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Scientific knowledge use and addressing uncertainties about climate change and ecosystem functioning in the Rhine-Meuse-Scheldt estuaries

J.A. Veraart[a,*], J.E.M. Klostermann[a], E.J.J. van Slobbe[b], P. Kabat[b,c]

[a] Wageningen Environmental Research, Wageningen University and Research Centre, PO Box 47, 6700 AA, Wageningen, the Netherlands
[b] Water Systems and global change group, Wageningen University and Research Centre, PO Box 47, 6700 AA, Wageningen, the Netherlands
[c] International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361, Laxenburg, Austria

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ABSTRACT

This paper analyses how scientists, policy makers and water users engage with scientific knowledge and uncertainties during a lengthy and complex decision-making process (2000–2014) about water quality, freshwater resources and climate adaptation in the Rhine-Meuse-Scheldt estuaries. The research zooms in on lake Volkerak-Zoom. Interviews confirm that 'negotiated knowledge', shaped by the agricultural sector, NGO's and water managers can lead to strategies to improve water quality problems. One such a strategy, based on negotiated knowledge, is to create an inlet to allow limited tides and inflow of saline waters in Lake Volkerak-Zoom. Meanwhile, during negotiations, monitoring showed an autonomous decline in the annually returning algal blooms, leading to new uncertainties and disrupting the negotiations. At another negotiation arena, water users and policy makers repeatedly disputed scientific assessments about costs and benefits regarding additional freshwater supply for agriculture and the knowledge underlying proposed decisions was still considered uncertain in 2014. Several strategies have been observed to deal with uncertainties in decision making, such as deconstruction of certainties, creation of deadlines for decisions and selection of preferred solutions based upon the 'No-regret principle'. The risk of a lengthy decision making process can be reduced when the responsible authorities recognize, acknowledge and give an equal role to these behavioural strategies to address uncertainties. Tailor-made strategies are needed to make knowledge use more efficient, for example, joint-fact-finding (in case of disputed knowledge and ambiguity), additional research and monitoring (in case of epistemic uncertainty) or commissioning research whereby temporarily a protected environment is created to allow research without political interference (in case of ontic/structural uncertainty).

1. Introduction

The impacts of climate change on freshwater resources are becoming noticeable in many parts of the world (IPCC, 2014b). Concerned policy makers and scientists in the Netherlands are increasingly posing questions as to whether current water management is able to cope with climate change or whether alternative strategies are needed (Dewulf and Termeer, 2015; Kabat et al., 2009, 2005). At the same time, the Dutch water system has been strongly modified during the past centuries in order to cope with flood risks and to support economic development. These modifications have, amongst others, resulted in unintended ecological impacts, like cyanobacterial blooms in Lake Volkerak-Zoom (Hooghart and Posthumus, 1992) and the disappearance of eelgrasses in the Wadden Sea (van der Heide et al., 2007; Van Katwijk et al., 2009).

Both climate change impacts and ecosystem functioning are associated with scientific and societal uncertainties. The question is to what extent climate impacts and associated risks are acceptable for society (Dessai et al., 2004; Paavola and Adger, 2006). In climate science, in particular IPCC, uncertainties are usually addressed in a rational, methodological and structured way (Swart et al., 2009). Uncertainties about climate change impacts on freshwater resources are usually assessed with a set of plausible scenarios about how the climate will change in terms of temperature rise or changing precipitation patterns. The potential future (stochastic) mismatch between freshwater supply and freshwater demand varies greatly for the different plausible socio-economic and climate scenarios as used in Dutch water management (Jeuken et al., 2015; Berkhout et al., 2013; Van den Hurk et al., 2013).

Given the societal relevance of sound risk assessments in climate adaptation strategy development in water management it is relevant to

* Corresponding author.
E-mail address: jeroen.veraart@wur.nl (J.A. Veraart).

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ask who should be involved in research, decision making, financing and implementation (Gupta et al., 2010; Termeer et al., 2012; Veraart et al., 2014). Additionally, climate adaptation strategies may interfere with ongoing planning processes regarding other environmental issues at national and regional scale, which increases complexity (Verkerk et al., 2015; Zegwaard et al., 2015) and may create ambiguity (Brugnach et al., 2011) resulting from the simultaneous presence of multiple valid, but sometimes contradicting, ways of framing a problem (Byers, 2011). Consequently, evaluating and prioritizing envisaged interventions in view of climate change, solely based upon rational or quantifiable evaluation criteria, becomes difficult (De Boer et al., 2010; Hisschemöller and Hoppe, 2001; Vink et al., 2013).

Nevertheless, uncertainties and distrust in the existing knowledge base often give rise to commissioning research to reduce the complexity for water management. In an effort to manage the decision process in an orderly way, evaluation procedures such as environmental impact assessments (Jay et al., 2007; van Dijk, 2008) are obligatory when interventions in water systems are proposed. These types of procedures often do not lead to obvious conclusions. The outcome depends amongst other things on how involved actors address uncertainties. Some actors exhibit the behaviour to reduce uncertainties in decision making, while others continue to identify new uncertainties.

Knowledge and uncertainties about ecosystem functioning and climate change are interpreted, constructed and assessed by individuals with rational as well as irrational approaches (Kelly, 1955; Meijnders, 1998). Scientists and non-scientists (implicitly) both use simple ‘mathematical’ estimates (Polack, 2005) while addressing uncertainties in daily decision-making. For example, almost everyone makes estimations about the travel time needed to arrive at work by car or by bicycle, based upon variables such as average velocity or travel distance. However, the choice to travel by bicycle or car also depends on irrational motives such as one’s mood or personal principles. The uncertainty about the travel time is reducible and measurable but it remains difficult to predict how long the travel time will be for a random person because it also depends on modality preference and on weather conditions.

The objective of this paper is to explore how knowledge from research is used and how uncertainties are typified between scientists, policy makers and water users at two occasions (2009/2010 and 2014) during a lengthy decision making process (2000–2015) in which the complexity increases over the years as policy objectives and planning processes interacted with each other.

We examine this phenomenon by mapping uncertainties in a case study about freshwater resources management in the Rhine-Meuse-Scheldt Estuaries (RMS-Estuaries) in view of climate change and the ambition to rehabilitate estuarine dynamics in Lake Volkerak-Zoom in the period 2000-2014. We aim to formulate recommendations that support more efficient use of scientific knowledge in water management.

2. Conceptual framework & methodology

This study links use of knowledge from research and uncertainties in decision making within water management. Bertolini (2010) argues that a decision can be taken about an intervention when there is agreement and sufficient knowledge (Bertolini, 2010). Strategic planning concepts, planning instruments and research are, amongst others, options to address or reduce uncertainties in water management decision making. Some scholars (O’Toole and Coffey, 2013) state that connecting or integrating disparate *knowledge systems* each pertaining to different actor groups, like research communities and/or policy making arenas, is important to realize a decision.

Adaptation to climate change in water management can be framed as a scientific issue, as a socio-economic risk or as a societal challenge in a decision making process. The chosen angle influences how (climate) research is conducted and used in water management (O’Brien et al., 2007; O’Brien and Wolf, 2010). Research usability also depends on the context of potential use and on the process of scientific knowledge production itself.

