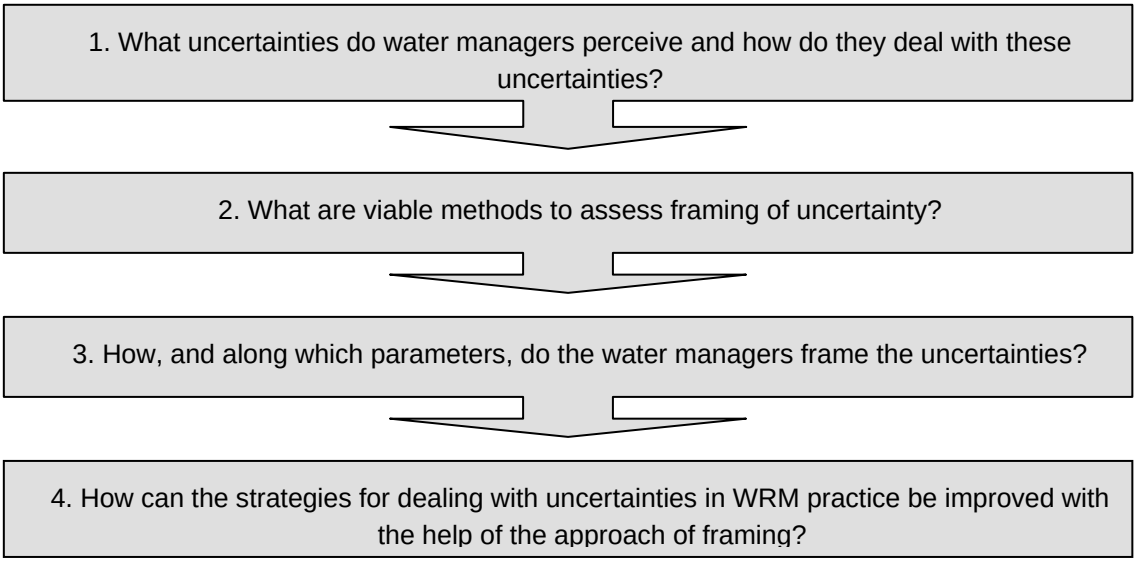
The concept of framing allows or even presupposes that change is possible. Framings are likely to influence each other mutually and iteratively. This change may be important at individual level or for single situations but also in a broader context. On a global scale, the way uncertainties are dealt with in Water Resources Management (WRM) may be related with the respective WRM

paradigm. Consequently, approaching uncertainty in WRM as a contextual social construction contributes to identifying and understanding the water management paradigm at hand, and changing the way uncertainties are framed may on the other hand induce changes in the WRM paradigm. Change can only be achieved deliberately when the starting point, in this case the framing of uncertainties, is known and intervention moments can be identified.

1.2 Objective & Research Questions

The present thesis investigates framing of uncertainties in water management practice. The challenge is to assess mental models and understand framing processes, i.e. to find a way to get insights in the framing of uncertainties. Framing processes are complex and to fully assess mental models is virtually impossible (Rouse and Morris 1986). In order to obtain workable and meaningful results of analysis the present thesis aims to identify parameters that are influential in the process of framing uncertainty in water resources management. For that purpose dealing with uncertainties in water management practice is analysed in several case studies. The empirical research concentrated on three European river basins: the German Wupper and the Dutch Kromme Rijn, both sub basins of the river Rhine, and the Doñana region located in the Guadalquivir Estuary in Spain. It draws on practical experiences of water managers at local and regional level in river basin management. Besides scientific purposes, the empirical work in case studies is drafted to enable a broadening of the view on uncertainties in the respective case studies and initiating and enabling reflection and reframing of uncertainties in water management practice.

In order to meet the outlined objectives the following research questions are addressed in this thesis:



Question n° 1 is an essential starting point to ensure the relevance for water management practice. If water managers perceive no uncertainties or measures are being developed for uncertainties that actually do not play a role in WRM practice any attempt to assess framing of uncertainties is groundless.

Question n° 2 explores how framing of uncertainty can actually be assessed in water management. The question is central to this research as it builds the ground for developing improvement options for dealing with uncertainties. Two different methods are developed and applied in the case studies.

Question n° 3 connects to the question on methods as it is meant to deliver the content, the concrete results, of the application of the different assessment methods.

Question n° 4 finally reflects the overall aim of the efforts of this thesis, i.e. to contribute to improving dealing with uncertainties in water management.

The research questions are addressed through literature research and, particularly with regard to RQ n° 1, 3 and 4, empirical work in the case studies. Firstly the way uncertainties are currently dealt with in water management practice is identified. Secondly, approaches are explored to understand how these uncertainties get framed, and thirdly, more systematic and structured approaches are developed how dealing with uncertainty can be improved under the paradigm of Adaptive Water Management by taking the concept of framing into account.

1.3 Structure of the thesis

The thesis is written cumulatively and, besides the present framework, contains three papers accepted for or published in peer-reviewed journals (sections 8.1-8.3). Research for the thesis has been closely linked to the EU research project NeWater (New Approaches to Adaptive Water Management under Uncertainty) (2005-2009). The project built on the approach of Adaptive Water Management (Pahl-Wostl 2007) and investigated current water management regimes and the changes (and needs for changes) they undergo towards more adaptive regimes. Special emphasis was given to the development of tools and guidance of practitioners based on new conceptual insights and experiences from field research. The present work is interlinked with and builds on earlier results of research on uncertainty within the NeWater project. Particularly the Uncertainty Dialogues (Dewulf et al. 2008) carried out with water managers in several European river basins in early summer 2006 have been a major impulse for the present work.

The thesis is structured as follows. Based on literature review the research context is outlined in section 2. First, water resources systems with their characteristics and their relation with uncertainties are delineated here. Next, the role of uncertainties in water management is illustrated, highlighting the need for introducing and improving uncertainty assessment and management in water management practice.

Regarding the concepts used for the analysis (section 3), frame theory is used as a basis for analysing how uncertainties get framed, with special attention on the concept of mental models. Complementary, the concept of uncertainty as a relational property is drawn upon which underlines the idea that uncertainties are socially constructed. Given the fact that empirical research for this dissertation is done in three different countries in Europe, some cultural implications are discussed as well in this section.

The methodology that was developed and used for the empirical research is explained for each phase of interaction with the water managers (section 4). A brief introduction is given to each case study regarding their geographical, climatic, administrative and societal characteristics (section 5). The central aspects and conclusions of the empirical research results and the three papers (see below) are taken up and discussed with regard to the research questions in the discussion section (6.1-6.4). Here also the overall experiences and use of the approach presented in this thesis are reflected upon (6.5). The conclusion and outlook section sums up the onset of this thesis and the key findings with regard to the research questions and gives an outlook into follow up options on the basis of the results of the research carried out and presented in this thesis (section 7).

In section 8 details are given to the empirical research methods and results.

The papers are attached separately to the main body of the thesis (section 9). They give insights mainly regarding the research questions 2, 3 and 4.

Paper 1 shows the results of an ex-post analysis of the Uncertainty Dialogues of narratives of water managers on their dealing with uncertainties concluding in a set of parameters of possible importance in framing of uncertainties in water management.

Paper 2 illustrates and discusses the results of the approach in the Wupper and the Kromme Rijn which built on the framing parameters of paper 1 in order to develop a more structured approach for dealing with uncertainty in water management practice.

Paper 3 presents the results of an alternative approach to assessing framing of uncertainty where participants were not given a pre-defined set of parameters but developed parameters themselves by use of the method of card sorting. This approach was applied in the Doñana case.

2 Research Context

Water systems and uncertainties have an inevitable relation. Uncertainties are inherent in water resources systems, because they behave as complex systems. Therefore problems and processes cannot be treated separately from the system and its dynamics (Koppenjan and Klijn 2004). Due to global changes such as population increase and global climate change more and new challenging uncertainties are rising. The dynamics are not calculable. Effects of the changes may have non-linear characteristics. We face an increased risk of catastrophes besides a generally increasing pressure on water resources concerning both quality and quantity. Thus, managing water resources is a complex and challenging task given the typical features of water as a resource, the numerous actors and interests involved and the interdependencies with other sectors such as agriculture, transport or spatial planning.

2.1 Water resources systems as complex adaptive systems

Water resources systems have many components that moreover change in space and time. They are complex systems with multi-level, non-linear behaviours. Funtowicz and Ravetz (1992) remark that it may not always be easy to distinguish complex from random or chaotic system behaviour. However, what all three have in common is that they are indeterministic and beyond predictability. Such systems are also referred to as complex adaptive systems (CAS) (Levin 1998) being in constant change and "*characterized by self-organization, adaptation, heterogeneity across scales and distributed control*" (Pahl-Wostl 2006: 2). As nowadays in water systems the natural processes are highly influenced by human activities it is appropriate to speak of water resources systems as human-technology-environment CAS. Different sectors and actors with different interests, objectives, and mental models are involved. Interpretations of reality and of other actors' actions and communication may not always correlate (see for ex. Pahl-Wostl 2006).

2.2 The role of uncertainty in water management

Alaerts (2003) highlights the intrinsic characteristics of water, which contribute to even increasing the potential for uncertainties:

- "Production" of water
  Water cannot be worked in a mine or generated in a production facility. Control over water is difficult as it is a fugitive resource and allows storage and demand regulation only to a certain extent and at comparably high cost.
- Ownership and access
  Water in most of the cases is a public good and often shows characteristics of a common-pool resource. This implies uncertainties about the extractability, about the distribution of water rights among competing water uses etc.
- Constancy in supply
  Water is a daily basic need for humans and hence shortage or interruptions of supply pose immense problems. Droughts and flooding are difficult to assess and manage while they increasingly question constant reliable water supply.

- Interdependencies in water use
  Since water often is a scarce resource, numerous conflicts arise about its use, with regard to both quantity and quality. Conflict between up- and downstream user is a typical example. Here, uncertainties with regard to the behaviour of actors can play a crucial role.
- Infrastructure and transaction costs
  Water distribution systems are much more expensive than for other resources as electricity for instance. Here uncertainties are of more technical character as to how much to invest in technology, e.g. to ensure water supply.
- Externalities
  Damage and remediation costs are unloaded to the next generation. This is due to the fact that cause-effect relationships are difficult to assess because impacts of changes in the water system (e.g. through deforestation, eutrophication, infrastructure like dams or canalization) usually take a long time to become visible.

Different approaches can be envisaged how to manage water in order to satisfy the different interests and deal with the problems and challenges outlined above. Recently, there has been a change in the water management paradigm which includes a different approach to uncertainties. Pahl-Wostl et al. (2006) define a management paradigm as a set of basic assumptions "*about the nature of the system to be managed, the goals of managing the system and the ways in which these goals can be achieved*." The paradigm is manifested in artefacts such as technical infrastructure, planning approaches, regulations, engineering practices or models. It is shared by an epistemic community of actors involved in the generation and use of relevant knowledge. In the following, two main opposing paradigms in water management are presented and discussed with their implications for the understanding and management of uncertainty, namely the 'prediction & control' paradigm and the 'integrated & adaptive' paradigm. For a detailed presentation and discussion of the two paradigms see Pahl-Wostl (2007).

2.2.1 Water management under the 'prediction & control' paradigm

Traditionally, technical engineering approaches dominated water resources management where uncertainty was considered an objective attribute associated with the quality of technical information used to characterize or understand a system if at all (Pahl-Wostl 2002; Koppenjan and Klijn 2004). Empirical evidence suggests that people mostly do not like uncertainty (Friend and Hickling 1997; Aarts and van Woerkum 2002: 425; Sigel 2007). Aarts and van Woerkum (2002: 430) distinguish between 'uncertainty-oriented' and 'certainty-oriented' people. The first view uncertainty as a challenge, the second tend to ignore and avoid uncertainty where possible and, if that is not possible, to reduce and eliminate it. The latter attitude certainly is prevailing in traditional water management which builds on prediction and control of the system. Uncertainty has to do with a lack of control (see section 3.1). Hence, as a response to this lack, under the prediction and control paradigm control is exerted, thereby sometimes simply bypassing or ignoring the uncertainties, e.g. in models or parameters, which suggests that the ideal of full prediction and control can be achieved (Morgan and Henrion 1990: 43). If the uncertainties then impose themselves, water managers expect science to eliminate them. Besides, uncertainties are mostly addressed in a quantitative way in terms of uncertainty in technology and modelling with the attempt to reduce the respective uncertainty (for a review see Walker et al. 2003; Koppenjan and Klijn 2004). An uncertainty about the discharge of a river, for instance, typically is reduced by controlling the river system with infrastructure (e.g. a dam). Uncertainties stemming from

system complexity and ambiguity are not addressed comprehensively in the prediction and control paradigm (Pahl-Wostl et al. 2007b). Ambiguity means that there are two or more different, equally plausible and most likely conflicting ways of understanding or interpreting a situation or a system (Dewulf et al. 2005; Brugnach et al. 2008). Either those aspects are ignored or they are forced into reductionist approaches feigning certainty and reducing the freedom for action. The focus is on controlling the system by unilateral top-down measures through technological improvement and thus avoiding or eliminating uncertainty (Pahl-Wostl et al. 2007b). Aarts & Woerkum (2002) have considered how stakeholders differentially deal with uncertainty and ambiguity in negotiation processes. Among the strategies they identify are: reconstructing or informing threatening information, shifting responsibility and blaming others, and reducing complexity by relying on overly simplistic heuristics. The tendency of practitioners in water management practice to address uncertainty only implicitly, mostly through intuition and experience, is confirmed by numerous authors (e.g. Friend and Hickling 1997; Einsiedel and Thorne 1999; see Gigerenzer and Selten 2001 for a review of heuristics; Sigel et al. 2010). This is a valid but limited approach for dealing with new uncertain situations. Different to analytical approaches that are based on the structure of the problem, relating choice and outcome, intuitive decisions are not based on understanding (Selten 2001: 28). Quick intuitive judgements do not leave space for uncertainty as they are being taken fast and without much reasoning. Doubt and uncertainty are characteristics of deliberate reasoning, "*a meta-cognitive appreciation of one's ability to think incompatible thoughts about the same thing*" (Kahneman 2002: 456) (see also section 3.2 on mental models). Whereas in science doubt is a value, in policy-making it is not. Policymakers in their search for solutions often expect scientists to provide certainties (e.g. Bradshaw and Borchers 2000; Walker et al. 2003). This may explain why policymakers do not address uncertainties themselves but look for scientists to resolve them. On the other hand it explains why policymakers dislike uncertainty in the scientific knowledge base.

Commonly in environmental decision-making processes, decisions are taken in a more expert driven way where uncertainties are not communicated openly (Pahl-Wostl et al. 2007a). The expert mode also dominates analytic assessment of uncertainties (Walker, Harremoes et al. 2003; Klauer and Brown 2004; Lowe and Lorenzoni 2007). "*[D]ecision-makers have come to depend more and more on those who wield technical expertise. As social problems become more complex, and as the institutions that deal with those problems match that complexity, policy-making becomes more opaque to the citizen*" (Ney and Thompson 1999: 208). There are numerous scientific approaches to assess and analyze uncertainties in a structured and systematic way (see Friend and Hickling 1997; van Asselt and Rotmans 2000; Walker et al. 2003; Klauer and Brown 2004; Sigel et al. 2010). The idea is to gather more and more reliable information through methods such as sensitivity analysis, formal scenario analysis, hedging-oriented methods, and modelling exercises. Analysing uncertainties in modelling has a long tradition (Refsgaard et al. 2007; Beven 2009). More innovative approaches include stakeholder perspectives like the probability-based method of Bayesian Belief Networks (Henriksen and Christiansen Barlebo 2008), the NUSAP approach (Numeral, Unit, Spread, Assessment, and Pedigree) (van der Sluijs et al. 2003) or pluralistic uncertainty management approaches with perspective-based[1] model routes (van Asselt et al. 1995; van Asselt and Rotmans 2000). However, all approaches rely heavily on experts for running the methods.

[1] Following the three 'active' as main perspectives suggested by Cultural Theory, i.e. hierarchist, egalitarian, and individualist (Thompson et al. 1999)

In sum, "*research usually aims to reduce uncertainty or control it more effectively*" (Mathijssen et al. 2008: 24). One means comprised in several of the above mentioned methods is to reduce uncertainty by translating it into risk. Already in the beginning of the 1970s Michael (1973: 119) emphasised that the problem is that not all uncertainties may be transformed into risks (see section 3.1.1 below) but that actually often this is done without reliable variables pretending to have a ground on which to act. Koppenjahn and Klijn (2004) call such solutions for one-dimensional problems applied for complex problems 'taming the untamed problem'. Processes like these are rationalized by arguments as 'it's the best we can do' or 'it's better than nothing'. "*One of the most serious consequences of this behaviour is that the resulting emotional relief encourages all involved to believe they really do know what is important, what is going on*" (*ibidem*). On the other hand attempts to reduce uncertainty by scientific research methods may decrease the uncertainty as the knowledge base is extended and new insights are gained, but it may as well increase the uncertainty in case that the information may add to the complexity, point of further knowledge gaps and reveal formerly unrecognized uncertainties (e.g. Walker et al. 2003; Mathijssen et al. 2008; van der Keur et al. 2008). Such positivist approach with the ideal to reach absolute objectivity, certainty and truth is limited when dealing with the management of complex socio-ecological systems (SES).

2.2.2 New approaches in water management

Given the post-normal situation (facts are uncertain, values in dispute, stakes high and decisions urgent) scientific consensus about the truth of complex environmental risks is unlikely to be achieved (Funtowicz and Ravetz 1993).

First, science is not neutral or objective (Bardwell 1991; Funtowicz and Ravetz 1993; Cortner 2000; van Asselt and Rotmans 2002; Koppenjan and Klijn 2004; Oreskes 2004; Sarewitz 2004; Hajer and Versteeg 2005). Scientific analyses always reflect the respective scientific point of view, research and other interests. Thus an objective value free assessment and analysis is not possible. Von Storch remarks that nowadays the scientific method and correctness is not the focus anymore but the utility and social acceptability of scientific results (von Storch 2009). Moreover, a certain subjectivity or option for strategic use of science suggests that there may be other equally valid kinds of knowledge and points of view to be considered. Or as van der Sluijs remarks: "*when facing the uncertainties involved in complex risks, scientists sometimes are lay people as well*" (2007: 591). Consequently the search for one single truth is no longer feasible.

Second, technological advances such as computer modelling are enabling calculations that cannot be grasped anymore by human skills or intuition. Through modelling, reality and mathematical certainty is transformed and the result are opaque and incomprehensive outcomes associated with numerous uncertainties and doubts (Funtowicz and Ravetz 1992). Traditionally, uncertainties are assessed by science with the aim to reduce them. But not all uncertainties can be solved by more research, particularly not those stemming from ambiguity and system complexity (O'Connor 1999; Dewulf et al. 2005; Newig et al. 2005; van der Sluijs 2007; van der Keur et al. 2008; Wardekker et al. 2008). In such cases, more information is likely to increase the uncertainties as new possibilities and unforeseen uncertainties are detected. The question up to which point more knowledge should be acquired in order to improve accuracy, reliability and certainty of information and be able to take a decision in practice is often difficult.

One strand of reasoning for dealing with complex decision problems is that a search for an optimal solution is not helpful (Cortner 2000; Folke et al. 2002; Pahl-Wostl and Hare 2004; Ostrom 2005; Messner et al. 2006; Pahl-Wostl 2006; Olsson and Andersson 2007; Paneque

Salgado et al. 2009). Already in the 1980s, Checkland (1985) pointed to the fundamental difference between soft systems thinking and the conventional hard systems approach focusing on optimal solutions for achieving a predefined goal. When dealing with complex problems, it is impossible to identify one single optimal solution. Here the soft systems approach is more promising. It focuses on learning processes and accommodation of differing preferences. Moreover, optimization activities do not guide decision-makers in learning about the dynamics of a situation as optimizing always refers to a static state. Those who study the opportunities and constraints instead of focussing on an optimal solution are on the better way for finding robust solution options (Klein 2001; Groves and Lempert 2007).

There is evidence that in complex systems there is no blueprint for dealing with uncertainty (see for instance Mathijssen et al. 2008). However, there are more general lines of action that are highlighted by several authors. One basic concern is that avoiding uncertainty is no option as it does not solve the problem but only postpones it (e.g. Aarts and van Woerkum 2002). Instead, an explicit, systematic and open way to deal with uncertainty is needed (Mathijssen et al. 2008; Sigel et al. 2010). The approach of Adaptive Water Management (AWM) argues for acknowledging uncertainty and aims to take uncertainties explicitly into account. Adaptive Management has been discussed for long in ecosystem management (Holling 1978). In water management, it emerged as a response to the shortcomings of the traditional management paradigm based on predict and control mechanisms (Pahl-Wostl et al. 2007b). Adaptive Management takes up the challenges to manage complex SES, building on adaptive and flexible structures and strategies in order to be prepared for and to cope with ongoing and future changes. It refers to a "*systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies*" (Pahl-Wostl 2007). The emphasis is drawn away from a controlling approach towards an adaptive and learning approach for dealing with uncertainties. This manifests in more flexible modes of decision-making where experimenting, monitoring, evaluation, learning and adaptation play a paramount role. Managing for learning, however, requires a different kind of knowledge generation and management (Koppenjan and Klijn 2004; Ridder et al. 2005). The dominating role of scientific knowledge over other kinds of knowledge has to be questioned. Instead, knowledge has to be produced in a joint manner, involving all relevant stakeholders. In that, taking into account the plurality of views is important. Uncertainty is not regarded as something purely objective any longer but as something that emerges out of the constellation of actors in decision situations. Not only uncertainty due to incomplete knowledge and system complexity are considered but also ambiguity is recognized as important part of uncertainty in social systems. As unambiguity and commensurability are no longer fulfilled there is a need for discussion and negotiation of meaning, goals etc. to build a shared problem perception as a basis for taking action (Friend and Hickling 1997; Ney and Thompson 1999; O'Connor 1999; Pahl-Wostl 2002). Where the technical had masked the political (Ney and Thompson 1999: 208) now different perspectives and framings have to be explicitly addressed, enhancing open dialogue on uncertainties among all actors involved in decision-making. In post-normal situations, transparency of the various positions and learning to live with ambiguity and pluralism in risk assessment has to be the centre of attention (Funtowicz and Ravetz 1993; O'Connor 1999; van der Sluijs 2007). Altogether, the focus is drawn away from expert based search for information and certainty towards robust and socially accepted decisions (Pahl-Wostl 2002). This goes in line with more pluralistic management of natural resources (O'Connor 1999; Stirling 2006).

Such an approach entails an increasing importance of actor involvement. If a problem or an uncertainty cannot be treated in isolation but requires embedment in a broader context the decision scope of a problem has to be expanded and co-ordination and negotiation with others involved has to be ensured (Friend and Hickling 1997: 9). There are numerous arguments for enhanced participation of the public in decision-making, among others the claim of robust knowledge it renders, which is necessary in order to be able to deal with the nowadays challenges, complexities, and uncertainties (Mostert 2003; Ridder et al. 2005; Stirling 2006; Tabara and Pahl-Wostl 2007; Gooch and Huitema 2008). This means opening the debate to all stakeholders and deliberately address uncertainties involved in the issues at stake (Funtowicz and Ravetz 1992). Also legally, there is increasing demand for participation, e.g. European Water Framework Directive where it is stated that "…*the success of this Directive relies on close cooperation and coherent action at community, member state and local level as well as on information, consultation and involvement of the public, including users*" (EC 2000). It is crucial to ensure a plural policy process in order to avoid disastrous decision-making: "*Those who protest that it is easy to be wise after the event can usually be silenced by pointing to those who are wise before the event but were given no place at the table*" (Ney and Thompson 1999: 220). Ney and Thompson (*ibidem*) are conscious that is not possible to "*eradicate lock-in and entrenchment*" (e.g. in ecosystems, climates and technologies) through participation but to minimise them.

More stakeholder involvement may, however, temporarily increase uncertainty. As Pahl-Wostl (2002) remarks, the role of individuals and stakeholder groups changed and decision-making got more diverse and contested with the introduction of decentralized technologies. The diversity of stakeholders' expectations and value systems lead to conflicting views about how the system operates and provoke disagreement and uncertainties about how the river basin should be managed. This should nonetheless not be a reason to not involve stakeholders but reminds to treat participatory design of human interventions with care (Pahl-Wostl 2002; Stirling 2006; Pahl-Wostl et al. 2007a). Van der Sluijs points out that it is important to include stakeholder knowledge and perspectives not only in the phase where response options are debated, but also in the problem framing and risk assessment processes that precede it (2007: 591). But how to go about involving stakeholders, engage in a transparent and open dialogue, taking uncertainties and different points of views explicitly into account? The concept of AWM formulates promising principles but is not very precise in terms of how to implement them. The research and findings of the present thesis aim at making the principle of addressing uncertainty more tangible and contributing to improving dealing with uncertainty in water management practice.

2.3 What is needed in order to better deal with uncertainty in water management practice?

In sum, the prevailing aspects of uncertainty in current water management are that

- uncertainties are ignored or addressed in mostly quantitative ways through complex scientific methods
- decisions are made in an expert mode with little involvement of stakeholders
- uncertainty communication is limited to experts, and
- practitioners deal with uncertainty implicitly by experience and intuition or ask scientists to solve the uncertainty and provide certainty.

The weaknesses of such an approach have been elaborated on in the previous chapters and the need for improvement in dealing with uncertainty, particularly in water management practice, is apparent. The simplifications and biases mostly used in water resources management (WRM)

practice can be helpful in making decisions, but such heuristics are not always helpful in a broader context, especially in domains where decision-makers are confronted with novel situations as is the case when dealing with uncertainties (Goldstein et al. 2001: 177). Acting on intuition based on years of experience does not help in such situations. Moreover, decision-making through heuristics is not transparent and can be hard to explain or justify which can create difficulties, particularly when decisions are being made by public administration. Thus, structured, analytical approaches are needed to effectively deal with uncertainties.

In order to aid decision-making, approaches have been developed in form of formalized decision support tools (Reichert et al. 2007). Decision support systems comprise methods such as Multi-Criteria Analysis, Monte-Carlo-Simulation, Bayesian Belief Networks etc. They are designed for enhancing operational and strategic decision-making in complex situations where more than one solution to a problem is possible. In terms of supporting and directing dealing with uncertainty in water management practice, however, the existing tools are not directly useful. On the one hand, they are not always easily understandable, accessible or usable for practitioners on the ground (Brugnach et al. 2007; Groves and Lempert 2007; McCulloch 2007; Patt 2007). The methods are rather rigid, lack flexibility in application and require sophisticated software and respective skills (Westmacott 2001; Wardekker, van der Sluijs et al. 2008; Prager and Freese 2009; Starkl, Brunner et al. 2009). Analysis often is performed by scientists or other experts rather than by the practitioners themselves (Messner et al. 2006: 70). On the other hand, uncertainties are not necessarily addressed comprehensively. Either they are not assessed explicitly or are assessed only in a limited way; they may, for instance, regard uncertainties as restricted to probabilities, or model and data uncertainty, or uncertainty with respect to unforeseeable future developments that is addressed through a range of scenarios (*ibidem*). Frequently, uncertainties are made explicit but no strategies are conceived on how to deal with them (Paneque Salgado et al. 2009). Decision aid tools aiming at supporting effectively dealing with uncertainty in water management practice have to be designed differently. Besides offering a structured and systematic approach they have to be applicable without major expert skills and meet practitioners' needs for fairly quick decisions in situations marked by uncertainty. Moreover, it is helpful if tools can be used in a an adaptive and exploratory way rather than in a rigid sequence (Friend and Hickling 1997).

Sigel (2007) presents a framework for systematizing the description of uncertainty as a first step for getting away from the 'muddling through' approach of practitioners in water management. The framework is meant to provide a comprehensive assessment of different perspectives of uncertainty in order to systematically obtain a basis for decision-making under uncertainty. It consists of five perspectives of uncertainty whereby the source of uncertainty, the fact whether the uncertainty is fact- or norm-related, the cause and reducibility of the uncertainty as well as the probability can be assessed (Sigel et al. 2010).

In order to develop tools that are useful for practitioners, I argue that furthermore it is important to understand how water managers frame uncertainties. There is evidence in uncertainty literature pointing to the potential relevance of linking framing and uncertainty. Van der Keur et al. (2008) remark that it is not trivial to classify uncertainties as types of uncertainty often overlap. On the one hand this points to the complexity of uncertainty analysis, on the other it hints to ambiguity possibly involved in classifying uncertainty. Different actors are likely to have different foci, emphases etc. on looking at one and the same uncertainty and would accordingly classify it differently. Walker et al. (2003) allude to the fact that despite nowadays widespread acknowledgement of uncertainty "*there is little appreciation for the fact that there are many different*

dimensions of uncertainty, and there is a lack of understanding about their different characteristics, relative magnitudes, and available means of dealing with them". Likewise Einsiedel and Thorne (1999: 44) emphasize that it is critical to understand the many different forms and degrees of uncertainty, how they are framed and what people do with it.

While the idea that issues do not exist per se but differ according to somebody's framing has gained more and more attention in research on environmental problems (Gray 2003; Dewulf, Craps et al. 2005; Newig, Pahl-Wostl et al. 2005; Kamp 2007; Henriksen and Christiansen Barlebo 2008; Carton and Thissen 2009; Renn and Schweizer 2009) it has not been applied yet to uncertainties. There are a few exceptions in literature, where the importance of framing in uncertainties has been pointed out and the differences in the search of solutions it can make (Bardwell 1991; Koppenjan and Klijn 2004). Analysing framing with regard to uncertainty means to give up the traditional view of uncertainty as an objective property. On the contrary, uncertainty is understood as relational, meaning that an uncertainty arises out of the interaction between actors and objects (Brugnach et al. 2008). Hence, an uncertainty may be framed differently according to changes in the relation between actors and objects. Scientific approaches to uncertainty tend to reflect the scientists' framing of uncertainties, namely as something to get rid off by advancing knowledge (Cortner 2000; Sarewitz 2004; Dewulf, Craps et al. 2005). Water managers are not primarily concerned with advancing knowledge but with practical water management issues. Consequently, a method for dealing with uncertainty to be applied by and for water managers has to be based on water managers' framings. If strategies to deal with uncertainties in water management practice are to be effective and implementable they need to take into account how water management practitioners understand and relate to uncertainties. Often, stakeholders are only involved at a later stage of process when the issue has already been framed in a specific way, mostly influenced by the convenors and experts involved in a project or decision-making process. If stakeholders are to really take part in decision-making it is important to assess how they themselves conceive of the problems AND also of the uncertainties. The present research may thus be seen as preparatory for decision-making, i.e. to assess water managers' and other stakeholders' framing before the actual decision-making process starts. This goes in line with the approach of 'creative competition' of Koppenjahn and Klijn (2004: 167) where emphasis is given to the identification of perceptions and preferences before the fixation of problem and goal setting the traditional approach would start with.

Van Asselt and Rotmans argue that "*because uncertainty is multi-dimensional, it is unlikely that a single approach will suffice to capture all the salient forces of uncertainty*" (2000: 49). They suggest a list of methods in terms of types of uncertainty to be used for uncertainty analysis. The approach presented in the present thesis is meant to be one of those, focussing on the perspective of water management practice.

3 Conceptual Foundation

In any assessment or decision-making situation framing plays an important role. Different actors have differing interests and values they bring into the discussion of a real world issue they interpret in a certain way. The concepts in literature on how to make sense of the world differ in terminology but nonetheless are partly used in overlapping meaning. In this thesis, special focus is given to the concepts of framing and mental models. As a new element to the discussion of framing, I connect the concept with that of uncertainty.

3.1 Uncertainty

In order to address research question n° 1 as to what uncertainties water managers perceive the concept of uncertainty has to be outlined. A commonly shared terminology of uncertainty does not exist; neither does an agreement on a typology (cf. e.g. Wynne 1992; van Asselt and Rotmans 2000; Walker, Harremoes et al. 2003; Klauer and Brown 2004; Norton, Brown et al. 2006; Sigel 2007; van der Keur, Henriksen et al. 2008). Not only is the diversity of the meaning high among the different scientific disciplines but also the use of other terms besides 'uncertainty' such as 'ignorance', 'doubt' or 'risk'. A discussion around 'uncertainty' may be different to one around 'risk' or 'future challenges' as the use of a certain term already influences one's framing (Dewulf et al. 2004: 181). It is thus useful to delineate uncertainty from other similar concepts. The same holds true for uncertainty categorizations. There is a variety of approaches available for categorizing uncertainties. In the present research, the Uncertainty Matrix by Brugnach et al. (2008) is used as conceptual base and structuring means for the assessment and discussion of the uncertainty situations in two of the case studies. It was chosen over others as it constitutes a fairly simple means for categorization of uncertainty, appropriate for meeting the needs of water management practice.

