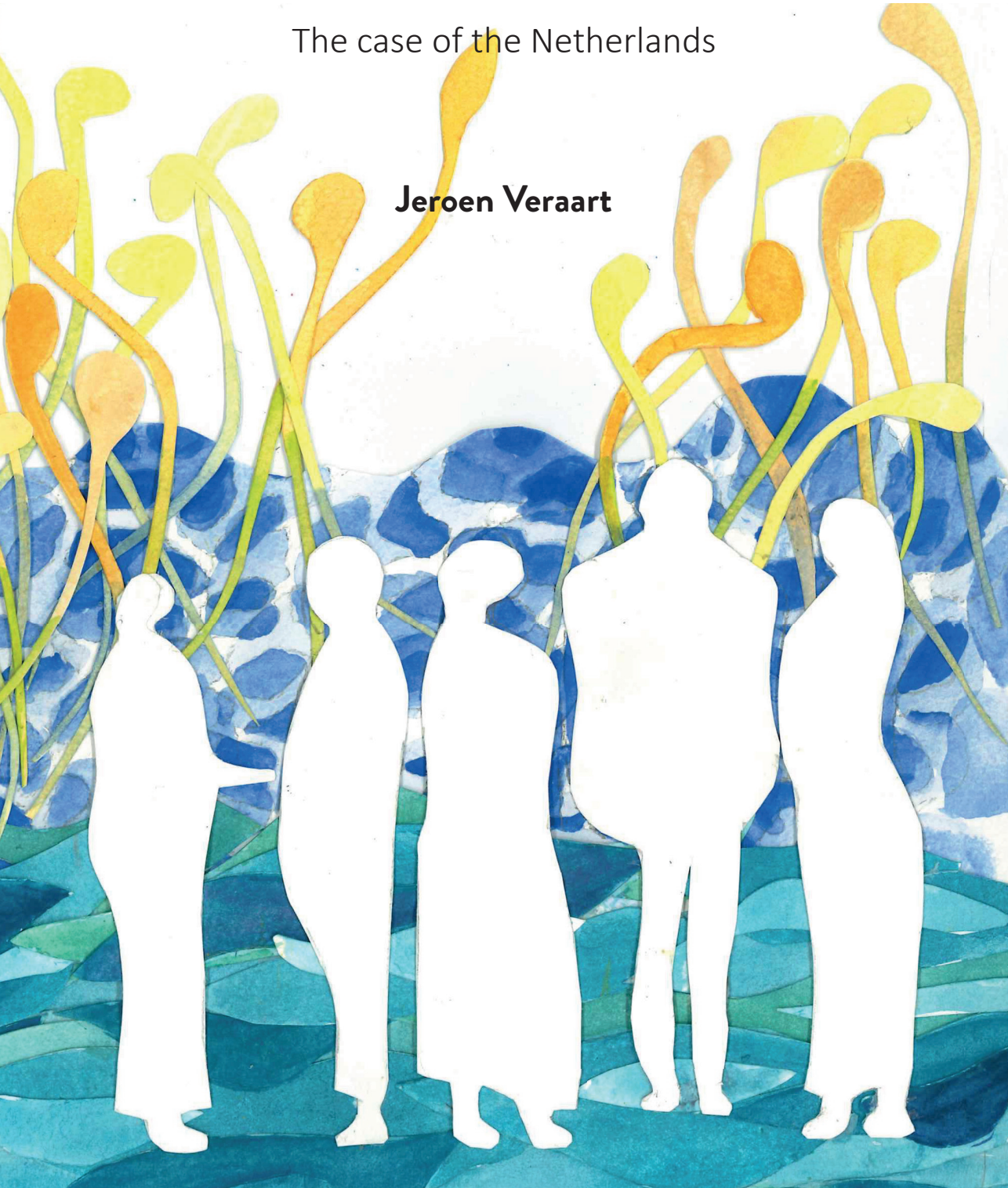
Addressing uncertainties at the interface between climate adaptation research and water management

The case of the Netherlands

Jeroen Veraart



Propositions

1. Applying epistemic research methods to address ontic uncertainties may lead to climate adaptation decisions that water managers regret in the future.
   (this thesis)

2. Boundary objects have substantially enhanced exchange of scientific knowledge on climate adaptation between research institutions and water-management practice.
   (this thesis)

3. Uncertainties are negotiable, even though scientific facts are not negotiable.

4. Interdisciplinarity is praised in theory but often resisted in academic practice.

5. A society that values certainty over curiosity limits its own capacity for innovation.

6. The societal usability of climate adaptation research is limited when it focuses on predicting the future instead of preparing for surprise.

7. A PhD-trajectory is like that of a good wine: after 25 years of maturation, scientific quality finally emerges.

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Addressing uncertainties at the interface between climate adaptation research and water management

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J.A. Veraart

Thesis committee

Promotor

Prof. Dr P. Kabat
Secretary -General, The International Human Frontiers Science Program Organization (HFSPO), Strasbourg, France

Emeritus Professor in Earth Systems and Global Change
Wageningen University & Research, the Netherlands

Co-promotor

Dr ir. I.M. Voskamp
Assistant Professor in Landscape Architecture and Spatial Planning
Wageningen University & Research, the Netherlands

Other members

Prof. Dr A.M.G. Klein Tank, Utrecht University

Prof. Dr Ir. C.J.A.M. Termeer, Wageningen University and Research

Prof. Dr J.C.J.H. Aerts, Vrije Universiteit Amsterdam

Dr A.G. Bhave, Leeds University, United Kingdom

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J.A. Veraart

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SUMMARY

Introduction

Human activities have caused global warming, with surface temperatures rising 1.1°C above pre-industrial levels. In the Netherlands, climate change necessitates changes in infrastructure, water systems, and spatial planning. Water managers and researchers are developing climate adaptation strategies, yet decision-making at the interface between research and practice is complicated by various forms of uncertainty. This thesis investigates how uncertainties are addressed in interactions between climate adaptation research and Dutch water management, particularly within co-existing and nested science-policy interfaces across spatial scales. The research, as described in this dissertation, aims to improve knowledge exchange and enhance the usability of climate adaptation research.

Research Questions

- Q1: What are the type and role of uncertainties at the interface between climate adaptation research and Dutch water management?
- Q2: What is the role of boundary objects in knowledge exchange between climate adaptation research and water management across spatial scales?
- Q3: What are strategies to address uncertainties from the perspectives of research and practice respectively, and how to enhance the usability of climate adaptation research in water management?