2.1. Methodology

The presented analysis is mostly based on qualitative research methods but also has quantitative elements. The methodological design of this research (Fig. 1) builds on a case study approach (Flyvbjerg, 2006; Ford et al., 2010; Yin, 2009, 2012). It is a nested case study (Flyvbjerg, 2006) in which two policy processes regarding freshwater resources management are studied over a longer time period (2000–2014). It is therefore also a longitudinal case study (Thomas, 2011).

The case study comprises two policy processes: (1) the National Delta programme (climate change adaptation) and (2) the Environmental Impact Assessment project ‘Improvement Water Quality Lake Volkerak-Zoom’ (EIA Volkerak-Zoom). Both policy processes took place within Rhine-Meuse-Scheldt estuary and in both the Programme Office South West Delta was involved (Fig. 1).

2.2. Participant observation in Programme Office South West Delta (data collection)

The principal investigator participated in 20 stakeholder meetings (2007–2011) organized by the Programme Office South West Delta (programme office SWD), and his role could be described as peripheral

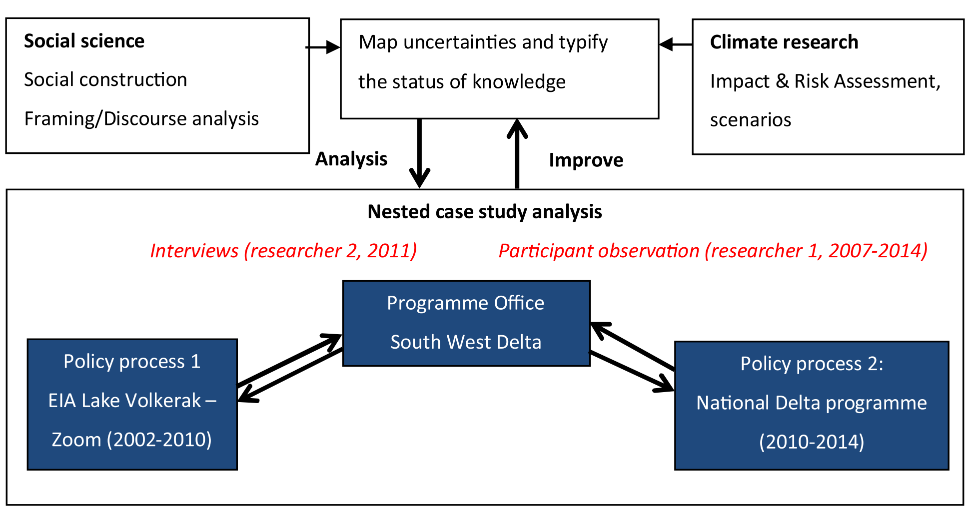

Fig. 1. Overall methodological design *of this study.*

Table 1
Characterisation of the interviewed respondents.

	Organisations	Functions
Nature conservation (n = 3)	Staatsbosbeheer, Stichting Het Zeeuwse Landschap, Natuurmonumenten	Lobby Nature interests, terrain officers
Water management and regional policy (n = 7)	Water board Scheldestromen, Water board Brabantse Delta, Rijkswaterstaat (2x), Province of Zeeland, Self-employed consultant	Policy maker, specialist hydrology, Delta Programme, Programme Office SWD, Project leader EIA Volkerak-Zoom
Freshwater users Agriculture (n = 4) Drinking water supply (n = 1)	Horticulture (flower bulbs), Fruit cultivation, arable farming, horticulture (vegetables), drinking water supply (Evides), Farmers organisation (ZLTO)	Farmer, manager drinking water supply, Lobby (ZLTO)
Scientists (n = 4)	Deltares, Alterra, Wageningen University	Experts in Freshwater resources, ecology, geohydrology, agro hydrology and soil physics

member of this network. In 2011–2014, the principal investigator participated in the monthly Programme Office SWD policy team meetings. This team was responsible for drafting the long-term policy for fresh water resources management and coastal safety. In this period his role could be described as participant observant (Atkinson and Hammersley, 1994) with an active membership role (Adler and Adler, 1987). The principal investigator had a formalized task to assist the team with the formulation of an annual research agenda. In a later stage (2014) the principal investigator also conducted 17 additional interviews for a different project (Veraart and Leemans, 2014) with the objective to explore how Dutch and Flemish stakeholders in the Rhine-Meuse-Scheldt think about the idea to initiate a new science-policy interface in the Rhine-Meuse-Scheldt Delta. These results are not presented in this paper, but were a relevant resource to validate and fine-tune our conclusions.[1]

2.3. Interviews (data collection)

A series of interviews was conducted in 2011 by another researcher, not acquainted with the programme office SWD. Ethnographic interview techniques were used (Spradley, 1979). The 19 interviews were meant to explore the maximum variety in ideas in the region by involving representatives of the water users; NGO's, scientists, policy makers and water authorities (Table 1). The respondents were selected from participant lists of public consultation evenings and stakeholder meetings in which the programme office SWD was involved.

Many respondents referred to each other, which is an indication of a lively and closely connected network. The selected respondents mostly cover the network involved with the EIA Lake Volkerak-Zoom, the programme Office SWD and the national Delta programme (Fig. 1). However, as a result, we probably missed the dissident ideas from outside the network. At least one important 'outsider', the Ministry of Agriculture and Nature, was not interviewed.

2.4. Mapping uncertainties and classifying knowledge (analysis)

Uncertainties that played a role in the national Delta programme and EIA Volkerak-Zoom were qualitatively mapped using the 19 interviews (J.E.M. Klostermann et al., 2013), analysis of policy and research reports (Veraart and Klostermann, 2013). Two crucial moments in decision-making were selected in order to structure the analysis:

- The presentation of the preferred intervention strategy to mitigate the water quality problems in Lake Volkerak-Zoom (2009/2010);
- The decision about the preferred strategy to cope with climate change in the RMS Estuaries (2014).

Atlas-ti software (Boeije, 2008; Friese, 2011) was used to cluster and analyse the mentioned uncertainties within the interviews. The initial coding was based upon the interview questions and incrementally adjusted and supplemented with sub-codes, e.g. axial coding (Boeije, 2008). The analysis and interpretation and the clustering of the coding (Table 2), was done in collaboration with the participant observant. In this way interview results (2011) and the Programme Office Southwest Delta observations (between 2007 and 2014) could be aligned and differences/similarities in knowledge use and addressed uncertainties could be detected.

2.5. Classifying knowledge (analysis)

Subsequently we explored how the status of the scientific knowledge could be characterized for each theme (Table 2). The following labels are used: ***negotiated, disputed*** and ***uncertain*** (Table 3). We have consciously opted for this fairly rough classification to keep the analysis manageable, however, to underpin our final classification we also use additional classifications of knowledge and uncertainties derived from other conceptual frameworks (De Boer et al., 2010; Hisschemöller and Bos-Gorter, 2006; Klostermann et al., 2013).

In this article we speak about *negotiated* knowledge when actors agree upon the (scientific) validity of a problem–solution combination (Hommes et al., 2009) and consensus exists about the significance and meaning of the associated knowledge base (Koppenjan and Klijn, 2004). We explore problem-solution combinations because it is difficult to debate a wicked problem without judging the possible solutions (De Bruijn and Ten Heuvelhof, 1999).