This research is based on the understanding that uncertainties do not exist per se and can be described objectively but depend on the object in question and the involved actor. This reflects a relational concept of uncertainty (as opposed to purely objective or subjective concepts). It is most instructive for the purpose of the present research as it connects well with the concept of framing. According to the relational principle, an uncertainty evolves according to one's framing of an issue that is how a situation or issue respectively the related uncertainty is made sense of. Framing an uncertainty differently can also result in establishing new relationships between actors and objects in an uncertain situation, e.g. from 'eliminating' to 'accepting' uncertainties.

3.1.1 Definition of uncertainty

The concept of uncertainty is broadly used in various disciplines and contexts. It is helpful to distinguish it from other concepts. One concept often found in relation with uncertainty is risk. Risk is commonly defined as a translated uncertainty where the system behaviour and the variables involved in characterizing a situation are rather well known and it is hence possible to assign probabilities to outcomes that depend on those variables (e.g. Michael 1973; Morgan and Henrion 1990; Wynne 1992). Characteristic for uncertainty is that one believes to have "*either too much or too little information to feel confident about what variables define the situation*" (Michael 1973: 110, emphasis omitted). In such a situation probabilities of the outcome are difficult to assign. Regarding uncertainty the possible outcomes may be known but it is uncertain which outcome may occur when. Hence, uncertainty is often associated with a lack of control (see Sigel 2007: 60).

Uncertainty in general has to do with not knowing or with the perceived knowledge about something. However, uncertainty is more than absence of knowledge or information (e.g. van Asselt and Rotmans 2000; Walker et al. 2003). Different grades of uncertainty can be distinguished, ranging from inexactness ('we roughly know') over conflicting evidence ('we don't know what we know') to more fundamental or radical uncertainty up to indeterminacy ('we can never know') and irreducible ignorance ('we cannot know') (Funtowicz and Ravetz 1990; Wynne 1992; van Asselt and Rotmans 2002). For a detailed review on the different kinds and grades of uncertainty see van Asselt and Rotmans (2002).

Beyond the pure inadequacy of information many definitions of uncertainty make reference to the opposite of uncertainty, i.e. certainty, as levelling board respectively the deviation from "*the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker et al. 2003; also van der Keur et al. 2008). The definition of uncertainty used for this thesis rejects the idea of the ideal of certainty as it entails a reductionist approach towards uncertainty (for a critical review of the approach of Walker et al. 2003 see also Norton et al. 2006). The present research follows the relational approach of uncertainty (see section 3.1.3) of Brugnach et al. who define uncertainty as "*a situation in which there is not a unique and complete understanding of the system to be managed*" (2008). This relates to an individual actor's understanding of an event or action as well as of the behaviour and interest of other actors that are possibly involved in the situation. It includes lack of knowledge as well as ambiguity and unpredictability due to variability and complexity of the system (see section 3.1.2). As an uncertainty always involves one or more individuals, the definition includes not only the understanding of a situation but also the quality of it, translating into a state of confidence: "*a person is uncertain if he lacks confidence about the specific outcomes of an event or action*" (Klauer and Brown 2004: 126).

3.1.2 Typology of uncertainty

A basic distinction of uncertainties is the classification regarding their nature. Further differentiations may be the source, level or location of uncertainty (e.g. Walker et al. 2003). Nature of uncertainty is commonly referred to as type or kind of uncertainty (e.g. Brugnach et al. 2008). The main different kinds of uncertainty in scientific analysis as well as in decision-making are discussed in the following.

3.1.2.1 Classification of types of uncertainty for scientific analysis

A commonly used distinction of uncertainty in literature is between ontological (variability and unpredictability) and epistemological (knowledge) uncertainty (e.g. van Asselt and Rotmans 2000; Walker et al. 2003; Klauer and Brown 2004). Different to those conventional approaches Brugnach et al. include ambiguity[2] or 'multiple knowledge frames', not only as a possible additional source of uncertainty, but as a fundamentally different type of uncertainty (Brugnach et al. 2008).

Ontological uncertainty

This type of uncertainty refers to the inherently unpredictable aspects of a system due to variability in the system, i.e. chaotic or complex system behaviour (Brugnach et al. 2008). It implies the acceptance of the unpredictability of complex systems as something that will not

[2] Ambiguity usually is differentiated from uncertainty in literature. Weick suggests 'equivocality' as an alternative term to ambiguity since it may not only refer to two or more plausible interpretations but also to lack of clarity, which "*makes it quite similar to uncertainty*" (Weick 1995).

change in the foreseeable future. Variability in van Asselt & Rotmans (2000) comprises natural randomness, cognitive variety in the sense of value diversity, behavioural variety of humans, societal randomness in the form of social, economic and cultural dynamics as well as technological surprise or randomness. In literature, ontological uncertainty is most often referred to as intrinsic, deeply rooted, substantive, strong, external or random uncertainty (e.g. Denzau and North 1994; van Asselt and Rotmans 2000; Walker et al. 2003). "*Strong […] uncertainty would occur when a chooser cannot be viewed as capable of having even subjective probability distribution functions defined over a set of possible outcomes*" (Denzau and North 1994: 5).

Epistemological uncertainty

This type of uncertainty refers to the state of knowledge about a system or a situation. It may be expressed as lack of knowledge or incomplete knowledge. This can be due to a lack of information or data, to the unreliability of the data available, to lack of theoretical understanding, or to ignorance (Brugnach et al. 2008). Other overlapping terms are subjective, informative, secondary and internal uncertainty (for an overview of terminology see van Asselt & Rotmans 2000). Epistemological uncertainty may principally be reduced, depending on the boundary conditions such as time and financial resources. Typical examples are statistical or data uncertainties. Van Asselt and Rotmans present different states of lack of knowledge on a continuum from inexactness to indeterminacy (van Asselt and Rotmans 2000: 17): It comprises inexactness that may be metrical uncertainty or measurement errors, lack of observation if data could have been collected to data that indeed can not be collected for practical reasons, e.g. due to resource or time constraints, conflicting evidence on for instance different data sets, ignorance regarding processes that are out of imagination at the point in time, and finally indeterminacy referring to things that are impossible to know for a human mind (van Asselt & Rotmans 2000: 16).

Ambiguity

Ambiguity refers to the fact that there is no universal meaning to everything. Two or more different, equally plausible and most likely conflicting ways of understanding or interpreting a system may exist (Dewulf et al. 2005; Brugnach et al. 2008). Van Asselt and Rotmans (2000: 12) talk of scientific controversy and multiple manifestations of a problem.

Ambiguity or multiple knowledge framings can originate from differences in professional backgrounds, scientific disciplines, value systems, societal positions and so forth. Different opinions may exist about where to set the boundaries of a system or what to put in the focus of attention. Information may be associated with entirely different meanings (e.g. what the most urgent problems are) or there can be contradictory evidence about what the implications are.

An issue that gains in importance in the application of this categorization type in practice is the awareness of the people involved. Some people may apply conflicting mental models in a situation but not be aware about it. Multiple knowledge framings may arise also within or rather in addition to variability and incomplete knowledge. So far, multiple knowledge framings have received very little attention in water management literature even if it shows to play an important role. Van der Keur, Henriksen et al. (2008: 1704) observed that multiple framings of uncertainty were a source of uncertainty in over half of the identified uncertainty locations in the Integrated Water Resources Management (IWRM) cycle.

3.1.2.2 Classification of types of uncertainty for decision-making

In decision-making (DM), uncertainty is categorized differently. Going back to a concept of Friend and Jessop of the late 60s, Friend and Hickling (1997) distinguish three types of uncertainty in DM: uncertainties about the working environment (UE), uncertainties about guiding values (UV) and uncertainties about related decisions (UR). These imply different needs: UE the need for more information, UV the need for clearer objectives, and UR the need for more coordination. Mostly in DM situations UE, UV and UR all are present and people disagree on which one is most important in the situation (see also Michael 1973: 115/6). Similarly, Koppenjahn and Klijn (2004) present a categorization of uncertainty to account for complexity in nowadays modern society. In their network approach they address three dimensions of uncertainty: Substantive uncertainty refers to the nature of complex problems, the lack of information on the one hand and the perception or interpretation of the information on the other hand. Beyond substantive uncertainty they distinguish strategic and institutional uncertainty. Strategic uncertainty refers to the fact that actors make strategic choices which are not evident and may be hard to predict for the other actors involved. As such, strategic uncertainty is hard to reduce and can never be completely eliminated. In addition, in complex problem solving the involved actors may work from different institutional backgrounds, that is different administrative levels and networks. Institutional uncertainty manifests in uncertainty about procedural aspects of an interaction process.

Newig et al. (2005) distinguish two types of uncertainty relevant for DM: informational and normative uncertainty. Informational uncertainty (similar to Friend's UE) relates to knowledge deficits of a decision maker, e.g. inexactness due to measurement errors, missing measurements. Normative uncertainty (similar to institutional uncertainty of Koppenjahn & Klijn) means that there are no detailed prescriptions but room for interpretation and subsequent decisions. One example are recent European regulations such as the European Water Framework Directive where the member states are supposed to implement the broadly formulated directives through more concrete laws and regulations at national level. Normative uncertainty only prevails as long as no decision is made. Similar to Newig's normative uncertainty, van Asselt & Rotmans (2000: 19) distinguish uncertainty due to various alternative action options (action uncertainty), including the respective costs and benefits (yield uncertainty) as well as goal uncertainty relating to a decision-maker's preferences and political uncertainty in the broader sense of feasibility of options in the respective political setting.

3.1.3 Uncertainty as relational

Uncertainty can be looked at in numerous ways. Traditionally in science, it has been considered an attribute associated only with the quality of technical information used to characterize or understand a system (for a review see Walker et al. 2003). This description is limited when dealing with water management issues, where the conflicting views about how the system operates, the diversity of stakeholders' expectations and value systems may provoke disagreement about how the river basin should be managed. In order to address the role of uncertainties in decision-making processes it is thus important to adequately take into account socially constructed realities.

Numerous scientists share the idea of uncertainty as a subjective property (cf. e.g. van Asselt and Rotmans 2002; Klauer and Brown 2004; Dewulf, Gray et al. 2009). It means that uncertainty is not an attribute of an object but has a subjective connotation. It relates to certain values or

interests of the one who states the uncertainty and gives an idea about someone's level of confidence. Hence, uncertainty here is often also referred to as 'doubt' (Sigel 2007: 75). To a considerable extent uncertainty also depends on the context, i.e. the respective situation and the person who perceives and formulates the uncertainty (Klauer and Brown 2004: 126; Brugnach et al. 2008). Brugnach, Dewulf et al. (2008) describe this as the relational aspect of uncertainty stemming from how decision makers relate to the human-technology-environmental system to be managed. Different to the notion of uncertainty as a objective property where the focus is on the uncertainty attached to the object and to uncertainty as a subjective property where the focus resides on the uncertainty attached to a person, in the relational approach the emphasis is on the relation between the object and the subject. Here the link with the concept of framing becomes evident. Uncertainties are getting framed differently depending on an actor's relation towards an object or a decision situation. In order to assess and express uncertainty (and its meaning) it is therefore useful to place uncertainty at the relation between an actor and a decision situation (figure 1).

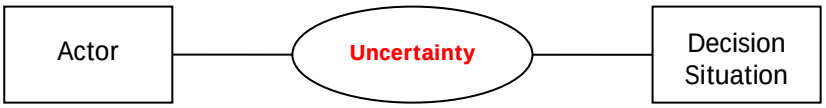


Figure 1: Uncertainty as relational property

For representing this relational uncertainty, objects or issues, e.g. flood prevention, are not really feasible but rather questions related to the situation out of which it evolves, e.g. uncertainty about "how can region XY be prevented from flooding?"

Uncertainty may in theory be constructed independently (from actor and action) but is then irrelevant for dealing with uncertainty in practice. Following that logic, a prerequisite for the occurrence of an uncertainty is an actor's awareness and subsequent attention or worry about a situation. In case the actor is aware of a situation but attention or importance is zero, obviously uncertainty does not play a role in that situation for that specific actor, but it may play a role for another actor. It is also possible that one situation pertains over a long time, only that the attention to it changes if somebody develops an interest or concern towards it (see Renn 2009: 561).

The perceived uncertainty depends on an individual's state of knowledge and the confidence in the knowledge that is available. The knowledge component regards the combination of the knowledge required to understand the situation and the actor's actual knowledge. The more knowledge required for understanding a situation, e.g. the more complex a system or an issue, and the less knowledge the actor holds the bigger the uncertainty. Vice versa if the system is not too complex and the actor holds considerable knowledge about it is likely that no huge uncertainties will arise. The problem in practice often is to identify what actually is possible to know, i.e. to know the border between epistemological and ontological uncertainty. The knowledge problem may increase or loose importance according to the state of confidence of the respective actor. Thus, two individuals with the same state of knowledge with regard to a certain situation but with differing confidence are likely to have differing degrees of uncertainty in that situation.

The Uncertainty Matrix by Brugnach et al. (2008)

To make the relational concept of uncertainty operational Brugnach et al. developed their Uncertainty Matrix (UM) (2008). The UM takes up the two classical scientific distinctions between types of uncertainty, i.e. epistemological (unpredictability) and ontological (incomplete knowledge), and adds the above outlined more innovative type of multiple knowledge framings[3]. These are coupled to the system in a threefold manner through the categories of the natural, the technical and the social aspects (similar to the categories of 'context' of uncertainty of Walker et al. (2003)).

The Uncertainy Matrix by Brugnach et al. is different from other approaches, for instance the very prominent 'RIVM/MNP Guidance for Uncertainty Assessment and Communication' (http://www.mnp.nl/guidance) inspired by the uncertainty matrix of Walker et al. (van der Sluijs et al. 2003; Walker et al. 2003; Janssen et al. 2004), and more comprehensive in that sense, because it includes multiple knowledge framings as a separate kind of uncertainty and not merely as a source of it. Given the focus of the present work on the concept of framing this embedment constitutes an important aspect for analysis.

The UM is designed to structure the identification and diagnosis of uncertainties and support a process of learning and change (Brugnach et al. 2008). The matrix furthermore constitutes a bridging approach between the classifications of uncertainty for scientific analysis and the categorizations in decision-making. Besides the above mentioned scientific classifications of uncertainty the matrix also covers the classifications in decision-making presented above. Though not all classifications may be possible to allocate to the cells of the UM one-to-one similarities and differences are worth pointing out.

Compared to the UM by Brugnach et al. Koppenjan & Klijn (2004) present the most comprehensive approach: Their class of substantive uncertainty roughly correlates with the upper part of the UM (cells 1-6), distinguishing between 'lack of information (implying both unpredictability and incomplete knowledge) and 'interpretation of information' (implying multiple knowledge framings) as subtypes. Their class of strategic uncertainty may be related to cell 7 of the UM although strategic uncertainty can also be a form of incomplete knowledge, e.g. one could improve knowledge about how end-users will react to higher drinking water pricing through marketing research. Institutional uncertainty by Koppenjahn & Klijn finally may be related to incomplete knowledge about legal aspects (cell 8). Similar to the latter Newig et al.'s (2005) normative uncertainty may be understood.

The informational, and in a broader sense also the normative uncertainty by Newig et al. goes in line with the column of incomplete knowledge of the UM. Same holds true for the Environment Uncertainty by Friend & Hickling (1997) which is about knowledge deficits as are the classes 'action-' and 'yield uncertainty' by van Asselt & Rotmans (2000). The political uncertainty by van Asselt and Rotmans would be best represented by cell 7 of the UM, same as the Related Decisions Uncertainty by Friend & Hickling as they are close to the strategic uncertainty by Koppenjahn & Klijn and the unpredictability in the social area expressed through the UM.

The classifications which come closest to multiple knowledge framings finally are the Values Uncertainty by Friend & Hickling as well as the goal uncertainty by van Asselt & Rotmans. However, here the assumption as in Brugnach et al. that the understanding of the system is

[3] For purposes of coherence with the terminology of the present thesis (see section 3.2.2), the last type of uncertainty by Brugnach et al. is adapted to 'multiple knowledge framings' but does not change in the meaning.

controversial is not considered and multiple framings merely relate to the values and goals according to which the system should be managed and not to the knowledge per se. Framing as in Brugnach et al., however, refers to the fundamental question of defining 'what is it' and 'how does it work', and not only to 'what should be done and how', i.e. framing is about disagreement about the facts.

Table 1: Uncertainty Matrix (adapted from Brugnach et al. 2008)

Type of knowledge relationship / **System**	**Unpredictability** (due to variability and/or complexity of the system)	**Incomplete knowledge** - lack of or unreliable information - lack of theoretical understanding - ignorance	**Multiple knowledge framings** [4] - different and/or conflicting ways of understanding the system - different values and beliefs
Natural aspects - climate impacts - water quantity - water quality - ecosystem - …	**1**	**2**	**3**
Technical aspects - infrastructure - technologies - innovations - …	**4**	**5**	**6**
Social aspects - organizational context - stakeholders - economical aspects - political aspects - legal aspects - …	**7**	**8**	**9**

The UM constitutes a tool for both analysis and practical application. Owing to its plain terminology and straightforward design it is apt for use in interaction with practitioners (Brugnach et al. 2008; Dewulf et al. 2008). The idea is that with help of the UM different framings of uncertainty may be detected and made explicit. Furthermore, the matrix makes an exploration of reframing possible. One and the same uncertainty may be framed as unpredictability, incomplete knowledge or multiple knowledge framings. Taking on a different kind of knowledge relationship, i.e. of an actor towards the object or system in question, may result in a different framing of the uncertainty, which can be illustrated by the UM. The uncertainties around the regional impacts of global climate change for instance can be viewed as a problem of lack of knowledge or may as well be seen as a problem of unpredictability of the system. In using the UM such differences and demarcations can be made explicit and different strategies be designed to deal with the uncertainties.

[4] 'multiple knowledge frames' in the original

3.2 Framing & Mental Models

Research question n° 3 on how uncertainties are getting framed is assessed by help of the concepts of mental models and framing. Due to inherent limitations of the human mind and according to their personal, professional and cultural backgrounds people have a specific and restricted view on the world around them. That means they cannot and do not consider all details and information relevant to a specific situation but observe selectively according to their interest and concern (cf. e.g. Denzau and North 1994; Schaap and van Twist 1997; Doyle and Ford 1998; van Asselt and Rotmans 2000; Gray 2003; Dewulf et al. 2004; Dewulf et al. 2009). Perfectly rational decisions as promoted by rational choice theory are rarely possible. Tversky and Kahnemann describe flaws of rationality with their example of the Asian Disease problem where they show that invariance is an essential aspect of rationality which is often not fulfilled by humans: One problem framed differently, though in essence containing the same information, is evaluated differently by respondents (Tversky and Kahneman 1981; Kahnemann and Tversky 2000). Mathijssen et al. assert that how something is framed and formulated has an effect on how it is perceived by others (2008). Thus, framings are likely to influence each other mutually and iteratively. Especially in settings with multiple actors the concept of framing becomes paramount. The framing concept draws the attention to the concrete interactions "*where actors bring in their conceptions of problems and possible solutions, and how they affect each other's frames in and through a developing relationship*" (Dewulf et al. 2005: 117). In the following, frame theory is outlined focussing on framing and mental models as concepts of how meaning is developed in a socially constructed world (Oliver and Johnston 2000) and how the concepts are used for the present research.

3.2.1 Social Constructivism

For a long time science has been considered as the 'provider of certainty'. This is the result of the era of enlightenment or the 'Age of Reason' (van Asselt and Rotmans 2000: 9) where reason and objectivity ruled and mathematics and quantification dominated in the search of the absolute truth. Contesting this worldview, social-constructivist scholars argue that complete and objective knowledge is not possible but that knowledge is socially constructed and negotiated (e.g. Funtowicz and Ravetz 1993; van Asselt and Rotmans 2000). In a social-constructivist view, problems are socially and culturally defined and comprise the perception of a situation which is perceived as unsatisfactory, pointing to the perceived necessity of developing intervention options to improve the situation (Renn 2009: 561). The same can be argued for uncertainty. The present research follows the understanding that uncertainty cannot be fully and accurately represented in an objective way but that people's perceptions and interpretations influence the description of real world phenomena. However, I here do not follow strict constructivism that is neglecting any basis of external reality human knowledge is based on. The concepts of framing and mental models used for this research are in line with 'moderate constructivism' (see Jones 2002). It argues that the very existence of nature and the (constructed) meaning of it are not necessarily mutually exclusive. Whereas ontological relativism or strict constructivism holds that there is absolute truth or reality but several possible ones depending on the observer, moderate constructivism accepts the existence of a single external reality or that we share a common physical world (ontological realism) as well as the fact that we can never know reality as it is exactly (epistemological relativism) (Burningham and Cooper 1999; Jones 2002: 35). Moderate constructivism rejects the idea that through objective rational enquiry we may come to know the

world exactly as it is (epistemological realism) but argues for understanding the plurality of constructions of reality (Jones 2002: 248).

3.2.2 Terminology

The process of giving meaning to things is captured differently in various disciplines and referred to with concepts such as 'perception', 'perspective', 'frame', 'lens', 'filter', 'mental model' or 'world view' (cf. e.g. Tversky and Kahneman 1981; Schön and Rein 1994; Kickert et al. 1997; Doyle and Ford 1998; Oliver and Johnston 2000; van Asselt and Rotmans 2000; Kolkman 2005; Pahl-Wostl 2006; Dewulf et al. 2009). Often definitions are weak or vague, sometimes even contradicting, and the terms are used in a, partly deliberately, overlapping and interchangeable way. Table 2 below shows some examples of definitions and use of the various concepts.

A common denominator is the idea that situations can be understood or portrayed in different ways and that these different meanings are not neutral, because they direct the search for solutions or the type of actions or strategies that are considered (Bardwell 1991; Sheppard et al. 1994; Kickert et al. 1997; Cortner 2000; Koppenjan and Klijn 2004; Dewulf et al. 2007). Ultimately, how an issue is framed has considerable influence on how it is being dealt with. Hajer and Versteeg (2005) in their study of sustainable development in environmental politics similarly argue that "*the terms according to which particular issues are discussed, define the way in which the topic is experienced and thereby also the perceived possibilities to act*". Beyond framing influencing or directing one's search for solution this also implies that other people may be influenced by one's own framing. In terms of uncertainty: How an uncertainty is framed and formulated has an effect on how it is perceived by the respective audience of the formulated uncertainty (Mathijssen et al. 2008). This may refer to how scientific uncertainty is presented but as well to how one policy-maker reacts to somebody else's formulation of an uncertainty.

From the multitude of terms around the phenomenon of picturing the world in a specific way the concepts of 'mental model' and 'framing' were chosen to guide the present research. Strategies for dealing with uncertainty are influenced by the underlying (possibly changing) mental models that shape the way an uncertainty is framed.

The concept of 'mental models' relates to individuals, and differs in this sense from the 'frames' concept, which is also used in terms of categories of sense-making devices such as identity frames, power frames, conflict management frames etc. (Lewicki et al. 2003). 'Mental' relates to 'mind' which belongs to an individual. Denzau and North (1994: 2) speak of mental models as "*internal representations that individual cognitive systems create to interpret the environment*". However, one individual can hold different mental models (see also the following sections) For the concept of 'shared mental models' going beyond the individual see section 3.2.4. The concept of 'framing' then is chosen over others as e.g. 'perception' because it better captures the active aspect of sense making involved. Following Weick (1995), in the present thesis, individuals are conceived as active sense-makers rather than passive perceivers of the world. Framing involves several activities as Dewulf (2006) describes it, which are selecting, embedding and focussing (see figure 2). Or as Lewicki, Gray et al. (2003) put it: "*Framing involves shaping, focussing, and organizing the world around us*".

Table 2: Concepts of making sense of the world

Concept	Description / Definition
Schema	Bartlett, one of the early pioneers of cognitive psychology, finds in his study on remembering (1932) that memory is selective and constructive and depends on schema of the individual's mind, which depend *"upon an interplay of appetites, instincts, interests and ideals peculiar to any given subject*". Snow et al. from the social movement theory follow the idea of the sociologist Goffman (1974) *"'schemata of interpretation' that enable individuals to 'locate, perceive, identify and label' occurrences*" (1986: 464).
Frame	On the basis of the work of Bartlett (1932) on schemes and Kuhn (1970) on paradigms, the cognitive psychologist Minsky (1974) defines a frame as a cognitive structure, "a network of nodes and relations". The (cognitive) psychologists Tversky and Kahnemann (1981: 453) use the term 'decision frame' to refer to *"the decision-maker's conception of the acts, outcomes, and contingencies associates with a particular choice*". Schaap et al. from public and organization sciences ascribe a filtering effect of frames to perceptions of information between actors (1997: 67). The policy analysts Schön & Rein talk of frames more generally as *"underlying structures of belief, perception and appreciation*" (1994: 23). Similarly, Kaufmann, professor for planning and administration, (2003) describes frames as being built upon underlying structures of beliefs, values and experiences. The sociolinguists Gray & Donnellon (1989) present frames as categories in conversation and negotiation processes which reflect the interaction rather than mental states.
Framing	The term 'framing' is used by the policy analysts Schön & Rein (1994: 30) in the meaning of *"making sense of complex, information-rich situations through the operation of selectivity and organisation*". For Benford and Snow from the social movement theory, framing *"denotes an active, processual phenomenon that implies agency and contention at the level of reality construction*" (2000: 614). The management scholars Lewicki, Gray et al. describe framing as a *"process of constructing and representing our interpretations of the world around us*" (2003: 12).
Mental Model	For Kolkman, from a water management perspective, a mental model determines what data an actor perceives and which knowledge he derives from that (2005: 53). Pahl-Wostl from a integrated resources management perspective talks of a mental model as *"a specific mental representation of information about reality*" (2006: 3). At Denzau and North from (institutional) economics we find that mental models are *"internal representations that individual cognitive systems create to interpret the environment*" (1994: 2). Doyle and Ford from a system dynamics background see mental models as *"a relatively enduring internal abstraction of an external system to aid and govern activity*" (Doyle and Ford 1998: 17).
Perspective	Van Asselt and Rotman from an integrated assessment approach link perspective with perception: *"A perspective is a coherent and consistent description of the perceptual screen through which (groups of) people interpret or make sense of the world and its social dimensions, and which guide them in acting*" (2000, emphases omitted).

This means that when one frames an issue first a range of certain aspects of the issue is selected (dotted square in figure 2), then these aspects are set into relation with each other (embedding) and, finally, a certain aspect is focused on. The dots in figure two are thus not static but are moved and may appear differently according to the framing of different individuals. Thus, even when talking about the same issue, individual framings may differ according to which aspects are selected, how they are embedded and what is focused on. This may include both conscious and unconscious or pre-conscious processes (e.g. Kaufman et al. 2003).

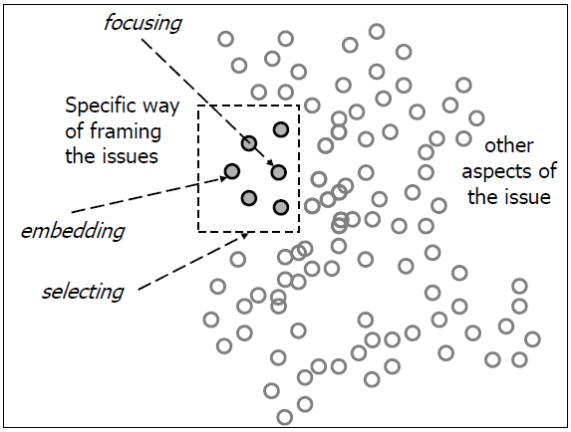


Figure 2: Aspects of issue framing (Dewulf 2006)

In the research on framing two approaches can be differentiated which are elaborated on in the following sections: 'cognitive framing' and 'interactional framing' (Dewulf et al. 2009) (see table 3). In line with the interactional approach, Lewicki, Gray et al. (2003: 12) talk of framing as a process of "*constructing and representing our interpretations of the world around us*". The other connotation of framing they make reference to, in line with the cognitive approach, is a representational process in which "*we present or express how we make sense of things*" (*ibidem*). It is argued that the different approaches are not necessarily mutually exclusive, but should instead be viewed as different lenses that highlight different aspects of the same situation (Lewicki et al. 2003; Dewulf et al. 2009: 14). The two approaches help to shed light on different aspects of the construction of meaning (cognitive or interactional), covering both structural (what is in somebody's mind) and dynamic aspects (construction of meaning through interaction), and imply different methods of analysis (cf. Dewulf et al. 2009).

Table 3: Mapping approaches to framing (adapted from Dewulf et al. 2009)

What is the nature of frames?	What is it that gets framed?		
	Issues	**Identities & relationships**	**Process**
Frames as cognitive representations	**(1) Cognitive issue frames** How parties cognitively represent the substantive issues	**(2) Cognitive identity and relationship frames** How parties cognitively represent self, others and relationships	**(3) Cognitive process frames** How parties cognitively represent the interaction process between them
Framing as interactional co-construction	**(4) Interactional issue framing** How parties interactively construct the meaning of issues	**(5) Interactional identity & relationship framing** How parties interactively construct the meaning of self, other and relationships	**(6) Interactional process framing** How parties interactively construct the meaning of the ongoing interaction process between them

The general difference between the cognitive and the interactional approach is that for the cognitive approach what is in the mind determines one's action and interaction with others whereas for the interactional approach the interaction between individuals determines what is in the mind. This implies that the cognitive structures we hold are "*the result of meanings constructed in previous interactions*" (Dewulf et al. 2009).

The 'cognitive framing' approach studies how internal cognitive structures or mental models of a person are related to a situation. Mental models as cognitive representations can be differentiated in 'issue-', 'identity and relationship-' and 'process'-frames (table 3). The concept of framing, and particularly 'interactional framing', by contrast emphasizes the active aspect of sense-making. Creating a mental model as a non-interactive process is what Kaufmann & Smith call "*adopting a frame*" (1999) with no direct interactive consequences. Framing in the sense of cognitive framing then can be understood as expressing or translating the mental model of a person into the outside world (outside of the mind). The 'interactional framing' approach by contrast, refers to a discursive process involving social interaction where meaning is produced interactively over a certain time.

3.2.3 Mental Models & Cognitive Framing

There is no agreement in literature about what exactly constitutes mental models or what they are like regarding their structure, content and function. Characterizations range from simple to complex as well as from deeply ingrained and stable to floating and unstable. Most definitions are rather vague. In their review of the range of partly contradictory definitions Doyle and Ford (1998) develop a shared conceptual definition for mental models in system dynamics which will be used as a basis for this research. Doyle and Ford (1998) regard a mental model as a relatively enduring and accessible but limited internal conceptual representation of an external system to aid and govern activity of an individual holding the mental model. Their definition offers a coherent and comprehensive characterization of assets of a mental model through a process of questioning and selecting from the available definitions and uses. Doyle and Ford state that the stability of mental models is hard to describe. 'Relatively enduring' in their definition means that parts of the mental model may change easily and quickly while the mental model as a whole may be stored in memory over a longer time.

The malleability of mental models may be illustrated following the iceberg model of George Ambler (2006). His iceberg model represents system thinking where events are at the top of the iceberg, which are visible and relatively easy to change whereas going down the iceberg we find 'trends and patterns' and 'structure' as next layers and 'mental models' at the very bottom of the iceberg. The bottom line accordingly is the most difficult to get hold of. I here use a similar iceberg model to illustrate layers of mental models. The most concrete and transient aspects such as interests and goals to current problems or issues are at the top of the figure. Those may be manifested in speech, invested money, plans etc. As they are relatively visible and relate to current problems they are more likely to be relatively easy to influence and change. Culture and institutions which form the bottom row of the figure are of most stable and long term significance and constitute basic values, e.g. 'environmental protection is good' (Pahl-Wostl et al. 2008) (see also 'deep core values' at Ney and Thompson (1999: 216). Beliefs, in the middle row of the figure, are in line with those values. Pahl-Wostl et al. differentiate between normative beliefs (e.g. 'everyone should consume less to protect the environment') and generalized beliefs (e.g. 'less consumption helps to protect the environment') (2008: 488). These beliefs are

grounded in one's education as well as personal experiences and the knowledge one gains and are thus possible to influence and change more easily than values. Both values and beliefs are under the water line of the iceberg, which implies that they are more difficult to trace and influence than the top of the iceberg. If very strong values and beliefs impede learning and change (Pahl-Wostl et al. 2008).