Approach and framework

A nested longitudinal case study was conducted, examining freshwater management in the Netherlands in detail from 2000 to 2014, with a forward-looking outlook extending to 2025. Eight interfaces were examined at national, regional (Rhine-Meuse-Scheldt Estuaries), and local (farm-level water supply) scales. The study engaged professionals involved in strategic freshwater planning, primarily within the Delta Programme and national climate research initiatives. The thesis applies a typology of uncertainty - ontic, epistemic, and ambiguity - to analyse how each type of uncertainty is addressed in decision making regarding climate adaptation strategies. In this way, specific strategies can be identified that are employed by the various knowledge systems (water managers, researchers, water users), as well as the mechanisms through which knowledge is exchanged among them. The dissertation comprises an introduction (Chapter 1), a case study description (Chapter 2), and six chapters detailing the research (Chapter 2-8). It concludes with a synthesis (Chapter 9).

Chapter 2 presents a temporal analysis of the evolving interface between climate adaptation research and water management policy across spatial scales. It traces the trajectory of developments from the inception of Dutch climate research in the 1960s, the formulation of climate adaptation strategies in the period 2000- 2014 and subsequent developments between 2014 and 2025. The chapter explores how uncertainties were addressed in these three periods and what the boundary role of climate scenarios and climate adaptation was. Across three decades climate scenarios and the term climate adaptation have repeatedly functioned as boundary objects, but their roles have evolved in line with institutional shifts, scientific developments, and changing governance priorities. The chapter concludes that, although the exchange of knowledge between the domains of water management and climate adaptation research has strengthened over time, significant challenges remain in formulating cross-sectoral climate adaptation strategies. Furthermore, the current approaches to address epistemic and ontic uncertainties, as well as ambiguity within nested interfaces, could be improved.

Chapter 3 analyses a survey assessing stakeholder and expert perceptions of climate change impacts on Dutch water management that was conducted in 2001. Consensus was found regarding flood risks, with alignment in knowledge, values, and objectives. However, divergent views from experts and stakeholders proved present regarding freshwater resource impacts, complicating prioritization, and climate adaptation strategy formulation. The chapter concludes that climate adaptation scientists in 2001 increasingly engaged stakeholders in co-designing regional and sectoral adaptation strategies.

Chapter 4 conceptualizes "climate proofing" as a strategic framework integrating risk thresholds, uncertainty, and long-term resilience. It contrasts the foundational paradigm - based on hydrological stationarity and structural measures - with adaptive water management, which embraces uncertainties and the precautionary principle. Climate proofing also involves scenario-based visioning, experimental learning, and evaluation through decision-support tools. Boundary organizations are identified as essential for facilitating science-policy-society dialogue. The chapter positions climate proofing as a dynamic, interdisciplinary process aimed at enhancing adaptive capacity and resilience.

Chapter 5 investigates how scientific uncertainties were managed during decision-making processes concerning water quality and climate adaptation in the Rhine-Meuse-Scheldt estuaries, with a focus on Lake Volkerak-Zoom (2000–2014). Based on interviews, participant observation and literature research the status of scientific knowledge was classified as negotiated, disputed and uncertain. It highlights the role of consensus about knowledge, shaped collaboratively by scientists, water managers, NGOs, and agricultural stakeholders. One proposed water management strategy - introducing saline tidal inflow in lake Volkerak-Zoom - was based on this shared understanding. However, an unexpected

decline in algal blooms, introduced new ontic uncertainty and ambiguities regarding future climate-proof freshwater supply for agriculture revealed persistent. The chapter identifies strategies for addressing uncertainties, such as joint fact-finding, deadline setting, and applying the no-regret principle. Tailor-made approaches were recommended to improve the usability and legitimacy of results of climate adaptation research in complex governance settings.

Chapter 6 examines socio-economic factors shaping the adoption of innovative drainage systems in the southwestern part of the Netherlands in response to anticipated reductions in freshwater availability due to climate change and salinisation. Researchers and farmers conducted three pilot experiments collaboratively to evaluate the hydrological performance of novel drainage systems. Complementary, a participatory feasibility assessment and a regional drought risk survey were undertaken. Findings indicate that while participating farmers gained confidence in the reliability of the recent technologies, broader stakeholder scepticism remained. Factors such as reliable access to freshwater, supportive legislative conditions, economic incentives (subsidies) and sector specific crop planning strategies were identified as critical to adoption of the investigated drainage systems at farm level, alongside with addressing uncertainties by improving agro-hydrological modelling. These elements collectively influenced farmers' willingness and capacity to implement the investigated drainage measures.

Chapter 7 presents a comparative case study examining the adoption of Nature-based Solutions for food production and water resource management in both countries. Employing the Food System Approach, the analysis focuses on rainwater harvesting, innovative drainage systems and wastewater reuse. Although these technologies are technically feasible and socially acceptable, their implementation is constrained by a range of biophysical, technical, institutional, and socio-cultural barriers. Spatial information, co-produced with stakeholders, was identified as a pivotal enabler of adoption. The study highlights persistent ontic uncertainties in rendering spatially explicit scenarios for freshwater demand in the Netherlands based on national climate scenarios, due to limitations in data availability and quality. These ontic uncertainties and data limitations were a result of the difficulty to become spatial explicit about the future land use and the calculation of associated crop evaporation with the National Hydrological Model.

Chapter 8 reflects on a decade of Dutch climate adaptation research by two large research programmes: Climate changes Spatial Planning (2004–2012) and Knowledge for Climate (2008–2014). These initiatives bridged science, policy, and practice, evolving from scenario driven impact assessments to integrated approaches from local and regional spatial scale. The interdisciplinary and demand-driven nature of these programs enriched both fundamental and applied climate adaptation research in the Netherlands. Within this

10-year period, a trend emerges. Climate impact assessments based at national scale are increasingly being complemented by 'bottom-up' approaches that enrich top-down approaches with experiences from local en regional level. This shift is evident in the development of climate adaptation strategies in different sectors, including water management.

Conclusions (chapter 9)
Over the past 25 years, Dutch climate adaptation research has evolved significantly, developing strategic approaches to address ontic, epistemic, and ambiguity-related uncertainties. Early efforts focused on climate scenario development and exploratory research, supported by national programmes such as *Climate Changes Spatial Planning* and *Knowledge for Climate*. These initiatives fostered knowledge exchange about climate adaptation in water management across national, regional, and local scales, though uncertainties about climate change remained. Events like the 2018 drought and 2021 Meuse floods heightened urgency, while ontic uncertainties regarding sea level rise remained persistent. Tensions between nature-based and engineered solutions further intensified ambiguity. Furthermore, the current approaches to address epistemic and ontic uncertainties, as well as ambiguity within nested interfaces, could be improved.