Knowledge can also be *disputed* between or amongst stakeholders. Disputes and different discourses about environmental problems are widely described in literature (Hajer, 1995). In this article we speak about disputed knowledge when heterodox ideas, denial claims or the existence of different discourses can be identified (Adger et al., 2001). The parties, involved in a dispute, often develop a narrative that is frequently repeated (McLean, 2013). Narratives use reason, logic and science to argue their (heterodox) ideas (Verweij et al., 2006).

We view knowledge as *uncertain* when either debate in a sector or amongst sectors exists about the seriousness of a problem and/or the

Table 2
The clustered themes regarding uncertainties and the number of interview respondents that elaborated on those themes.

Theme	# respondents
Definition of Fresh and Salt water	19[a]
Economic aspects of the considered interventions	10
Future fresh water supply and demand in and around Lake Volkerak-Zoom	6
Crop damage risks for agriculture	10
Salt water intrusion risks between Lake Volkerak-Zoom and surrounding water systems	5
Ecosystem functioning of Lake Volkerak-Zoom (algal blooms, value of brackish nature)	7
Combining solutions: river water retention in Lake Volkerak-Zoom and Grevelingen	2

[a] This was answered by every respondent, as it was a specific interview question (see supplementary material).

[1] See also supplementary material.

Table 3
Labels used for the classification of (scientific) knowledge within this case study.

Classification of knowledge	Sub-labels
Negotiated	
Disputed	
Uncertain	Epistemic (Kwakkel et al., 2010)
	Structural or ontic uncertainty (Zandvoort, 2017)
	Ambiguity (Brugnach et al., 2011)
	Ignorance (Merton, 1987; Stocking, 1998)

feasibility of a solution. Involved actors have doubts about the available knowledge; however, denial claims do not occur. We view knowledge also as uncertain when stochastic variability or ecological surprises are the causes of the uncertainty (structural uncertainty). An increase in knowledge can lead to an increase in knowledge about what we do not know (specified ignorance), so then the uncertainty is increasing (Merton, 1987; Stocking, 1998).

We are aware that within climate science often tighter definitions for "uncertainty" and "ignorance" are used (Ha-Duong et al., 2007; IPCC, 2014a; Kabat et al., 2009; Swart et al., 2009; Linde et al., 2011). In this article, uncertainty is understood as the product of social interactions allowing for ambiguity and differences in interpretation. Therefore uncertainties are more seen as a social construct (Klostermann and Cramer, 2007). We are interested in how people respond to these broad qualifications regarding the status of knowledge.

3. Case study description

Firstly, we provide a brief description of the Rhine-Meuse-Scheldt Estuaries as a physical water system. Then the case study description elaborates on the main process steps in our case study: formulation of the Environmental Impact Assessment (EIA) for Lake Volkerak-Zoom; establishment and functioning of the Programme Office Southwestern Delta (SWD) and the initiation of the National Delta programme. An overview of the investigated process is provided in Fig. 1.

3.1. Rhine-meuse-scheldt estuaries

In the case study area (Fig. 2), the rivers Rhine, Meuse and Scheldt come together. The interplay between sea and rivers is currently controlled by a comprehensive system of protective dykes and storm surge barriers developed between 1953 and 1997 in order to reduce flood risks (Abrahamse et al., 1977; Correljé and Broekhans, 2015; Maris et al., 1956; Stuvel, 1962). These measures caused water quality problems and unforeseen ecological shifts (Saeijs, 1982), for example in Lake Volkerak-Zoom (Breukers et al., 1997), Lake Grevelingen (Bannink et al., 1984) and the Eastern Scheldt (Bui et al., 2010; Eelkema et al., 2013; Vranken et al., 1990).

The estuaries within the Rhine-Meuse-Scheldt delta (RMS-Estuaries) are also important as a freshwater resource for agriculture (Haringvliet, Lake Volkerak-Zoom), potential river discharge regulation (Lake Volkerak-Zoom, Lake Grevelingen) and as the gateway to the port of Antwerp (Western Scheldt) and Rotterdam (Nieuwe Waterweg) (Correljé and Broekhans, 2015; De Vries et al., 2012). In addition, the estuaries and associated natural resources have a socio-economic value for recreation, aquaculture and fisheries. The estuaries are a refuge for several nationally highly valued bird and fish species of both freshwater and saltwater ecosystems (Meire et al., 2005).

3.2. Environmental impact assessment improvement water quality Lake Volkerak-Zoom

In 1969, the Volkerakdam was finished. The dam disconnected the estuary from the rivers Rhine and Meuse, but tidal influence was still present. After completion of the Phillipsdam (1987), the saline tidal system was transformed into a stagnant freshwater lake, called Lake Volkerak-Zoom (Hooghart and Posthumus, 1992). The lake provided neighbouring farmers the opportunity to start horticulture. At first, the ecology of the lake developed in line with the expectations, providing a habitat for freshwater species. However, since 1991 excessive cyanobacteria blooms (algae) became a regular phenomenon in late summer, with negative impacts for swimmers (health), agriculture (unusable for irrigation) and the built environment (odour nuisance) (Wanningen and Boute, 1997). Several measures were taken to combat the algal blooms (Meijer and De Boois, 1998), without success. In order to identify alternative strategies an Environmental Impact Assessment procedure (EIA) was initiated in 2002 (Rijkswaterstaat directie Zeeland et al., 2009). After several iterations, the various alternative solutions were summarized and simplified into two possible strategies in 2009/2010: (strategy 1) *Increased freshwater flushing of Lake Volkerak-Zoom with river water; (strategy 2) Increase of chloride concentrations (up to 10,000* mg/l) *by influx of Eastern Scheldt water combined with limited tidal influence.*

The EIA procedure ultimately concluded around 2010 that strategy 2 was the preferred solution to improve water quality. However, this solution would have negative consequences for freshwater supply for agriculture in the area around Lake Volkerak-Zoom (Hommes et al., 2009; Vinke-de Kruijf et al., 2010). Therefore, the agricultural sector asked for alternative freshwater supply arrangements. This delayed the decision-making process and the EIA procedure was put on hold (Fig. 3).

3.3. Programme Office Southwest Delta

Since 2004, a steering group in the Rhine-Meuse-Scheldt estuary has been active with decision makers from Provinces, Water boards, Rijkswaterstaat, the former[2] ministry of Public Transport & Water Management and the ministry of Agriculture, Nature and Food Security. The steering group was supported by the Programme Office Southwest Delta (Programme Office SWD). The steering group discussed the proposed interventions in water management and tried to align those with regional economic development strategies. Vision building also took place for the whole region (Adriaanse and Hoekstra, 2009). The involved authorities kept autonomous responsibility for implementation of specific interventions. In 2009 this steering group took responsibility for the formulation of a climate adaptation strategy (Staf Deltacommissaris, 2014). The programme office SWD supported the steering group in these tasks and was responsible for communication and stakeholder dialogue. Staff members were employed by the involved authorities, in particular Rijkswaterstaat and the Province of Zeeland. The Ministry of Agriculture, Nature and Food security (and its successors) chaired the policy team within the programme office that was responsible for drafting a climate adaptation strategy (2010–2014).