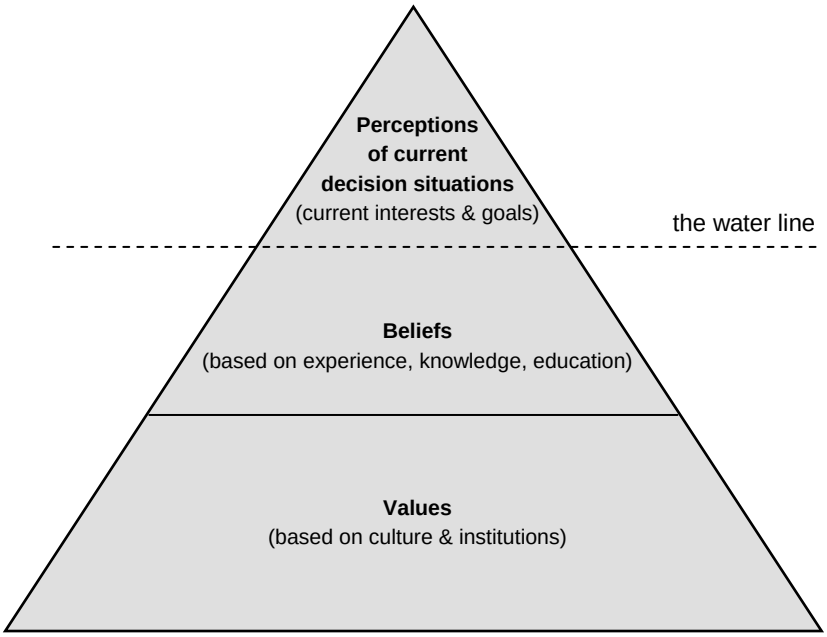


Figure 3: A mental model as an iceberg figure

The iceberg figure thus gives an idea about the endurance and accessibility of different parts or aspects of a mental model. 'Accessible' in the definition of Doyle and Ford means that the cognitive structures are "*relatively available to conscious introspection*" (1998: 18). They suggest using the term 'implicit model' after Rouse and Morris for mental model-like structures that are "*outside conscious awareness*" (*ibidem*). I consider it difficult and question the need to make the distinction between conscious and unconscious processes and include both in my understanding of mental models. Even if not fully accessible, the unconscious processes may have a considerable influence on somebody's actual mental model which will be difficult to access only by conscious reasoning. The 'limited' in the definition of Doyle and Ford points to the limitation of information a mental model contains. A mental model does not comprise all knowledge available but refers to a "*"precompiled" subunit of information held in memory*" (Doyle and Ford 1998: 18). 'Internal' refers to the fact that mental models are only in the mind. As a distinction to the internal mental models, external representations of what is inside somebody's mind are called mental maps. However, it is not trivial to assess mental models and transform them into mental maps. Doyle and Ford state that it is inherently difficult to describe mental models "*since they are not directly observable and can change during procedures designed to assess them*" (1998: 22). Doyle and Ford describe mental models as 'conceptual' since they regard them not only as image-based but based on concepts, ideas or other language-influenced components. 'Representations' finally relate to cognitive structures as described above.

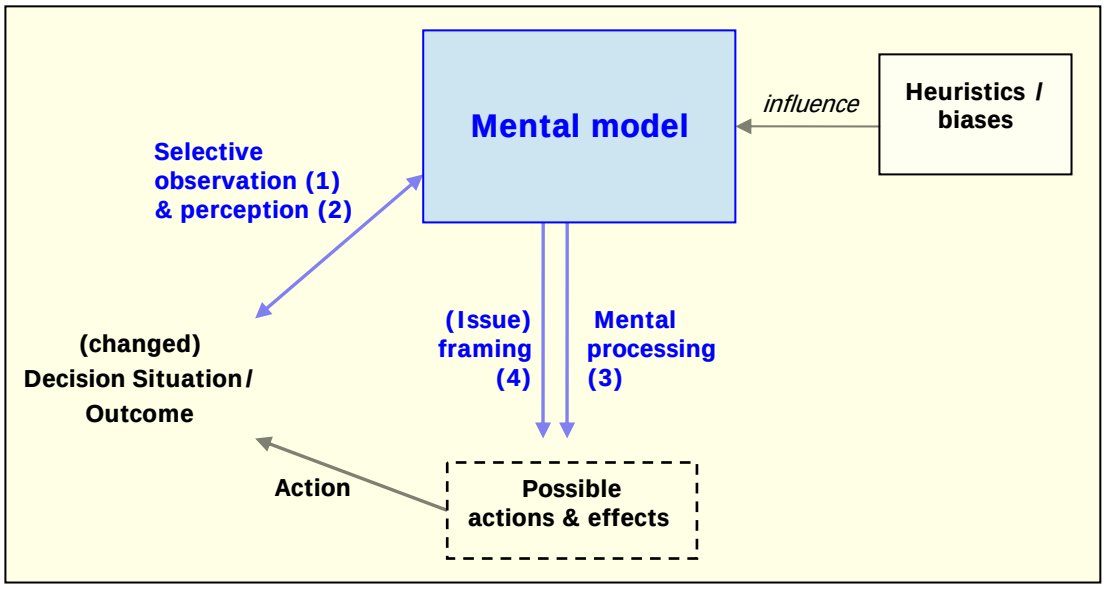
It is difficult to look into someone's head and get hold of the mental model. It may be easier to try to understand how mental models work and are embedded in decision-making.

Figure 4: Mental model in a decision situation (adapted from Denzau and North 1994; Ostrom 2005)

Figure 4 schematizes key aspects and processes of a mental model of an individual in a decision situation. The figure draws on the work of Denzau and North (1994) on mental models, elaborated further on by Elinor Ostrom (2005). The figure shows both relations and processes.

The figure is to be read starting with the box of the mental model. The different aspects and layers illustrated in the iceberg figure are here subsumed and implicit in the mental model box. The blue arrows show activities of the mental model. The numbering indicates the relative sequence although the processes cannot be strictly separated.

Individuals cannot and do not consider all details and information of a certain situation but through their 'limited' mental model observe selectively as to what is in their interest and concern



[(1) in figure 4]. This selective observation necessarily is a partly unconscious process but may be also used deliberately. Consequently, in a decision situation one perceives only those parts the attention has been drawn to or that make sense to the observer (2). Kahnemann (2002: 460) remarks that perception moreover is reference-dependent. A prior stimulation or a difference in neighbouring areas may thus influence the perception of a specific issue or phenomenon.

The perceived information is processed (3) and translated (4) into approaches to deal with the respective situation [box 'possible actions & effects']. Issue framing may occur on the basis of an individual's mental model (meaning constructed "*between the ears*" (Dewulf et al. 2009)) or in interaction with others (see section 3.2.5 on interactional framing for the latter). All those four processes of observation, perception, mental processing and issue framing may be influenced by heuristic cognitive processing. Heuristics are short cuts or cognitive simplification processes (Hosseini 2001) that allow human beings to survive and act in a very complex and partly unpredictable world without deeply analyzing and calculating every detail (Gigerenzer and Selten 2001; Mathijssen et al. 2008). Such intuitive judgements operate between automatisms and deliberate reasoning and are "*fast, automatic, effortless, associative, and difficult to control or modify*" (Kahneman 2002: 450). Heuristics lead to biases. One of the most frequently heuristic-induced

biases reported in literature is the confirmation bias, which posits that information confirming one's beliefs is privileged over contradicting evidence (e.g. Termeer and Koppenjan 1997). Mathijssen, Petersen et al. (2008: 19) have a broader understanding of heuristics, considering a wider range such as modelling and social techniques, organisational cultures, guidelines, objects, rules of thumb and intuitive approaches. Hosseini (2001: 267) mentions prior hypothesis bias, adjustment and anchoring, escalating commitment, and reasoning by analogy as cognitive simplification processes focused on governmental problems.

Once an issue is framed and possible actions and effects are envisaged, a decision is taken and performed [arrow of 'Action'] which leads to an outcome and implies a change in the earlier decision situation ['outcome/ changed decision situation']. This process of selective observation and consequent perception usually does not start from zero but most often is related to a certain outcome of some former action. So the process is iterated permanently as actions are taken and a decision situation evolves as the triangular sequence of arrows in figure 4 from mental model to possible actions to outcome and again mental model shows. Beyond the iterative aspect of the circle in each step of the process the mental model may be revised as conclusions are drawn from observations, new information is gained, actions are taken resulting in new outcomes or also through interaction with other persons holding different mental models. An interactive reframing process between two or more individuals can not be captured with the figure above though. The approach through mental models is a more 'static' one in the sense that cognitive structures are analysed at a point in time different to the interactional approached where mental models are built through and studied in interaction with others.

For the present research, cognitive framing through mental models is the main approach used for analysis. I study how the internal abstractions, mental models, on uncertainties are translated to the outside world, i.e. how the participants in the case studies (verbally) frame uncertainties. In that, the attempt is not to draw an accurate picture of the mental models but to get insights into what are important parameters in the framing of uncertainties. Abundant available literature on frames is used complementary to the concept of mental models as far as it refers to frames in the meaning of cognitive structures (see section 3.2.3) but will else not be used in order to avoid confusion. The concept used throughout the present work is the one of mental model.

3.2.4 Shared mental models

At the very extreme, all mental models ever existent in the world at one point in time differ from each other since after all we are all individuals – "I am not!" (Monty Python movie 'The Life of Brian') – and unique though there are ideas of group-mind like constructs (Koppenjan and Klijn 2004). Klimoski and Mohammed for instance talk of 'team mental models' referring to a model of 'teams' consisting of "*differentiated and interdependent members*" (1994: 404) as opposed to a 'group' as a collection of individuals. The team mental model is supposed to be an "*emergent characteristic of the group, which is more than just the sum of the individuals*". The authors remain vague, however, about how this goal or characteristic is achieved. At the same time they acknowledge that the individual mental models are never 100% equal in a team but that there are "*multiple mental models co-existing among team members at a given point in time*" (1994: 432), meaning that in fact the members maintain their individual mental models, which may be enriched by group dynamics and team forming but still the mental models differ at individual level. Klimoski and Mohammed propose the construct of a team mental model in light of the "*growing belief that cognitions is almost always a social phenomenon*" and "*the individual-level focus in the study of cognition is no longer perceived as adequate for capturing even*

individual level thinking in all of its variety" (1994: 406). The team mental model construct, however, is limited to teams as the name suggests. For capturing the social and interactive dimension in cognition and knowledge production in more general terms the interactional approach is better suited.

I argue that mental models may but do not necessarily have to be restricted to one actor but that there may be different parts of a mental model that may be shared to a greater or lesser extent. The idea of shared mental models (SMM) is also discussed at Denzau and North (1994: 1): "*Individuals with common cultural backgrounds and experiences will share reasonably convergent mental models, ideologies and institutions*". Klimoski and Mohammed propose three different meanings of 'sharing' (1994: 421): having something in common, dividing something, e.g. tasks, or show overlap in knowledge and expectations. My understanding of sharing mental models in the present research primarily refers to the latter meaning.

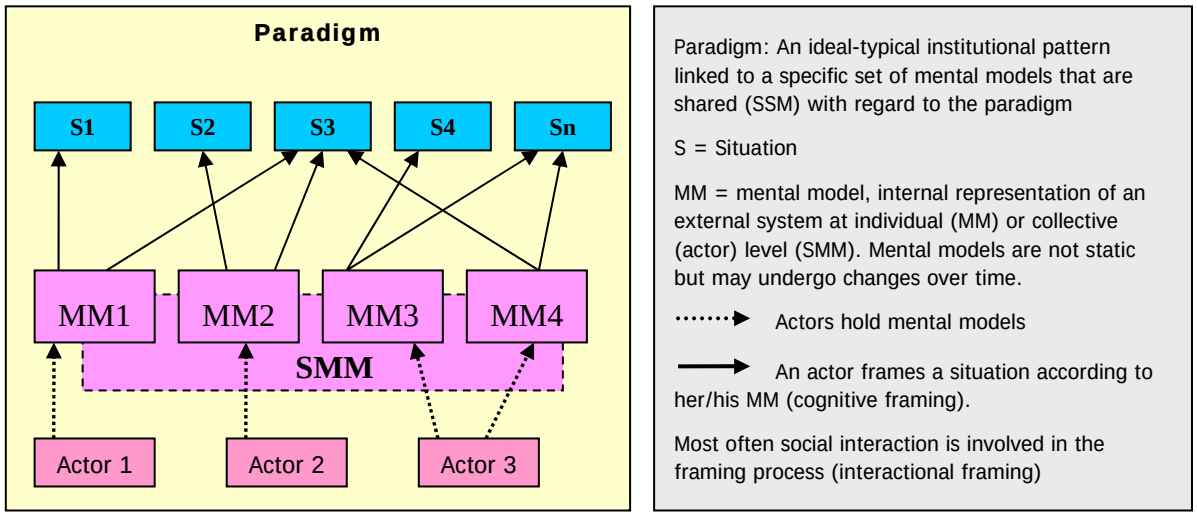


Figure 5: Relation between mental models and paradigms

Within one paradigm (see section 2.2) there is a considerable overlap between individual mental models with regard to that paradigm, e.g. adaptive water resources management, i.e. actors share big parts of their mental models, values and definitions of reality and frame the situations which they seek to influence and manage accordingly (Koppenjan and Klijn 2004). One actor may as well hold different mental models within one paradigm, e.g. about different sub-parts in the paradigm such as water supply, water quality or actor networks. In figure 5 this is illustrated exemplarily for actor 3. To the idea of sharing ideas on a larger basis Schön and Rein remark that nevertheless "*for specific issues frames may diverge*" (1994: 43). This can happen due to different reasons. Mental models can never be shared to a hundred percent. Thus, expectations towards shared actions have to be reserved for the extent or part to which the mental models are shared, e.g. with regard to how to deal with the problem of droughts. Beyond and besides that, people may still not behave according to the shared mental model simply because humans to not always behave logically or consistently (e.g. Denzau and North 1994). Strategic framing is a further option of non-conformance with a shared mental model or a paradigm. Besides, it may be difficult to identify shared mental models because evidence at the phenomenological level (e.g. all actors behave the same way) does not automatically imply identicalness at the causal level. People may as well engage in the same action for entirely different reasons, holding different mental

models. However, with regard to management, agreement at the causal level is not necessarily required (see section 3.2.6 on reframing and changing mental models).

In figure 5, mental models are displayed in connection with different situations [S1 to n] in a paradigm. Through the sketch several aspects of cognitive framing (see table 3) can be explained schematically. Actors hold mental models [MM], parts of which they share [SMM, dotted line] with regard to the paradigm under which they operate [P]. The situations are getting framed through the mental models [dotted arrows]. One actor may maintain the same mental model with regard to different situations [arrows e.g. from MM4 to S3 and Sn]. Likewise situations may be framed differently through different actors or mental models [e.g. S3 getting arrows from MM1, MM2 and MM4]. Moreover, one actor may hold several mental models, even about the same issue, e.g. mental model how to best combat climate change either with the mental model as a representative of public administration or as a private person.

In the present research, several case studies are analysed with regard to how uncertainties are getting framed and being dealt with by water managers. Additional attention is given to the extent to which the participants in the case studies share their ideas of and approaches towards uncertainty, i.e. the (possibly shared) mental models they hold about certain issues or uncertainties, and if more general patterns can be detected as evidence of different paradigms of dealing with uncertainty in water management practice.

3.2.5 Interactional Framing

As mentioned above, there is a different approach to framing, i.e. the interactional approach (Dewulf et al. 2009). It focuses on interactive production of meaning over a certain time that is an actor frames a situation through the interaction. In that way 'interactional framing' different to 'cognitive frames' reflects a process and interaction between various actors. That means that the emphasis is on communication rather than on cognitive processing (Dewulf et al. 2004: 185). People communicate differently in different situations or with different people which implies different and changing framings of an issue or a situation. In some situations strategic framing may occur or even conscious manipulation "*but a more moderated interpretation is that people use frames that serve their current interactional concerns in a conversation*" (Dewulf et al. 2004: 185).

Similarly, Ney and Thompson in their approach towards policy making argue that rather than a strategic rational choice approach, a communicative one is needed, that is goals emerge from interaction of actors (1999: 214). Consequently they claim that the attention "*has to focus on discourse – on the different ways in which the policy problem is being defined – rather than directly on decisions and policy outputs*" (Ney and Thompson 1999: 214, italics omitted). Dewulf et al. also talk about framing as a discursive process where meaning is constructed "*between the noses*" (2009). This is further pronounced through the role of language. Language is considered the primary instrument for social interaction (Dewulf et al. 2004: 185): Where for mental models "*language is a system of symbols that primarily serve to represent the world"* in the interactional approach "*framing is an action that is achieved through language use*" (Dewulf et al. 2009: 11).

The 'interactional framing' approach is more difficult to apply in the present research as the interventions of the empirical research imply one point in time contacts with water managers, partly in group, partly in individual meetings. For those discourse analysis is not feasible. Observation over longer time is not possible. It looks more promising thus for the research as a whole to focus on the cognitive approach and compare the results over the period of time the point-in-time interactions are taking place. That way, results of previous (changes through)

interactions may be captured as well. The group meetings that are held in each case study may also be a kind of interface or "*starting point for exploring possible connections between the cognitive and the interactional approaches. The individuals bring their specific cognitive frames to the interaction and start co-constructing a specific path of interaction*" (Dewulf et al. 2009: 34, emphasis omitted). Accordingly, during the group sessions attention was also given to the dynamics of communication on the uncertainties and possible changes or evidence of reframing.

3.2.6 Reframing

Both approaches, the cognitive and the interactional, allow room for changes in framing, mostly referred to as 'reframing' in literature. Reframing is interpreted differently in the cognitive and interactional approach. In the present thesis, the emphasis is on analysis of reframing according to the cognitive approach.

In the interactional approach, as the very name suggests, change may be achieved through interaction (Kickert et al. 1997; Dewulf et al. 2005; Dewulf et al. 2009). Reframing happens through a change in how a topic is framed in a discussion (e.g. people start talking about climate change as a lost cause rather than as a challenge). In the cognitive approach change happens at the level of mental models. Mental models are not static, "*they do not appear out of the blue, nor are they immutable*" (Schaap and van Twist 1997: 69) and are thus likely to be subject to change. A change of the mental model of an individual indicates that reframing has taken place. As "*frames that stakeholders use to make sense of situations are both a reaction and an anticipation to a specific problem domain and to specific other stakeholders*" (Dewulf et al. 2005: 118) it is difficult to separate where framing starts and who influences who in the framing. Any framing may thus already be a change to a previous framing.

When talking about changes in mental models one has to differentiate several dimensions. Not all aspects of a mental model are equally easy to change. In the iceberg figure above (figure 3) 'layers' of a mental model are conceived with the malleability from top to down as easiest to most difficult. We find a similar distinction at Sabatier (1988: 139) who describes a belief system as including problem definitions, causal assumptions and basic values. Basic values are then part of the 'deep core' of the belief system which defines the person's, organization's or coalition's underlying identity and which is much more resistant to change than both the 'outer' policy core (which consists of basic strategies and policy positions) and the secondary aspects (a multitude of instrumental decisions).

What are the conditions now for mental models to change or for interactional reframing to take place? It is stated that mental models change in response to discontinuities (cf. Schön and Rein 1994: 39). Such a discontinuity may be the confrontation with a different interpretation of a given situation provoking a reinterpretation by others (Dewulf et al. 2004). Termeer and Koppenjan call this cognitive and social variation, the first referring to a change in mental conceptualization and the latter to a change in ways of action such as changes in context or the introduction of new actors or exclusion of others (Termeer and Koppenjan 1997: 86; Doyle and Ford 1998). Extreme events or catastrophes may trigger such variations. This is a similar distinction as Dewulf et al. take on between the cognitive rather one-point-in-time approach and the more dynamic interactional one. In the cognitive approach change happens in the mental models whereas for the interactional approach change happens in discourse. With the cognitive approach then, it may still be possible to capture results of a previous interaction over time though not followed in real time as through the interactional approach. This would mean to trace the cognitive variation as a

consequence of the social. However, cognitive variation may also occur without social variation and vice versa.

Confrontation with new information or encountering a different mental model most often is not sufficient for one's own model to change (e.g. Kickert et al. 1997). This is partly due to cognitive biases as laid out above. Individuals tend to look for information and actors, consciously or unconsciously, which (re-)confirm their own perceptions (Termeer and Koppenjan 1997: 83). Thus, confrontation with new and possible contrasting information or new mental models may simply be avoided or else ignored or not taken into account. Else, according to Festinger's (1957) theory, cognitive dissonance is provoked, which people tend to reduce as it is experienced as an uncomfortable state. If a mental model or belief is contested by a different one, one may accordingly either a) change the cognitions and adopt the new mental model, b) add cognitions to reduce the dissonance between the two very opposing mental models, or c) alter the importance of the cognition, i.e. to downplay one or the other information or mental model so that the dissonance gets smaller (Festinger 1957; Bradshaw and Borchers 2000). Besides the tendency to avoid getting one's mental model contested, the very limitation of the mental model may not allow to even grasp what another person is intending to communicate: "*Information from other actors is not perceived in the way it is intended but in the way that this, modified by the filtering effect of the frame, is interpreted by an actor*" (Schaap and van Twist 1997: 67). Dewulf et al. (2004: 181) likewise report in their analysis of the management of a National Park that the different actors had difficulties in connecting their different frames which resulted in confusion and misunderstandings. Threat to one's model is even worse in that it makes people not only stick to their mental models but reinforce them (e.g. Lewicki et al. 2003; Gray 2004). In general, reframing is more likely to happen in an atmosphere of openness and mutual respect and trust.

Reframing is unlikely to be achieved through a formalized structure but rather through personal and emotional confrontation with somebody else's framing (Dewulf et al. 2005). The ability to reframe is also influenced by the willingness of the individual to question one's own framing: "*As long as parties believe that their own view is the only one possible to understand the issues in dispute, they cannot reframe*" (Lewicki et al. 2003: 32). Hence, a basic precondition for reframing is that actors become aware of their own framing and critically reflect on it and acknowledge that there may be other legitimate framings contesting their own (referred to as 'frame reflection' in the reference literature). Mental models are likely to be changed through reflection on rather concrete problems ((Dewulf et al. 2004) what Schön and Rein call 'situated frame reflection' (1994: 174). Also in the interactional approach, reframing is likely to happen rather through discussing concrete problems than abstract ideas or concepts. Basic underlying cultural components of mental models that are shared by one culture are not changed on the meta-level but on the individual level (Schön and Rein 1994). That is the shared cultural values and habits change through cumulating individual changes and discussions and negotiations on concrete issues rather than by however induced changes from 'above'. Termeer and Koppenjan also draw the emphasis on individual's behaviour identifying three conditions or steps for change: firstly differences between one's own framing and those of others have to be recognized, second differences have to be experienced as problematic, and finally a willingness to reflect on one's own framing must be present (1997: 82). Once reframing takes place, a new mental model may be jointly constructed by the involved actors, synthesizing elements of the former individual framings (Schön and Rein 1994: 43) or developing a completely new view on a problem. Lewicki, Gray et

al. remark that such reframing often is difficult without the help of a neutral third party or someone who does not have a direct stake in the conflict (2003: 32).

Changing the mental models thus seems to be a crucial and logical thing to overcome differences in mental models as one of the key reasons for communication problems among actors (e.g. Koppenjan and Klijn 2004; Pahl-Wostl 2006). Indeed, in conflictive situations, making each others mental models or points of views explicit often is a first step in order to constructively deal with a problem. However, mental models do not always necessarily have to be changed in order for the involved actors to be capable of joint action. It may be sufficient and it is more common to pragmatically converge on a common means in terms of what has to be done without switching or reframing the whole reason behind and motivation for it (Schön and Rein 1994: 170; Termeer and Koppenjan 1997: 86). Donnellon et al. talk of "*equifinal meaning*" (1986), that is convergence on the objectives. Consensus building is not mandatory here.

Reframing processes are important for learning which in turn is considered indispensable for the long-term performance in management of natural resources (Ison et al. 2007; Jiggins et al. 2007; Pahl-Wostl et al. 2007a; Borowski and Pahl-Wostl 2008; Berkes 2009; Lejano and Ingram 2009). I hope that with my intervention in the case studies through the use of participatory methods and group discussions I have given an impulse not only for making different framings explicit but also for reframing. Analysis of reframing in the present thesis is limited. Occurrence of reframing is traced as far as possible through the interactions with the stakeholders in the empirical research phase, particularly in the phase of designing improvement options for dealing with uncertainty.

3.2.7 Taking the concept of framing further

So far I have argued that uncertainty has to be analysed with the help of frame theory as it is no objective phenomenon but depends on the relation between an object and an actor. On the one hand, the perception and framing of an uncertainty depends on the state of knowledge of an individual. The more knowledge required for understanding a situation and the less knowledge the actor holds the bigger the uncertainty. On the other hand there are other aspects that influence how an uncertainty is being framed, i.e. individual experiences, personal interests, cultural norms and more.

Hitherto approaches in frames analysis have focused on identifying different types of frames that are used in interaction, e.g. control frames, identity frames, negotiation frames and more (Fischer 1997; Gray 2003; Lewicki et al. 2003; Carton and Thissen 2009). A similar approach may be useful with regard to uncertainty if one wants to assess which types of frames people use when dealing with uncertainty. The present thesis now aims to shed light on the process before, i.e. how uncertainties are framed. Therefore, approaches are elaborated and tested to assess if there are salient influential parameters in the framing of uncertainties. Such parameters are assumed to build a basis on which to develop options for change in dealing with uncertainty in a structured way, so far not addressed in water management practice. Two different ways of developing a set of parameters of importance in the framing process are designed (RQ 2) and tested in the case studies (RQ 3) on the basis of which strategies are developed how to improve strategies for dealing with uncertainty (RQ 4). The two approaches are outlined in section 4 (methodology) and the results are presented in the discussion section (6.1-6.4) as well as in the papers (section 9).

3.3 Cultural considerations

Commonly, in evaluation of field work comprising different countries and contexts, high importance is ascribed to cultural contextual factors. Since the practical research of the present dissertation covers three different case studies and countries, some lines on cultural implications may be helpful. In the evaluation, attention is drawn to possible cultural differences as to how uncertainties are framed and dealt with.

Pahl-Wostl, Bouwen et al. state that "*remarkably little work has been devoted to develop a sound foundation for investigating this relationship*" (2008: 29). There is no readily applicable framework for case study analysis to take into account the influence of different cultural contexts. I have argued that mental models are influenced among others by the cultural background (see figure 3). However, it is not evident or easy to identify how exactly culture takes influence when analysing decisions in water management at individual practical level. For the present dissertation, where feasible the ideas of concepts of culture will be used to support the findings, especially with regard to paradigms in water management. Hence, the link between uncertainty and culture is not drawn immediately but both linked to the discussion about different paradigms and paradigm change in water resources management.

The term 'culture' has many different meanings, connotations and scientific and social uses. Often the concept of culture is used in connection with national or ethnic identity, differentiating one from another and emphasizing the homogeneity within each group (cf. Pahl-Wostl et al. 2008: 8). This approach encompasses and links a group of people of the same or similar values and beliefs and their manifestations in behaviour, habits, norms and routines etc. (Pahl-Wostl et al. 2008: 13). Berninger et al. (2009) citing Strauss & Quinn (1997) refer to cultural models as schemas that are socially shared and learned through explicit teaching or observation. Thus, culture shows similar traces as a management paradigm (see section 2.2) but is, however, a broader or superordinate concept as it does not make claims as to the goals or the management of a system.

Pahl-Wostl et al. (2008) resume that same as paradigms culture in literature is often referred to as "*very stable, both at the individual and social level, internally consistent and exclusive: every person is supposed to have only one fundamental (usually national, ethnic or religious) culture*". But there are also voices in disagreement. Dogan for instance (in Thompson et al. 1999: 2) states that "*there is not a British civil culture, nor a German, French or Italian one. The differences among countries are differences in degree, not of kind […]. The differences within nations appear greater than the differences among nations. There are more similarities in the beliefs of a French and German social democrat than between a French socialist and a French conservative or between a German social democrat and a German Christian democrat.*" Pahl-Wostl et al. argue likewise that professional cultures (e.g. farmers beliefs and practices) may be more important than national cultures (2008: 25). "*Stronger than the influence of national cultures seems to be the influence of the technology/expert culture characterizing the community of water resource practitioners across national boundaries*".

This view of culture as an integrated system may refer to shared beliefs and values as well but irrespectively of the respective society people live in or belong to. "*It is enacted (reflected) in the interactions within this group context, rather than engrained in the minds of its members. Each group develops his own culture as result of the social interaction of its members and shared experiences*" (Pahl-Wostl et al. 2008: 9). This makes culture a less static and more flexible and malleable phenomenon, which may be changed over time and through interaction. Cultural changes are said to be rather achieved through changes at individual level (see section 3.2.6 on reframing) (Schön and Rein 1994) but

nonetheless cultural traits are among the most difficult to change in the mental model (see figure 3 with layers of MM).

It also implies is that people may be part of or participate in different cultures since they may form part of (culturally) different groups. Pahl-Wostl, Bouwen et al. here refer to culture as "*always enacted"* (2008: 14). This view has a strong link with the idea of Cultural Theory and its solidarities as "*emergent properties of human transactions*" (Thompson et al. 1999: 12). Pahl-Wostl, Bouwen et al. also talk of different social roles individuals hold and which makes them belong to more than one social and thus cultural group. *"Hence, it is possible that different cultural frames occur within individual persons and may be activated in different social contexts*" (Pahl-Wostl et al. 2008: 24).

4 Methodology

A central issue of this research is the way how actors in water management deal with uncertainties, how they perceive and conceive and tackle them. Thus, besides literature research, the focus has been on development of methods to assess framing of uncertainty and on interaction with practitioners in water management.

4.1 Challenges, limitations and drawbacks for analysis

There are several conceptual and practical challenges, limitations and drawbacks to the venture of the present research. To start with, there are limits as to what can be known. Regarding the approach of mental models it is clear that the black box will never be completely transparent (Rouse and Morris 1986: 360). One should bear in mind that it is not possible to get hold of the complete mental model that is inside an individual's head but what will be displayed "externally" is always a limited part of the whole. Moreover, mental models tend to be not logically coherent (e.g. Denzau and North 1994: 14). That means that all attempts of developing structured approaches (in this case to better deal with uncertainties) that seem to be "logical" or coherent with the mental models at hand may be foiled by unpredictable incoherencies. Assessing an individual's mental model, moreover, can always only be the "*approximation of approximations of reality*" (Rouse and Morris 1986: 353) in the sense that the researcher develops or deduces a model of the subject's mental model of a real world phenomenon. The aim hence can not be to search for the ultimate scientific truth and objectivity. The idea of assessing mental models is rather of pragmatic nature to obtain information that helps to better understand and improve dealing with uncertainty in water management practice (cp. Rouse and Morris 1986: 360)

4.2 Case study research

The present research is based on three case studies. In social science where predictive theory is unlikely to be possible, research through case studies plays an important role though often disregarded as arbitrary, subjective and not generalisable (for a review see Flyvbjerg 2006). Even if knowledge gained in case study research may not be completely generalisable it contributes to accumulation of knowledge and allows learning, particularly due to the context-dependent knowledge it produces. Moreover, as has been shown above, science is never neutral and to a certain degree arbitrariness and subjectivity hold for all scientific endeavours and hence are moot as a hindrance argument to case study based research. Another option of case study research is to compare across case studies. For the present research this is not really feasible due to the limited number of case studies. However, further case studies could be added since the chosen approach can be easily repeated.

As Flyvbjerg (2006) stresses, case knowledge is central to human learning. The advantage of case study research is that it can 'close-in' on real life situations and enables advancing the research through feedback from participants. Empirical research for the present thesis has been undertaken in the German Wupper and the Dutch Kromme Rijn, both sub-basins of the Rhine, plus one further case study, the Doñana region in the Guadalquivir estuary in Southern Spain[5]. According to the categorization by Flyvbjerg (ibidem: 230) of selection criteria for case studies the three cases have been chosen according to information-orientation with a focus on particular,

[5] Referred to hereafter as Doñana

'extreme' cases. Though the background to all cases is fairly similar as they are all European basins facing the challenge to implement the European Water Framework Directive (WFD), they show particular features with regard to water management. The Wupper and the Kromme Rijn form case studies of the NeWater project and are engaged in innovative pilot activities, a pilot regarding the implementation of the WFD participatory process in the Dhünn as sub basin of the Wupper and the participatory process for the water area plan of the Kromme Rijn. The Spanish case study was selected for its diversity in actors and institutions and emerging activities in adaptive management with regard to the restoration of the ecosystem (Marín Cabrera and Garcia Novo 2006). All three case studies thus promise to be a good field for studies on experiential learning processes as is the case for exploring new ways for dealing with uncertainty.

4.3 Methods for the assessment of framing of uncertainty

A potentially problematic aspect in interactive research on mental models and framing is the reliability of what the participants in the empirical case studies actually communicate. It is certainly interesting and of value what subjects say they are thinking about or intend to do. However, verbalizations of a nonverbal (e.g. pictorial) image or mental model may result in distortions and biases. On the one hand individuals are not always able to formulate precisely what they think as it is a reduction of a complex mental model. It may also be possible that they formulate what they mean themselves but are understood differently from the researcher or other actors as ideas and concepts are nor self-evident or neutral in their meaning but depend on the interpretation of others (Dewulf et al. 2007). In the worst case, the individuals' verbalizations reflect what they think they are expected to tell rather than how they actually (would) perform (Rouse and Morris 1986), be it to satisfy the researcher or the other participants, to make the answer politically correct or avoid showing incompetence or other kinds of embarrassment.