Since 1990, climate scenarios and the concept of climate adaptation have repeatedly functioned as boundary objects in the Netherlands, but their bridging roles have shifted over time. They played a significant role in facilitating communication across disciplines and governance levels in Dutch water management. Before 2000, IPCC climate scenarios linked climate science to international climate policies, but those scenarios were too coarse for Dutch water management. The first KNMI scenarios (1998) functioned as a boundary object between climate research and water management at national level. Between 2000 and 2014, KNMI scenarios became formally embedded in national water policy, and climate adaptation emerged also as a boundary object. The term climate proofing supported strategic planning but often lacked operational clarity for local stakeholders. Climate scenarios became more usable by the development of climate services such as scenarios for river discharge and additional drought indicators, yet water users continued to struggle with interpretation of these climate services. Institutional reforms, including KNMI scenario updates and Delta Programme reviews, reflect progress in embedding climate knowledge into water governance. Despite formal mechanisms for climate scenario updates and climate adaptation strategy reviews as a way to address uncertainties, the interface reverted partially to a sectoral structure. The emergence of the Sea Level Rise Knowledge Programme (KP-SLR) in 2019 highlighted renewed urgency in face of ontic uncertainties. Although the exchange of knowledge with support of both boundary objects between water management and climate adaptation research has strengthened over time, significant

challenges remain in formulating cross-sectoral climate adaptation strategies for both water management and land use.

A range of strategies emerged to address uncertainties since 2000 at the interface of climate adaptation research and water management. Epistemic approaches were common at national and regional levels, whereas developing strategies at the interface with water users was more complex due to the diversity of stakeholders involved. Shared strategies between climate adaptation research and water management included joint fact-finding, narrowing solution options, and integrating experimental knowledge. Water managers and policy makers also employed procedural tools such as Environmental Impact Assessments and decision deadlines - less common in research settings. Recognizing the distinction between scientific and negotiated knowledge is essential for improving the usability of climate adaptation research.

This dissertation's nested longitudinal case study illustrates how climate adaptation research has navigated diverse knowledge needs. The Delta Programme's three national strategies - flood risk management, freshwater supply, and spatial adaptation - are tailored to regions like the Southwestern Delta and Wadden Sea, yet local stakeholders require more context-specific insights. Despite increased integration between research and practice, a coordinated strategy to embed transdisciplinary knowledge into research programming strategies is still lacking lacking. Final recommendations emphasize the need for context-sensitive research design, expanded joint fact-finding, and early stakeholder engagement. Strengthening climate services and aligning formal procedures with exploratory monitoring can enhance adaptive capacity in water management. Future case study research should adopt structured, comparative methodologies to support transformational adaptation across scales.

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1



***Picture**: The author observes the water (© The Albufera Initiative for Biodiversity, Mallorca, 2008).*

1 INTRODUCTION

1.1 BACKGROUND

Climate change

In the latest IPCC report it is stated that human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020. Human-caused climate change is already affecting many weather and climate extremes across the globe. This has led to widespread adverse impacts and related losses and damages to nature and people (Intergovernmental Panel on Climate Change, 2023). The 1.5 degrees global temperature increase compared to pre-industrial levels (1850-1900) will be reached around 2030 (IPCC, 2021), a decade earlier compared to the projections of previous IPCC assessments (IPCC, 2014a). The average temperature increase in the Netherlands has been 2,3°C over the past hundred years (CBS et al., 2024) and evidence is mounting that recent weather extremes in the Netherlands can be attributed to climate change (Philip et al., 2020) and will require a structural change of our living environment and infrastructure (Ligtvoet et al., 2021).

Water management and climate change

The impacts of climate change on freshwater resources and related land use are noticeable in many parts of the world (Intergovernmental Panel on Climate Change, 2023; IPCC, 2021, 2018, 2014c; Shukla et al., 2019). Amongst others, reduced and erratic rainfall, reduced streamflow and groundwater recharge and increased crop water demand pose major climate related risks to agriculture, water utilities and hydropower production (Immerzeel et al., 2020), necessitating cost-effective and multifunctional adaptation options (IPCC, 2018).

Policy makers and scientists in the Netherlands are, therefore, working on measures and climate adaptation strategies in water management and spatial planning with high priority (Dewulf & Termeer, 2015; Haasnoot et al., 2020a; Haasnoot et al., 2020b; Kabat et al., 2009; Kabat et al., 2005; van Alphen, 2016; Witte et al., 2020). The Dutch water system has been strongly modified during the past centuries in order to cope with flood risks and to support economic development (Wang et al., 2018). The water system is designed and managed to drain water towards the sea. These modifications have altered natural dynamics at many locations in the Dutch lakes, rivers, estuaries and regional water

systems. Dutch water management has been oriented towards optimizing economic returns in sectors such as agriculture, while minimizing flood risks in urban areas at the lowest possible cost and with minimal spatial loss (OECD, 2014; Wiering, 2019). As a result, ecology and land use in the Netherlands have become more vulnerable for extreme hydrometeorological circumstances, such as high river discharge, extreme precipitation and drought, that will occur more frequently due to climate change (van Dorland et al., 2024). Since climate change has become evident, Dutch water management and land use change strategies are increasingly aiming to retain water in the water system and in the soil, making land use less vulnerable to drought (Bartholomeus et al., 2023).

Climate adaptation, spatial planning and perceived climate risks by stakeholders

It is a societal question to what extent climate impacts and associated risks for society are acceptable (Dessai et al., 2004; O'Brien & Wolf, 2010; O'Brien et al., 2007; Paavola & Adger, 2006). When climate adaptation strategies are explored, the question arises who should be involved in research, decision making, financing and implementation (J. Gupta et al., 2010; Molenveld et al., 2020; Termeer et al., 2012; Veraart et al., 2014a). This is particularly relevant because policymakers and stakeholders frequently rely on scientific research to quantify the risks associated with climate change and to determine the minimum climate adaptation measures required. However, climate adaptation inherently involves normative choices about risk distribution, equity, and long-term sustainability. Decisions about who participates in adaptation processes influence whose values, knowledge systems, and interests are prioritized, potentially reinforcing or challenging existing power structures (Eriksen et al., 2015). This also influences how research on climate risks and climate adaptation is conceptualized.