3.4. National Delta Programme

In 2007 the Dutch government installed a commission that formulated recommendations about flood risk reduction strategies and long-term freshwater supply in view of climate change (Deltacommissie, 2008). Subsequently the national Delta Programme (2009) was initiated along with a Delta commissioner (2010), a Delta act (2011), and an investment fund (2011) (Vink et al., 2013). The investment fund, on average approximately €1 billion yr^{-1}, was meant for investments in adaptive water management (Restemeyer et al., 2016). Decisions about new standards for flood risk management, guidelines for allocation of freshwater, and

[2] The ministry of Public Transport and Water Management (V&W) and the ministry of Housing Spatial Planning and Environment (VROM) merged into the ministry of Infrastructure and Environment (I&M) (2012). In addition, the ministry Agriculture, Nature Conservation and Food security (LNV) and the ministry of Economic Affairs (EZ) merged, called the Ministry of Economic Affairs (EZ).

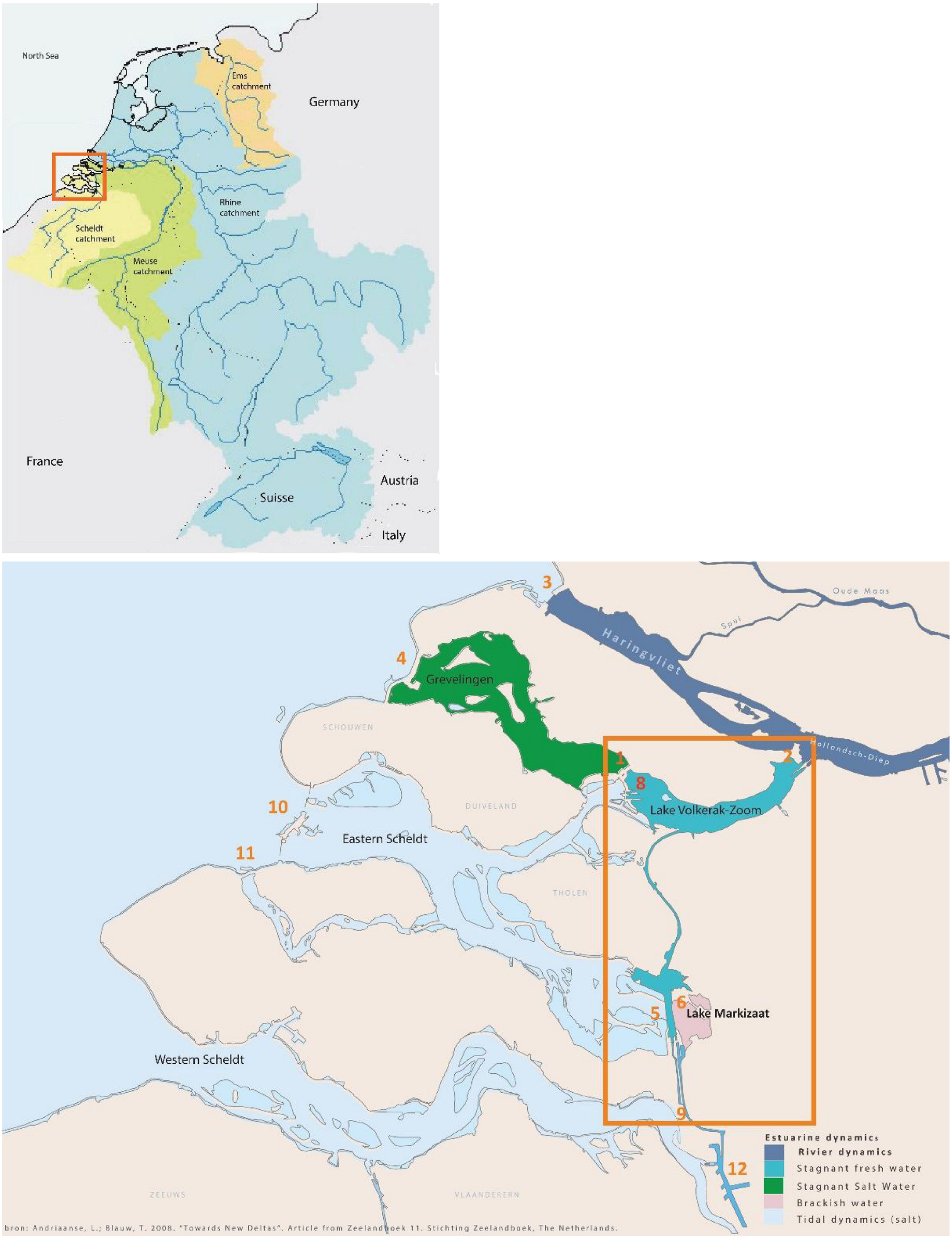

Fig. 2. Rhine-Meuse-Scheldt Catchments (left) with a cutout of the estuaries in the southwestern part of the Netherlands (below). Numbers: 1. Grevelingendam, 2. Volkerakdam, 3. Haringvlietsluizen, 4. Brouwersdam, 5. Oesterdam, 6. Markiezaatkade, 7. Zandkreekdam, 8. Philipsdam, 9. Bathse Spuisluis, 10. Storm Surge Barier Eastern Scheldt, 11. Veerse Gatdam, 12 Antwerps Kanaalpand. The orange rectangle below shows Lake Volkerak-Zoom.