The methods developed for the present research aim at overcoming such drawbacks. For the assessment of framing of uncertainty two methods were developed and applied in the three river basins (table 5). The rationale was to test out two different approaches for assessing framing of uncertainties in water management. Both aim at identifying parameters of importance in the process of framing uncertainty in order to understand how uncertainties are getting framed. Parameters are considered a promising means to operationalise the concept of framing and mental models as they are relatively easy to assess, display and provide a basis to develop more structured approaches for dealing with uncertainty in water management practice.

For the first approach, framing parameters were identified through an ex-post analysis of narratives of water managers on their dealing with uncertainties (for a detailed description see paper 1). By analysing narratives the above described problem of satisfying the researcher is reduced as the primary objective of the narratives was not to have the participants report on their likely parameters of framing but on what uncertainties they perceive and how they deal with them. The resulting set of parameters (table 4) was used for assessing uncertainty framings in the Wupper and Kromme Rijn along selected uncertainty situations.

Table 4: Parameters of framing (adapted from Isendahl et al. 2009)

Parameter	Definition
Type of Uncertainty	Type of knowledge relationship to an uncertainty as unpredictability, incomplete knowledge or multiple knowledge framings
Positioning	Positioning as the evaluative quality people attach to uncertainties
Urgency	Urgency related to the point of time for taking a decision in the uncertainty situation or to the time frame within which a decision is supposed to have an effect
Responsibility	Responsibility for having caused and/or dealing with the uncertainty, including the perceived scope of influence on the uncertainty situations
Trustworthiness	How trusting actors are towards components of an uncertain situation, e.g. towards data, methods or other actors, including patterns of communication and dependency between actors.

A second alternative approach was developed for two reasons. On the one hand there was the idea if parameters developed by the actors themselves would not better reflect the actors' framings and needs. On the other hand a method was searched to reduce the limitations of direct verbal communication. Thus, as an alternative to the researcher-structured approach, a participant-structured approach was developed and applied in the Doñana region where participants developed parameters themselves with help of the method of card sorting. Card sorting as a contrived method for knowledge elicitation allows overcoming limitations of direct speech. For details on the method of card sorting and the participant-structured approach see paper 3.

4.4 Setup of the empirical research

Interaction in the case studies took place in form of personal and phone interviews and focus group discussions. Furthermore, meetings beyond the present research were attended in the case studies (e.g. a meeting open to all interested parties with regard to the implementation of the water area plan in the Kromme Rijn ('gebiedsavond'), a seminar on Adaptive Management in Doñana organized by several local organizations and institutes, and others). The interactions with stakeholders were all held in the participants' original language in order to make sure the participants had the chance to express themselves in a way they were used to. Speaking in a foreign language often hinders people from speaking freely and naturally and thereby distorts statements. Documentation was done through notes, recordings and transcripts, where necessary translated into English for presentation in the present thesis. Verification of the results obtained in personal interaction was done by further phone calls, through email or postal communication.

The empirical research was divided into three interactive phases according to the research questions 1, 3, and 4.

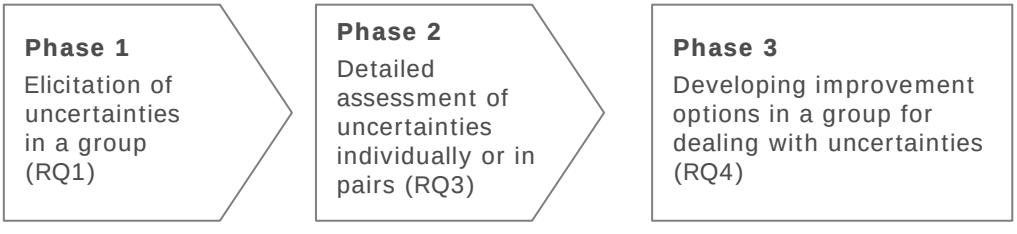


Table 5 gives an overview over each phase in the two different approaches and the outcome or link to the next phase. Preceding the first phase the participants of were asked per phone about their familiarity with the concept of uncertainty (see Appendix I in section 8.1) in order to be better prepared for the group discussion of phase 1. The first phase addressed the question of how actors in water management frame uncertainty with regard to different water management situations and what their current strategies are for dealing with the perceived uncertainty. In the second phase, a selection of the identified uncertainties was characterized in more detail with help of framing parameters or criteria. Finally in phase three, options of improving strategies for dealing with uncertainties were explored along the details of the selected uncertainty examples. The phases were all interlinked as each phase built on the results of the previous one. Throughout the phases the collaboration was performed with the same participants.

In the table below a sketch with the different phases and their outcomes is outlined. Phases that follow the same approach in all case studies are displayed jointly in one cell.

Table 5: Empirical research structure[6]

Phases / results	Researcher-structured approach	Participant-structured approach	Research question
	Preceding questionnaire on familiarity with concept of U		
1	Group session: Elicitation of U-situations along UM (by Brugnach et al. 2008) in a semi-structured discussion	Group session: ▪ Elicitation of U-situations (free discussion) => U-situations put on cards Individually/in pairs: ▪ Card sorting to define criteria relevant to the participants	RQ1: What U do water managers perceive and how are they dealt with?
Outcome / link	▪ UM filled with examples of uncertainty ⇒ Agreement among participants on 2-3 U-situations to proceed with	▪ Sample of U-situations ▪ Set of participants' criteria ⇒ Agreement among participants on 2-3 U-situations to proceed with	
2	Individual contacts: Assessment of framing parameters along the U-situations identified in phase 1.	▪ Clarification of results from card sorting ▪ Elaboration of shared list of criteria	RQ3: How are the U getting framed?
Outcome / link	Individual viewpoints on framing parameters as entry point for strategy discussion	List of criteria of relevance for participants	
3	Group session: Discussion in each case study of strategies for dealing with U along the results of phase 2		RQ4: How can the strategies for dealing with U be improved by help of parameters of framing?
Overall outcome	Strategies or intervention moments to improve dealing with U		

[6] U = uncertainty, UM = Uncertainty Matrix

4.5 Selection of participants

As participants for the empirical research key actors[7] in water management responsible for the implementation of the water policy at regional and local level, i.e. basically those from public administration and regional governments, were identified. The participatory method of a focus group (Morgan 1996; Slocum 2005) was chosen. The rationale was to convene a small group of three to a maximum of seven participants so that everybody's point of view could be sufficiently heard. The limitation to local and regional level as well as group size also intended to keep the discussion level within certain boundaries in order to not get too global or abstract and also to create an atmosphere of trust and familiarity so that the participants could freely express their thoughts as opposed to a bigger group with possibly intimidating politically important representatives from national or international level. As far as possible participants were selected that already knew each other or had been in contact through work, thus enhancing adhesion within the group. Drop out rate was fairly small with one to two participants in each case study. However, all participants who withdrew from the research did so before the first group session started. Hence the major part of the research could be performed with the same group of participants.

The research focused on actors from public administration or similar responsibility on decision-making in water management and did not include further possible interest groups such as water users or NGOs for reasons of practicability. A bigger group size would have been beyond the manageability for the purposes of the present research. Nonetheless, I consider the involvement of further stakeholders in a second step very relevant for the search of solutions as most problems involve multiple stakeholders and it is important to take into account all relevant points of views.

The actual composition and group size differed due to the respective institutional structure in the areas under investigation (see table 6).

Table 6: Participants of the case studies

Case study	Participants
Kromme Rijn	Water Board (2) Municipality (1)
Wupper	Regional government (2) Water board (2) Municipality (1)
Doñana	River Basin Authority (2) Research station within National Park (2) National Park management (1) Researcher/regional project (1) Regional water institute (1)

[7] Actors and stakeholders are used interchangeably as terms in the present work and refer to people or organisations who are involved in decision-making in water management in their respective basin

4.6 Phase 1 – Elicitation of uncertainties

The uncertainty situations of the participants were elicited differently in the researcher-structured and the participant-structured approach.

Researcher-structured approach: Uncertainty Matrix (UM)

For eliciting uncertainty situations discussions were held in focus groups in order to find out what uncertainties practitioners are confronted with in their work of water management. The discussions were guided along the Uncertainty Maxtrix by Brugnach et al. (2008) building on the results of the Uncertainty Dialogues in the NeWater project in summer 2006 (Dewulf et al. 2008). The Uncertainty Matrix by Brugnach et al. (2008) differentiates between the type of knowledge relationship towards an uncertainty situation in relation with the aspects of the system (table 1, for details see section 3.1.3). The participants were asked to report on concrete examples of uncertainty from their professional life and allocate them to the cells of the Uncertainty Matrix. The allocation was left to the participants on purpose in order to capture their point of view and not impose a categorization/ framing. As some of the participants were the same as in the Uncertainty Dialogues (Dewulf et al. 2008) the group of participants of the present research was shown the UM of the Uncertainty Dialogues for them to decide if they wanted to take over some uncertainty situations relevant for them.

After filling the table the interviewees were asked to decide on uncertainty situations they were interested in working on further with in the next steps of the research. These were then used for phase 2, the further assessment of uncertainties through individual contacts.

Participant-structured approach: free discussion

Similarly to the researcher-structured approach, in the participant-structured approach a discussion was held in a group in order to find out what uncertainties practitioners were confronted with in their work of water management. As a difference, the Uncertainty Matrix was not used as a guiding tool but the discussion evolved freely. The discussion resulted in a sample of 13 uncertainty situations (see paper 3), which was put on cards, each uncertainty in a key word, for the exercise of card sorting of phase 2. Besides, the interviewees were asked individually to name 1-2 uncertainty situations they were interested in working on further with which were used for the strategy discussion in phase 3.

4.7 Phase 2 – Assessment of framing of uncertainties through parameters

Following the elicitation of uncertainties, the selected examples were used to detail on the uncertainties along a set of parameters of framing. The approach differed in the researcher-structured and the participant-structured approach. Whereas the researcher-structured approach made use of the framing parameters that had been developed earlier, in the participant-structured approach the participants themselves developed a list of parameters through a card sorting exercise.

Researcher-structured approach: Framing parameters

The elaboration of the framing parameters is described in paper 1 of this dissertation "Assessing framing of uncertainties in water management practice". Here some more details on the method beyond the scope of the paper will be illustrated. The framing parameters have been extracted from transcripts of the Uncertainty Dialogues in a discourse analytic process (see paper for

details on that). Discourse analysis was deemed an adequate approach to obtain parameters of importance in the framing of uncertainties as language and framing of information play a central role in it. Discourse analysis is based on the assumption that perceptions of reality are influenced by language instead of language being a "*neutral medium mirroring*" reality (Hajer and Versteeg 2005). Especially for complex problems involving multiple actors, as typically is the case for environmental problems, the framing of information and uncertainty can be decisive. In line with social constructivist approaches discourse analysis takes a critical stance towards discovering the absolute truth but puts the emphasis on communication through which knowledge is exchanged. The analysis of meaning becomes central (*ibidem*).

The parameters the analysis rendered are

- Positioning towards uncertainty
- Perceived responsibility for having caused uncertainty and for dealing with it
- Perceived urgency of the decision related to the uncertainty
- Trust (among actors/towards data and methods)

These parameters were assessed through individual semi-structured interviews in the case studies along the selected uncertainty situations from phase 1. Each interview took about 1.5 hours and was recorded and transcribed. According to the familiarity of the interviewees, in the interviews more time was given to the uncertainty situations the respective participant was more involved with. Yet, attention was paid that the participants would not simply skip one uncertainty situation in the answering. The elicitation was done individually and not in groups as participants were expected to have their individual framing and phrasing which was not to be distorted by group discussions. The intention was to identify possible framing differences or conflictive views. Furthermore, agreements among the participants without them being mutually influenced were looked for in the evaluation of the individual contributions. Once carried out all interviews, the individual contributions were compiled and compared and overlaps as well as framing differences extracted for phase 3.

For the questions of the semi-structured interviews see section 8.6.

Participant-structured approach: Card sorting

For the card sorting exercise the 13 uncertainty situations from phase one were used. Card sorting is a fairly fast method to elicit knowledge indirectly. Participants have to group a set of cards with a concept written on each and give a name for each grouping and the corresponding categories. Depending on the number of participants of the meeting the card sorting can be done individually or in pairs. Each sorting has to be supervised and documented by a moderator. For the implementation in the Doñana case study three additional moderators were employed as the participants were grouped into three pairs and one individual.

Before starting the exercise the method of card sorting was explained to the participants, giving a concrete example of grouping the provinces of Spain according to certain criteria like geography, politics, size etc. The participants were asked if they had understood the method well which was answered positively. A sum-up of the method was visualized for all via a PowerPoint screen during the exercise. The card sorting exercise was done for a maximum about 30 min. with each participant/pair. After the exercise the criteria and categories each pair or participant produced were collected and handed over to a 'blind judge' for further proceeding. The resulting composed list of criteria served as a basis for deriving a shared list of criteria within the group of participants.

For details on the card sorting method and results of the Doñana case see paper 3 of this dissertation.

4.8 Phase 3 – Elaboration of improvement options

The results of phase 2 were used as a basis to trigger discussion and to develop improvement options for dealing with uncertainty in phase 3.

Researcher-structured approach: Guided discussion

In this group session, strategies of dealing with uncertainty were discussed. The individual interviews from phase 2 were evaluated with regard to overlaps and salient framing differences or controversies. The overlaps in framing were reported back to the participants for their confirmation. The framing differences were discussed in the group of participants. From both overlaps and initial differences options were derived by the participants on how dealing with uncertainty could be improved with regard to each framing parameter.

The results of this phase are illustrated more elaborately in paper 2.

Participant-structured: Guided discussion

In the Doñana case, strategies for dealing with uncertainty had partly already been discussed in the first group meeting of phase 1. The criteria from phase 2 served as an entry point for developing strategies or improvement options for dealing with uncertainty in a more structured way. The elaborated general strategies from phase 1 were to be checked against the improvement options along the criteria. Due to time constraints, this was only possible for one selected uncertainty situation.

For details see paper 3 of this dissertation.

5 The Case Studies

Three case studies were investigated for the analysis of the present work, the German Wupper, the Dutch Kromme Rijn and the Spanish Doñana region. In the following they are outlined regarding their geographical and climatic characteristics. The key actors are presented as well as the main structures of water use and administration, including the principal activities in water use and related problems.

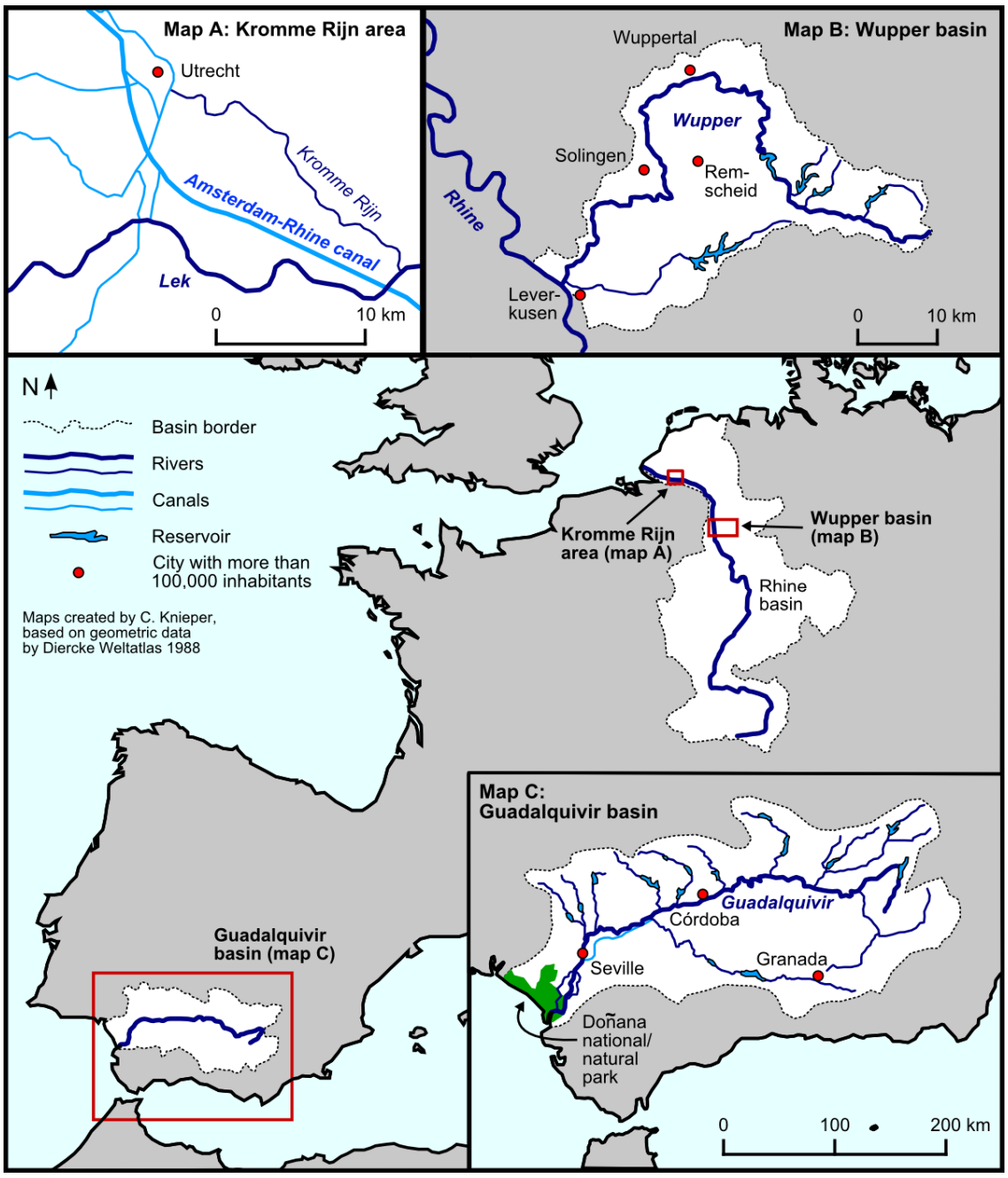


Figure 6: Map of case study river basins

5.1 Wupper

The river Wupper is a direct tributary to the Rhine (figure 6, map B). The catchment area encompasses about 814 km² and the Wupper itself has a length of 115 km. Rainfall in the Wupper catchment is characterized by high variability, ranging from about 1,400 mm/a in the upper part to about 750 mm/a in the lower parts of the basin (average about 1,200 mm/a, German average about 770 mm/a). (www.newater.uos.de, www.wupperverband.de)

The basin is located in the German state of North Rhine Westphalia, which is characterised by industrial uses and a high density of population with an average of 1,040 inhabitants per km². Since decades, the anthropogenic development of the region has influenced the rivers in their use and appearance. Rivers have been polluted and their flow was changed. Due to the latter fish migration is hampered. However, with the amelioration of the water quality during the last years, different fish species have repopulated the catchment and the rivers have also become more attractive for recreational uses, such as fishing and hiking. Dams were constructed in order to provide the region with drinking water.

The Wupper is mainly managed by one water authority, the Wupperverband (WV), which also coordinates different water uses in the Wupper basin. At state level 'Land' there is the regional government 'Bezirksregierung Düsseldorf' (BR Düss) with their departments related to water management as well as several public authorities on different lower levels (districts, municipalities). Apart from those multiple public authorities and the WV itself, important stakeholders in the Wupper basin include among others more than 1000 companies, about 1000 farmers, 5 water suppliers, 55 fishing clubs, and 16 environmental action groups. The region now faces the challenge to implement the WFD. The Wupperverband led the participatory process in a subcatchment of the Wupper, the Dhünn basin, as a pilot project for the implementation of the WFD, which then fed into the formal decision-making process at the BR Düss. The main aim for the Dhünn catchment was to restore the fish population and reach a better ecological status as required by the WFD. (Möllenkamp et al. 2008)

5.2 Kromme Rijn

The Kromme Rijn is a subcatchment of the Rhine basin in the Netherlands (figure 6, map A). The total catchment of the Kromme Rijn is approximately 350 km². The Rhine changed its course several times over the past. Nowadays the Kromme Rijn drains the water from the surrounding hilly and sandy area of about 50m above sea level.

The land use of the catchment is diverse: woodland in the hilly area including a drinking water extraction area and a large nature reserve and several large estates and some villages. The lower part used to be fed by seepage water from the hilly area, but got drier as the seepage was reduced due to increased drinking water extraction and drainage of the fields in the lowlands, largely used for pastures and horticulture. The area is also increasingly used for recreational purposes, given the growing urbanization around Utrecht city (300,000 inhabitants).

Water is managed by the water board ('waterschap') Hoogheemraadschap De Stichtse Rijnlanden (HDSR) in accordance with the national and provincial government. Water boards are governmental institutions in charge, at regional and local level, of development, maintenance and monitoring of water bodies, including dikes, granting permits for water use, and treating urban waste water. They are composed of different groups of stakeholders such as owners of real estate of land and buildings, residents and companies (Havekes et al. 2008). HDSR is responsible for

several water areas for each of which they have to set up and implement a water area plan. The Kromme Rijn water area plan served as a pilot project for setting that plan up in a participatory way. That way the main water issue in the area of a need of increased water supply for the area was addressed and discussed with the conflicting farmers groups. The fruit farmers need more water whereas the dairy farmers do not but would have to concede part of their land if water supply should be increased (www.newater.uos.de, www.hdsr.nl).

5.3 Doñana

The Doñana region is located in Southern Spain, in the Western part of Andalusia (figure 6, map C). Hydrologically, it belongs to the estuary of the Guadalquivir River. The climate is Mediterranean with hot and dry summers. The landscape is characterized by rather dry scrubland, and stable as well as mobile dunes along the coast. Most characteristic for the region though are the large marshes, one of the most important remaining wetlands in Europe, of international importance for breeding, staging and wintering birds (Marín Cabrera and Garcia Novo 2006).

Doñana holds several protected areas and different kinds of protection status[8]. In 1969, the Doñana National Park was founded for the protection of the wetland area, added by the Natural Park as buffer zone around it in 1989. In 1999, the two parks were joined into one protection area END (Espacio Natural de Doñana), since then managed by the regional government (Junta de Andalucía). The total protected area is about 110,000 ha (Marín Cabrera and Garcia Novo 2006: 77).

Through various activities such as canalizations, transformation into rice fields and eucalyptus plantations the marshes got reduced from formerly 140,000 ha to nowadays 27,000 ha. The main economic activities in the area which are directly or indirectly using water or affecting water dependent eco-systems are cultivations of rice and strawberries, cattle farming, and tourism (Serrano and Serrano 1996).

The River Basin Authority CHG (Confederación Hidrográfica del Guadalquivir) is responsible for water management and sets up water plans for the basin. The next one is due to approval in 2009 (www.chguadalquivir.es). The regional government (Junta de Andalucía) manages the END. Another important player is the Doñana Biological Station EBD, a public research institute belonging to the Spanish Council for Scientific Research CSIC. Besides there are several restoration projects, the most important one being Doñana 2005 which was launched in 1998 after the toxic spill of the mine accident in Aznacóllar upstream the Guadalquivir Estuary with the aim of hydrological regeneration of the watersheds and river channels flowing toward Doñana. Currently, there are discussions underway for a proposal of a Doñana 2015 project.

The interests of the actors in the region are diverse and the interwoven and shifting responsibilities for the management and positions in the different projects complicate coordinated and transparent decision-making. What has been lacking so far is a shared objective for the management of the marshlands and the whole area. A lot of action plans, restoration projects etc. have been launched and implemented but so far there is no superordinate goal for the region accommodating the different interests.

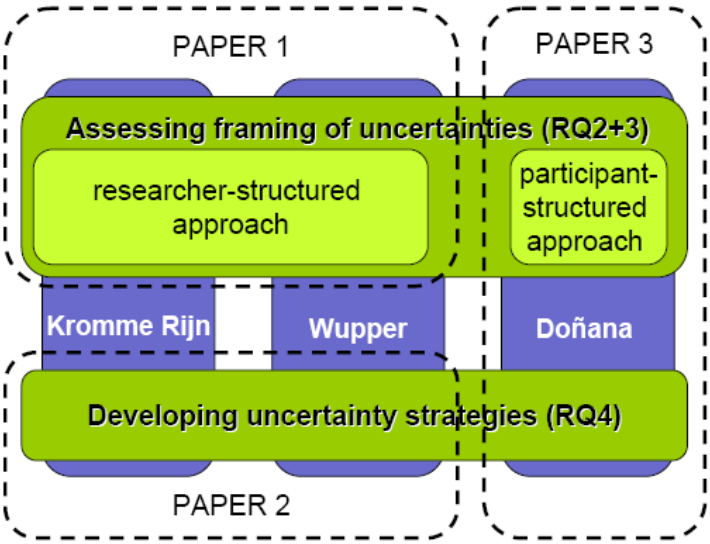
[8] UNESCO Biosphere Reserve (1980), RAMSAR (1982), SPA (Special Protection Area for Birds, 1988), UNESCO World Heritage (1994) (Marín Cabrera et al. 2006)

6 Results & Discussion

In the following, the case study findings of this research are discussed. The section sums up the main findings of the present research and discusses them in relation with the four main research questions (RQ). As the three papers (section 9) contain the bulk of the results of the present research they are referred to throughout the results and discussion section for more detailed information.

Figure 7 illustrates the relation between the different approaches, research steps, and research questions as well as the case studies and the three papers.

Figure 7: Thesis structure



Findings to the RQ 1 on what uncertainties water managers perceive are presented in section 6.1. RQ2 on the different methods of assessing framing of uncertainty is dealt with in section 6.2 (papers 1 and 3). Section 6.3 addresses RQ 3 on how uncertainties are getting framed (mainly papers 1 and 3). Current ways of dealing with uncertainty and RQ 4 on how the strategies for dealing with uncertainties in WRM practice can be improved with the help of parameters of framing is discussed in section 6.4 (paper 2). Section 6.5, finally, gives a critical reflection on the overall project of this thesis.

6.1 Uncertainties in the case studies

In the following sections the uncertainties are presented that the participants of the case studies reported on in the first meeting (phase 1). The uncertainty situations that were selected by the participants of the case studies as most interesting to focus on in the phases 2 and 3 of the research are illustrated in bold letters in the tables 7 and 8. The eventually selected uncertainty situations in each case study can be found in the sections 8.2 and 8.3.

6.1.1 Uncertainties in the Wupper case

The uncertainty situations the participants in the Wupper case study mentioned in the discussions of the group meeting of phase 1 of the present research are presented in table 7. The main strategies to deal with uncertainty that resulted from the group discussion are modelling,

improving the knowledge base by either generating own data through gauging systems, exchange with colleagues and other experts or else input from scientists. Usually there are no formalized approaches for dealing with uncertainty. Frequently, uncertainty is dealt with by experience or by intuition.

The allocation of the uncertainty examples to the cells of the UM was not always evident. Some examples required discussion among the participants before agreeing on a cell where to place it. Some examples were found to cover various cells (see uncertainty examples in extra boxes in the matrix). The most debated part of the matrix were examples from cell 9 on multiple framings of social aspects of the system. In general, the uncertainties of the social area, involving the broad public or society as a whole in relation to decisions taken in water management prevailed in the discussion of the examples.

Table 7: Uncertainty Matrix Wupper[9]

Type of knowledge relationship / System	**Unpredictability** (due to variability and complexity of the system)	**Incomplete knowledge** - lack of information - unreliable information - lack of theoretical understanding - ignorance	**Multiple framings of knowledge** - different and/or conflicting ways of understanding the system - different values and beliefs
Natural aspects - climate impacts - water quantity - water quality - ecosystem - ...	**1**	**2** • **Identification of parameters, e.g. for flood risk maps**	**3**
Technical aspects - infrastructure - technologies - innovations - ...	**4** • **Unclear impacts of land use change (see cell 7)**	**5** • **Interdependencies of system parts and processes: methods not available or deficient, e.g. fish (quality)** • **Kind & extent of public participation in decision-making processes***	**6**
Social aspects - organizational context - stakeholders - economical aspects - political aspects - legal aspects - ...	**7** • Unclear impacts of land use change in the catchment, i.e. agriculture, e.g. on the dynamics of run off • Singular events/ catastrophes as consequences of demographic change • Change of trend or paradigm at the WFD • **Economic development*** • **Societal behaviour under pressure***	**8** • Acceptance of WFD in society* • **Communication/ translation of goals*** • Communication of remaining risks ("*Restrisiken*") towards the public/society*	**9** • **Incorporation of climate change impacts in flood risk maps** • Habits in dealing with flood risk (technically solvable but question of ways how to do so) • Change of trend or paradigm at the WFD: from euphoric with regard to implementation up to hesitant and delaying. Increased pressure through deadlines • **Acceptance of WFD in society*** • Political system - who gets his ideas through?* • **Societal priorities*** • **Administrative levels***

Ecosystems: no adequate models for the description of processes

Stever project: Macro-zoobenthos (surprises)

Communication of uncertainty to public and media

[9] The uncertainty situations from the Uncertainty Dialogues (Dewulf et al. 2008) the participants of the present research considered relevant are included in table 11 as well (marked with *).

6.1.2 Uncertainties in the Kromme Rijn case

The uncertainty situations the participants in the Kromme Rijn case study mentioned in the discussions of the group meeting of phase 1 are presented in table 8. The main strategies to deal with uncertainty the participants reported were derived from the uncertainty examples discussed in the group. Same as in the Wupper, the allocation of the uncertainty examples to the cells of the UM was not always evident. Some examples required discussion among the participants before agreeing on a cell where to place it. Moreover, several issues were found to cover various cells (e.g. uncertainty n° 5) which were then specified and split up into sub units. Besides, the distinction between natural and technical system was considered to be blurred for the case of the Kromme Rijn since in the Netherlands nature is mostly controlled and modified by technology. This is reflected in the example 5.a which was placed on the line between the natural and technical system, covering both aspects. All in all, examples of uncertainty in the social area prevail. This may be due to the fact that technical and natural aspects were reported to be perceived as easier to deal with.

One important strategy to prevent uncertainties was seen in detailed planning, including making responsibilities clear. On the other hand control of established systems, monitoring, evaluation and revision of decisions is seen as important. The Kromme Rijn participants acknowledge that not all uncertainties can be prevented and that one has always to be prepared for the unexpected.

Table 8: Uncertainty Matrix Kromme Rijn

Type of knowledge relationship / System	**Unpredictability** (due to variability and complexity of the system)	**Incomplete knowledge** - lack of information - unreliable information - lack of theoretical understanding - ignorance	**Multiple framings of knowledge** - different and/or conflicting ways of understanding the system - different values and beliefs
Natural aspects - climate impacts - water quantity - water quality - ecosystem - ...	**1** 5.a) U due to climate change	**2**	**3** 10) U about how to integrate differing policy goals in NL
Technical aspects - infrastructure - technologies - innovations - ...	**4** 4) U about the future of the fruit farming sector	**5** 5.c) U in modelling of precipitation (climate)	**6** 4) U about the future of the fruit farming sector 5.b) Multiple views on how to deal with climate change impacts
Social aspects - organizational context - stakeholders - economical aspects - political aspects - legal aspects - ...	**7** 7) U about market conditions for agriculture **8) U if a good decision from today will still be good in the future** 9) U about the development of land use 12) U in the political field (elections) 13) Hypes **16) Accidents / coincidences**	**8** 1) U about the reliability of information 6) U about the development of the water quality (WFD, vague goals)) 14) U about finances (e.g. co-financing, sponsoring of measures etc.)	**9** **2) U due to differing views on the responsibility for water supply in the region** 3) U about the possibility to implement the water area plan 15) U in the planning process in relation with communication 5.b) differing points of view on how to deal with climate change impacts **11) Contradictory advice for one situation (e.g. from two different ministries)**

- Numbers of the uncertainty situations according to their occurrence in the discussion/ transcript

6.1.3 Uncertainties in the Doñana case

The uncertainty situations the participants of the Doñana case study mentioned in the discussions of the group meeting of phase 1 are listed in table 9.

Table 9: Uncertainty situations Doñana

1. How to communicate uncertainties to the public?
2. How to set priorities when dealing with several uncertainties?
3. How would the marshlands react to the removal of the dike?
4. What are the socio-economic consequences of the WRM in the region?
5. What do we know about the natural system (marshlands)?
6. What Doñana/ marshlands do we want?
7. What is the security of an economic investment?
8. Have I considered all uncertainties?
9. How does the society react on a management decision? (example Agrio reservoir and question of distribution of water)
10. How does the agricultural sector evolve (e.g. effects CAP change)?
11. How do the different interests affect decision-making in management?
12. How to predict the medium recharge of the aquifer?
13. How to model the ecosystem?

6.2 Ways of assessing framing of uncertainty

For the empirical work in the case studies a variety of methods has been applied. Some of the methods have been developed explicitly for the purpose of the present thesis, i.e. to assess framing of uncertainty. The Uncertainty Matrix (UM) by Brugnach et al. (2008) has been used to distinguish different kinds of uncertainty (section 6.2.1). In addition to that, two different approaches were developed in the present thesis to assess the framing of uncertainty in water management practice (section 6.2.2). These two approaches are presented below and evaluated regarding their importance and applicability (section 6.2.3).