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. Climate change therefore could be defined as a wicked problem, associated with different types of uncertainties (van Buuren et al., 2015).

The term ‘wicked problem’ is today widely used in sustainability research as well as in many other disciplines (Lönngren & van Poeck, 2021). The term can be described as a problem that is ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing (Lönngren & van Poeck, 2021; Rittel & Webber, 1973).

Because climate change is considered as a wicked problem it is difficult to evaluate considered interventions in water management to address climate change solely based upon climate adaptation research (de Boer et al., 2010; Hisschemöller & Hoppe, 2001; Vink et al., 2013). Knowledge about climate change and climate adaptation is interpreted, constructed and assessed with logics from climate adaptation research but also with other logics or perspectives (Kelly, 1955; Meijnders, 1998; Nguyen et al., 2019; Polack, 2005; Poortvliet et al., 2020; Saxena et al., 2018). For instance, the delta works in the Netherlands were constructed to achieve a societal level of safety, wherein the logic of cost-efficiency in decision-making was, to a significant extent, subordinated to the collective imperative to prevent a recurrence of the catastrophic 1953 flood (Correljé & Broekhans, 2015; Saeijs, 1982). Had economic reasoning, specifically cost-benefit analysis, been the sole guiding principle in the aftermath of the disaster, the safety standards for dikes and dams would likely have been set at a lower level (van Beek, 2009).

During the period covered by this study (2000–2014), the establishment of new water safety standards in the Netherlands, as a part of the national climate adaptation strategy, also reflected a complex interplay between economic and hydrological flood risk assessment logic, as well as less rational, value-driven considerations (Kraan et al., 2025; van der Stoep et al., 2017; van Doorn-Hoekveld et al., 2022). This exemplifies how decision-making in water management may be informed by multiple scientific paradigms, each internally coherent. However, when these paradigms are brought together inconsistencies may arise, thereby increasing uncertainty for decision makers. To navigate such paradigm-induced uncertainties, especially in complex domains like water management, institutional mechanisms are needed that facilitate the integration of diverse knowledge systems. One such mechanism is the development of science-policy interfaces.

Knowledge exchange at the interface between science and policy

When boundaries between knowledge systems are seen as a barrier to solve wicked problems, the development of science-policy interfaces may be considered.

Interfaces between science and policy, sometimes called boundary organisations (Koehrsen, 2017), could be defined as social structures where knowledge (Box 1.1) about problems and possible solutions is created in a collaborative way. Science and policy have their own knowledge systems that are partly shared and redefined at the interface. A knowledge system refers to a network or framework composed of knowledge components, processes, and actors that work synergistically to generate, disseminate, and apply knowledge. Such systems integrate institutional, social, and technological dimensions to optimize knowledge utilization across various domains (Cash et al., 2006b; Cash et al.,

2003). At a science-policy interface, structured interactions take place such as assessments and dialogues to define jointly problems and explore solutions. Organizations or networks are designated to facilitate this process either on a long-term basis or through project-based arrangements, fulfilling boundary-spanning roles. These may take the form of a commission, a project, or an institution. A task-specific commission, such as the Delta Commission, exemplifies a temporary interface, whereas the IPCC can be regarded as a permanent interface without a predefined end date.

Box 1-1, *Definition of knowledge.*

Many definitions exist for the term 'knowledge'. Often it is described as a justified true belief that encompasses information, skills, and understanding gained through experience, education or scientific inquiry (Blankesteijn, 2011; Ichikawa & Steup, 2024). Scientific knowledge differs from other forms of knowledge by adhering to methodological standards and being open to revision and verification, ensuring its reliability and robustness over time (Chalmers, 1999).

Drawing and redrawing the division of roles between science and policy is also a characteristic of the science-policy interface (Tuinstra et al., 2006; Tuinstra, 2006). Communities of a knowledge system tend to draw boundaries between each other by, for instance, using specific vocabulary, striving for distinct objectives, and cultivating specific values and habits (Koehrsen, 2017). The institutions and individuals that attempt to change these boundaries are sometimes called boundary workers (Huitema & Turnhout, 2009) and boundary work is mostly interpreted as an active effort of researchers to successfully exchange knowledge across different social worlds and to inform policy-making through practices of safeguarding, withdrawing and (re-)negotiating boundaries (Schut et al., 2013; Turnhout et al., 2013). Conducting boundary work requires a balancing act between separating and prescribing proper behaviour of science and policy on one hand and integration of knowledge from science and policy on the other hand (Hage et al., 2010; Halffmann, 2003; Sundqvist et al., 2018; Sundqvist et al., 2015). The effectiveness of knowledge exchange and the usability of scientific results at the science-policy interface depends on participation of both scientists and policy makers, dual accountability to both scientific and policy standards, the use of boundary objects and the orchestration of knowledge across jurisdictional levels (Cornell et al., 2013; Driessen et al., 2010; Hoppe et al., 2013).

Usability of science and uncertainties at the interface

In this dissertation usable science is defined as science produced to contribute directly to the design of a policy or the solution of a problem (Dilling & Lemos, 2011). In addition, it is taken into account that actors perceive the usefulness of scientific information differently (O'Brien & Wolf, 2010; Pielke, 2009).

Uncertainty is widely recognized as a critical barrier in the science-policy interface, particularly in climate adaptation, where decisions must be made under conditions of incomplete knowledge and contested values. Moreover, when the scientific uncertainty is substantial, researchers tend to offer highly nuanced recommendations or advocate for additional research instead of formulating a clear recommendation on how to adapt to climate change in water management (Dhungana et al., 2025).

One way to enhance the usability of scientific research for policy-making in climate adaptation is to systematically address different types of uncertainty—ranging from data limitations to model assumptions and stakeholder values—with the aim of improving transparency and decision relevance (Kwakkel et al., 2010; Walker et al., 2003). This approach is exemplified by the IPCC's evolving framework for communicating uncertainty, which includes calibrated language for terms such as 'confidence' and 'likelihood', reflecting both scientific complexity and policy needs (Dessai & Hulme, 2004; Ha-Duong et al., 2007; Swart et al., 2009) (section 1.2). In climate adaptation research specifically, there is growing recognition that integrating insights about actors' attitudes towards uncertainty - such as risk perception, trust in science, and normative preferences - is essential for developing robust and socially acceptable modelling frameworks (Moure et al., 2023). However, tensions persist around how to incorporate these normative and procedural dimensions, particularly when scientific authority intersects with contested values and governance processes (Lorenzoni & Whitmarsh, 2014; Turnhout et al., 2016).