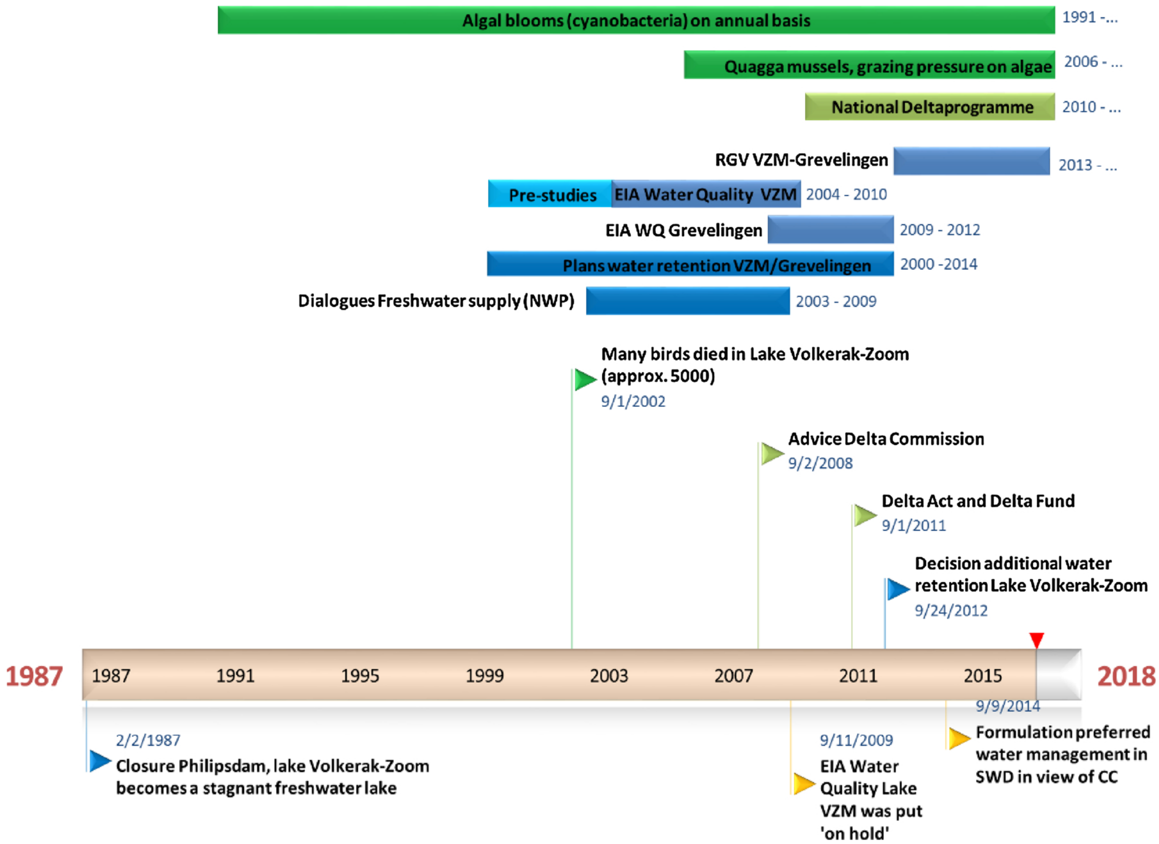

Fig. 3. Timeline of analysed planning processes. The dark green rows are ecological changes within Lake Volkerak-Zoom, while the blue rows describe the responses in planning and policy processes, the light green rows represents the response to climate adaptation. The two yellow flags represent the two moments on which the analysis is focussing. The other flags represent important milestones in decision making and planning. Abbreviations: EIA = Environmental Impact Assessment; VZM = lake Volkerak-Zoom; SWD = Southwest Delta; CC = Climate Change; NWP = National Water Plan (2009–2015); RGV = Policy plan for interventions in lake Grevelingen and lake Volkerak (In Dutch: Rijksstructuurvisie Grevelingen & Volkerak-Zoommeer); WQ = Water Quality (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

regional climate adaptation strategies were prepared between 2009 and 2014 (Staf Deltacommissaris, 2015). This involved exploring strategic alternatives and early selection of the preferred strategy. The National Delta Programme aimed to address uncertainties with a new planning concept entitled 'adaptive delta management' (Dewulf and Termeer, 2015), inspired by national climate research programmes (Veraart et al., 2014) and the Delta Commission (Kabat et al., 2009).

A regional climate adaptation strategy for the Rhine-Meuse-Scheldt estuaries was prepared by the Programme Office SWD and adopted by the Steering group. This regional strategy included the creation of a connection between Lake Volkerak-Zoom and the Eastern Scheldt combined with river water retention and an alternative freshwater supply for agriculture (Deltaprogramma | Zuidwestelijke Delta, 2014).

4. Mapping uncertainties: results

4.1. Addressed uncertainties and classification of knowledge

Table 4 presents the knowledge status per theme per period. The text below explains the basis for this qualification.

4.2. Respondents' definitions for freshwater and saline water

Because of the frequent use of the terms 'freshwater', 'saline water', 'salinisation', and 'saline water intrusion' we explored how the interview respondents framed freshwater and saline water, in terms of chloride concentration (mg l^{-1}) and in terms of qualitative associations (Table 5). The respondents framed their definition for 'fresh' or 'salty' water based on completely different understandings of the water system: Lake Volkerak-Zoom (NGO's policymakers), the root zone of the crops (scientists, farmers) or the regional water system (water boards, policy makers). The NGO's elaborated also on the definition of brackish water. They stated that temporal fluctuations and spatial gradients in salinity are important for the development of nature in Lake Volkerak-Zoom.

Most respondents (16) based their definition of freshwater, in terms of chloride concentration, on the most salt sensitive water use (drinking water or specific agricultural sectors). The mentioned thresholds ranged between 50–600 mg/l. Four respondents define 'saline water' as sea water with a chloride concentration of 18,000 mg/l, while the other respondents use lower chloride concentrations to define 'saline water', the lowest estimate being 350 mg/l.

The difference between the lowest and highest definition of saline water (350–18000 mg l^{-1} chloride) is larger than the range for freshwater (50–600 mg l^{-1} chloride). Two respondents (a scientist and a policy maker) refused to connect numbers to the term 'salt water'. They both preferred to say 'too saline water'. The policymaker added that 'too saline water' is an opinion and not a fact. The scientist explained that still many uncertainties exist about the salt tolerance of crops; therefore, he refused to give a definition of 'saline water'.

The qualitative arguments to describe freshwater and saline water suggest more consensus compared to the accompanying quantitative specifications of the chloride concentration. In other words: when the respondents talk about fresh and saline water amongst each other, virtually in agreement as observed (participant observation), they fail to discover that they have different views about fresh and saline water (interviews).

Table 4
Assessed classification of knowledge by theme in 2009–2010 & 2014–2015 (summary).

Theme	Status knowledge 2009–2010	Status knowledge in 2014–2015
Definition of Fresh and Salt water	uncertain	Not investigated.
Economic aspects of the considered interventions	disputed	uncertain
Future fresh water supply and demand in and around Lake Volkerak-Zoom	uncertain	uncertain
Crop damage risks for agriculture	uncertain	uncertain
Salt water intrusion risks between Lake Volkerak-Zoom and surrounding water systems	disputed	uncertain
Ecosystem functioning of Lake Volkerak-Zoom (algal blooms, value of brackish nature)	negotiated	uncertain
Combining solutions: river water retention in Lake Volkerak-Zoom and Grevelingen	uncertain	negotiated

Table 5
Used expressions and comparisons by interview respondents to define 'salinisation' and to make distinction between freshwater, salt water and brackish water (Derived and translated from *(*J.E.M. Klostermann et al., 2013*)*.

Used expressions and comparisons to qualify fresh and salt water	Water management/ policy	Water users (agri & drinkw.)	NGO's (Nature)	research
Current/ past chloride concentration in Lake Volkerak-Zoom	x	x	x	x
Chloride concentration in other (bordering) water systems (Eastern Scheldt, Grevelingen, Haringvliet, Biesbosch, Nieuwe Waterweg, Bernisse, Lake Veere, North Sea, Eendracht, North Sea)	x	x	x	X
Chloride concentration in root zone/ shallow rainwater lenses	x	x	x	x
Chloride concentration in groundwater bodies/seepage water	x	x		X
Chloride Concentration in irrigation water /ditches /flushing	X	x		X
Chloride requirements land use, agriculture, industry and cities	x	x		x
Chloride requirements nature	x		X	
Chloride requirements Mussel cultures (fisheries)				x
Threshold chloride concentration to avoid blue algae blooms	x			
Freshwater & Salt Water	x	x	x	X
Freshwater & Brackish water & Salt water	x	x	x	
Temporal fluctuations in chloride concentrations (surface water)			x	
Gradients in chloride concentrations	x			
Tap water = freshwater		x		
Distilled water = freshwater	x			
Taste threshold	x			
Sea water = Salt water	x	X		
Cations & salinity (instead of chloride)				x
Electric Conductivity (EC)		x		x

4.3. Economic aspects of considered interventions

The preferred intervention (2009/2010) included an inlet in the Philipsdam to connect Lake Volkerak-Zoom with the Eastern Scheldt (saline water) as well as technical measures to prevent leakage of saline water from Lake Volkerak-Zoom into Haringvliet and other water bodies. Public authorities were willing to pay the costs caused by salt leakage prevention, but they were hesitant to finance the alternative freshwater supply system. The interviews confirm that agricultural water users, but also the drinking supply company Evides and Water board Hollandse Delta, requested *guarantees* about an alternative freshwater supply in order to avoid unforeseen costs and loss of income.