6.2.1 The Uncertainty Matrix as a tool

In the present research, the concept of uncertainty as a relational property has been followed. This is an important difference to traditional approaches since uncertainty as an objectively identifiable property excludes the possibility of uncertainty as residing in multiple framings, which precisely is an important kind of uncertainty in water management as could be seen in the case studies of the present work (section 6.1). On the one hand there may be differing framings towards an uncertainty, e.g. uncertainty about climate change as unpredictability or as lack of knowledge, and on the other hand there may be differing views on one and the same uncertainty, e.g. different ways of incorporating climate change into flood risk maps. Each of the kinds of uncertainty requires a different approach for dealing with it (Brugnach et al. 2008). Differences in framings of uncertainty need to be made explicit in order to effectively deal with them in multi-party settings. Else every actor will apply strategies according to his/her way of understanding the uncertainty resulting in conflicts that will get manifested if no efforts for mutual understanding are made (Gray 2003). The Uncertainty Matrix (UM) by Brugnach et al. (2008) proved to be a useful tool for specifying and distinguishing framings of uncertainty. By help of the UM the

uncertainty situations discussed in the Wupper and the Kromme Rijn could be structured (see tables 7 and 8). The participants themselves allocated the examples to the matrix. The allocation of the examples was not always undisputed. At numerous uncertainty examples the participants were not immediately in agreement where in the UM to locate the respective example, a clear sign for framing differences. Besides shifting the examples around the cells of the matrix some uncertainties also were eventually split up into several aspects, thus covering different cells (e.g. the example of climate change in the Kromme Rijn, see table 7).

6.2.2 Two approaches for assessing framing of uncertainty

Beside the use of the Uncertainty Matrix as a tool for a first distinction of framings of uncertainty two approaches have been developed and presented in the present research to assess the framing of uncertainty in water management (section 4.3). One approach to assess framing of uncertainty in water management is based on a set of parameters (referred to as framing parameters FP hereafter) (table 4). The FP were developed in an ex-post analysis from earlier interactions with water managers in several river basins within the NeWater project (the Uncertainty Dialogues (Dewulf et al. 2008), see also section 4.3 and paper 1). They are derived in a researcher-structured approach and were then used in the present research for assessing uncertainty framings in the case studies of the Wupper and the Kromme Rijn without further case-study specific adaptation.

The other approach presents a set of participant-developed criteria[10] (referred to as participatory framing parameters PFP hereafter)[11] (table 11). These criteria have been developed by the participants of the Doñana case study themselves by help of the method of card sorting (see paper 3).

Both approaches aim at assessing the framing of uncertainties through a set of parameters. These parameters are regarded as influential in how uncertainties are getting framed in water management. But what exactly can be the overall usefulness of parameters of framing for dealing with uncertainty? Is not a method that is based on a few parameters in order to assess somebody's framing of uncertainty doomed to failure when framing is a complex process with conscious and unconscious processes, deep-rooted values and beliefs, changing interests and feelings according to changes in the environment and interactions with other actors? An inherent drawback in identifying parameters of importance in the framing of uncertainties certainly is "*that we almost never know what the factors [are] that result in a decision that we have made. Much of our understanding in a choice situation can be tacit knowledge […]. We perceive things which we are not even consciously aware of, and this data can affect a decision. Attempts to determine the factors and their weights can be made, but the basic problem is that we are always uncertain as to the dimensions of the knowledge space that must be measured*" (Denzau and North 1994: 10). This is true for any decision situation. However, that does not mean that nothing can be done. The idea of the present thesis was to contribute to making decision-taking under uncertainty in water management practice more explicit and structured which so far is mainly based on intuition and experience. Both approaches applied in the present research have shown potential for making framings and differences in framings explicit (see sections 6.1, 6.3, and 9). As the way an uncertainty is framed in turn influences the search for a solution the parameters of framing may also be used, individually or in a group, for

[10] The term "criteria" stems from the method of card sorting. For the present research "criteria" and "parameters" are used interchangeably.

[11] As a more general term 'parameters of framing' is used, subsuming both FP and PFP, and which in principle is open to further parameters as well.

developing strategies for better dealing with uncertainty and thereby structure decision-making in water management practice under uncertainty.

6.2.3 Evaluation & Application options of the two approaches

With regard to my concern to develop a directly participant-structured approach for analysing framings of uncertainty as an alternative to the parameters derived by ex-post analysis several observations can be made. In general terms no clear superiority of either approach could be discerned. Still, strengths and weaknesses of the two may be pointed out. The identification of parameters in the ex-post analysis by the researchers may have missed aspects that are important for the actual actors in water management practice (see also Shrader-Frechette 1995). Hence, the participant-structured approach promises to be more meaningful and practically useful for the actors in water management as it has been directly elaborated by them. Nonetheless, the pre-structured approach may render additional information beyond the participants' point of view, adding aspects that water managers may be reluctant to discuss or unable to identify as they are bound by their framing from water management practice.

This implies several possible ways for developing and using parameters of framing of uncertainty from the two approaches:

1. Using a combined list of parameters: The list of parameters developed through the card sorting (PFP) may be joined with the FP into one list of parameters for a more comprehensive approach to uncertainty framing. The usefulness of combining the two lists would have to be tested in practice in a number of case studies.

2. Using the card sorting method to develop context-specific parameters in each new case: Parameters can be elaborated newly for each case, making use of the card sorting method, in order to develop parameters that are definitely meaningful for the actors in the respective cases. Through applying such an approach across a range of case studies the developed parameters of the present approach can be validated or alternatively, a set of 'basic' parameters shared among the case studies and added by context-specific parameters may be identified. Certainly, eliciting knowledge individually in each case is demanding and time consuming. This concerns more the analytical part than the exercise itself. Semantic analysis requires time (McGeorge and Rugg 1992; Fincher and Tenenberg 2005), especially when participants use semantically similar labels as in the present case (see paper 3). Disentangling the different meanings and concepts within the group of participants then takes time. Nonetheless this option has the advantage that the process of interactively elaborating the criteria and categories helps to raise the awareness among the actors on framing differences through in-depth discussion of the criteria and categories.

A third, combined option may prove useful to make use of the advantages of both approaches discussed earlier. This would involve starting with the card sorting method to develop locally relevant parameters, and afterwards provide the comprehensive checklist to give the participants the chance to broaden their insights by using checklist parameters that they did not come up with but may consider relevant. This approach is also promising regarding the establishment of a sound knowledge base on the framing of uncertainties which would allow deriving more general conclusions on the importance of local factors compared to generally applicable parameters.

6.3 Participants' framing of uncertainty in water management practice

The different assessment methods of framing of uncertainty rendered different results. Below the results of the assessment of framing of uncertainty are illustrated for the three case studies. The framings were elicited at the example of selected uncertainty situations in each case study (see sections 8.2-8.4). The results are presented here in an aggregated form. Overlaps and salient differences in framings are highlighted. However, it is impossible to sum up the interview results into universal findings. Details on the framings assessment and the individual interviews are available on request in German, Dutch and Spanish respectively.

With regard to cultural differences no major peculiarities could be observed. Despite being located in different countries with different institutions, challenges and issues at stake no salient cultural differences could be detected. If at all, then in the Dutch case study participants seemed to be more open to experimentation whereas in the German case orientation at norms and prescriptions was higher. The Spanish case did not stand out for a special feature. No other group category such as profession, age or sex gave hints for a noticeable difference between the case studies either. Neither could general conclusions be drawn throughout the cases with regard to uncertainty-averse or uncertainty-oriented attitudes other than that it appears to be a primarily personal matter regardless of the nationality, profession or experience in dealing with uncertainty. This goes in line with findings of (Dörner 1993) on the search of characteristics for the capacity for dealing with complexity and indeterminacy. According to Dörner features such as sex, political views or intelligence prove to be non-determinant but rather personal traits as eagerness for learning and self-assuredness.

6.3.1 Framing of uncertainty in Wupper & Kromme Rijn

The results of the Wupper and the Kromme Rijn are presented jointly along the framing parameters. Where appropriate, differences between the case studies are pointed out[12]. For details please see paper 2.

Positioning

As a more general tendency one can state a dominance of a negative stance towards uncertainty with the preference of certainty over uncertainty and the positive aspect of uncertainty considered as a chance to reduce and overcome the uncertainty. This reflects a more traditional view on uncertainties in line with the command and control paradigm. That does not mean that all and every participant shares this view. In fact, there is heterogeneity in all three cases in terms of the attitudes and stances the participants take with regard to uncertainty in water management, ranging from clearly disliking uncertainty and trying to eliminate it where possible to considering uncertainty as an interesting challenge and a positive attribute that allows a lot of freedom in decision-making; the latter however clearly being less frequent.

Trustworthiness

In both case studies trust is seen as very important. Decision-making in water management often is a multi-party process where the action or outcome depends on the goodwill of all actors involved. Mutual trust is considered important among the participants in order to avoid lock-in situations. Trust is also expressed by somebody's expectations to another actor, i.e. the trust that

[12] WUP = Wupper and KR = Kromme Rijn

the expectation will be met. In this regard, project leaders in the case studies reported to not expect participants of a process to contribute more than saying what they think – and sometimes not even that since some respondents anticipate that stakeholders might hold back their cards or not commit fully in order to be able to withdraw later. Consequently, a common finding throughout the cases and discussed uncertainty situations was that open communication and transparency play an important role in enhancing trust and constructively dealing with uncertainty. Scientists by contrast, are commonly expected to give guidance and provide data and certainty (please see paper 2 for extensive discussion).

One concrete example of expectations towards others is the case of the updating of flood maps in the Wupper region. The request of the participants of the present research would be to update the maps more frequently in order to better evaluate the current situation and prepare for the future. The realization, however, is seen rather sceptical since the regional government is cutting down personnel and expenses more and more.

Type of uncertainty

The three types of uncertainty addressed in the present research, i.e. unpredictability, lack of knowledge and multiple knowledge frames, were all recognized by the participants (cf. section 6.1). Besides, the participants acknowledged the role of framing and found that indeed one uncertainty situation may even be no uncertainty at all for another person.

Uncertainty of unpredictability, variability, and complexity of the system is seen as difficult to overcome. The link with the type of uncertainty 'lack of knowledge' was pointed out as the achievement of complete knowledge is considered impossible. Knowledge is seen as always to be imperfect due to necessary generalization or simplification of descriptions. However, there are knowledge gaps that can be closed. One example from Wupper was lack of knowledge about how actor participation required by the WFD should take place. Eventually the knowledge gap was closed and the uncertainty was solved through experience and trying out a participatory process (under external guidance). But even if the approach proved to be successful some participants stated that there still remained the uncertainty about which approach would be the best to tackle the problem. Even if the chosen one had worked quite well it might be that another way could also prove to be useful or even better. With regard to multiple frames communication is seen as very important when dealing with differences in views and knowledge (KR).

Urgency

Usually in environmental decision-making there is a discrepancy between the time required for solving the uncertainty and the time available for decision-making. The participants reported for almost all uncertainty situations that ideally a lot of time should be invested to solve the uncertainty while the decisions had to be taken under time pressure. The Kromme Rijn participants differentiated between different phases in a process and according changes of uncertainty from many uncertainties in the rather broad and vague beginning of a process which focuses and narrows down along the phases of the process.

Responsibility

Responsibility in water management is seen to be in the hands of the public administration in both case studies. Others may participate and give their opinion but the responsible entity, e.g. a water board, takes the final decision.

Hardly concrete persons were seen as responsible for having caused an uncertain situation but rather situational complex circumstances (WUP) respectively an unclear situation of responsibility for a certain task (in this case water supply in the KR) and a shared responsibility in terms of a policy that has not been thought through very well (KR). Responsibility issues tend to be formulated carefully and not person specific, e.g. "*if the decision had been taken earlier, there would not have been an uncertain situation in the area now*" (interview statement).

6.3.2 Framing of uncertainty in Doñana

Different to the method applied in the Wupper and the Kromme Rijn, in the Doñana case the development of the method and the assessment of framing was performed in one step. The discussion in the first group meeting had rendered a sample of 13 uncertainty situations. As a next step no individual interviews were held as in the other two case studies but the framing was assessed indirectly through the method of card sorting (see section 4.7 and paper 3 for details). With that method the participants produced a range of criteria and categories (table 10).

The allocation of the individual uncertainty situations to the categories differed among the participants which clearly manifests differences in framing among the participants.

Table 10: Overview of number of criteria and categories derived per subgroup

Subgroup n°	Criteria	Categories per criterion	Remarks
1	3	3-4	for one of the criteria some cards were discarded
2	5	3	
3	./.	./.	methodology was performed differently due to misunderstandings and no usable criteria were produced
4	6	2-4	

For instance, for the uncertainty n°1 on how to communicate uncertainty to the public, with regard to the criterion 'capacity to tackle the uncertainty' one group of participants would give it the category 'easy' whereas another group categorizes it as 'difficult'. Same holds for the uncertainty situation n°11 of how different interests affect decision-making in management. Here as well there are huge differences among the participants as to how easy or difficult they consider this uncertainty to be tackled and solved. Similar differences could be observed for other uncertainty situations and with regard to other criteria of framing. Such differences can be instructive for making framing differences clear, enhance mutual understanding and enable reframing.

The total of 14 individual criteria with a total of 42 categories produced among the subgroups was merged into a shared list of 9 criteria and 27 categories (see table 11). The list reflects criteria (or parameters) that are important for the participants of the case study in dealing with uncertainty.

For more details on the card sorting process and results please see paper 3.

Table 11: Doñana list of criteria and categories derived from subgroup results (Isendahl 2010a)

Criteria through card sorting in workshop I	**Categories**
1. Capacity to tackle the uncertainties	▪ difficult / no methodology available/ intrinsic/ perception or social criterion ▪ medium / ideas how to develop methodology/ functioning and response of the natural-ecological and socio-economic systems ▪ easy/ methodology available/ status of knowledge
2. Type of uncertainty/ sectoral structure	▪ Social ▪ Environmental/ ecological ▪ Economic ▪ Philosophical-political
3. Urgency/ Priority to deal with the uncertainties	▪ 1st step (very urgent) ▪ 2nd step (medium) ▪ 3rd step (less urgent)
4. Conceptual clarity/ knowledge about the problem or the uncertainty	▪ big ▪ middle ▪ small
5. Level of action	▪ local/day to day ▪ general/ strategic ▪ theoretic
6. Recognition of the uncertainty as such by the public	▪ easy ▪ medium (recognition of the uncertainty is minor) ▪ not perceived as uncertainty by the public
7. Strategy to tackle the uncertainties	▪ traditional-technical ▪ adaptive management ▪ unsolvable
Additional criteria through discussion in workshop II	
8. Capacity to assess ['*valorar*'] the unforeseen consequences of the uncertainty	▪ high / easy ▪ medium ▪ low / difficult
9. Cause of the uncertainty	▪ complexity ▪ unpredictability

6.3.3 Validity and importance of the parameters of framing of uncertainty

The PFP are evidently purely based on the participants' framings in the Doñana case and thus primarily reflect a local importance. The FP, by contrast, are based on a range of case study findings in several European river basins. They therefore may be of more general importance in framings of uncertainty in water management practice. It is thus interesting to asses whether those FP capture issues identified elsewhere in literature and whether they can be assumed to be promising to actually integrate the most important framing parameters over a wide range of cases. Deriving such a generalization would be valuable in order to develop standardized methods.

The relevance of the Framing Parameters

Evidence of the importance of individual framing parameters is supported by findings in literature on frames analysis and on dealing with uncertainty in policy-making (Aarts and van Woerkum 2002; Kaufman et al. 2003; Lewicki et al. 2003; Mathijssen et al. 2008). In their analysis of frames in environmental conflicts Lewicki et al. (2003: 15) note that "*[f]rames are used to (1) define issues, (2) shape what action should be taken and by whom, (3) protect oneself, (4) justify a stance we are taking on an issue, and (5) mobilize people to take, or refrain from taking, action on issues.*" This listing hints to various FP identified in this thesis: The second point indicates the importance of 'responsibility' as FP, the fourth one points out the relevance of 'positioning', while the fifth point can be related to urgency matters in dealing with uncertainty. In Kaufmann et al. (2003) we find annotations to the risk and information frames that give hints to the importance of 'urgency' as well as 'trustworthiness'. Kaufmann refers to the potential of these frames for indicating the reliability of information for a disputant (FP 'trustworthiness of data') on the "*degree to which the risk is dreaded*" as influential for the frames (*ibidem*). The latter opens space for analysis of both 'positioning' and 'urgency'. With regard to the latter two, Aarts and van Woerkum (2002: 426) also highlight the discrepancy between new ways of thinking that may be inevitable or even desirable for the long term but not considered as feasible in the short term for fears of taking concrete decisions that would be necessary to clear the way for structural change. This clearly reflects the discussions in the Wupper on the issue of how to assess and deal with likely climate change impacts (see paper 2).

Lewicki et al. (2003) again link 'positioning' with 'responsibility'. They state that framing means to position oneself or take a stance with respect to an issue or an event, which also includes claims about the causality of the issue (how and why events have occurred) as well as the question of responsibility ('naming and blaming' (Dewulf et al. 2005)). Responsibility is mentioned in several other studies as well. In a project on decision-making under uncertainty Wardekker et al. (in Mathijssen et al. 2008: 12) report of several dilemmas amongst which, one is the unclear distribution of responsibilities ('the government is going too far' versus 'the government is not doing enough'). Another feature common in decision-making by governments or public administration is that responsibility is put to formal structures and norms. "*Politicians would like to 'learn' but they do not dare 'try' for fear of being told they 'failed' at a later stage*" as Mathijssen et al. phrase it (2008: 22). This confirms findings in the Wupper and the Kromme Rijn of administrative rules as being in the way of sound decision-making (see paper 1). Responsibilities are also identified as an important issue by Aarts and van Woerkum (2002). They report that actors often put forward the 'blame-question', i.e. who is responsible for having caused a certain problem (*ibidem*: 429). This gives the basis for an interesting connecting question, i.e. who is considered responsible for dealing with the problem or uncertainty. As the results of my case studies show, the question of dealing with the uncertainty may be crucial and is not always made explicit. Often, responsibilities are assumed to be obvious as was the case for the question of responsibility for the water supply in the Kromme Rijn or the responsibility for finding the right measures to deal with climate change impacts in the Wupper (cf. paper 2).

This leads over to the link of responsibilities with expectation. An experience from a project in the Netherlands points to the role of expectations: "*The cabinet concluded that the Dutch government is incapable of preventing or controlling all of society's problems, but that society expects them to*" (Mathijssen et al. 2008: 12). Similar findings were frequent throughout the case studies of this thesis. Particularly representatives from governing organs or public administration feel themselves confronted with

expectations of the public to act in a certain way. The findings suggest that it is important to make such expectations explicit and most importantly to verify assumed expectations in order to be able to constructively deal with the situation. Else, the uncertainty may be left unaddressed for a long time if person A expects person B to solve it but B is not aware of that. Expectations furthermore always reflect a certain trust in the other party to meet that expectation. Koppenjahn and Klijn (2004: 83) remark that trust is actually intrinsically linked with uncertainty as uncertainty is constituent for trust. Without uncertainty there would be no need for trust. Besides trust in other involved actors, Aarts and van Woerkum (2002) state self-confidence, i.e. trust in oneself, is also crucial when goals have to be achieved and particularly if the goals have to be changed in a multi-actor setting.

These findings from literature suggest a more general importance of the FP identified in this research beyond the findings of the case studies of the Uncertainty Dialogues (Dewulf et al. 2008) they are based on. The case study findings of the present thesis also confirm the usability of the parameters (paper 2).

The relevance of the Participatory Framing Parameters

In spite of the positive findings of applying the FP in the case studies, different ways may be possible for assessing the framing of uncertainty in water management practice. The participant-based approach followed in the Doñana case study (paper 3) proved to be useful as well and rendered slightly different benefits. Through the process of elaboration of the criteria by the participants themselves, discussion about the criteria and underlying implicit concepts was enhanced when various terms were used in an overlapping and exchangeable way. Through the clarification of each participant's understanding of the terms, framings were made explicit and a common base was achieved on which to build on for further discussions and elaboration of strategies to deal with uncertainty. The experience in the Doñana case suggests that a participant-based approach enhances the cohesion among the participants and fosters the identification with the results which is more promising for commitment to future actions. Moreover, it points to the importance of an interactive process of communication and making framings explicit (see paper 3).

Possibly, the FP would have also made sense and been useful for the Doñana participants. However, in their elaboration the participants came up with mostly different criteria (see paper 3). Of course it is difficult to draw general conclusions from a few case studies. Reasons for the observed differences in criteria may be multiple. The case studies differed in terms of relevant issues in the regions as well as the institutional and cultural setting. In fact, all those three factors may have been of influence but they are difficult to trace. However, signs of shared mental models and beliefs can be found within and among the case studies (see section 6.4).

6.4 Improving dealing with uncertainty

In the following the approaches and strategies developed in the case studies are evaluated with regard to their aptness for improving dealing with uncertainty, particularly in light of the requirement for adaptive innovative approaches.

6.4.1 On the way to adaptive management?

An overarching finding is that uncertainty is mostly dealt with by experience or by intuition in the case studies. This confirms recent findings in environmental decision-making (Mathijssen et al. 2008; Sigel et al. 2010). Deliberate dealing with uncertainty in a comprehensive systematic and structured way has not taken place so far. The strategies for dealing with uncertainty that were found in the case studies cover both traditional and more innovative adaptive approaches. No clear relation can be drawn to solely the 'prediction & control' or the 'adaptive management' paradigm in either of the case studies based on the findings of this research.

The ways of considering uncertainty, and addressing it, differ in the case studies. In terms of adaptive approaches in water management there is most evidence in the Kromme Rijn even if inheritance of the traditional controlling paradigm is still abound there as well. Due to lacking indicators or other concrete guidelines for the evaluation of adaptive management approaches, the strategies to deal with uncertainty developed in the case studies are evaluated against the more general parameters for AM, i.e. to which extent the elaborated strategies to deal with uncertainty contribute to or allow for an overall acknowledgement of uncertainty, joint knowledge production, flexibility in decision-making and for fostering of experimentation and learning processes.

The participants of the Kromme Rijn were notably influenced by the novel participatory process of elaborating a water area plan and showed to be most open for trying out new ways of action. The more general strategies currently applied in the Kromme Rijn reflect a learning process from previous actions (within the context of the development of the water area plan). What the Kromme Rijn participants concluded from earlier uncertainty situations is that detailed planning may prevent the occurrence of too many uncertainties and that it is helpful to make responsibilities clear. These findings show that learning processes, same as for adaptive management (AM) in general, are equally important for dealing with uncertainties. As a consequence, the Kromme Rijn demonstrated one of the more adaptive approaches in the case studies of dealing with uncertainty in an example of drawing intermediate deadlines to a decision problem where uncertainty could not be solved or eliminated completely (see paper 2). Such an approach is contrary to traditional approaches of refraining from action unless full knowledge is achieved (or at least sufficient knowledge with regard to an established goal). In the Kromme Rijn, one possible solution option was tried out, i.e. purchase of land necessary for broadening a water supply channel on a voluntary basis, which will be revisited if not successful after a time period of two years.

In the Wupper, the main strategies to deal with uncertainty that are currently applied are rather traditionally oriented such as modelling, improving the knowledge base by either generating own data through for instance gauging systems, exchange with colleagues and other experts or else input from scientists. One salient example for adherence to traditional approaches in the Wupper case, which can also be found widely in literature, is that of the assessment of climate change impacts, where voices are kept being raised asking for more certainty, which, with the current

state of the art, cannot be delivered (e.g. Bergkamp et al. 2003; Renn 2009). "*Decisions will need to be made before conclusive scientific evidence is available*" even if the knowledge basis is incomplete (van der Sluijs 2007: 591). The role of the scientists as providers of certainty and that of public administration to demonstrate certainty and provide information for the public ('*Garantenpflicht*', '*Bringschuld*') as conveyed by the participants reflects a classic distribution of roles, under which implementation of adaptive management is difficult or unlikely.

In the Doñana case, there is consensus or a shared belief in the group of participants that uncertainties need to be taken more into account in water management and that adaptive management can provide a useful approach for that. This belief, in the opinion of the participants, is not necessarily shared (yet) by the other actors in the region, probably also a reason why precisely those participants were willing to engage in the participatory research of the present thesis while others that had been invited declined. So far, no explicit approaches have been undertaken in the case study region in order to address uncertainties beyond sensitivity analysis for models performed by scientists. In order for the idea of Adaptive Management to gain ground in the Doñana case more time is required. The approach is very new in the region and first experiences according to the principles of Adaptive Management are being made in an example of ecological restoration (Marín Cabrera and Garcia Novo 2006).

This may be a reason as well why not all optimization strategies are straightforward or compatible. The participants in Doñana emphasized the importance of assessing not only the natural and technical processes but also the social ones. While arguing for an integrative and learning oriented management approach where the objective is not to find the best solution but the one that 'causes least damage to the patient' (table 16) they still give considerable importance to increasing the knowledge base and improving predictions aiming for the best possible knowledge and stress the importance of scientists and scientific findings as basis for sound decision-making. In the participants' point of view scientists are to not only show the variety of possible action options in a situation of uncertainty but also to advise policy-makers, which alternative to best follow. This reflects a similar reluctance of taking on responsibility and taking action without a complete backing from scientists as in the Wupper case. Adaptive Management, however, precisely requires an experimental way of action.

At the same time the participants are aware that in natural resources management regardless of the strategy employed there will always remain a rest of uncertainty. These seemingly contradictory statements may be interpreted in the way that the Doñana participants are well aware of a need for change in the management style but have not yet given up the old traditional management ideal of maximizing knowledge and prediction for steering the system.

One important point that was put forward by the participants in all case studies was the need and importance to take into account uncertainties more deliberately. The participants are mostly aware of drawbacks of the traditional management approach and opt for acknowledging uncertainty, taking into consideration system complexity and including uncertainty assessments in their management of the water resources. However, this does not automatically mean that adaptive management is implemented and that adequate means are envisaged or employed to deal with uncertainty. In fact, most research of environmental psychology shows there is no or only a small relation between somebody's attitude and behaviour (Ajzen and Fishbein 1977; Limbourg 1999). Ajzen and Fishbein suggest that a strong relation between attitude and behaviour can only be discerned when both their target and action correspond (1977). The authors state that often attitudinal and behavioural measures are selected arbitrarily by the investigator which then leads

to supposedly inconsistent research findings. However, most of such research is directed at assessing individual behaviour. The case for representatives of public administration in water management as in the present thesis may be different. Here, rather a reason distinguished by Baumgartner (2005) for non-compliance with one's attitude applies, that is institutional and structural conditions. Evidently, it is more difficult to change behaviour within certain institutional boundaries, especially when they are in place since long and routines are established (Limbourg 1999). Limbourg also talks of a 'deficit in competence' for acting accordingly to one's attitude which relates to knowledge problems. The water managers may simply lack concrete methods and approaches to constructively deal with uncertainty and to implement adaptive management. As argued in section 2.2 the new threads of management, such as Adaptive Management (AM), participatory management or sustainable development, suggest a set of basic principles to address nowadays environmental problems characterized by high stakes, uncertain facts, disputed values and urgent decisions. These principles include acknowledging uncertainty and deliberately addressing them. However, concrete means of implementation, how to actually take into account uncertainty, are not specified. It is thus not astonishing to find positive attitudes with regard to more innovative and adaptive approaches but little implementation on the ground. In fact, there is no clear evidence for a full mind switch towards more innovative adaptive approaches in either of the case studies[13].

A trigger for change towards AM and related concepts in practice may be successful implementation of pilot projects or other innovative approaches which increase the likelihood for imitation (Limbourg 1999). This indeed can be observed in the researched case studies, e.g. in Doñana where approaches for ecological restoration according to AM principles were set up as a consequence of positive experiences in Canada (Marín Cabrera and Garcia Novo 2006). Another answer to the deficit in concrete methods for practitioners is the present research where methods for improving dealing with uncertainty have been developed in close interaction with water managers on the ground.

6.4.2 Tools for improving dealing with uncertainty

In Doñana, the participants concluded in a set of overall strategies for improving dealing with uncertainty during the first group meeting. These strategies could now be evaluated and extended along the PFP that were developed in the case study and applied to the uncertainty examples identified by the participants. In the Wupper and Kromme Rijn, the discussion of the individual framings and differences rendered a checklist containing a set of intervention options according to each framing parameter (table 12). The purpose of the checklist is to be used as a tool by practitioners when being faced with uncertainty in order to disclose uncertainty framings and differences, make them explicit and deal with them in a constructive and flexible way so that sound decision-making is enabled. In that, the list constitutes a structured yet simple and flexible tool for aiding decision-making in water management.

[13] For a comprehensive discussion of the suggestions of the Kromme Rijn and the Wupper for strategy options along the FP for improving dealing with uncertainty see paper 2.

Table 12: Check-list for improving dealing with uncertainty (Isendahl 2010b)

Strategy	**Concrete options for improving dealing with uncertainties**
Revaluing uncertainties (FP positioning)	▪ Acknowledge uncertainties as a fact of life ▪ Get a more positive stance towards uncertainties. Look out for positive aspects an uncertainty situation ▪ Be more daring and take on responsibility involved in being confronted with an uncertain future with multiple possible outcomes ▪ Maintain a level of mindfulness by looking out for uncertainties to avoid getting wedged in traditional habits ▪ Always leave some space for improvisation and positive coincidences ▪ Find other people who frame the uncertainty more positively
Enhancing trust (FP trustworthiness)	Trust towards other actors: ▪ Ensure involvement of all relevant actors ▪ Ensure and maintain open and transparent communication among actors ▪ Get clear about each other's stakes and expectations and verify with the respective actor if the expectations are likely to be met or not ▪ Rethink the role (and related communication pattern) of each, e.g. who is proposing, who is answering things, who is consulted, informed etc.) ▪ Transparent (and early) communication of uncertainties
Reconsidering the nature of the uncertainties (FP type of U)	▪ Reflect your dominant framing of type of uncertainty as unpredictability, incomplete knowledge or multiple knowledge frames (Brugnach et al., 2008) and consider if a reframing to another category would be more helpful in terms of strategies ▪ Unpredictability: thorough planning in the beginning, good organization and preparation including emergency plans, monitoring and evaluation, modelling, scenario development, precautionary measures, being flexible & able to improvise ▪ Lack of knowledge: get as knowledgeable as possible about the situation, that is narrow down, solidify and condense information, modelling. ▪ Multiple knowledge frames: communication (different patterns)
Reconsidering timelines & setting priorities (FP urgency)	▪ Prioritize uncertainty situations ▪ Design a deadline to draw a line and enforce a decision rather than constantly postpone taking action due to perceived lack of knowledge and certainty ▪ Actors' differences in urgency perception may be indications for high or low performance in solving the uncertainty situation – establish agenda/list with stepwise tasks and goals and a timeline for all involved actors
Reconsidering responsibilities (FP responsibility)	Responsibility for having caused an uncertainty: ▪ Acknowledge situational and system complexity Responsibility for dealing with an uncertainty: ▪ Check out who is formally responsible for what to get a clearer picture. If appropriate cross-check if that is the best distribution or if responsibilities may be shifted ▪ Check if you or other actors could help to solve the situation, e.g. take over some responsibility (e.g. shift to higher level), split tasks etc., i.e. strive for shared responsibility ▪ If responsibility not taken over (by anyone), start communication process with the actor/entity perceived as responsible

Most of the strategies proposed by the participants in the case studies, however, refer to future needs for dealing with uncertainty as compared to strategies that have been applied successfully in the past. With regard to yet unapplied strategies it has to be seen if they will indeed be approached and implemented in the case studies as envisaged. As pointed out in section 4.3 there may be discrepancies between verbalizations and actual performance.

6.4.3 Time for a mind switch

In all case studies, uncertainty is seen as something negative by most participants, which should eventually be solved or eliminated. Despite the recognition of the existence of uncertainty and of the illusion of complete knowledge in environmental decision-making, the participants pursue the ideal of certainty. This mindset is still very much in line with the traditional command and control approach. The actors are uncomfortable to deal with uncertainties since they lack the routines in professional life to deal with them. I argue that there is a need for a mind shift in direction of a more positive attitude to uncertainties. Grunwald (2008) in his work on sustainable development likewise argues for getting away from the 'lamenting tone' when discussing uncertainty. Of course, this does not mean to not solve any uncertainty anymore (because they are so much fun) and to open the doors to ignorance, but to look out positively for uncertainties and deal with them constructively. There is a need for education of people to be more 'uncertainty-oriented' in the sense of Aarts and van Woerkum (2002), which includes the recognition that decisions based on scientific information must be made in a context of uncertainty (Bradshaw and Borchers 2000). This means to move away from standard responses of traditional water management to uncertainty such as delaying or abandoning decisions due to lack of certainty and engage in research activities to improve the knowledge base (Koppenjan and Klijn 2004). Full knowledge as said before can, however, not be achieved in complex systems.