1.2 TYPIFYING UNCERTAINTIES

In this thesis a distinction is made between epistemic uncertainty, ontic uncertainty, and ambiguity when uncertainties were listed and classified. Often functional distinctions can be observed between *epistemic uncertainty*, *ontic uncertainty* and *ambiguity* when uncertainties are addressed in policy making (Kwakkel et al., 2010; Zandvoort, 2017). The distinction between these types of uncertainty is useful because each entails different options regarding the reducibility of uncertainty (Dewulf & Biesbroek, 2018).

Epistemic uncertainty is the incompleteness or imperfection of knowledge, originating from a lack of data (Walker et al., 2003). The uncertainty can be addressed and reduced by collecting more data or improvement of data collection (the research strategy).

Ontic uncertainty is associated with inherent variability, randomness, or complex nonlinear system behaviour (Bevan, 2022). Phenomena related to ontic uncertainty are unpredictable and the uncertainty cannot be resolved by solely more or better high-

resolution data collection (Kwakkel et al., 2010). The climate system is an example of a complex non-linear system whose future behaviour is not predictable solely based on monitoring data. It requires a different research strategy to address uncertainties, for example, by developing climate scenarios. In that way insight can be obtained about the bandwidth of the uncertainty without having certainty about the probability of each of the scenarios.

Ambiguity is a distinct type of uncertainty that results from the simultaneous presences of multiple valid ways of framing a problem (Brugnach et al., 2011). These different ways of problem framing often contradict each other (Byers, 2011) and may result in disputed knowledge. In case of ambiguity, (contradicting) narratives may occur driven by science, policy and the interests of stakeholders. The prevailing narratives in a decision-making process may not only contradict each other but can also be based on different interpretation of scientific knowledge. *Disputes* and different *discourses* about environmental problems are widely described in literature (Hajer, 1995). In case of ambiguity, scenario analysis, experiments and data collection are not sufficient to address uncertainties. Ambiguity requires an approach in which uncertainties are reduced through interactive processes in which stakeholders confront and integrate diverse views on a problem (Huntjens et al., 2011; Pahl-Wostl et al., 2007; Vinke-de Kruijf et al., 2025).

Theoretical concepts used in this thesis to assess the research questions

Figure 1-1 illustrates the theoretical concepts used in this thesis and how these concepts are related. The blue blocks in figure 1-1 represent the knowledge systems of the actors that play a role in the case study (O'Toole & Coffey, 2013). The white blocks represent the three types of uncertainty (Zandvoort, 2017) that influence knowledge exchange (black arrows) at interfaces that climate adaptation research has with water management and water users. Frequently, multiple partially interconnected interfaces exist at different spatial scales, where researchers, water managers and water users encounter one another in varying constellations (Dąbrowski, 2018). Accordingly, this dissertation refers to them as nested interfaces (section 1.3.1).

Those types of uncertainties also determine the usability of climate adaptation research. The green block indicates the phenomenon of study: the way in which uncertainties were addressed, including the role of boundary objects, in co-existing interfaces at different scales.

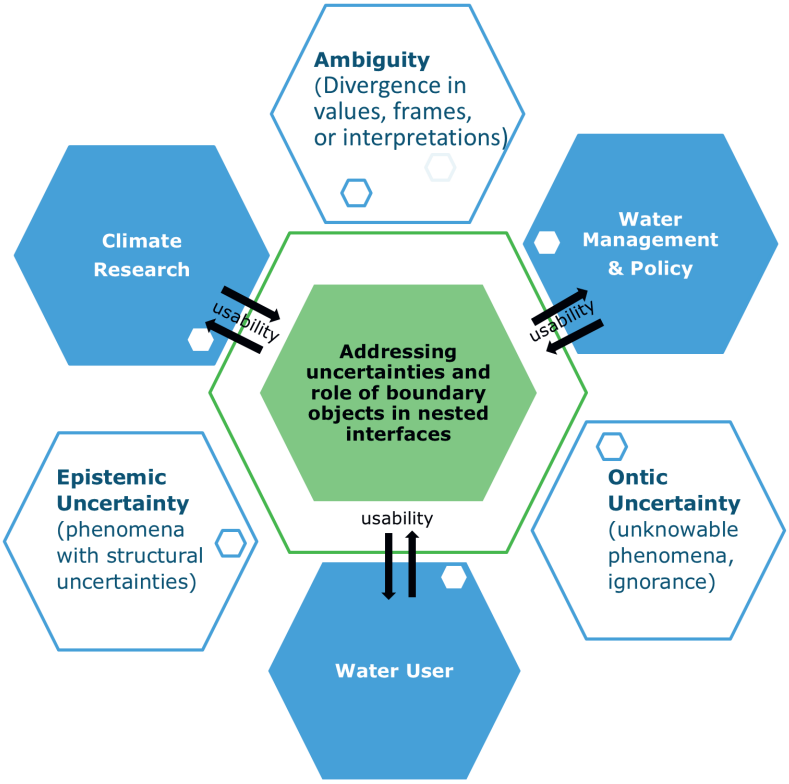


***Figure 1-1**, Addressing different types of uncertainties in interfaces between climate adaptation research, water management and water users in nested interfaces.*

Addressing uncertainties

In case of *epistemic uncertainties* researchers but also water managers, water users and policy makers (implicitly) both use simple 'mathematical' estimates (Polack, 2005) to reduce epistemic uncertainty. For example, 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. These uncertainties can be addressed, for example, by using a model in which the travel time is calculated for different scenarios. The cyclic use of climate and hydrological models is assumed to be indicative for prevailing epistemic uncertainties. There may be differences per unit of analysis, spatial scale and in time. Epistemic uncertainties can also be addressed without research, for example by using a safety margin when building a dike.

In case of *ontic uncertainties,* water managers may commission explorative research, additional to structural research regarding climate impacts and adaptation strategies. Ontic uncertainties can also be addressed without research, for example by *changing* the allocation rules for freshwater supply in summer. Also adaptive delta management (ADM) can be seen as a way for water managers to address a mixture of epistemic and ontic uncertainties *(Dewulf & Termeer, 2015; van Alphen, 2016)*, by putting emphasis on 'iterative' decision-making in resources management. Whenever there are new insights into the functioning of a complex system, the management of natural resources can be adapted accordingly *(Cvitanovic et al., 2015)*.