Illustrative quote[3]:

"*The word warranty is often used, because we want to guarantee freshwater supply at any place and at any time. Many involved actors claim this warranty, in particular agriculture but also other water users and the water boards, who are often farmer oriented. Decision makers who fear opposition regarding the idea of a salinized lake Volkerak-Zoom sometimes also ask guarantees that this idea is reconsidered. And, of course, these types of guarantees you cannot give, despite the claims (17:12)*"

Organically and autonomously this developed into a narrative represented by the slogan: *'First fresh water supply for agriculture, then a Saline Lake Volkerak-Zoom'* (In Dutch: 'Eerst het Zoet, dan het Zout') (LTO-Noord, KAVB, and ZLTO, 2009). This narrative was frequently repeated in stakeholder meetings. The allocation of the additional costs for an alternative freshwater supply system between the public and private sectors was a disputed decision in 2009/2010 (Table 3). Some stakeholders argued that the alternative fresh water supply system would create additional income for agriculture instead of compensating income loss. For that reason, several studies were commissioned to quantify the necessary alternative fresh water supply around Lake Volkerak-Zoom (De Bruine and Van Tuinen, 2011; A. De Vries et al., 2009; I. De Vries et al., 2010; Witteveen + Bos, 2005, 2010) and associated costs (Rijk et al., 2009). The outcomes were frequently disputed in 2009–2010.

Illustrative quotes:

"*The government uses the currently observed decline of algal blooms in lake Volkerak to postpone the decision: we need more time for doing research. Nevertheless, in fact, it is just a financial issue. (…). We currently[4] know what approximately the costs are to realize the alternative freshwater supply system. However, the current decision makers do not have enough budget (9:19)*"

"*Farmers ask us to arrange fresh water, but as soon as we put the price tag on the table, a whole lot of them will opt out. (5: 8)*"

[3] The presented quotes in this article should be seen as illustrative examples from individuals. They do not represent the wide variety of ideas as reported in the project report (Klostermann et al., 2013), nor should be seen as the opinion of a whole sector. In addition, the Dutch to English translation of the ‚language of speech 'is difficult.

[4] This interview was done in the summer of 2011.

After that, a 'joint-fact-finding process' was initiated about alternative freshwater supply under the guidance of the Delta Programme. The status of knowledge regarding alternative freshwater supply could be qualified as 'uncertain' in 2014 (explanation below). In the preferred strategy (2014) of the National Delta Programme, an alternative freshwater supply system was included for the region around Lake Volkerak-Zoom. However, the national government did not want to be solely responsible for the financing through the Delta Fund. The cost allocation is still under negotiation and a decision is still pending (2018).

4.4. Future freshwater supply and demand in and around Lake Volkerak-Zoom

The national Delta programme wondered whether the current freshwater supply in the area around Lake Volkerak-Zoom would be sufficient in view of climate change. The farmer's organisation ZLTO argued that climate change was another external risk that would create income loss for agricultural entrepreneurs around Lake Volkerak-Zoom in Zeeland (Tholen), West-Brabant and Zuid-Holland (Flakkee). This new uncertainty was an additional argument for farmers to ask for guarantees with regard to the fresh water supply and to claim budget from the national Delta Fund.

Illustrative quote:

"*If these dry summers*[5] *continue, and the summers become like the more extreme KNMI climate scenarios (W+) we cannot sufficiently mitigate saline seepage at the beginning of the growing season (1 April). As a result, we already have a bad situation at the start of the growing season. (11:25)*"

Research about the additionally needed freshwater supply was initiated during the Environmental Impact Procedure (Table 5). Several stakeholders disqualified the results in 2009/2010.

After 2010 additional studies have been conducted to assess future freshwater supply and demand and the risks of income loss for water users (Baltissen et al., 2014; I. De Vries et al., 2012; Schipper et al., 2014a;, 2014b). The research findings were discussed within the network of the SWD programme office. Similar uncertainties were raised as during the EIA procedure (Table 5). However, this time the research results were not disqualified by involved actors. Therefore, we conclude that the knowledge status regarding freshwater supply and water demand was disputed in 2009/2010 and uncertain in 2014/2015 (Table 3). Table 6 illustrates that on sub-topics or specific research issues nuances exist.

4.5. Crop damage risks for agriculture

The status of knowledge was classified as uncertain in both 2009/2010 and 2014 based on observations from interviews and participant observations. Some respondents speak about crop yield reduction risks in relation to exposure to salt in soil moisture, while others relate crop yield reduction risks in relation to the availability of irrigation water. Some mention both risks.

The farmer respondents'perception is often that chloride concentrations will grow in the ditches bordering agricultural land, when flushing with freshwater from Lake Volkerak-Zoom is no longer possible. In earlier research it was concluded that it is difficult for farmers and scientists to distinguish between crop yield reduction due to drought or due to increased salinity in the root zone (L.C.P.M. Stuyt et al., 2011). Researchers and policy makers frequently mentioned that it was uncertain to what extent agricultural crops are salt tolerant, while farmers raised questions about the measures to avoid crop damage.

[5] In the period March-July 2011, the precipitation deficit was very high in the Netherlands. Many farmers in this area had reduced crop yields, including this respondent. In August, much rainfall occurred but the damage had already been done.

4.6. Salt water intrusion risks between Lake Volkerak-Zoom and surrounding water systems

It was observed that decision making on the connection between the Eastern Scheldt and Lake Volkerak-Zoom became completely dependent on commissioned model research regarding the risk of salt exchange through the proposed sluice management between Lake Volkerak-Zoom and surrounding water bodies, in particular Haringvliet (Beijk, 2008; de Vries et al., 2008) and Antwerps Kanaalpand (Van Pagee et al., 2009).

Drinking water company Evides, the port of Antwerp and water board Hollandse Delta disputed the model results and were uncertain about the effectiveness of the proposed mitigation measures by Rijkswaterstaat to minimize saline water intrusion (Zegwaard and Wester, 2014). One of the reasons respondents gave was that the two-dimensional model, which was used, presented an over-simplification of the process at stake: estuarine dynamics. The same concerns were raised by WNF in the decision-making on the management of the Haringvliet sluices (participant observation).