In conflict management, there are voices to move away from the unachievable "ideal" of consensus and harmony and give room for a more pluralistic management, which does not primarily focus on the reduction and elimination of conflicts (Stirling 2006; van den Hove 2006). For uncertainty management it can be argued in a similar way that the ideal of certainty is questionable, not only in terms of feasibility but in terms of desirability, and that not all uncertainty needs to be reduced or solved. Emphasis instead should be given to making uncertainties, and particularly the different framings of uncertainty, explicit. If in a pluralistic process uncertainties are not solved, of course this does not prevent from decision-making. But, the decisions then are made based on value judgement in the political sphere and not on supposedly certain knowledge or optimal solutions (Michael 1973; Koppenjan and Klijn 2004). Renn (2009: 562) puts forward that working with qualitative and semi-quantitative methods is often more adequate for analyses of relations between natural and social sciences problems and that for that purpose a tolerable impreciseness ("*tolerable Unschärfe*") may be even desirable. In other fields closely related with uncertainty authors have argued likewise. With regard to 'risk' Aaron Widalvsky remarks that "*no risk is the highest risk at all*" (1984, cited in Renn 2009: 564). Similarly, for uncertainty one can argue that if there is no uncertainty, or if people do not have uncertainties, they feel certain about taking action and thus have a limited perception that does not question what they are deciding and doing. Similarly, Koppenjahn and Klijn (2004) have argued that with convergence on perceptions actors run the danger to fail to recognize new problems and solutions. Therewith they are likely to pay less attention to possible failures and drawbacks and to be less attentive and careful to possible side effects or unforeseen consequences. The same holds true for uncertainty. Dewulf et al. (2005) follow a similar line with regard to ambiguity. They put forward that in fact ambiguity is needed to make transitions and innovations possible. Consequently, for uncertainty one could argue that uncertainty is a positive asset, particularly in a situation of impasse, as it constitutes a trigger for change. Without uncertainty people would not question what they are doing. Critical self-reflection is a first step towards reframing and learning which in turn is important for effectively dealing with problems

on a long term basis (Michael 1973; Friend and Hickling 1997; Lewicki et al. 2003; Koppenjan and Klijn 2004; Tippett et al. 2005; Dewulf et al. 2007; Ison et al. 2007; Berkes 2009). A second step is to acknowledge that there is not one unique way of representing the uncertainty but that other people may have different views (Lewicki et al. 2003; Koppenjan and Klijn 2004; Dewulf et al. 2007). It is essential to make framings of uncertainty explicit and disclose possible framing differences. It is widely argued that a necessary basis for taking action in environmental management is a shared problem perception (Friend and Hickling 1997; Ney and Thompson 1999; O'Connor 1999; Pahl-Wostl 2002; Dewulf et al. 2004; Koppenjan and Klijn 2004; Dewulf et al. 2009). On the basis of getting to know other people's framings of an uncertainty, different framings can be discussed and negotiated and new meaning can be jointly created in an interactional way (see also sections 3.2.5 and 3.2.6). This insight got manifest in the Doñana case with regard to the approach to a major uncertainty in the Doñana region, i.e. that of a lack of a shared vision for the region.

In the present research there is only scattered evidence of changes in framing and only with regard to concrete situations, in the sense of 'perceptions of current decision situation' (see figure 3), as opposed to more substantial change in the mental models. Reframing at the level of beliefs and values obviously takes more time and is difficult to judge. The present research may nonetheless have given impulses and triggered readiness for deeper change in the mental models of the participants of the case studies. This prospect is substantiated by the fact that the participatory research has introduced both cognitive and social variation on grounds of which reframing may be provoked (see section 3.2.6). The deliberate assessment of uncertainty in water management has been novel in all case studies (cognitive variation), and the participants were confronted with the others' mental models on uncertainty (social variation).

6.5 Critical reflection on the present research

The present research investigated how a process to deliberately address uncertainties can be prepared and guided through the approach of framing. The chosen concepts of framing and mental models applied to the relational concept of uncertainty proved to be useful for the purposes of the research. The three concepts complement one another and are instructive for analysing uncertainties from the perspective of water management practice. The interactive deliberate assessment of framings of uncertainty through the empirical research of this thesis was perceived positively by the participants in all case studies. It helped to raise the awareness about uncertainties and details of uncertainties, and the participants considered it helpful to get to know other actors' points of views. The individual assessments of the FP in the Wupper and the Kromme Rijn rendered a picture of how each actor frames the uncertainty examples with regard to the parameters.

The methods applied in the present research proved to be useful for their purposes, both practically and content-wise. Working in case studies in the unit of focus groups was appropriate for analysing framings. The size of the groups of participants enabled a productive and manageable combination of group and individual contacts. In group discussions individual voices could still be heard and singled out. In purely individual contacts the dynamics of connecting different framings in a group and jointly develop strategies would have been lost. In a group with too many participants by contrast, it would have been impossible to address every participant individually and differences between individuals would have most likely have got blurred.

The Uncertainty Matrix by Brugnach et al. used in the Kromme Rijn and the Wupper for the assessment of uncertainties was easy to understand for the participants. The participants also could relate the uncertainty situations to the framing parameters. However, conceptually, the framing parameters cannot always be delineated sharply from each other. The type of knowledge relationship 'incomplete knowledge', for instance, among others comprises unreliable information. This is very close to the FP of 'trustworthiness' in the sense of trustworthiness of data. However, not all trustworthiness relates to unreliable information and not all incomplete knowledge is untrustworthy. Trustworthiness also refers to trust among actors while incomplete knowledge may also simply be a lack of knowledge regardless of the reliability of information. Indeed, Syme and Williams in their study on perceptions on drinking water quality in Western Australia find that perceived credibility or trustworthiness of the water authorities proves to be more important with regard to the perceived quality of water than the actual water quality itself (Syme and Williams 1993). Besides, the case study findings of this research suggest that often the FP are interlinked and hard to clearly separate from each other in terms of occurrence and analysis. A certain positioning most often correlates with one's framing of urgency. A participant of the Kromme Rijn with a general attitude of seeing uncertainties as something negative for instance reported to be quite alert to the occurrence of uncertainties and to be eager to tackle and eliminate them. A different participant in the Wupper by contrast showed to be more relaxed in dealing with uncertainties and did not demonstrate too much urge to tackle the uncertainties that were discussed in the group.

The method of card sorting applied in the Doñana case for the development of participatory framing parameters proved to be a useful method in terms of results it rendered as well as practicability. For instructors, previous experience in application of card sorting is essential though as the results may be of limited use if the methodology is not strictly followed as was the case for one of the subgroups in the Doñana case. The iterative interaction (two group sessions plus individual contacts) with the participants in all case studies was time consuming but useful in the sense that it takes time to get acquainted with a new way of thinking, as the framing concept as well as explicitly dealing with uncertainty had been rather new for the participants. Moreover, it takes time to develop trust, which is essential for discussing in a free and open way.

One drawback in terms of eliciting framings of uncertainty of practitioners is that initiating such research may already influence and thus bias or distort the results. This, however, is a general feature of interactive approaches in social sciences and difficult to assess (or bypass). No claims are made in the present research for having assessed and represented the actors' framings without any distortion.

7 Conclusions & Outlook

Framing differences are an impediment to effective management of natural resources. Thus there is a need for making framing and differences in framing explicit and constructively dealing with them. With respect to uncertainty, so far no approaches have been developed that would address this. The present thesis aims to fill this gap, parting from an assessment of uncertainties in water management practice in several case studies.

The primary endeavour of the present thesis was to understand how uncertainties get framed in water management practice. The rationale was that understanding framing of uncertainties would make it possible to develop more systematic and structured approaches for water management practice for dealing with uncertainty. For that purpose dealing with uncertainties in water management practice has been analysed in three case studies.

The empirical research was designed to answer four main research questions (RQ):

1. What uncertainties do water managers perceive and how are they dealt with?
2. What are viable methods to assess framing of uncertainty?
3. How, and along which parameters, do the uncertainties get framed?
4. How can the strategies for dealing with uncertainties in WRM practice be improved with the help of parameters of framing?

The four RQ were addressed in succession as they are based on each other. RQ 1 was the starting point of the empirical research to ensure the relevance for water management practice. For answering RQ 2 different methods were developed for assessing framing of uncertainty. RQ 3 was answered by applying the methods developed for RQ 2 in the case studies. RQ 4 was addressed on the basis of the results of RQ 3, i.e. the framings of uncertainty in the case studies. The key findings to the four RQ are summed up in table 13.

The empirical research confirmed that indeed water managers are faced with a range of uncertainties and that so far no systematic approaches are applied for dealing with those in management practice. The participants in the case studies were eager to learn how to better deal with uncertainties. As pointed out earlier dealing with uncertainty is no easy task and can not be covered comprehensively by one single approach. The approach presented in the present thesis on the basis of the concept of framing advances the challenge of improving dealing with uncertainty from the perspective of water management practice.

Table 13: Summary of central findings to the research questions

RQ	Summarized findings	To find in
1	The assessment of uncertainties proved that uncertainty is an issue in current water management. The uncertainties mentioned in the case studies cover a huge range of uncertainties, ranging from more simple, technical uncertainties to substantive uncertainties stemming from system variability and complexity as well as from multiple knowledge frames. In the case studies, so far no explicit structured approaches had been used or applied to deal with uncertainties. Uncertainties have rather dealt with by intuition or based on experience from the past.	Sections 6.1, 8.2-8.4
2	Two approaches have been explored to assess the framings of uncertainty. Both offer a set of parameters that can be used to make sense of uncertainty situations in a structured way and make framings and differences in framings explicit.	Sections 4.3 & 6.2 Papers 1 & 3

	The approach followed in the Wupper and the Kromme Rijn is based on a set of pre-defined parameters (FP) stemming from an ex-post analysis of a range of narratives of water managers. It is thus a rather researcher-structured approach whereas the approach in the Doñana region used a more participatory set-up where participants themselves developed participatory framing parameters (PFP) through the method of card sorting. The approaches rendered a set of parameters each. There is no huge overlap among the parameters of the two methods. The options for extension and combination of the two methods that have been outlined in the present work can be summarized as follows: 1. The two elaborated lists may be combined into a joint list for a more comprehensive approach to uncertainty framing. The usefulness of combining the two lists would have to be tested in practice. 2. Context-specific parameters could be developed newly for each case for the assessment of framing of uncertainty. That way meaningfulness for the actors in the respective cases is ensured. 3. The two approaches explored in the present research could be combined in a sequential order. For the assessment of framing of uncertainty in a certain case study, first a participant-based approach could be followed, concluding in a locally relevant list of parameters. Afterwards, the parameters and intervention options of the pre-structured approach of the present thesis could be provided to the participants in order to broaden their insights by using parameters that they did not come up with but may consider relevant. The latter approach is also promising regarding the establishment of a sound knowledge base on the framing of uncertainties which would allow deriving more general conclusions on the importance of local factors compared to generally applicable parameters. All suggested options would require more research involving practitioners in water management.	
3	The uncertainty situations were framed differently by the participants in the case studies. The framings were elicited at the example of selected uncertainty situations and made explicit through the FP and the PFP. In the Wupper and the Kromme Rijn the framings were assessed individually along the FP. Participants were partly overlapping and partly diverging in their framings. The results of the individual interviews served as an input for the subsequent group discussion for developing improvement options for dealing with uncertainty. In the Doñana case, the development of the PFP and the framing assessment was performed jointly. Participants developed criteria for framing and allocated the uncertainty situations to the criteria and categories they developed. By comparing the elaborated criteria and allocations framing overlaps and differences got apparent. The results in all case studies suggest that there are no universal findings as to how actors frame uncertainties but rather that framings are dependent on the respective uncertainty situation, on roles (e.g. project leader, public administration, scientist etc), and most often on personal traits.	Section 6.3, Papers 2 & 3
4	The parameters of framing build the basis to, individually or in a group, develop strategies and intervention options for the uncertainty situations, which eventually allows for more structured decision-making in water management practice under uncertainty. A checklist was developed to be used by water managers in practice when confronted with situations marked by uncertainty. The checklist contains of a set of overall strategies according to the FP each of which is specified by concrete action options. Those were synthesized from the case study findings of the Wupper and the Kromme Rijn. By using the checklist uncertainties can be addressed in an explicit and structured way and sound decision-making is enabled. Suggestions were made how to use the PFP of the Doñana case for improvement of decision-making under uncertainty.	Sections 6.4, 8.5 Papers 2 & 3

Parameters of framing have been developed and used according to two different approaches. Both approaches proved to be practicable and useful for the participants and rendered two mostly different sets of parameters, the framing parameters (FP) in the pre-structured approach and the participatory framing parameters (PFP) in the participant-structured approach. The importance of the FP is also supported by findings in literature whereas the PFP elaborated by the Doñana participants appear to be more bound to the participants of the case study. The case study findings suggest that there are no universally valid parameters of influence in the framing of uncertainties. Neither could a clear superiority of one approach over the other be discerned. Nonetheless, the parameters of framing of uncertainty proved to be a supportive tool for preparing and structuring decision-making in the case studies and developing improvement options for dealing with uncertainty. In that it meets the challenge targeted for this research to develop an approach that would meet the needs of practitioners in water management.

Beyond the results of the development of approaches for the assessment of framing of uncertainty in water management practice, processes of communication and learning turned out to be of major importance. Making framings of uncertainties explicit by help of parameters of framing proved to be useful in the case studies for revealing different points of views on the uncertainties and with regard to the strategies to deal with them. This is a first step in enabling dialogue among opposed framers. The participants of the Wupper and the Kromme Rijn also emphasized the importance of communication for dealing with framing differences. In the participant-based approach in the Doñana case the interactive development of the PFP showed to be particularly useful and important to gain mutual understanding. These are important preconditions for reframing and learning which are crucial for the long-term performance in management of natural resources.

Through my research, I hope to have captured important features in the framing of uncertainties. Although for effective use in practice it may be necessary to complement the proposed lists of parameters according to the needs of the applicants, the presented work constitutes a step forward in the search of adequate ways for dealing with uncertainty in water management practice. As the strategies developed in the case studies primarily constitute suggestions for the future their actual usefulness for improving decision-making in water management under uncertainty is yet to be seen through implementation on the ground. For that purpose involvement of actors from different sectors and levels is crucial. For this thesis the range of actors had been restricted to primarily entities responsible for decision-making in water management at regional and local level. For application of the developed approaches in water management practice, however, involvement of all relevant actors in each case is paramount as all framings have to be considered for successful decision-making in the long term.

Regarding future research a certainly interesting question with regard to effective dealing with uncertainty over the long run is how scientific approaches addressing uncertainty and approaches from water management practice to deal with uncertainty can be integrated for mutual benefit.

Beyond the present thesis, the question remains if there are other approaches conceivable which are appropriate for assessing framing of uncertainty that do not build on parameters but follow a different concept.

And finally, the whole concept of uncertainty may be called into question. The findings in the case studies of the present research showed that beyond gathering knowledge factors such as trust, responsibilities and communication processes played an important role in effectively

dealing with uncertainty and enabling robust decisions. It is widely accepted that not all uncertainties may be overcome and even if reducible there always remains some uncertainty. Dealing with uncertainties then eventually is a matter of choices and priorities on the basis of value decisions. It would thus be interesting to investigate if focussing on the concept values would be more fruitful in coming to solutions to problems than drawing the attention to the uncertainties in a decision situation.

"*The quest for certainty blocks the search for meaning.*
Uncertainty is the very condition to impel man to unfold his powers."

Erich Fromm (1900-1980)
German-American Philosopher, Social Psychologist and Psychoanalyst

References

Aarts, N. and C. van Woerkum (2002). Dealing with uncertainty in solving complex problems. In: Wheelbarrows full of frogs: social learning in rural resource management. C. Leeuwis and R. Pyburn. Assen, Netherlands, Royal van Gorcum**:** 421-435.

Ajzen, I. and M. Fishbein (1977). Attitute-Behavior Relations: A Theoretical Analysis and Review of Empirical Research. Psychological Bulletin 84 (5): 888-918.

Alaerts, G. J. (2003). Institutions for River Basin Management – A Synthesis of Lessons in Developing Cooperative Arrangements. In: Integrated Water Management at River Basin Level, An Institutional Development Focus on River Basin Organizations. G. J. Alaerts and G. Le Moigne. Washington DC, The World Bank**:** Ch. 18.

Ambler, G. (2006). Systems Thinking as a Leadership Practice. from http://www.thepracticeofleadership.net/2006/01/14/systems-thinking-as-a-leadership-practice/.

Bardwell, L. V. (1991). Problem-Framing: A Perspective on Environmental Problem Solving. Environmental Management 15 (5): 603-612.

Bartlett, F. C. (1932). Remembering: A study in experimental and social psychology. Cambridge, UK, Cambridge University Press.

Baumgartner, C. (2005). Umweltethik – Umwelthandeln. Ein Beitrag zur Lösung des Motivationsproblems. Paderborn, Mentis Verlag.

Benford, R. D. and D. A. Snow (2000). Framing processes and social movements: An overview and assessment. Annual Review of Sociology 26: 611-639.

Bergkamp, G., B. Orlando and I. Burton (2003). Change. Adaptation of Water Resources Management to Climate Change. Gland, Switzerland and Cambridge, UK., IUCN.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. Journal of Environmental Management 90: 1692-1702.

Berninger, K., D. Kneeshaw and C. Messier (2009). The role of cultural models in local perceptions of SFM - Differences and similarities of interest groups from three boreal regions. Journal of Environmental Management 90: 740-751.

Beven, K. (2009). Environmental modelling: An uncertain future? London, Routledge.

Borowski, I. and C. Pahl-Wostl (2008). Where Can Social Learning Be Improved in International River Basin Management in Europe? European Environment 18: 216–227.

Bradshaw, G. A. and J. G. Borchers (2000). Uncertainty as Information: Narrowing the Science-policy Gap. Conservation Ecology 4 (1). URL: http://www.ecologyandsociety.org/vol4/iss1/art7/.

Brugnach, M., A. Dewulf, C. Pahl-Wostl and T. Taillieu (2008). Towards a relational concept of uncertainty: about knowing too little, knowing too differently and accepting not to know. Ecology & Society 13 (2). URL: http://www.ecologyandsociety.org/vol13/iss2/art30/.

Brugnach, M., A. Tagg, F. Keil and W. J. de Lange (2007). Uncertainty Matters: Computer Models at the Science–Policy Interface. Water Resources Management 21 (7): 1075-1090. DOI: 10.1007/s11269-006-9099-y.

Burningham, K. and G. Cooper (1999). Being constructive: Social constructionism and the environment. Sociology 33 (2): 297-316.

Carton, L. J. and W. A. H. Thissen (2009). Emerging conflict in collaborative mapping: Towards a deeper understanding? Journal of Environmental Management 90: 1991-2001.

Checkland, P. (1985). From Optimizing to Learning: A Development of Systems Thinking for the 1990s. The Journal of the Operational Research Society 36 (9): 757-767.

Cortner, H. J. (2000). Making science relevant to environmental policy. Environmental Science & Policy 3: 21-30.

Denzau, A. T. and D. C. North (1994). Shared Mental Models: Ideologies and Institutions. Kyklos 47 (1): 3-31.

Dewulf, A. (2006). Issue framing in multi-actor contexts: How people make sense of issues through negotiating meaning, enacting discourse and doing differences, Unpublished doctoral thesis. Centrum voor Organisatie- en Personeelspsychologie, K.U.Leuven.

Dewulf, A., M. Craps, R. Bouwen and C. Pahl-Wostl (2005). Integrated Management of Natural Resources: dealing with ambiguous issues, multiple actors and diverging frames. Water Science and Technology 52 (6): 115-124.

Dewulf, A., M. Craps and G. Dercon (2004). How issues get framed and reframed when different communities meet: A multi-level analysis of a collaborative soil conservation initiative in the Ecuadorian Andes. Journal of Community and Applied Social Psychology 14 (3): 177-192.

Dewulf, A., G. François, M. Brugnach, N. Isendahl, T. Taillieu, C. Pahl-Wostl and S. Möllenkamp (2008). The role of uncertainty, ambiguity and framing in transition to adaptive management. About knowing too little, accepting not to know and knowing too differently. Deliverable of the EU 6th FP NeWater project. www.newater.info.

Dewulf, A., G. François, C. Pahl-Wostl and T. Taillieu (2007). A Framing Approach to Cross-disciplinary Research Collaboration: Experiences from a Large-scale Research Project on Adaptive Water Management. Ecology & Society 12 (2): Art. 14. URL: http://dlc.dlib.indiana.edu/archive/00004795/01/ES-2007-2142.pdf or: http://www.ecologyandsociety.org/vol12/iss2/art14/.

Dewulf, A., B. Gray, R. Lewicki, L. Putnam, N. Aarts, R. Bouwen and C. Van Woerkum (2009). Disentangling approaches to framing in conflict and negotiation research: mapping the terrain. Human Relations 62 (2): 155-193 DOI: 10.1177/0018726708100356.

Donnellon, A., B. Gray and M. G. Bougon (1986). Communication, meaning and organized action. Administrative Science Quarterly 31 (1): 43-55.

Dörner, D. (1993). Denken und Handeln in Unbestimmtheit und Komplexität. GAIA 2 (3): 128-138.

Doyle, J. K. and D. N. Ford (1998). Mental Models Concepts for System Dynamics Research. System Dynamics Review 14 (1): 3-29.

EC (2000). Directive 2000/60/EC establishing a framework for Community action in the field of water policy (Water Framework Directive). Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:HTML, European Commission. Official Journal L 327, 1-73.

Einsiedel, E. and B. Thorne (1999). Public Responses to Uncertainty. In: Communicating uncertainty: Media coverage of new and controversial science. S. M. Friedman, S. Dunwoody and C. L. Rogers, Lawrence Erlbaum Associates

Festinger, L. (1957). A theory of cognitive dissonance. Stanford, Stanford University Press.

Fincher, S. and J. Tenenberg (2005). Making sense of card sorting data. Expert Systems 22 (3): 89-93. Guest editorial.

Fischer, K. (1997). Locating Frames in the Discursive Universe. Sociological Research Online 2 (3). URL: http://www.socresonline.org.uk/socresonline/2/3/4.html.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. Holling and B. Walker (2002). Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformation. AMBIO: A Journal of the Human Environment 31 (5): 437–440. URL: http://www.sou.gov.se/mvb/pdf/resiliens.pdf

Friend, J. and A. Hickling (1997). Planning under pressure - The strategic choice approach, Butterworth-Heinemann.

Funtowicz, S. and J. Ravetz (1993). Science for the port-normal age. Futures 25 (7): 739-755.

Funtowicz, S. O. and J. R. Ravetz (1992). The good, the true and the post-modern. Futures 24 (10): 962-976.

Gigerenzer, G. and R. Selten, Eds. (2001). Bounded Rationality: The Adaptive Toolbox. Report of the 84th Dahlem Workshop on Bounded Rationality: The Adaptive Toolbox, Berlin, March 14-19, 1999, MIT Press.

Goldstein, D. G., G. Gigerenzer, R. M. Hogarth, A. Kacelnik, Y. Kareev, G. Klein, L. Martignon, J. W. Payne and K. H. Schlag (2001). Group Report: Why and when do simple heuristics work? In: Bounded Rationality: The Adaptive Toolbox. G. Gigerenzer and R. Selten, MIT Press

Gooch, G. D. and D. Huitema (2008). Participation in Water Management: Theory and Practice. In: The Adaptiveness of IWRM. Analysing European IWRM research. Timmermann, IWA Publishing

Gray, B. (2003). Framing of environmental disputes. In: Making sense of intractable environmental conflicts - frames and cases. R. Lewicki, B. Gray and M. Elliot. Washington, Covelo, London, Island Press

Gray, B. (2004). Strong Opposition: Frame-based Resistance to Collaboration. Journal of Community & Applied Social Psychology 14: 166-176.

Gray, B. and A. Donnellon (1989). An Interactive Theory of Reframing in Negotiation Unpublished manuscript, Pennsylvania State University, College of Business Administration.

Groves, D. G. and R. J. Lempert (2007). A new analytic method for finding policy-relevant scenarios. Global Environmental Change 17 (1): 73-85.

Grunwald, A. (2008). Working Towards Sustainable Development in the Face of Uncertainty and Incomplete Knowledge. In: Governance for Sustainable Development. Coping with ambivalence, uncertainty and distributed power. J. Newig, J.-P. Voß and J. Monstadt. London, Routledge**:** 53-70.

Hajer, M. and W. Versteeg (2005). A Decade of Discourse Analysis of Environmental Politics: Achievements, Challenges, Perspectives. Journal of Environmental Policy & Planning 7 (3): 175-184.

Havekes, H., F. Koemans, R. Lazaroms and R. Uijterlinde (2008). Water governance - The Dutch waterschap model. The Hague, Opmeer drukkerij bv.

Henriksen, H.-J. and H. Christiansen Barlebo (2008). Reflections on the use of Bayesian belief networks for adaptive management. Journal of Environmental Management 88 (4): 1025-1036.

Holling, C. S. (1978). Adaptive Environmental Assessment and Management. New York, John Wiley and Sons.

Hosseini, H. (2001). Uncertainty and perceptual problems causing government failures in less advanced nations. Journal of Socio-Economics 30 (3): 263-271.

Isendahl, N., A. Dewulf, M. Brugnach, G. François, S. Möllenkamp and C. Pahl-Wostl (2009). Assessing framing of uncertainties in water management practice. Water Resources Management 23 (15): 3191-3205.

Isendahl, N., A. Dewulf and C. Pahl-Wostl (2010a). Making Framing Of Uncertainty In Water Management Practice Explicit By Using A Participant-Structured Approach. Journal of Environmental Management 91 (4): 844-851. DOI: 10.1016/j.jenvman.2009.10.016.

Isendahl, N., C. Pahl-Wostl and A. Dewulf (2010b). Using framing parameters to improve handling of uncertainties in water management practice. Environmental Policy and Governance 20 (2): 107-122. DOI 10.1002/eet.533.

Ison, R., N. Röling and D. Watson (2007). Challenges to science and society in the sustainable management and use of water: investigating the role of social learning. Environmental Science & Policy 10 (6): 499-511.

Janssen, P. H. M., A. C. Peterson, J. P. van der Sluijs, J. S. Risbey and J. R. Ravetz (2004). Towards guidance in assessing and communicating uncertainties. Fourth International Conference on Sensitivity Analysis of Model Output (SAMO). Santa Fe.

Jiggins, J., E. van Slobbe and N. Röling (2007). The organisation of social learning in response to perceptions of crisis in the water sector of The Netherlands. Environmental Science & Policy 10 (6): 526-536.

Jones, S. (2002). Social constructionism and the environment: through the quagmire. Global Environmental Change 12 (4): 247-251.

Kahneman, D. (2002). Maps of Bounded Rationality: A perspective on intuitive judgment and choice. Prize Lecture, December 8, 2002**:** 449-489.

Kahnemann, D. and A. Tversky (2000). Judgement under Uncertainty: Heuristics and Biases. In: Judgement and Decision Making. An interdisciplinary reader. T. Connolly, H. A. Arkes and K. R. Hammond, Cambridge University Press

Kaufman, S., M. Elliot and D. Shmueli (2003). Frames, framing and reframing. In: Beyond Intractability. G. Burgess and H. Burgess. Conflict Research Consortium, University of Colorado, Boulder. Posted: September 2003, http://www.beyondintractability.org/essay/framing/?nid=1129

Kaufman, S. and J. Smith (1999). Framing and Reframing in Land Use Change Conflicts. Journal of Architecture, Planning and Research 16 (2): 164-180. URL: http://urban.csuohio.edu/~sanda/papers/frames98.htm.

Kickert, W. J. M., E.-H. Klijn and J. F. M. Koppenjan (1997). Managing complex networks - strategies for the public sector, Sage Publications.

Klauer, B. and J. Brown (2004). Conceptualizing Imperfect Knowledge in Public Decision Making: Ignorance, Uncertainty, Error and Risk situations. Environmental Research, Engineering and Management 1 (27): 124-128.

Klein, G. (2001). The fiction of optimization. In: Bounded Rationality: The Adaptive Toolbox. G. Gigerenzer and R. Selten, MIT Press

Klimoski, R. and S. Mohammed (1994). Team Mental Model: Construct or Metaphor? Journal of Management 20 (2): 403-437.

Kolkman, M. J. (2005). Controversies in water management - framing and mental models, Universitiet Twente**:** 232.

Koppenjan, J. and E.-H. Klijn (2004). Managing Uncertainties in Networks. A network approach to problem solving and decision making, Routledge.

Kuhn, T. (1970). The Structure of Scientific Revolutions, University of Chicago Press.

Lejano, R. P. and H. Ingram (2009). Collaborative networks and new ways of knowing Environmental Science & Policy 12 (6): 653-662. DOI: doi:10.1016/j.envsci.2008.09.005.

Levin, S. A. (1998). Ecosystems and the Biosphere as Complex Adaptive Systems. Ecosystems 1 (5): 431-436.

Lewicki, R., B. Gray and M. Elliot (2003). Making sense of intractable environmental conflicts: Concepts and cases. Washington D.C., Island Press.

Limbourg, M. (1999). Vom Umweltbewußtsein zum Umwelthandeln. Psychologie des Umweltschutzes. Fachkonferenz „Umweltschutz in Essen" am 6. und 7. Mai 1999.

Marín Cabrera, C. and F. Garcia Novo, Eds. (2006). Doñana - Water and Biosphere. Madrid, Doñana 2005 Project - Confederación Hidrográfica del Guadalquivir (Guadalquivir Hydrologic Basin Authority).

Mathijssen, J., A. Petersen, P. Besseling, A. Rahman and H. Don (2008). Dealing with Uncertainty in Policymaking. Final report on the conference Dealing with Uncertainty in Policymaking, 16 and 17 May 2006. The Hague, The Hague/Bilthoven/Leiden, Netherlands Environmental Agency (PBL). Netherlands Bureau for Economic Policy Analysis (CPB). Rand Europe.

McCulloch, C. S. (2007). Integrating Research for Water Management: Synergy or Dystopia? Water Resources Management 21 (12): 2075-2082. DOI: 10.1007/s11269-007-9161-4.

McGeorge, P. and G. Rugg (1992). The uses of 'contrived' knowledge elicitation techniques. Expert Systems 9 (3): 149-154. Published Online: 129 Apr 2007.

Messner, F., O. Zwirner and K. Matthias (2006). Participation in multi-criteria decision support for the resolution of a water allocation problem in the Spree River basin. Land Use Policy 23 (1): 63-75.

Michael, D. N. (1973). On learning to plan - and planning to learn. San Francisco, Jossey-Bass Publishers.

Minsky, M. (1974). A Framework for Representing Knowledge. MIT-AI Laboratory Memo 306, June, 1974.

Möllenkamp, S., M. Lamers and E. Ebenhöe (2008). Institutional elements for adaptive water management regimes. Comparing two regional water management regimes in the Rhine basin. In: Adaptive and Integrated Water Management – Coping with Complexity and Uncertainty. C. Pahl-Wostl, P. Kabat and J. Möltgen Berlin Heidelberg, Springer-Verlag**:** 147-166.

Morgan, D. L. (1996). Focus Groups as Qualitative Research, SAGE Publications, Inc.

Morgan, M. G. and M. Henrion (1990). Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, Cambridge University Press.

Mostert, E. (2003). Public Participation and the Water Framework Directive. A Framework for Analysis. Inception report of the HarmoniCOP project – Harmonising COllaborative Planning. E. Mostert.

Newig, J., C. Pahl-Wostl and K. Sigel (2005). The Role of Public Participation in Managing Uncertainty in the Implementation of the Water Framework Directive. European Environment 15 (6): 333-343.

Ney, S. and M. Thompson (1999). Consulting the frogs - the normative implications of Cultural Theory. In: Cultural Theory as political science. M. Thompson, G. Grenstad and P. Selle. London, Routledge 206-223.

O'Connor, M. (1999). Dialogue and debate in a post-normal practice of science: a reflexion. Futures 31 (7): 671–687.

Oliver, P. E. and H. Johnston (2000). What a Good Idea! Ideologies and Frames in Social Movement Research. Mobilization: An International Quarterly 5 (1): 37 - 54.

Olsson, J. A. and L. Andersson (2007). Possibilities and problems with the use of models as a communication tool in water resource management. Water Resources Management 21 (1): 97-110. DOI: 10.1007/s11269-006-9043-1.

Oreskes, N. (2004). Science and public policy: what's proof got to do with it? Environmental Science & Policy 7 (5): 369-383.

Ostrom, E. (2005). Understanding Institutional Diversity. New Haven, Princeton University.

Pahl-Wostl, C. (2002). Towards sustainability in the water sector - The importance of human actors and processes of social learning. Aquatic Sciences 64 (4): 394-411. DOI: 10.1007/PL00012594.

Pahl-Wostl, C. (2006). The implications of complexity for integrated resources management. Environmental Modelling & Software 22 (5): 561-569.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. Water Resources Management 21 (1): 49-62. DOI: 10.1007/s11269-006-9040-4.