In case of *ambiguity,* it can be observed that research or water managers try to deconstruct the knowledge base behind heterodox ideas. If ambiguity is involved, associated uncertainties can be addressed by, for example, joint fact-finding (Ehrmann & Stinson, 1999), whereby you also agree on disagreements (accepting different frames instead of consensus building) (Byers, 2004). Some scholars recommend social learning as a strategy to address ambiguity (Jiggins et al., 2007; Leys & Vanclay, 2011; Pahl-Wostl et al., 2007; van der Wal et al., 2014; Vinke-de Kruijf et al., 2025). Social learning can broadly be defined as practices that facilitate knowledge sharing, joint learning, and co-creation of experiences between stakeholders around a shared purpose in ways that go beyond individual learning and enable new shared ways of knowing that lead to changes in practice (Ensor & Harvey, 2015).

1.3 PROBLEM STATEMENT AND RESEARCH OBJECTIVES

1.3.1 PROBLEM STATEMENT

The interface between climate adaptation research and water management

This thesis investigates the interface between climate adaptation research, water management, and water users, conceptualizing it as a science–policy interface. The interface can be found in various places around the world, including in the Netherlands. The control over the interface usually shifts between research, policy and water management over time and temporary interfaces may exist side by side (co-existing interfaces). In this context, control refers to the actor or institutional domain that initiates, coordinates, or dominates the functioning of the science-policy interface at a given time. This includes decisions about which knowledge is mobilized, which experts are consulted, and how the interface is structured. The hypothesis is that decision-making benefits when

all involved actors are aware of the different perspectives on (climatic) uncertainties in the various co-existing interfaces.

Addressing uncertainties

Addressing uncertainties during knowledge exchange in co-existing and partial nested/separated interfaces between climate adaptation research and water management is complex. It requires novel approaches to accelerate the usability of climate adaptation research. At each spatial scale interfaces between water management and climate adaptation research exist with different associated knowledge systems and different temporal dynamics in decision making. For example, decisions about freshwater supply at entrepreneur level often take place at a different moment in time than decisions about water management at national level. Sometimes deliberate consideration has been given to this, but more often, the approach to address uncertainties stems from practical choices and coincidental contextual factors.

Various studies (Driessen et al., 2010; Hanger et al., 2013; Jull et al., 2024; Mauser et al., 2013; Rosemartin et al., 2023; Trouwloon et al., 2024), indicate that exchange of scientific knowledge about climate adaptation is challenging when the three different types of uncertainties (section 1.2) are not sufficiently acknowledged. This can, for example, lead to delay in decision making or misaligned expectations between research and water management. For instance, scientists may focus on reducing epistemic uncertainty through better models, while policymakers may be more concerned with conflicting stakeholder values or political feasibility (ambiguity).

This holds also true when uncertainties are separately addressed at different spatial scales or in different knowledge systems at the interface between water management and climate adaptation research (Groot et al., 2015; Turnhout et al., 2013). As a result it is difficult to address uncertainties which may limit the usability of climate adaptation research by water management and water users (Dilling & Lemos, 2011; Kirchhoff et al., 2013; Lemos, 2015).

Strategic use of boundary objects

The strategic use of boundary objects (Franco-Torres et al., 2020; Hoppe et al., 2013; Koehrsen, 2017; Shaw et al., 2013) is increasingly considered at interfaces between science and policy to address uncertainties and to improve knowledge exchange (Janasoff, 2004; Rosemartin et al., 2023). An example of uncertainty-reducing behaviour is the deliberate introduction of boundary objects at science-policy interfaces by so-called boundary spanners (Shaw et al., 2013; Williams, 2002). Boundary objects are artefacts

(things, concepts, discourses, processes, models, language, scenarios, etc.) that can simultaneously project disparate interpretations. They have interpretive flexibility, while constituting a solid nexus for communication and collaboration among disparate worldviews or knowledge systems (Franco-Torres et al., 2020). How exactly this mechanism of boundary objects works in the field of climate adaptation and water management is not yet clear (Willems et al., 2023).

The use of boundary objects is a promising strategy to increase knowledge exchange between climate adaptation research and water management. However, the conditions under which boundary objects are most effective remain insufficiently understood. First, it is often not entirely clear in which phase of the decision-making process a boundary object (for example a flood risk map) can play a useful role. Second, the design characteristics that make boundary objects effective (e.g., simplicity vs. complexity, flexibility vs. standardization) are often debated (Wlazlak & Säfsten, 2025). Third, the facilitation process—including who introduces the object, how it is used in stakeholder interactions, and how it evolves over time, can significantly influence its function as a boundary object (Janssen et al., 2023). Fourth, the diversity and inclusivity of stakeholder networks can influence how boundary objects are used. Studies about climate adaptation in the urban context show that there is still a lack of clarity on which types of boundary objects (e.g. visual tools vs. conceptual models) work best in different contexts, and how they should be designed or facilitated to maximize knowledge exchange (Willems et al., 2023; Willems & Giezen, 2022).

1.3.2 OBJECTIVES

The objective of this thesis is to explore how uncertainties are addressed between climate adaptation research and water management in situations where science-policy interfaces co-exist at different geographical scales.

The following research questions are formulated:

- **Q1:** *What are the type and role of uncertainties at the interface between climate adaptation research and Dutch water management?*
- ***Q2:*** *What is the role of boundary objects in knowledge exchange between climate adaptation research and water management across spatial scales?*
- **Q3:** *What are strategies to address uncertainties from the perspectives of research and practice respectively, and how to enhance the usability of climate adaptation research in water management?*

These research questions were assessed with a nested longitudinal case study approach (section 1.4). By exploring this process in the Netherlands, at different geographical scales, in detail from 2000 to 2014, with a forward-looking outlook extending to 2025 guidance is provided for improving knowledge exchange between climate adaptation research and water management.

The case study concerned climate adaptation research in Dutch water management, particularly the period 2001-2014. The mechanisms and governance arrangements of the science-policy interface are not the primary object of this study, but they provide an important context when investigating alternative ways to address uncertainties. The insights gained from this dissertation aim to contribute to the improvement of existing approaches for addressing uncertainties in climate change adaptation at the interface between climate research and water management, including applications beyond the Dutch context.

1.4 METHODOLOGICAL DESIGN

1.4.1 METHODOLOGICAL DESIGN OF THE NESTED CASE STUDY

The case study approach

The methodological design of this research builds on a case study approach (Flyvbjerg, 2006; Ford et al., 2010; Yin, 2012, 2009). The case study method is defined and understood in various ways (Berg & Lune, 2012). Berg and Lune (2012) conclude that taken together, these various definitions suggest that the case study approach is capable of intensive and detailed examining of simple or complex phenomena, with units of analysis varying from single individuals to large corporations and to world changing events within its real-life context (Flyvbjerg, 2006; Yin, 2009).