These uncertainties were still relevant within the Delta Programme in 2014, although in the meantime pilots to prevent saline water leakage between saline and freshwater systems near sluices showed promising results (Uittenbogaard et al., 2015). However, a definite scientific conclusion that these measures could completely prevent salt water leakage remained absent. The reliability of the salt distribution model seemed to become less relevant for the decision about Lake Volkerak-Zoom. Therefore, we classify the status of knowledge as 'uncertain' in 2014–2015 (Table 3). In addition, it was decided to intensify the saltwater intrusion monitoring near the Haringvliet sluices so that the models could be improved. This can be seen as an instrumental strategy to address (structural) uncertainty.

4.7. Ecosystem functioning of Lake Volkerak-Zoom

The interviews (2011) reconfirm the agreement between the agricultural branche organisation (ZLTO); NGO's and water managers that the creation of a connection between Lake Volkerak-Zoom and the Eastern Scheldt is the preferred intervention to reduce the nuisance of algae in 2009–2010.

Illustrative quotes:

"Even if Lake Volkerak became purple, that would not bother me, as long as fresh water supply is guaranteed for agriculture; that is our core business." (3:23)

"Lake Volker-Zoom needs to be more robust and dynamic and flexible. We will lose natural values related to freshwater, okay, but we should assess these impacts at a different scale. It is better to create a salt water system with a proper tide, fluctuations in salinity and dynamic water tables" (8:6).

However, discussion continued amongst national and local NGO's about the desired future for Lake Volkerak-Zoom (participant observation). The local NGO's prefer conservation of valued rare freshwater species around Lake Volkerak such as Orchids, while the national NGO's put more emphasis on the ambition to rehabilitate estuarine dynamics. In addition, it is uncertain how the ecosystem of Lake Volkerak-Zoom will develop after implementation of the connection. In contrast to the socio-economic and hydrological aspects, the responsible authorities trusted the conclusions about the ecological impacts as formulated in the EIA-report.

Illustrative quote within EIA report (Rijkswaterstaat directie Zeeland et al., 2009):

"The proposed connection with the Eastern Scheldt in the preferred strategy stimulates the development of a more complete and healthier functioning water system, in which the area of valuable intertidal area increases with positive effects on the present habitat diversity and natural

Table 6
Raised uncertainties about freshwater supply and water demand around lake Volkerak-Zoom around 2010 (disputed) and 2014 (Uncertain), conclusions based upon participant observation.

Uncertainty	2009–2010	2014–2015	Used research in policy
Representation of shallow rainwater lenses and seepage processes in hydrological models used by national Delta programme; coupling climate models with used hydrological models in national Delta programme.	uncertain	uncertain	Uncertain: (F. Klijn et al., 2011; F. Klijn et al., 2012)
Model assessments regarding salt water intrusion to bordering water systems (Δ Chloride concentration in surface water)	disputed	uncertain	Disputed:(Beijk, 2008; I. de Vries, van Pagee, & Beijk, 2008; Van Pagee et al., 2009) Uncertain: (Spijker and van den Brink, 2013; Uittenbogaard et al., 2015)
Chloride requirements water users near Lake Volkerak-Zoom	disputed	uncertain	Disputed:(L.C.P.M. Stuyt et al., 2006) Uncertain: (Schipper et al., 2014a;, 2014b)
Estimations of current regional freshwater demand, in particular for irrigation (mm in growing season)	disputed	uncertain	Disputed:(A. De Vries et al., 2009; Rijkswaterstaat directie Zeeland et al., 2009)
Normative Water demand (irrigation, flushing & water table) and scenarios for future water demand in de different regions around Lake Volkerak-Zoom ($\Delta m^3/s$)	Disputed	Uncertain	Disputed:(Rijkswaterstaat directie Zeeland et al., 2009) Uncertain: (Visser et al., 2011; Visser and Van Hoorn, 2012; Visser and Van Tuinen, 2012) Negotiated: (Baltissen et al., 2014)
Significance of impact of climate change on (agricultural) water demand around Lake Volkerak-Zoom	Disputed	Uncertain	Disputed:(A. De Vries et al., 2009) Uncertain: (Schipper et al., 2014a;, 2014b)
Associated crop yield reduction due to climate change and intended change in water management (Δ€/ha)	Disputed	Uncertain	Disputed:(Rijk, 2010) Uncertain: (Schipper et al., 2014a;, 2014b; Van Rhee, 2012)
Overall conclusion	Disputed	Uncertain	

values in the southwestern delta." (p.10). […] Lake Volkerak Zoom is a protected Natura 2000 area for which freshwater and estuarine conservation targets are formulated for specific species. The creation of an inlet in the Philipsdam will have a negative impact on freshwater Natura 2000 objectives, but on the other hand, the measure will increase the intertidal area which is currently threatened in this area." (P.19–20)

Meanwhile, the number of indications grew that the annual returning algal blooms was declining autonomously (structural uncertainty). We conclude that the status of knowledge shifted from 'Negotiated Knowledge' in 2009 into 'Structural Uncertainty' in 2012. The second uncertainty is an example of specified ignorance (Gross, 2008).

Outside the network of the programme office SWD and the national Delta programme, we observed alternative narratives regarding the proposed long-term adaptation strategy in relation to Lake Volkerak-Zoom and the Rhine-Meuse-Scheldt estuary. Some of these could be identified as heterodox ideas (Borm et al., 2012; Borm and Huijgens, 2010; Stichting De Levende Delta, 2012), while others do not dispute the issues at stake but propose alternative strategies (Kuiper et al., 2013; Ministerie van Economische Zaken, 2014; Spaargaren, 2014).

4.8. Combining solutions: river water retention in Lake Volkerak-Zoom and Grevelingen

The desire to create additional water retention capacity in Lake Volkerak-Zoom, Grevelingen and Eastern Scheldt stems from the notion of higher flood risks due to climate change (Projectbureau Ruimte voor de Rivier, 2006). Water levels in the Rotterdam area can, in theory, be lowered with water retention in these (former) estuaries (DHV, 2010; Slootjes, 2012). This is relevant for the Rotterdam region in case of extreme river discharge combined with storm surges at the North Sea. Under these conditions river water discharge via 'de Nieuwe Waterweg' (the main navigation canal that connects Rotterdam harbour with the sea) is impossible. Also interventions were under consideration in a separate EIA procedure to improve the water quality of Lake Grevelingen by creating inlets between lake Grevelingen, the North Sea (Brouwersdam, Fig. 2) and Lake Volkerak-Zoom (Grevelingendam, Fig. 2) (Bestuurscommissie MIRT Verkenning Grevelingen, 2010).

The EIA-VZM (2010) concluded that the creation of an inlet in the Philipsdam (Fig. 2) to combat the algal blooms in Lake Volkerak-Zoom would only be cost effective when combined with additional river water retention in the Eastern Scheldt. However, almost simultaneously, the program "Room for the River" concluded that river water retention in the Eastern Scheldt is rather complex due to the storm surge barrier (Slootjes, 2012).

From the 'Room for the River perspective' it was preferred to make a connection between Lake Grevelingen and Lake VZM and not with the Eastern Scheldt. We conclude that complexity suddenly increased for decision makers when the results of both planning processes were brought together in 2010 (uncertain, Table 3). One of the interview respondents qualifies this ambiguity as a 'Gordian knot'. Synergies between problem-solution combinations in view of climate change and ecosystem functioning in the estuaries had to be explored with 'learning by doing 'because separate planning processes were not synchronized in time (Verkerk et al., 2015).