Pahl-Wostl, C., R. Bouwen, M. Craps, A. Dewulf, E. Mostert, D. Ridder, D. Tábara and T. Taillieu (2008). The importance of social learning and culture for sustainable water management. Ecological Economics 64 (3): 484-495.

Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara and T. Taillieu (2007a). Social Learning and Water Resources Management Ecology & Society 12 (2): 5. URL: http://www.ecologyandsociety.org/vol12/iss2/art5/.

Pahl-Wostl, C. and M. Hare (2004). Processes of Social Learning in Integrated Resources Management. Journal of Community & Applied Social Psychology 14 (3): 193-206. DOI: 10.1002/casp.774.

Pahl-Wostl, C., N. Isendahl, S. Möllenkamp, M. Brugnach, P. Jeffrey, W. Medema and T. Tessa de Vries (2006). Paradigms in Water Management, deliverable 1.1.2 Project NeWater.

Pahl-Wostl, C., J. Sendzimir, P. Jeffrey, J. Aerts, G. Berkamp and K. Cross (2007b). Managing Change toward Adaptive Water Management through Social Learning. Ecology & Society 12 (2): 30. URL: http://www.ecologyandsociety.org/vol12/iss2/art30/main.html.

Paneque Salgado, P., S. Corral Quintana, Â. Guimarães Pereira, L. del Moral Ituarte and B. Pedregal Mateos (2009). Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Málaga). Ecological Economics 68 (4): 990-1005. DOI: 10.1016/j.ecolecon.2006.11.008.

Patt, A. (2007). Assessing model-based and conflict-based uncertainty. Global Environmental Change 17 (1): 37-46.

Refsgaard, J. C., J. P. van der Sluijs, A. L. Hojberg and P. A. Vanrolleghem (2007). Uncertainty in the environmental modelling process – A framework and guidance. Environmental Modelling & Software 22 (11): 1543-1556.

Reichert, P., M. Borsuk, M. Hostmann, S. Schweizer, C. Spörri, K. Tockner and B. Truffer (2007). Concepts of decision support in river rehabilitation. Environmental Modelling & Software 22 (2): 188-201.

Renn, O. (2009). Integriertes Risikomanagement als Beitrag zu einer nachhaltigen Entwicklung. In: Zukunftsforschung und Zukunftsgestaltung. Beiträge aus Wissenschaft und Praxis R. Popp and E. Schüll. Berlin Heidelberg, Springer**:** 553-568.

Ridder, D., E. Mostert and H. A. Wolters (2005). Learning Together to Manage Together. Improving Participation in Water Management. (The HarmoniCOP Handbook). Osnabrück.

Rouse, W. B. and N. M. Morris (1986). On Looking Into the Black Box: Prospects and Limits in the Search for Mental Models. Psychological Bulletin 100 (3): 349-363.

Sabatier, P. A. (1988). An advocacy coalition framework of policy change and the role of policy oriented learning therein. Policy Sciences 21 (2-3): 129-168. DOI: 10.1007/BF00136406.

Sarewitz, D. (2004). How science makes environmental controversies worse. Environmental Science & Policy 7 (5): 385-403.

Schaap, L. and M. J. W. van Twist (1997). Network Dynamics and Management. In: Managing complex networks - strategies for the public sector. W. J. M. Kickert, E.-H. Klein and J. F. M. Koppenjan, Sage Publications**:** 62-78.

Schön, D. A. and M. Rein (1994). Frame reflection - toward the resolution of intractable policy controversies, Basic Books.

Selten, R. (2001). What is bounded rationality? In: Bounded Rationality: The Adaptive Toolbox. G. Gigerenzer and R. Selten, MIT Press

Serrano, L. and L. Serrano (1996). Influence of Groundwater Exploitation for Urban Water Supply on Temporary Ponds from the Doñana National Park (SW Spain). Journal of Environmental Management 46 (3): 229-238.

Sheppard, B. H., K. Blumenfeld-Jones, J. W. Minton and E. Hyder (1994). Informal Conflict Intervention: Advice and Dissent. Employee Responsibilities and Rights Journal 7 (1): 53-72.

Shrader-Frechette, K. S. (1995). Evaluating the Expertise of Experts. Risk: Health, Safety & Environment 6 (2): 115-126.

Sigel, K. (2007). Umweltprobleme und Unsicherheit. Eine konzeptionelle und empirische Analyse am Beispiel der EG-Wasserrahmenrichtlinie. Marburg, Metropolis-Verlag.

Sigel, K., B. Klauer and C. Pahl-Wostl (2010). Conceptualising uncertainty in environmental decision-making: The example of the EU water framework directive. Ecological Economics 69 (3): 502-510.

Slocum, N. (2005). Participatory Methods Toolkit. A practitioner's manual. Focus group. In: Participatory Methods Toolkit. A practitioner's manual. S. Steyaert and H. Lisoir, King Baudouin Foundation & Flemish Institute for Science and Technology Assessment (viWTA)

Snow, D. A., E. Burke Rochford Jr., S. K. Worden and R. D. Benford (1986). Frame Alignment Processes, Micromobilization, and Movement Participation. American Sociological Review 51 (4): 464-481.

Stirling, A. (2006). Analysis, participation and power: justification and closure in participatory multi-criteria analysis. Land Use Policy 23 (1): 95-107.

Syme, G. J. and K. D. Williams (1993). The Psychology of Drinking Water Quality: An Exploratory Study. Water Resources Research 29 (12): 4003-4010.

Tabara, D. and C. Pahl-Wostl (2007). Sustainability Learning in Natural Resource Use and Management. Ecology & Society 12 (2): Art. 3. URL: www.ecologyandsociety.org/vol12/iss2/art3/

Termeer, C. J. A. M. and J. F. M. Koppenjan (1997). Managing Perceptions in Networks. In: Managing complex networks - strategies for the public sector. W. J. M. Kickert, E.-H. Klein and J. F. M. Koppenjan, Sage Publications**:** 79-97.

Thompson, M., G. Grenstad and P. Selle (1999). Cultural Theory as political science. In: Cultural Theory as political science. M. Thompson, G. Grenstad and P. Selle. London, Routledge**:** 1-24.

Tippett, J., B. Searle, C. Pahl-Wostl and Y. Rees (2005). Social learning in public participation in river basin management - early findings from HarmoniCOP European case studies. Environmental Science & Policy 8 (3): 287-299.

Tversky, A. and D. Kahneman (1981). The framing of decisions and the psychology of choice. Science 211: 453-458.

van Asselt, M. and J. Rotmans (2000). Uncertainty in integrated assessment - A bridge over troubled water, ICIS (International Centre for Integrative Studies) Maastricht University**:** 60.

van Asselt, M. and J. Rotmans (2002). Uncertainty in Integrated Assessment Modelling: From Positivism to Pluralism. Climatic Change 54 (1-2): 75-105. DOI: 10.1023/A:1015783803445.

van Asselt, M., J. Rotmans, M. den Elzen and H. Hilderink (1995). Uncertainty in Integrated Assessment Modelling - a cultural perspective-based approach. Global Dynamics & Sustainable Development Programme. Bilthoven, RIVM**:** 71.

van den Hove, S. (2006). Between consensus and compromise: acknowledging the negotiation dimension in participatory approaches. Land Use Policy 23 (1): 10-17.

van der Keur, P., H. J. Henriksen, J. C. Refsgaard, M. Brugnach, C. Pahl-Wostl, A. Dewulf and H. Buiteveld (2008). Identification of Major Sources of Uncertainty in Current IWRM Practice. Illustrated for the Rhine Basin. Water Resources Management 22 (11): 1677-1708. URL: http://www.springerlink.com/content/t642474715728880/fulltext.pdf.

van der Sluijs, J. P. (2007). Uncertainty and precaution in environmental management: Insights from the UPEM conference. Environmental Modelling & Software 22 (5): 590-598.

van der Sluijs, J. P., J. S. Risbey, P. Kloprogge, J. R. Ravetz, S. O. Funtowicz, S. Corral Quintana, A. Guimarães Pereira, B. De Marchi, A. C. Petersen, P. H. M. Janssen, R. Hoppe and S. W. F. Huijs (2003). RIVM/MNP Guidance for Uncertainty Assessment and Communication: Detailed Guidance, Utrecht University and RIVM/MNP. Available at http://www.nusap.net/guidance/.

von Storch, H. (2009). Klimaforschung und Politikberatung - zwischen Bringschuld und Postnormalität. Leviathan 37 (2): 305-317. DOI: 10.1007/s11578-009-0015-8.

Walker, W. E., J. Harremoes, J. Rotmans, J. P. van der Sluijs, M. van Asselt, P. Janssen and M. P. Krayer von Kraus (2003). Defining Uncertainty - A conceptual basis for uncertainty management in model-based decision support. Integrated Assessment 4 (1): 5-17.

Wardekker, J. A., J. P. van der Sluijs, P. H. M. Janssen, P. Kloprogge and A. C. Petersen (2008). Uncertainty communication in environmental assessments: views from the Dutch science-policy interface. Environmental Science & Policy 11 (7): 627-641.

Weick, K. (1995). Sensemaking in organizations Thousand Oaks: Sage.

Wynne, B. (1992). Uncertainty and environmental learning. Global Environmental Change 2 (2): 111-127.

8 Appendices

The appendices contain the following:

8.1 The preparatory questionnaire used in all case studies

8.2 The selected uncertainty situations in the Wupper case

8.3 The selected uncertainty situations in the Kromme Rijn case

8.4 The selected uncertainty situations in the Doñana case

8.5 The envisaged strategies in the Doñana case

8.6 The semi-structured interview on the framing parameters

8.1 Preparatory questionnaire

Before starting off with the first group meeting in the case studies a special introduction was given for those actors who had participated in the Uncertainty Dialogues already (Dewulf et al. 2008) and might thus have a different view on uncertainty already. This concerned one participant in the Kromme Rijn as well as one in the Wupper.

Introductory text: *"Last year we held 'Uncertainty Dialogues' in several river basins related to the NeWater project where you participated. In order to confirm and deepen findings of a preliminary evaluation of these dialogues we would here like to ask you for additional input. Moreover, your answers to the questions below will be helpful to us for adjusting and improving the design of the next group meeting in your basin."* ('The next group meeting' here refers to group session of phase 1 of the present research.)

The questionnaires were held in German, Dutch, and Spanish for the respective case studies, and are here presented in English.

1) When you hear the term 'uncertainty' what do you think of? What do you associate it with? What does it mean for you? (in general, not necessarily related to a specific issue or your work. Please specify if you do wish to relate it to a specific issue or area)
2) a) Based on what you answered in question one, can you think of other terms (than 'uncertainty') that would better capture the descriptions of your answer of question one? If yes, which? b) If yes, which one of these is the most meaningful for you or the one most frequently used by you?
For the moment we proceed here with the term 'uncertainties'. Uncertainties are often addressed through scientific analytical methods. 3) Have you been in contact with any such method? Y/N a) if yes, what kind of/ which way? b) what was your experience with that? i) were you involved in the active analysis? Y/N ii) did you get the results of the scientific analysis? Y/N iii) was it a positive or negative experience? Pos./neg. iv) were you happy with the outcome? Y/N v) did it help overcome/ handle the U? Y/N vi) what went wrong / was difficult/ dissatisfy you? (specify) vii) what would you improve? (specify)
4) Where or in which context in your work life (in water management) do you feel the need to address uncertainties (in a systematic way/ more explicitly)?

8.2 Selected uncertainty situations in the Wupper case

The participants were given two stickers to mark the uncertainty situations they were interested in working further with (for phase 2 of the empirical research). The preferences of the participants are highlighted in bold letters in the Uncertainty Matrix resulting in a final selection of uncertainty situations that is summed up in Table 14. Criteria for the final selection were overlap of preferences of the participants as some uncertainty situations were named by several participants, coverage of all columns of the Uncertainty Matrix (UM) if possible, diversity of topics, consideration of all participants, and special uncertainties, that is for instance those covering more than one cell of the matrix.

Table 14: Selected uncertainty situations (Wupper)

Uncertainty	**allocation U-Matrix**
Ecosystems: no models available for appropriately assessing ecosystem processes	Natural aspects – unpredictability/ incomplete knowledge (cell 1-2)
Kind & extent of public participation in decision-making processes	Technical aspects - incomplete knowledge (cell 5)
Societal behaviour under pressure	Social aspects – unpredictability (cell 7)
Incorporation of climate change impacts in flood risk maps	Social aspects – multiple framings (cell 9)

U example cells 1-2: Modelling: no models available for appropriately assessing ecosystem processes

In the context of achieving a good ecological status of the water bodies required by the EU Water Framework Directive (WFD), methods are needed to assess the status of the water bodies. In the Wupper, this is partly approached through modelling. But there is uncertainty how natural process can be adequately displayed through models. For instance, for the assessment of the fish fauna, there is a method which is not adequate in that small fish play a proportionally too dominant role in it. Other methods are currently not available.

U example cell 5: Kind and extent of public participation in decision-making processes

There is uncertainty how or to which extent the public should be involved in decision-making processes in the management of water resources. Public participation is required by the WFD (art. 14) but is not specified clearly in terms of procedures. How can stakeholders and the broad public be involved while keeping the final decision with the administrative organs? The uncertainty relates to participatory processes as being a relatively new issue in water management (lack of knowledge about possible procedures) and to the decision-making process as to how much influence in decision-making should be given to the stakeholders or the public (multiple framings regarding the decision weights).

U example cell 7: Societal behaviour under pressure

The uncertainty lies in how society reacts in situations of stress, e.g. in case of accidents, flood events and the like and what consequences the respective behaviour then has. How much pressure can society exert in a way that priorities on the political agenda are changed and for instance big amounts of money are quickly shifted for emergency purposes which are then lacking elsewhere. The participants consider it difficult to prepare for such situations. The

uncertainty does not reside in how the competent authorities (mostly administration) react with regard to catastrophes and accidents but how society can exert power to influence decision-making at administrative and political level.

U example cell 9: Incorporation of climate change impacts in flood risk maps

There are uncertainties with regard to the incorporation of possible climate change impacts into flood risk maps, e.g. for the case of the declaration of flooding areas. Currently, a global mark-up is given to account for climate change driven rise in precipitation. However, this is not satisfactory for the participants of the Wupper as the knowledge base is imprecise and holds large uncertainties.

8.3 Selected uncertainty situations in the Kromme Rijn case

The participants had two stickers to mark the uncertainty situations they were interested in working further with (for phase 2 of the empirical research). The preferences of the participants are highlighted in bold letters in the Uncertainty Matrix resulting in a final selection of uncertainty situations that is summed up in Table 15. Criteria for the final selection were overlap of preferences of the participants as some uncertainty situations were named by several participants, coverage of all columns of the Uncertainty Matrix (UM) if possible, diversity of topics, consideration of all participants, special uncertainties, that is for instance those covering more than one cell of the matrix. The selections are focused on the social aspects, however, as the participants clearly stated an interest in primarily going on further in the social sphere as they felt they managed the natural and technical part quite well or at least were more familiar and confident with regard to those areas.

Table 15: Selected uncertainty situations (Kromme Rijn)

N°	Uncertainty	allocation U-Matrix
2	Uncertainty due to differing views on the responsibility for water supply in the region	Social aspects – multiple framings (cell 9)
11	Contradictory advice for one situation (e.g. from two different ministries)	Social aspects – multiple framings (cell 9)
16	Accidents / coincidences	Social aspects – variability (cell 7)

N° 2: Uncertainty due to differing views on the responsibility for water supply

The uncertainty about the responsibility for water supply in the Kromme Rijn region arose out of different views on the issue and differing expectations that had not been made clear. The fruit farmers, who are interested in an increase in water supply for the sprinkling of blossoms to protect them from frost, thought that it was the task of HDSR since up to then the water supply was always ensured through the water board. HSDR, however, did not consider itself responsible for all supply of water, which in fact is also put down in law. However, in the water plan at provincial level there is a note that the water board is obliged to ensure water for the frost protection of the blossoms. So there are controversial statements within the administration at different levels, even more so as farmers representatives form part of the water board. So on the one hand there is the discussion about the legal status and on the other hand there is a more societal question how to make decisions. This uncertainty had to be solved in the context of the water plan for the Kromme Rijn which enforced a decision within 12 months.

N °11: Contradictory advice for one situation

This uncertainty stems from contradictory advice for one situation from different jurisdictions. In the Kromme Rijn there had been a case of the ecological restoration of river banks. At provincial level, the agricultural department had different ideas from the nature protection department. This is a conflict of interests which is difficult to solve at the implementation level.

N° 16: Accidents / coincidences

Accidents and negative coincidences were mentioned in the Kromme Rijn as a more general uncertainty that can always occur. Even if all possible scenarios for a certain development have

been considered the underlying unpredictability can never be eradicated. Unforeseen or unexpected coincidences may occur with regard to a process in general, the reactions of stakeholders, financial issues etc. These are uncertainties you cannot identify beforehand.

8.4 Selected uncertainty situations in the Doñana case

From the sample of 13 uncertainty situations the participants selected one example each which they were interested to detail on and learn more about in the next steps of the research. The examples 6 and 11 were agreed on by highest overlap in participants' preferences.

N° 6: What Doñana/ marshlands do we want?

The uncertainty stems from a lack of objectives for the Doñana region. There is no shared vision as to the goals, structure, function etc. of the region for the short and long term future. There are no shared objectives, neither from a scientific point of view nor from a management perspective. There are plans from different sectors, e.g. agricultural, but there is no conservation plan for the area which would integrate all. Every sector has its own management model. Historically, far reaching conservation interventions only took place as a consequence to disasters, e.g. emergency measures and subsequent restoration projects as a consequence of the accident in the mine of Aznalcóllar upstream the area in 1998. A related problem besides the lack of a shared management objective is the perceived inertia in Doñana to e.g. deliberately intervene in the ecological dynamics of the marshlands in the national park and provoke a change while change is actually happening due to the numerous and changing uses and natural evolution processes. This eventually is causing damages to the region that "nobody wanted".

N° 11: How do the different interests affect decision-making in management?

There is uncertainty as to how different interests affect decision-making in water management. The different sectors, such as industry, agriculture, urban development and nature conservation, negotiate and defend their interests in differing ways. Power distribution is not equal and often depends on individual personalities. Moreover, interests are not always made explicit, for instance in supposedly neutral and objective scientific research or deliberately due to strategic reasons. Negotiations are difficult as opposing parties tend to insist on pursuing their interests. An important question in the uncertainty is thus how the current process of opposing interests which often results in lock-in situations can be influenced towards a more negotiating and cooperative mode.

8.5 Envisaged strategies in the Doñana case

Strategies to deal with uncertainty the participants conceived in the first group meeting are displayed in table 16. These are strategies the participants are not yet effectuating but consider necessary to implement.

Table 16: Strategies to deal with uncertainty conceived by the Doñana participants[14]

Strategy	Details
Consider decision-making as experimentation	This is considered as basic strategy to develop any further strategy. The question then is not IF to do experiments but HOW.
Do not ignore problems – accept the fact that there are uncertainties	Until now lots of problems and uncertainties have been ignored, e.g. the complexity and interconnections between the different claims and uses of the ecosystem services of the Doñana region. This has as a consequence that now that uncertainties are starting to be recognized, there are no methods available to deal with them. Purely scientific approaches are deemed to fail. Along with the acceptance of uncertainties, the acceptance of the existence of different and possibly conflicting points of view is considered important. It is highlighted that in any given problem in natural resources management regardless of the strategy employed there will always remain a rest of uncertainty.
Establish shared objectives for the region	Currently there is a lack of shared objectives for the region. Above all, this concerns a necessary collaboration between the water authority CHG and the management of the National Park.
Broaden and improve knowledge base	The idea is to reduce uncertainties by improving the knowledge base and to aim for the best possible knowledge.
Reduction of uncertainty and prediction (depending on the type of uncertainty)	Two types of uncertainty were distinguished: one mainly consisting in data uncertainty which can be reduced by improved knowledge. The other type is uncertainty stems from unpredictability. The idea is that science always has to cover both, first try to increase the knowledge and reduce the uncertainty and second to try to improve predictions.
Valuation of ecosystem services	The valuation of ecosystem services is seen as a possible basis to evaluate which are the relevant uncertainties, which role they do play and what is prioritary in decision-making. For that purpose, operational definitions are necessary (see next point).
Establish (concrete) operational definitions in order to be able to valuate ecosystems	Global terms and values like biodiversity are not considered helpful in practice, e.g. when defining water management options, More precise definitions are needed. In the opinion of the participants most uncertainties related to ecosystems have their origin in a lack of such definitions as ecosystems are difficult to measure, compared to parts of it like water which can be measured in quantity and quality.
Communication to the public and education	Communication to the public and education are considered as crucial in dealing with uncertainty. If the public is better informed about decisions that are made the acceptance of those will be higher. Communication is also seen as a means to clarify misunderstandings and make different points of view explicit.

[14] The strategies have no sequential order

Strategy ctd.	Details ctd.
Create trust (in situations of differing points of views), legitimizing the different points of views	Lots of problems and uncertainties have to do with a lack of trust. One important means to increase trust is to start by acknowledging different points of views, and, particularly in case of the Doñana region, also legitimize the different uses. So far, the main efforts of all users have been to delegitimize the others. The challenge is also to find a shared language in which to communicate.
Evaluation and adaptation (in rather short circles)	Continuous evaluation and adaptation is considered important as well in dealing with uncertainty. One the one hand it is necessary to go on acting while searching for ways to deal with uncertainty, and on the other hand it is important to revise one's actions, learn from failures and adapt.
(For politicians) in decision-making it is not always best to know the maximum that is possible	Knowing too much can cause confusion as it may lead to too many options from which to choose. On the other hand more knowledge may decrease the range of liberty to act as one is bound by the available knowledge that may confine action options.
Involve scientists in decision-making	In order to deal with complex problems education of involved actors is seen as paramount together with involvement of scientists in decision-making. The latter are meant to play a role particularly in monitoring, evaluation and adaptation processes. The management has to change its focus towards a learning oriented management. The objective is not to find the best solution but the one that "causes least damage to the patient". Scientists are meant to help design experiments and appropriate management options. They are not supposed to make the final decision but still to position themselves, giving opinions about what they consider best or appropriate alternatives. Social sciences should not be forgotten as mostly discussions and assessments focus on ecological issues in natural resources management.

8.6 Semi-structured interview on the framing parameters

The interview guide displayed below was used for the individual interviews in the case studies of the Wupper and the Kromme Rijn subsequently to the first group discussion to elicit individual framings on the uncertainties that had been selected in the case studies.

The questions in English are translated from the originals in German and Dutch that were used in the case studies.

1. Which further actors are involved or play a role in the respective uncertainty situation? (as stakeholder, originator or decision-maker) (Anonymous reply possible)
2. Cause: Due to what or whom did the uncertainty situation arise? / Whose "fault" is it that an uncertainty situation arose?
3. a) Please describe the kind of exchange of information with other actors with regard to the uncertainty situation (with whom, how often, what for)

   b) Do you depend on the provision of information or data from others in order to be solve the uncertainty situation? → Y/N → If yes, from whom and what for?
4. a) What is your aim in terms of dealing with the uncertainty situation (also general answer possible)

   b) Whom do you see as responsible for dealing with the uncertainty situation?

   c) How do you currently deal with the uncertainty situation? Do you (or your entity) follow any formal procedure (e.g. from your entity) in that, respectively is there a standardized procedure or method or model to do so?

   d) If yes, do you consider that procedure as adequate and sufficient?

   e) What do you consider as important in terms of dealing with the uncertainty situation? Where do you see potential or need for improvement? (with regard to the current strategy or in general)

   f) How high do you estimate your own options to take influence in the uncertainty situation? → High – middle – low. Please explain

   g) How would you like the other involved actors to behave with regard to dealing with the uncertainty situation?

   h) Are the responsibilities, as you see them, currently being followed? What should be improved in that respect?
5. a) What is your positioning towards the uncertainty situation? What feelings does the uncertainty situation provoke in you? (Only give examples for the interviewee when there is no immediate answer → e.g. threat, annoyance, chance, risk, challenge)

   b) Is the uncertainty situation all in all rather positive or negative for you & why?
6. a) Do you (or would you) communicate the uncertainties you perceive towards stakeholders or the public? → Y/N → Please explain

   b) Do you communicate on how you yourself (or your entity) deal/s with the uncertainties? If yes with whom? If no why not?

   c) How important do you consider communication and/or collaboration with regard to dealing with uncertainty? Please explain

A- with other involved actors or experts?

B – with the public?

7. What role do financial resources play with regard to the uncertainty situation? Do you depend on financial support of others for dealing with the uncertainty situation?
8. Time line: When or within what time line does the uncertainty situation require a decision or action to be taken? → Now/ short term (> 0 < 6 months), middle term (> 6 months < 5 years), long term (> 5 years), "timeless"/ no deadline. Please explain
9. a) How important is it for you or your entity to solve the uncertainty situation & why? (Expected negative impacts?)

   b) How important is it to solve the uncertainty situation in more general terms, i.e. for the public or society? Please explain
10. Any additional remarks or questions from your side?

9 Papers

The papers include both presentation as well as discussion of case study results, primarily with regard to the research questions n° 2, 3, and 4.

Paper 1 addresses question n° 3 on how uncertainties are getting framed. It shows the results of an ex-post analysis of the Uncertainty Dialogues of narratives of water managers on their dealing with uncertainties concluding in a set of parameters of possible importance in framing of uncertainties in water management.

Paper 2 addresses question n° 4 on how strategies for dealing with uncertainties in WRM practice can be improved. It illustrates and discusses the results of the approach in the Wupper and the Kromme Rijn to develop a more structured approach for dealing with uncertainty in water management practice building on the parameters developed in paper 1.

Paper 3 addresses question n° 2 on the methodology. An alternative approach to assessing framing of uncertainty is presented and discussed where participants were not given a pre-defined set of parameters but had to develop parameters themselves by the method of card sorting. This approach was applied in the Doñana case study.

Paper 1: Assessing Framing of Uncertainties in Water Management Practice

Isendahl, N., Dewulf, A., Brugnach, M., François, G., Möllenkamp, S., Pahl-Wostl, C. (2009). Assessing Framing of Uncertainties in Water Management Practice. Water Resources Management 23 (15): 3191-3205. DOI: 10.1007/s11269-009-9429-y.

Water Resour Manage
DOI 10.1007/s11269-009-9429-y

Assessing Framing of Uncertainties in Water Management Practice

Nicola Isendahl · Art Dewulf · Marcela Brugnach · Greet François · Sabine Möllenkamp · Claudia Pahl-Wostl

Received: 21 July 2008 / Accepted: 18 February 2009

Abstract Dealing with uncertainties in water management is an important issue and is one which will only increase in light of global changes, particularly climate change. So far, uncertainties in water management have mostly been assessed from a scientific point of view, and in quantitative terms. In this paper, we focus on the perspectives from water management practice, adopting a qualitative approach. We consider it important to know how uncertainties are framed in water management practice in order to develop practice relevant strategies for dealing with uncertainties. Framing refers to how people make sense of the world. With the aim of identifying what are important parameters for the framing of uncertainties in water management practice, in this paper we analyze uncertainty situations described by decision-makers in water management. The analysis builds on a series of "Uncertainty Dialogues" carried out within the NeWater project with water managers in the Rhine, Elbe and Guadiana basins in 2006. During these dialogues, representatives of these river basins were asked what uncertainties they encountered in their professional work life and how they confronted them. Analysing these dialogues we identified several important parameters of how uncertainties get framed. Our assumption is that making framing

N. Isendahl (✉) · M. Brugnach · S. Möllenkamp · C. Pahl-Wostl
Institute of Environmental Systems Research (USF), University of Osnabrück, Osnabrück, Germany
e-mail: Nicola.Isendahl@usf.uos.de

A. Dewulf
Public Administration and Policy Group, Wageningen University, Wageningen, Netherlands

G. François
Research Group Work, Organizational and Personnel Psychology (WOPP), Catholic University of Leuven, Leuven, Belgium

Published online: 04 March 2009

of uncertainty explicit for water managers will allow for better dealing with the respective uncertainty situations.

Keywords Framing · Uncertainty · Water management practice

1 Introduction

Dealing with uncertainties in water management is an important issue and is one which will only increase in light of global changes, in particular climate change. So far, uncertainties in water management have mostly been assessed from a scientific point of view with the aim of representing them in an objective and quantifiable way (cf. review by Walker et al. 2003 or Klauer and Brown 2004). Scientific assessment and analysis of uncertainty is often complex and technical and not always easily understandable, accessible or usable for water managers (cf. Brugnach et al. 2007; McCulloch 2007). An increasing number of contributions to the literature therefore aim at understanding how scientific evidence of uncertainty analysis is received and being dealt with by practitioners (e.g. Xu and Tung 2008). In this paper, we would like to go one step further and investigate how practitioners themselves frame uncertainties that is how they make sense of a situation in terms of uncertainty.

In recent years, the importance of the human dimension of uncertainty has been more and more acknowledged and emphasized. Instead of regarding uncertainties as merely external and objective phenomena, the role of people involved in producing and using uncertainty assessments should be considered as well (e.g. Klauer and Brown 2004; van Asselt and Rotmans 2000; Friedmann et al. 1999; Pahl-Wostl et al. 1998). This introduces a subjective element into uncertainty assessments. However, going further than the notion of uncertainty as a subjective property where the focus resides on the uncertainty attached to a person, e.g. uncertainty as a "*state of mind*" (Einsiedel and Thorne 1999), in the relational approach we follow in this paper, the emphasis is on the relation between the subject and the object (Brugnach et al. 2008). That means an uncertainty arises out of the interaction between actor and object and may hence be framed differently according to changes in the relation between actors and objects. In that it is important that the aim is not to identify how an uncertainty really is and get to a universally valid description of it, but understand how people relate to it, how they frame it (cf. Table 1) and what changes in that relationship entail for dealing with an uncertainty.

There are approaches which aim at addressing the issue of dealing with uncertainty in management practice in a more structured way. Einsiedel emphasizes that it is important to understand what uncertainty is, how it is framed by actors in a social system and what people do with it (Einsiedel and Thorne 1999). Her focus is on how the public deals with science and scientific knowledge. She suggests eight dimensions of uncertainty to 'catalogue public uncertainty' that refer to different kinds of lack of knowledge (e.g. "*I don't know about X; I will leave it to experts to tell me what I need to know*"). Those dimensions can be categorized by individual factors (such as personal skill level, interest and motivation) and social-structural factors (e.g. access to information) which "*shape perceptions of uncertainty and subsequent coping strategies*" (*ibidem*). But what is it that shapes the framing process? Einsiedel's dimensions

Table 1 Uncertainty categorization of the Uncertainty Matrix by Brugnach et al. (2008)

Type of knowledge relationship	
Unpredictability	Unpredictable system behaviour
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 seriousness of situation, growth potential of problems, priority of actions or interventions

only partly give hints as to how somebody arrives at conclusions regarding either of the dimensions or what makes somebody frame an uncertainty as she or he does.

Building on the importance of framing in relation with environmental problems highlighted in various scientific contributions (cf. e.g. Gray 2003; Dewulf et al. 2005; Pahl-Wostl et al. 2007) we here relate the concept of framing to the issue of uncertainties in water management. Our aim is to identify parameters that shape the process of framing uncertainties in water management practice (Table 2).

As a theoretical basis for the analysis of framing of uncertainties we give a short introduction to the concepts of framing and uncertainty as used in this paper. Based on situations of uncertainties reported by practitioners in water management, we then analyze the narratives of those uncertainty situations and derive parameters that are of importance in the framing of uncertainties in water management practice. In the final section we discuss aspects of usefulness and applicability of the identified parameters of uncertainty for water management.

The examples from practice this paper draws on stem from the 'Uncertainty Dialogues' that were held in several case studies of the project NeWater (New

Table 2 Parameters for framing uncertainties

Parameter	Definition	Actor frames uncertainty as…
Positioning	Positioning as the evaluative quality actors attach to uncertainties	Positive: fun, challenge, risk
		Negative: threat, risk, doubt, problem, difficulty
Urgency	Urgency related to the point of time for taking a decision in the uncertainty situation or to the time frame within which a decision is supposed to have an effect	Urgent
		Long-term issue
Responsibility	Responsibility for having caused and/or dealing with the uncertainty	Own responsibility
		The responsibility of others
		The responsibility of scientists
		Being caused by/ having to be changed by rules/regulations
Trustworthiness	How trusting actors are towards components of an uncertain situation, e.g. towards data, methods or other actors	An issue of trustworthiness:
		Trustworthy
		Untrustworthy
		Danger of loss of trust

Approaches to Adaptive Management under Uncertainty, www.newater.info) in early summer 2006 (Dewulf et al. 2008).