A case study approach is useful for the objectives of this dissertation because the science-policy interfaces and the associated knowledge systems cannot be isolated from their context (Gerring, 2004). In addition, case study analysis is an accepted qualitative research method to unravel complex knowledge systems where rationality, power and intuition shape each other in decision making (Flyvbjerg, 2006). A case study approach is often used in vulnerability and climate adaptation research (Ford et al., 2010).

In a case study analysis various qualitative research methods can be combined, such as interview, workshops, questionnaires, analysis of media data, participant observation or

action-based research. The use of multiple methods is not only mentioned by scholars as a characteristic of case study research but also seen as a necessity (Berg & Lune, 2012). In addition, in a case study analysis the phenomenon of study is, preferably, representative for certain contextual conditions (Yin, 2012, 2009, 2005).

In qualitative case study research the research object refers to a specific process, event, entity, organization or individual that is studied within its real-world context (Berg & Lune, 2012; Yin, 2012, 2009, 2005). In this thesis the objective (section 1.3.2) is to study how uncertainties are addressed between climate adaptation research and water management in Dutch water management where science-policy interfaces co-exist, at different geographical scales.

The governance of Dutch water management is unique in its kind and is less comparable to other countries (OECD, 2014). The regional water authorities and Rijkswaterstaat have most of the operational water management while regional and national authorities (Provinces, Ministries) are involved in the development of water management policies and legislation. The case study is assumed to be representative for cases with a temperate climate such North-West Europe, comparable access to climate information (contextual condition) and an existent climate adaptation policy for water management (contextual condition).

In this thesis, water management is mostly limited to freshwater resources management in the Netherlands. This study predominantly, but not exclusively, looks at the professionals in the water sector (scientists, water managers, policy makers, water users) that are routinely engaged with strategic thinking about current and future management of freshwater resources in the Netherlands at different scales. A considerable part of the research presented in this thesis is grounded in knowledge exchange processes conducted within the national Delta Programme and various national climate research programmes. The study of operational water management focuses on water management at farm level. The thesis covers planning processes, initiated for other reasons, as well as policy making purely driven by the need for climate adaptation in water management. In this thesis, climate adaptation research comprises science about climate change, research into the impacts of climate change on water management and research on climate adaptation strategies.

Units of analysis of the nested case study

In this research, eight science-policy interfaces were considered as units of analysis (table 1-1). Other interfaces between climate adaptation research and water management also existed in the period studied, for example, other regional programmes of the national Delta program. With the selected units of analysis, it is possible to study interfaces at three

scales. Reflection on this Dutch case study is included with the 'international water and climate dialogue' (DWC) as a unit of analysis. A second international reflection is added with a case study about water reuse for drinking water and food production in Ghana and the Netherlands, conducted between 2020-2022 (outside the time period of 2000-2014).



Picture: *Freshwater supply at farm level (left) and at regional level lake Volkerak-Zoom (right).*

Table 1-1, *Overview of all studied science-policy interfaces (units of analysis), further elaborated in Chapter 2.*

Abbreviation	Logo	Name of unit of analysis, summary
NRP-GC	GLOBAL CHANGE	**Dutch National Research Programme Global Air Pollution and Climate Change (NRP-CC)** Integrated assessment of impacts of climate change and adaptation options for the Netherlands (NOP-IA) based on expert and stakeholder judgments (Kok et al., 2002; van Ierland et al., 2001). **Time frame:** 1989 – 2001 **Research:** 2001 **Chapter: 2, 3, 8** **Role PhD:** researcher (participant), water management (peripheral member)
DWC	dialogue on water and climate	**International Dialogue on Water and Climate (DWC)** DWC conducted 18 stakeholder dialogues about climate research and water management at different geographical scales all over the world (Kabat et al., 2003a,b; Kabat et al., 2002; Ludwig et al., 2009; Veraart & Kabat, 2003). **Time frame:** 2002-2008 **Research:** 2002-2008 **Chapter: 4** **Role PhD:** scientific support officer, water management (peripheral member)
CcSP	climate changes spatial planning	**The national research programme Climate changes Spatial Planning (CcSP)** CcSP was organised in themes: climate scenarios, mitigation, adaptation, integration and communication. CcSP was funded with 50% subsidy and supplemented with resources from stakeholders (Programme Office CcSP, 2012 (expired); Veraart et al., 2007). **Time frame:** 2004-2012 **Research:** 2004-2012 **Chapter: 2, 3, 4, 8** **Role PhD:** scientific support officer, water management (peripheral member/partic
KfC	Kennis voor Klimaat	**Research programme Knowledge for Climate (KfC)** The KfC programme was organised in themes: flood risk management, freshwater supply, rural areas, cities, infrastructure/networks, climate projections, governance of adaptation and decision-support tools. The interface was organized in 8 regions (Driessen et al., 2015; Programme Office Knowledge for Climate, 2014 (expired)). **Time frame**: 2008-2014 **Research:** 2008-2014 **Chapter: 2,3,5,8** **Role PhD:** research (participant), water management (participant)
DP	NATIONAAL DELTAPROGRAMMA	**National Delta Programme (DP)** A network of policy makers, water managers and scientists that develop long-term strategies for flood risk management, freshwater supply and spatial planning in view of climate change (Deltacommissie, 2008), along with a Delta commissioner (2010), an Delta act (2011), and an investment fund (2011) (Vink et al., 2013). **Time frame:** since 2008 **Research:** 2008-2014 **Chapter: 2, 3, 5,** **Rol PhD:** Participant observant & knowledge broker
DP-SWD	Zuidwestelijke Delta	**Programme Office Southwest Delta (DP-SWD)** A regional interface with the objective to discuss considered water management interventions, such as EIA the water quality lake Volkerak-Zoom, in order to align those with economic development strategies and climate adaptation (Adriaanse & Hoekstra, 2009; Programmebureau Zuidwestelijke Delta, 2017; Staf Deltacommissaris, 2014). **Time frame:** since 2004 **Research:** 2010-2014 **Chapter: 5** **Role PhD:** Participant observant & knowledge broker
GO-FRESH	GO-FRESH	**Water Resources at farm level (GO-FRESH) as part of KfC.** The GO-FRESH project, which stands for Geo-hydrological Opportunities Fresh Water Supply consisted of three pilots (2011 - 2014) with new technologies to improve freshwater supply at farm level. KfC, regional authorities & STOWA were the commissioners (Oude Essink et al., 2019). **Time frame:** 2010-2019 **Research:** 2010-2014 **Chapter: 6** **Role PhD:** research (participant), water management (participant)
WUR-KB	WAGENINGEN UR	**Water reuse in food chains and drinking water production (WUR KB)** A comparative case study analysis was conducted about the role of spatially climate information in adoption of water reuse techniques in the Southwest Delta and Ghana. This study was part of the Knowledge Base programme (KB) – Nature based Solution and Climate Smart Food Systems, commissioned by Wageningen University and Research (WUR) entitled (Keesstra et al., 2023). **Time frame:** 2020-2022 **Research:** 2020-2022 **Chapter:7** **Role PhD:** researcher with no role in water management.