In 2012, it was decided to discontinue the above-mentioned decision making processes. They were integrated into a new policy process called "Rijkstructuurvisie Lake Volkerak-Zoom – Lake Grevelingen" (Adviesgroep + Grevelingen en Volkerak-Zoommeer, 2013). The national Delta programme concluded in 2014 that additional water retention in Lake Grevelingen in view of climate change is not cost effective compared to heightening and strengthening the dikes in the Rotterdam area. It was advised to re-connect Lake Grevelingen solely with the North Sea and to reconnect Lake Volkerak-Zoom with the Eastern Scheldt. We conclude that this advice could be seen as negotiated knowledge, resulting in the decision to continue with measures to increase water retention in Lake Volkerak-Zoom as earlier decided in 2010, but to refrain from measures to increase additional water retention in Lake Grevelingen.

5. Addressing uncertainties in this case study

This case study shows that some of the actors in the network of the programme office SWD make instrumental use of the insight that rational and irrational aspects are important in knowledge use. We identified generic behavioural strategies that individuals used to address uncertainties (Table 7). Some of these strategies were used to accelerate decision-making (+) while others were strategically used to postpone decision-making (−). Of course, not all these behaviours were instrumental. Some actors had a critical attitude by nature with respect to the problems and solutions they were confronted with.

These strategies of individuals, institutions or science-policy organisations have impact on the length of the decision making process. It depends on the specific context whether these strategies will accelerate or postpone decision-making about climate adaptation in water

Table 7
Generic behaviours of interview respondents to address uncertainties.

Strategy	Effect on length decision-making process
Deconstruction of negotiated knowledge	–
Negotiation about guarantees in case of uncertainty	–
Acceptance of uncertainties and creation deadlines for decisions	+
Investigation of structural uncertainties	
Limitation of the number of possible solutions/ interventions	+
(Joint) Fact Finding/Identification of uncertainties	–
Reliance on assumptions of researchers and others	+

management. Trust and distrust in experts may play a crucial role in interactive knowledge creation; others therefore also advise to involve experts that are empathic to a variety of values and perspectives (Seijger et al., 2013). From the interviews, it can furthermore be concluded that policy makers and water users can be critical scholars while scientists sometimes have to rely on (subjective) assumptions in absence of empirical data.

6. Conclusions

We classified knowledge in this paper into three categories: uncertain, disputed and negotiated. The case study shows that processes do not always move from uncertain through disputed to negotiated knowledge; instead, movement is forward and backward depending on new issues entering the negotiating arena, new framing, and the discovery of new phenomena in nature; like:

- New issue: the question whether the current freshwater supply in the area around Lake Volkerak-Zoom would be sufficient in view of climate change;
- New framing: In the beginning (2000–2004) the problem was framed as an environmental problem (water quality) and, at a later stage, reframed as an socio-economic problem (2009/2010);
- New phenomenon: the autonomous decline of algal nuisance after 2006.

This case study confirms that it is difficult to evaluate and prioritize possible solutions for wicked problems in complex socio-ecological systems solely based upon rational evaluation criteria. The policy makers went by the book in involving stakeholders and researching sensitive issues; however, new policy issues crossed the agenda (climate change), and new phenomena showed up in nature (quagga mussels) in the lengthy decision making process. In the end, the most difficult discussion turns out to be the financial support for the chosen option.

Many policy processes in delta areas, like this case study, first attempt to reduce physical and social complexity in order to facilitate decision-making. However, this case study illustrates that this also can result in ambiguity and delays. This case study illustrates also that much progress has been made with working in interdisciplinary teams in which many relevant interests and scientific disciplines are combined to match the complexity at hand.

7. Recommendations

The risk of a lengthy decision making process can be reduced when the responsible authorities recognize, acknowledge and take into account behavioural strategies of involved actors (Table 7) to address uncertainties. This already begins at the start of a decision making process when policy teams are created and the first knowledge gaps are identified to assess the issue at stake. In this case study, and in comparable case studies (Edelenbos et al., 2011; Kunseler and Tuinstra, 2017; Runhaar et al., 2016), usually a balance is first sought in the representation of various expertise's and stakes in policy teams. We recommend to start with an exploration of the complexity of the (combined) issues at stake in an interdisciplinary team in which fact checkers, knowledge deconstructivists and knowledge constructors are equally represented from both science and policy. Knowledge constructors tend to prefer behaviour strategies to address uncertainties that accelerate decision-making processes. Knowledge deconstructivists ask whether the assumptions made by research or policy makers are correct and whether the negotiated knowledge claim is correct. Fact checkers emphasize epistemic uncertainties. These behavioural strategies with regard to uncertainties are all valuable at the stage of defining research questions. Absence of one of these approaches at the start of a policy making process may cause delays in decision making at a later stage. Interdisciplinary policy teams need tailor-made strategies to make scientific knowledge use more efficient. Based on our findings we formulate three strategies to improve the use of scientific knowledge in decision-making (Table 8).

The current available frameworks to typify uncertainty assessment frameworks are useful and valuable. We prefer neither to develop a new framework nor to make additional specifications and do not want to reformulate definitions. Instead, we recommend defining relevant categories of uncertainty in a collaborative way between climate research

Table 8
Tailored options to increase the usability of scientific knowledge in decision making in water management by taking into account different types of uncertainties.

Observed strategic behaviour in decision making	Uncertainties (in order of importance)	Tailored option(s) to increase the usability of scientific knowledge
Deconstruction of an achieved negotiated (scientific) knowledge base. Negotiation about guarantees in case of (known) epistemic and ontic uncertainties and known ambiguity.	(a) Epistemic (salt water dynamics), (b) ontic uncertainties (climate variability and change) and (c) ambiguity play a role.	Joint-fact-finding (Karl et al., 2007). This option helps to share advancing insights about the process at stake (for example salinisation risks for agriculture, Table 6) and to reconstruct the common knowledge basis, in this case study 'Joint-fact-finding' was conducted with regard to decisions about future fresh water supply (Baltissen et al., 2014).
The scientific knowledge base has been disputed repeatedly by stakeholder despite scientific research.	Ontic/structural uncertainty and ambiguity play both an important role.	Commissioning research whereby temporarily a protected environment is created to allow research without political interference (example: salt water intrusion risks between Lake Volkerak-Zoom, Haringvliet and surrounding water systems). Such a strategy creates the necessary room to explore controversial hypotheses. After this defined period, the results need to be discussed in a participatory setting.
Knowledge constructors and deconstructors are uncertain about the assumptions made in scientific research or policymaking. Uncertain knowledge in which epistemic uncertainty is important.	Most of the mentioned uncertainties within the negotiation arena could be qualified as epistemic.	A monitoring and research programme before and after implementation (example: ecosystem functioning of Lake Volkerak).

and knowledge users in water management, before commissioning research, prioritizing research themes or starting a policy process.

Of course, parallel to these recommendations, also the selection of a planning concept that recognizes the role of uncertainties in decision making can reduce the risk to lengthy decision making, in particular when ambiguity plays a role as stated by other scholars (van Popering-Verkerk and van Buuren, 2015; Vink et al., 2013; Zandvoort, 2017).

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2018.09.009.

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