2 Conceptual Frameworks on Framing and Uncertainties

Due to their personal, educational and cultural backgrounds people have a specific and restricted view on the world around them. That means they cannot and do not consider all details and information relevant to a specific situation but observe selectively according to their interest and concern (cf. e.g. Denzau and North 1994; Doyle and Ford 1998; van Asselt and Rotmans 2000). Consequently people tend to focus selectively on those aspects to which their attention is drawn, which are most relevant for their current activities or to the aspects they want to put on the foreground (Dewulf et al. 2009). This process of giving meaning to things is captured differently in various disciplines and referred to with concepts such as frames, mental models, perceptions, perspectives or world views. The definitions vary and often the terms are used in an overlapping and interchangeable way (cf. e.g. Dewulf et al. 2009; Kickert et al. 1997; Schön and Rein 1994; van Asselt and Rotmans 2000). A common denominator is the idea that situations can be understood or portrayed in different ways and that these different meanings are not neutral, because they direct the search for solutions or the type of actions or strategies that are considered. Making sense of a situation in terms of a threat rather than an opportunity, for example, will have consequences for the action strategies that are considered.

For our analysis of how people make sense of uncertainties we focus on the concept of 'framing' because it better captures the active aspect of sensemaking involved, as compared to e.g. the concept of 'perception'. We conceive of individuals as active sense-makers (Weick 1995) rather than passive perceivers of the world. In the research on framing two approaches can be differentiated: 'cognitive framing' and 'interactional framing' (Dewulf et al. 2009). Where the 'cognitive framing' approach studies how cognitive structures or mental models of a person are related to a situation, 'interactional framing' refers to a discursive process involving social interaction where meaning is produced interactively over a certain time. Mental models we understand as "*a relatively enduring internal abstraction of an external system to aid and govern activity*" (after Doyle and Ford 1998: 17). Mental models may be created in a non-interactive process what Kaufmann and Smith call "*adopting a frame*" (1999). However, usually framing does not start from zero but most often is related to a certain outcome of an interactive framing process (e.g. Weick 1995; Dewulf et al. 2009). So the two concepts can not be strictly separated but imply a different focus when analyzing framing. In the cognitive framing approach, the criterion for assessing mental models and change is located in the individual mind, while in the interactional framing approach the criterion is located in the interaction context.

The uncertainties we analyze have been framed by practitioners in water management, within the respective dialogue session, but also through prior interaction with other actors in their daily practice. Hence, in this study we are not able to analyze that preceding interactive framing process but consider only a snapshot of how the reported uncertainties are framed in the studied interaction contexts in the water management practice.

Uncertainty in this paper is defined as a situation in which there is not a unique and complete understanding of the system to be managed (following Brugnach et al. 2008). This relates to an individual actor's understanding of an event or action as well as of the behaviour and interest of other actors that are possibly involved in the situation. It may simply refer to a lack of knowledge or to an ambiguous situation where different approaches and solutions may be conceived. A third category and type of uncertainty is unpredictability due to variability and complexity of the system. This threefold categorization is reflected in the Uncertainty Matrix (UM) developed by Brugnach et al. which was used in the Uncertainty Dialogues (cf. Table 1).

In terms of assessing framing of uncertainty, these categories or 'types of knowledge relationships' give a fist clue as they allow to distinguish basic kinds of somebody's relation towards an uncertain situation. That is uncertainties may be framed as unpredictability, incomplete knowledge or multiple knowledge frames.

For any attempt at changing or improving the way uncertainties are dealt with in water management practice, it is crucial to understand how water management actors understand uncertainties. Identifying relevant parameters or dimensions of how uncertainties get framed in water management practice makes an important contribution to this end. In this paper parameters beyond the categories of the UM are presented which may shed light on how uncertainties in water management are framed and render a more comprehensive picture. As for practical implications, the parameters are expected to be accessible and easily applicable for practitioners in water management as they have been deliberately derived from examples from practice and may hence be of more use in water management practice than complex scientific computational models.

3 Methods

The empirical evidence on which this paper is based are the "Uncertainty Dialogues" carried out in case studies of the project NeWater, New Approaches to Adaptive Water Management under Uncertainty, in May 2006 (Dewulf et al. 2008). Participants were water managers, mostly representatives of the water departments of public administration or water management associations in the river basins of the Wupper (Germany) and the Kromme Rijn (Netherlands) as sub-basins of the Rhine, the Guadiana (Spain), and the Elbe (Germany and Czech Republic). In the dialogues they were asked to identify uncertainties they encountered in their professional work life and to explain the way they dealt or would deal with them.

Where possible the dialogues were held as focus groups with about three to five participants (Wupper and Kromme Rijn). Where this was not possible (Guadiana and Elbe) semi-structured individual interviews were conducted with representatives of the respective water management organisations. Participants for the focus groups were selected from amongst those responsible for water management decisions in their river basin and involved in current decision making processes. The main focus was on governmental organisations and water board members at local and regional level.

A discussion among people from a common work area helps the purpose of assessing framing of real life situations since it is likely to capture interaction (and framing) similar to the interaction and framing going on in day to day business. The

discussions lasted about 2 h on the average and were conducted in a semi-structured way along the Uncertainty Matrix by Brugnach et al. (2008). The discussions were led by scientists from the team with moderation skills. While introducing the UM they acted as experts, but during the discussions their role was limited to moderation. The meetings mostly took place in the participants' native language with exception of the Elbe where the meetings were held in English.

The Uncertainty Dialogues are evaluated in qualitative terms in a discourse analytic approach. We do not aim to make claims about the relative importance or frequency of the different framings. The evaluation is based on audio files, transcripts and notes taken during the Uncertainty Dialogues, particularly those of the Wupper, Kromme Rijn, Guadiana and the Czech Elbe basin. These were all recorded and fully transcribed. Notes were taken during all of the dialogues. For the analysis the transcript and the notes for the full duration of the meeting were analysed. Where necessary, quotations have been translated into English for presentation in this paper. All quotations were cross-checked with the respective stakeholders. They do not necessarily reflect the opinion of the related organisation but their personal views (NeWater internal reports 2007).

4 Results

In an ex-post analysis of the narratives about uncertainties in the different case studies we identified parameters of importance in the framing of uncertainties. The Uncertainty Dialogues allowed for detecting commonalities and differences in the water managers' framing of the uncertainties, rendering details on how the uncertainties were conceived which went beyond the initial distinctions by the use of the UM. We analyzed the way in which the participants of the Uncertainty Dialogues reported on their examples of situations of uncertainty in water management.

The text analysis of the respective recordings, transcripts, and notes of the Uncertainty Dialogues (cf. above) revealed many potential parameters. We chose to focus on those that were salient as recurrent issues across different countries, cases and examples of uncertainty, and thus are likely to be of more general importance. The four most important parameters we identified on this basis were: positioning, urgency, issues of responsibility and of trustworthiness. Among the others identified were: the relevance or importance of an uncertainty, the expected consequences of an uncertainty, the difficulty of dealing with an uncertainty or the perceived dynamics of uncertainties. These were not analysed further as they were not present or equally important in each case study.

Often the parameters were interlinked and could not be looked at strictly separately. In the following the four salient parameters are illustrated along the examples from the case studies.

4.1 Positioning

The different kinds of positioning towards uncertainty situations we encountered in the Uncertainty Dialogues varied according to the case studies and the participants of the dialogues. With positioning towards uncertainty we mean the evaluative quality people attach to the uncertainties, in other words whether they frame the uncertainty

as something positive or negative (Levin et al. 1998). This does not necessarily reflect deeper routed and more general beliefs and attitudes, but it does indicate how uncertainties get framed in the specific interaction contexts studied. These positive and negative framings of an uncertainty situation can have different manifestations, such as framings of uncertainty as risk, fun, challenge, essential part of life, threat etc. It may as well be quite ambiguous as an example in the Kromme Rijn case study shows. "*Uncertainty has a little bit negative connotations. Uncertainty, that's what you cannot grasp and that is annoying*" (NeWater Uncertainty Dialogue,[1] HDSR,[2] May 17, 2006); but then the speaker goes on that in fact her work is positively influenced by uncertainties, "*I live so to speak from uncertainties, and I enjoy it. The moment it gets certain it's not my work anymore"* (*ibidem*). One interviewee in the Elbe case study takes up a similar stance. He is very enthusiastic about water as an element and about rivers since they do not care about political boundaries. He sees the related uncertainty as something vital to life, "*I think that is the life. (…) and still there will be uncertainties. And to have a dream not to be [uncertain], wouldn't be life.*" (UJEP,[3] May 15, 2006). The same interviewee later makes another comment which may show his enjoyment in dealing with uncertainties and certainly his experience of uncertainty as a challenge in the work area of water pollution, "y*ou must be very smart, sometimes it is a detective story, to detect the pollutant, or the polluter*" (UJEP, May 15, 2006). Among the positive framings we encountered in the case studies the most frequent in fact was that uncertainty was framed as a challenge that people enjoyed.

Throughout the dialogues the participants used terms other than 'uncertainty' as well to express situations that implied uncertainty. These terms may include a certain positioning towards the uncertainty situation, e.g. a negative framing. Terms that came up in several case studies in this regard were 'risk', 'doubt', 'problem' or 'difficulty'. A lot of other expressions which display uncertainties were used in addition. Many of the examples were related to the issue of (not) knowing something which most participants experienced as something negative, e.g. for the task of internalizing external costs due to the cost recovery requirements of the EU Water Framework Directive, "*I do not know if we are able to evaluate environmental costs*" (CHG, May 25, 2006), or the assessment of the danger of drought: "*we do not know when it will happen; even the meteorologists do not tell us*" (CHG,[4] May 25, 2006). Evidence of uncertainty was also obtained through references to the contrary of uncertainty, that is certainty, "*the only certain thing is that some time the water pollution will come. You don't know where, you don't know which type, (…) which polluter, which amount (…) it is always an individual case*" (Elbe case study, about accidental water pollution by complex organic material, UJEP, May 15, 2006). Uncertainty was expressed with regard to rather technical issues, for instance concerning measuring systems in the Guadiana. The participants of the meeting were worried about not getting direct and accurate data from indirect measuring

[1]Where not referred to differently all further quotations from oral communication (with exact date) refer to the NeWater Uncertainty Dialogues (project internal documents).

[2]Hoogheemraadschap De Stichtse Rijnlanden (Dutch regional water board).

[3]University of Jan Evangelista Purkyně, Usti nad Labem, Czech Republic.

[4]Confederación Hidrográfica del Guadiana (Guadiana Water Authority).

systems such as remote sensing (CHG, May 25, 2006). But the political sphere was also referred to: "*a large part of the unpredictability is political. This is the total unpredictability*" (*ibidem*).

In our case studies we observed a certain predominance of negative framings though there were also some positive examples and other rather neutral ones that showed the acceptance of uncertainties as a fact without however really evaluating the uncertainty as positive or negative.

As pointed out earlier, the parameters often are interlinked. Positioning for instance also plays a role in connection with time frame and urgency. In the Wupper case study one interview partner pointed out the difficulties and uncertainties that came along with the passing of a new legal framework. "*I just wanted to emphasize how difficult it is for the execution of a legal system to suddenly get the Water Framework Directive*" (WV,[5] May 18, 2006).

4.2 Urgency

The time factor seems to play an important role in all investigated case studies with regard to framing of uncertainties. Some uncertainties are framed as urgent, requiring an action within the short term, while others are framed as long-term issues, requiring attention in or over a few years. This may relate to the perceived urgency of taking a decision as well as to the time frame within which a decision will be implemented or is supposed to have an effect.

Concerning the time frame within which a decision has to be taken, lots of examples in the case studies showed that dealing with an uncertain situation would optimally require a lot of time. This is due to the fact that often more or deeper time-intensive analysis, modelling and scenario building were considered as necessary for addressing the need to reduce or overcome an uncertainty, as illustrated by the case of accidental water pollution, "*to analyse the complex cyanide [i.e. the behaviour of a pollutant in the river after an accidental spill] it is not so easy, it takes time*" (UJEP, May 15, 2006). Here the need for sufficient time for analysis clashes with the need for urgency since decisions have to be taken in a relatively short time once an accident has happened. In this example the short-term pressure relates to the danger of the pollutants in the water which are spreading quickly. In administrative planning, long-term considerations and goals also typically have to be evaluated against short-term pressures. However, often the relation there is different. Short-term pressures in water administration are current problems to be solved, whereas what is impeding the implementation of longer-term policies is the (lack of) required resources and investments rather than the complexity of the problem as in the water pollutant case above. In the Wupper case study an employee of an administrative body expressed this view with regard to the tension between recognising the value and benefit of the ecosystems and the long-term goal to maintain them, and, on the other hand "*(…) the decision is short-termed considering the financial straits we have in North-Rhine-Westphalia*" (StUA[6] Düsseldorf, May 18, 2006). Time here plays a role with regard to the uncertainty associated with the unpredictability of the future—the more

[5]Wupperverband (German water association).

[6]Staatliches Umweltamt (former German regional state authority for environment).

distant the more uncertain. However, planning administration often has to take long-term decisions. Hence, the situation in the example above is difficult since "*these time concerns are related with high uncertainty and as a planning administration I can only think in a long-term time frame*" (*ibidem*). Another participant of the Wupper Uncertainty Dialogue frames the uncertainty related to short-term versus long-term planning in the following way: "*To what extent do we manage to meet the zeitgeist of 20 years ahead with the decisions we take today and that will still be important in 20 years?*" (municipality of Wuppertal, May 18, 2006).

An example of rather low urgency is the balancing of the economic versus ecologic and social benefits of a wetland ecosystem in the Guadiana case study. They are seen to play a role in the long run, "*the maintenance of an ecosystem such as the Tablas de Daimiel against the economic or social benefit that the agricultural use might bring—at a certain moment we will have to do this balance*" (CHG, May 25, 2006) which is not now.

Overall, the examples with high urgency and short-term pressures prevail, often outweighing the long-term goals, which are associated with increased uncertainties due to the difficulty of making predictions for the distant future.

4.3 Responsibility

Responsibility issues refer to different aspects of an uncertain situation. They may relate to the question of who is perceived as responsible for solving an uncertain situation and they also give an idea about the perceived range of options for taking decisions in a situation marked by uncertainty.

In the dialogues, the issue of who is responsible for dealing with an uncertainty situation came up most often. We would suggest that it may also be interesting to investigate who or what is perceived as responsible for having caused an uncertain situation. This may have implications in terms of who is perceived to be responsible for dealing with it as well as with regard to actual strategies for dealing with uncertainty. In the following, some examples from the case studies will illustrate how responsibilities got framed as part of dealing with uncertainty.

The question of responsibility for solving an uncertainty situation is quite delicate. The participants of the dialogues reported that they themselves as well as other people often refer to rules when taking a decision thus placing the responsibility on something external to them. Especially in administration, there are usually rules to be followed in an uncertain situation. This becomes explicit for instance in the Wupper case study in the issue of flood protection where the interview partner of the regional water board reports that the water administration personnel refer to rules, i.e. in this case standards for flood protection, "*the experts have developed state-of-the-art technology for a 100 year flood. Then the administration says, I have to meet the state-of-the-art technology*" (WV, May 18, 2006). These regulations are then difficult to by-pass, "*this [the regulation] is very difficult to turn back*" (*ibidem*). Administration generally needs to build its decisions on rules and regulations. Administration staff may consider stakeholders' suggestions but cannot necessarily build their decision on that. "*If the citizen says I do not need this [measure; here dike] and in 15 years, if something really happens, and the citizen says, "so, now I claim damages", then this goes back to the administration and I think this really is an uncertainty that gets in the way of many things and also of sound solutions*" (StUA Düsseldorf, May 18, 2006).

The pressure from the administration to comply with rules and regulations renders it difficult for individuals, in this case administration personnel, to take responsibility for dealing with an uncertain situation—in the example above, uncertainty about flooding. With hindsight, sticking strictly to the rules may not have been the best solution for the problem under consideration, but regardless of this it is usually seen to be the safest option in terms of formal or legal accountability.

An interviewee of the Guadiana case study makes a similar point for the case of the surveillance of groundwater extraction in the catchment area, "*the administration has to comply with the law*" (CHG, May 25, 2006), and makes similar references about the options for stakeholders influencing decisions of the state, "*there is a limit which is the law*" (*ibidem*). Consequently the solution is perceived in terms that the law should change, "*if you want the situation to be changed then the law has to be changed in the parliament*" (*ibidem*). Another example from the Guadiana basin is related to uncertainty related to drought. Decisions there are highly rule-based as well. There is a system of drought indicators consisting of different categories which each imply a different level of alert and corresponding actions to take in the respective situations (CHG, May 25, 2006). So, in general, following rules is adopted as a means to deal with the responsibility issue and thereby circumvent explicitly addressing the uncertainty. Sometimes however, rules or regulations can be even more confusing and increase rather than decrease uncertainty as is the case for the implementation of the EU Directives on Nitrate and Water which are partly contradictory and hence difficult to implement in an integrated way (MLU S-A, May 22, 2006).

A big concern in terms of responsibility during the Uncertainty Dialogues was that the participants felt they did not have the final decision in a situation of uncertainty. The responsibility often is at a higher level than those of the interviewees in the dialogues, "(…) *we are technicians. Technicians at a high level but we do not have the final decision*" (CHG, May 25, 2006). This implies that communication and coordination among actors involved in an uncertainty situation is of high importance.

Another aspect in (at least partly) getting around the responsibility for dealing with an uncertain situation is that tasks are usually clearly distributed, "*floods are not my field*" (UJEP, May 15, 2006), or at least perceived as such. In the Guadiana case study, for certain issues politicians are perceived as having duties towards taking a decision. The final decisions, e.g. on the issue of control of ground water extraction, are said to lie at the 'water commissar' from the Water Authority and the politicians in the region. "*The ones who have to wipe off the mortgage are the politicians, through their political decision. A political decision based on the actual reality*" (CHG, May 25, 2006). For the case of the threat of droughts due to climate change in the Guadiana case study the responsibilities are perceived differently for different parts of the problem. For the case of estimations of future precipitations the responsibility is perceived to be at the level of the national climate change office (as part of the National Ministry of Environment), "*(…) they are working out at the moment to define us what is the variation in the estimations*" (CHG, May 25, 2006). For helping out with uncertainties due to lack of knowledge scientists are perceived as responsible in the first place, "*with regard to the lack of knowledge (…) or the development of methodologies, technical systems, technologies etc.., this is a matter where there are universities to help and investigate*" (CHG, May 25, 2006).

In most examples in the investigated case studies the responsibility for dealing with uncertainty was external to the interviewee. That is the uncertainty gets framed as something which others are responsible for.

4.4 Trustworthiness

Components of an uncertain situation, such as actors or data, are framed as trustworthy (or rather not). This relates to the quality of relationship of actors between each other as well as to the reliability of data, both being possible triggers for or against uncertainty. In some situations one could even say that the uncertainty in fact consists in full of the perceived untrustworthiness.

There is evidence of the importance of trust towards certain information or people in all case studies, e.g. the Kromme Rijn: "*Also the state has been an unreliable partner once when they had regulations for subsidies (…) and from one day to the next they ended*" (municipality Wijk-bij-Duurstede, May 17, 2006). This remark may be extended to collaborative work in general, though usually not referring to daily work, when one of the parties stops its commitment without any prior notification. Such behaviour may then cause uncertainty (municipality Wijk-bij-Duurstede, October 16, 2007). This is an example of unpredictability in the social system behaviour.

Concerning framing of trustworthiness of information, trust in data in the Guadiana case study for instance is high, because, amongst other reasons, data are officially certified by the National Institute of Meteorology. Only in case of a wider time span, like in series of data, there could be some doubts, but in principle the data is considered as highly reliable. "*The measuring [of precipitation] usually is direct and from relatively trustworthy data, (…) moreover it is officially certified data of the National Institute of Meteorology. (…) We trust them, (…) they are also from the existing official network and therefore deserve full guarantee. These data maybe may have errors (…) in a certain moment in the meteorological series, in the series of precipitation, but in principle they have full reliability*" (CHG, May 25, 2006). In the Kromme Rijn case study, loss of trust was expressed as a potential result and risk of bad uncertainty management. The example related to the fact that sometimes possible negative side effects of plans during or after implementation are not being taken into account as possible risks beforehand: "*The side effect might then be that (…) trust in the State or the planners goes down*" (municipality Wijk-bij-Duurstede, May 17, 2006).

Framing of trustworthiness between actors or groups of actors is a delicate issue. It is an interesting issue as well in terms of who frames whom as trustworthy or not in a multi-actor constellation, most likely having implications for approaches how to deal with the uncertainty.

As shows the case of the Elbe on accidental water pollution, issues of organization and communication of data may aggravate or alleviate the uncertainty and related trustworthiness, "*there [in the Czech Republic] is a lot of data [on accidental water pollution], it is very good. In Germany it's not so easy, because nobody tells you the proper information. Nobody collects centrally, in Czech Republic yes.*" (UJEP, May 15, 2006).

In general, the trustworthiness of data or people in the case studies seems to be highly dependent on previous experiences with situations or people.

5 Discussion

In the previous chapter we illustrated the most important parameters that play a role in how the participants of the Uncertainty Dialogues framed uncertainties.

The focus of the analysis is on the relation of a person towards an uncertainty. The aim is not to assess objective boundary conditions but how people relate to those and the possibly uncertain issues. This gets clear through the identified parameters. Uncertainty gets framed in terms of positioning as positive or negative, as an urgent or a long-term issue, as an issue for which the actor herself versus other actors are responsible and as untrustworthy (or not). Many of the examples in the Uncertainty Dialogues are related to the issue of not knowing something, which most participants experience as something negative. In total, negative framings slightly dominate throughout our case studies. Among the positive framings we encountered, the most frequent was uncertainty framed as a challenge. There were also rather neutral framings that show the acceptance of uncertainties as a fact without however evaluating the uncertainty as positive or negative. Time proves to play an important role in all case studies with regard to framing of uncertainties. Recurrent evidence from the Uncertainty Dialogues is that the participants conceive of dealing with an uncertain situation as a long-term issue, optimally requiring substantial amounts of time. This is a challenge in face of the short term pressures that prevail in practice. Concerning responsibility issues mainly the issue of who is responsible for dealing with an uncertainty situation came up in the dialogues. In most examples in the investigated case studies responsibility is shifted to others (or to rules and regulations). That is the uncertainty gets framed as something others are responsible for. In that, questions of hierarchy and level of decision-making play a critical role. Typically, the responsibility for taking the final decision was referred to by the participants as not being in their hands since they were depending on decisions at a higher hierarchical or legal level. Issues of trustworthiness show through certain parts of the uncertain situations and are highly dependent on previous experiences, i.e. (un)trustworthiness regarding actors involved or towards data. Framing of trustworthiness between actors or groups of actors is a delicate issue and information and perceptions of actors involved is not easy to access. In the Uncertainty Dialogues it mostly shows through generalized opinions about actor groups.

Our analysis does not explain why an uncertainty situation is framed as it is but what is getting framed and how. This is important to understand in order to find adequate ways for dealing with uncertainties. Uncertainty in water management can no longer be ignored or trivialized given the increasing pace and dimension of changes and future challenges. Nowadays complex non-linear and multi-layered problems make the need to acknowledge different framings and to deal with them constructively more pressing (Bouwen and Taillieu 2004; Pahl-Wostl et al. 2007). To be able to confront these challenges in a constructive way it is important to make people and organizations aware about how they frame uncertainties such that they can consider possible ways of action. For a first assessment and broad distinction of framing of uncertainties the categories of the UM can be used. The parameters identified in this paper take this process further, and aim to capture the character of how an uncertainty gets framed. The parameters provide the option to further differentiate facets of the uncertainty situations distinguished through the UM.

Furthermore, the parameters have potential to be used for the development of more structured strategies to deal with uncertainty. An uncertain situation typically is a non equilibrium state that is likely to change or even requires change the actor needs or wants to perform but is uncertain how to put in practice. In water management, decisions are hardly ever taken by single actors in a disconnected way. Especially in situations with multiple actors as in water resources management it is important to arrive at connections between different ways of framing uncertainties in order to achieve joint action (Gray 1989). Normally in such multi-actor constellations the involved actors do not agree on everything. Thus learning is required to achieve a change in framing by at least some of the actors involved. Becoming aware of each other's framings, interests and needs is a first step towards (social) learning and reframing. This counts as well for framing of uncertainties. A setting where several actors are making their framings of uncertainty explicit enables social learning and constructive dealing with framing differences (Pahl-Wostl et al. 2007).

At an individual level, the assessment of framing parameters of uncertainty renders a better picture of one's own assumptions and action options including a clearer division of tasks as well as showing options for reframing by questioning one's own point of view. When dealing with various situations of uncertainty the assessment of the parameters allows for comparing the situations and prioritizing amongst them.

Commonly, uncertainties in management practice are dealt with intuitively (e.g. Einsiedel and Thorne 1999; Friend and Hickling 1997: 6). We suggest that making framing of uncertainty explicit will allow for better dealing with the respective uncertainty situations, particularly in multi-actor constellations. Mismatches in framing of uncertainties can block effective solutions. Not being aware of or not taking into account that uncertainties may be framed differently by different actors may cause problems in communication between the involved actors, and therefore also in dealing with the uncertainties.

While this is a first attempt to identify parameters of importance in framing of uncertainties, work in another context would be required to make this concept more general.

6 Conclusions

In this paper we discussed how practitioners in water management in three European river basins frame uncertainties by analyzing dialogues on uncertainty where water managers reported on their work experiences with uncertainty. From the analysis we derived a set of parameters that are important in the framing of uncertainties and illustrate the character of uncertainty.

We have argued that analyzing the framing of the context where an uncertainty arises together with the way that the uncertainties are framed (through both the type of knowledge relationship of the UM and the new parameters) makes differences in the framing of an uncertainty situation visible. Assessing framing parameters is relevant for water management practice as it forms a basis for developing strategies for dealing with uncertain situations and reaching a more structured way of dealing with uncertainty which eventually allows for more informed decisions. This is important for practice in water management where most often decisions are taken based on

experience or intuition and where scientific uncertainty analyses are difficult to deal with for practitioners.

The practical cases show that uncertainties in water management are framed in different ways. Concerning dealing optimally with uncertainty, one cannot draw general conclusions of what would be an ideal framing of an uncertainty. One could assume a negative framing to be a source of resistance but it can also be a trigger to change things. Likewise, differences in framings of actors are more likely to trigger learning and change than homogeneously sharing points of views. Nonetheless, one can conceive barriers for learning with regard to the framing of uncertainties. A rather disadvantageous starting point for learning would for instance be a framing in which actors frame other actors as untrustworthy, themselves as not responsible for dealing with the uncertain situation and the uncertainty at hand as not urgent to deal with.

In this paper, we used the four identified parameters in an ex-post analysis. The identified dimensions (both parameters and types of uncertainty from the UM) provide a set of potentially relevant aspects, whose relevance and relative importance can be assessed for a specific situation in future cases, and which can be complemented by contextual factors that are new, locally relevant dimensions in that specific situation. They could also be used as a checklist for active analysis in assessing uncertainty situations in a structured and systematic way to obtain a basis for developing strategies to deal with uncertainty and make better informed decisions. More research is then needed to conceive possible strategies according to the items of the checklist.

But one has to be aware that this would imply a considerable intervention and therefore might distort the findings if the aim is to elicit people's framing of uncertainties. For the latter we see a less structured approach as more promising. This may be achieved by eliciting important parameters directly from the practitioners—rather than through ex-post analysis. Conceivable methods for that would be card sorting techniques or similar (cf. e.g. Hare and Pahl-Wostl 2002) whereby participants themselves identify the parameters that have relevance for them.

Acknowledgements The work presented in this paper was financially supported by the European Commission (Contract N° 511179—NeWater).

We thank the participants of the Uncertainty Dialogues in the case studies of the Elbe, Guadiana, Kromme Rijn and Wupper for their kind collaboration and openness.

We further thank Catrin Egerton for proof-reading.

References

Bouwen R, Taillieu T (2004) Multi-party collaboration as social learning for interdependence: developing relational knowing for sustainable natural resource management. J Community Appl Soc Psychol 14:137–153. doi:10.1002/casp.777

Brugnach M, Tagg A, Keil F, de Lange WJ (2007) Uncertainty matters: computer models at the science–policy interface. Water Resour Manag 21(7):1075–1090. doi:10.1007/s11269-006-9099-y

Brugnach M, Dewulf A, Pahl-Wostl C, Taillieu T (2008) Towards a relational concept of uncertainty: about knowing too little, knowing too differently and accepting not to know. Ecol Soc 13(2). http://www.ecologyandsociety.org/vol13/iss2/art30

Denzau AT, North DC (1994) Shared mental models: ideologies and institutions. Kyklos 47(1):3–31. doi:10.1111/j.1467-6435.1994.tb02246.x

Dewulf A, Craps M, Bouwen R, Taillieu T, Pahl-Wostl C (2005) Integrated management of natural resources: dealing with ambiguous issues, multiple actors and diverging frames. Water Sci Technol 52:115–124

Dewulf A, François G, Brugnach M, Isendahl N, Taillieu T, Pahl-Wostl C, Möllenkamp S (2008) The role of uncertainty, ambiguity and framing in transition to adaptive management. About knowing too little, accepting not to know and knowing too differently. Deliverable of the EU 6th FP NeWater project. www.newater.info

Dewulf A, Gray B, Lewicki R, Putnam L, Aarts N, Bouwen R, Van Woerkum C (2009) Disentangling approaches to framing: mapping the terrain. Hum Relat 69(2):155–193. doi:10.1177/0018726708100356

Doyle JK, Ford DN (1998) Mental models concepts for system dynamics research. Syst Dyn Rev 14:3–29. doi:10.1002/(SICI)1099-1727(199821)14:1<3::AID-SDR140>3.0.CO;2-K

Einsiedel E, Thorne B (1999) Public responses to uncertainty. In: Friedmann SM, Dunwoody S, Rogers CL (eds) Communicating uncertainty: media coverage of new and controversial science. Lawrence Erlbaum, Hillsdale

Friedmann SM, Dunwoody S, Rogers CL (eds) (1999) Communicating uncertainty: Media coverage of new and controversial science. Lawrence Erlbaum Associates

Friend J, Hickling A (1997) Planning under pressure—the strategic choice approach. Butterworth-Heinemann, Oxford

Gray B (1989) Collaborating. Finding common ground for multiparty problems. Jossey-Bass, San Francisco

Gray B (2003) Framing of environmental disputes. In: Lewicki R, Gray B, Elliot M (eds) Making sense of intractable environmental conflicts—frames and cases. Island, London

Hare M, Pahl-Wostl C (2002) Stakeholder categorization in participatory integrated assessment processes. Integr Assess 3(1):50–62. doi:10.1076/iaij.3.1.50.7408

Kaufman S, Smith J (1999) Framing and reframing in land use change conflicts. J Archit Plann Res 16(2):164–180

Kickert WJM, Klijn E-H, Koppenjan JFM (1997) Managing complex networks—strategies for the public sector. SAGE, Newbury Park

Klauer B, Brown J (2004) Conceptualizing imperfect knowledge in public decision making: ignorance, uncertainty, error and risk situations. Environ Res Eng Manage 1(27):124–128

Levin IP, Schneider SL, Gaeth GJ (1998) All frames are not created equal. Organ Behav Hum Decis Process 76(2):149–188. doi:10.1006/obhd.1998.2804

McCulloch CS (2007) Integrating research for water management: synergy or dystopia? Water Resour Manag 21(12):2075–2082. doi:10.1007/s11269-007-9161-4

Pahl-Wostl C, Jaeger CC, Rayner S, Schär C, van Asselt M, Imboden DM, Vckovski A (1998) Regional integrated assessment and the problem of indeterminacy. In Cebon P, Dahinden U, Davies HC, Imboden DM, Jaeger CC (eds) Views from the Alps: regional perspectives on climate change. MIT, Cambridge, pp 435–497

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

Schön DA, Rein M (1994) Frame reflection—toward the resolution of intractable policy controversies. Basic Books, New York

van Asselt M, Rotmans J (2000) Uncertainty in integrated assessment—a bridge over troubled water. ICIS (International Centre for Integrative Studies) Maastricht University:60

Weick K (1995) Sensemaking in organizations. Sage, Thousand Oaks

Walker WE, Harremoes J, Rotmans J, van der Sluijs JP, van Asselt M, Janssen P, Krayer von Kraus MP (2003) Defining uncertainty—a conceptual basis for uncertainty management in model-based decision support. Integr Assess 4(1):5–17. doi:10.1076/iaij.4.1.5.16466

Xu Y-P, Tung Y-K (2008) Decision-making in water management under uncertainty. Water Resour Manage 22(5):535–550. doi:10.1007/s11269-007-9176-x

Paper 2: Using framing parameters to improve handling of uncertainties in water management practice

Isendahl, N., Pahl-Wostl, C., Dewulf, A. (2010). Using framing parameters to improve handling of uncertainties in water management practice. Journal of Environmental Policy & Governance 20(2): 107-122. DOI 10.1002/eet.533

Paper 3: Making framing of uncertainty in water management practice explicit by using a participant-structured approach

Isendahl, N., Dewulf, A., Pahl-Wostl, C. (2010). Making Framing of Uncertainty Management Explicit by Using a Participant-Structured Approach. Journal of Environmental Management. 91(4): 844-851. DOI: 10.1016/j.jenvman.2009.10.016