The longitudinal and nested aspects of this case study

This research comprises a nested case study (Flyvbjerg, 2006) in which policy processes and research regarding freshwater resources management are studied across spatial scales (figure 1-3) over a longer time period (2000-2014). It is therefore also a longitudinal case study (Thomas, 2011). The choice of Dutch water management and the role of climate adaptation research as a case study fits well because I was able to participate in the various parts of the case study and was not bound by the term of a PhD study (4 years).

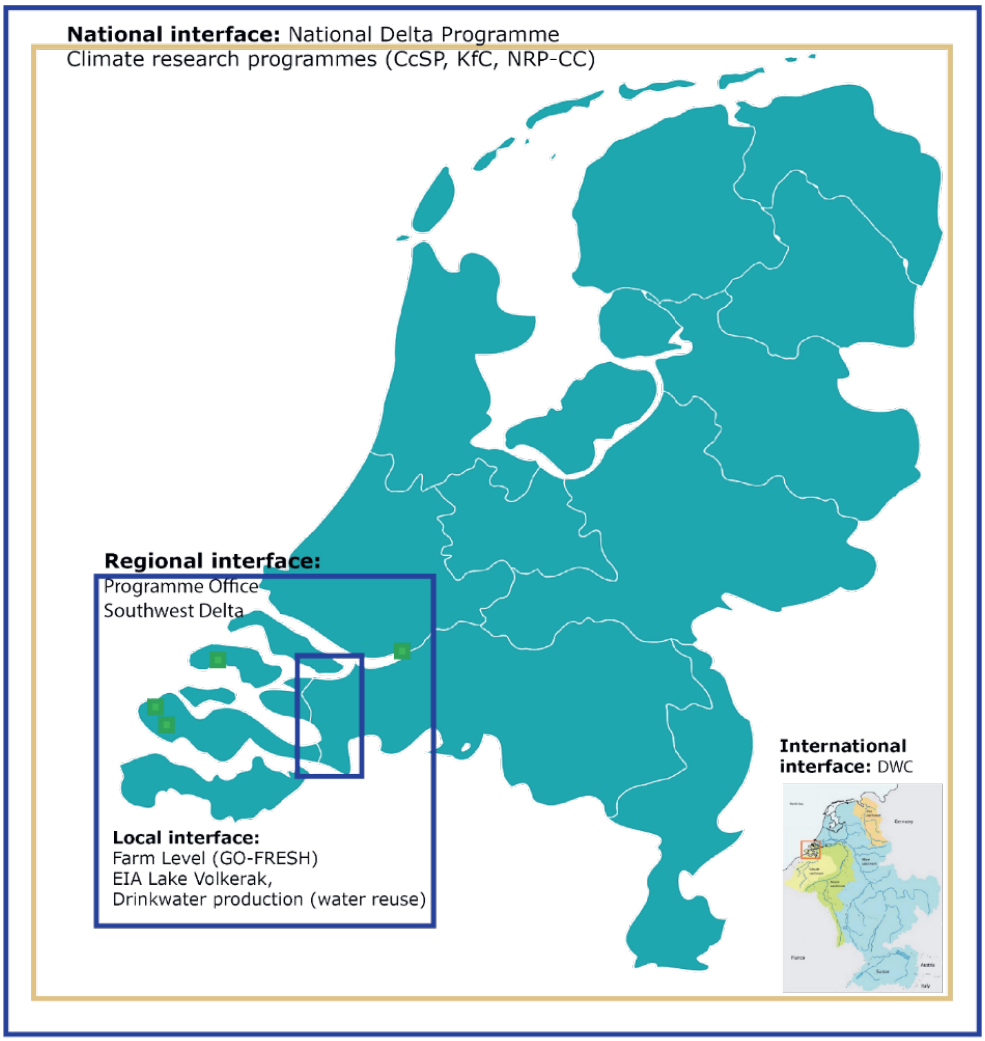


***Figure 1-3**, Illustration of the investigated interfaces between water management and climate adaptation research which are partly inter-connected (nested). Blue squares: interfaces initiated by water management. Orange square: interfaces initiated by climate adaptation research. Green squares: interfaces initiated by climate adaptation research with water users (farmers, water reuse for drinking water).*

Investigated time period

A longitudinal case study approach is valuable because decisions about water supply at national level take place at different moments than decisions at local or regional level. Decisions made at national level tend to influence those at local or regional level, and vice versa, although such interactions may unfold over extended periods of time. Especially when the relevant interfaces between water management, water users and climate adaptation research are, to some extent, interconnected or nested. It is therefore analytically relevant to examine how the process of addressing uncertainties in time evolve.

Between 2000 and 2014, many important decisions about climate adaptation were made in Dutch water management (at various scales) which after 2014 led to new research questions and other forms of collaboration between climate research and water management. The period 2000-2014 was selected because several investments were considered to enforce the National Economic Structure including infrastructure, water management and associated governance infrastructure for research and innovation. For this purpose a fund (abbreviated as FES) was developed in 1995 (Advisory Council Ministry of VROM, 1998). Questions were raised in the selected time period whether these investments were future (and climate) proof (Chapter 2). In addition, the third IPCC assessment report (2000) on climate adaptation became more prominent in the political agenda in various countries, including the Netherlands.

Applied research techniques and the role of the researcher in each unit of analysis.

It should be noted that each unit of analysis was part of a different research project with specific research objectives, project leaders and theoretical frameworks. My role in each unit of analysis was also different (table 1-1). In the initial period (2000-2003) the actors in water management were consulted (workshops, questionnaires, informal meetings) (Chapter 2). At a later stage (2004-2007) dialogues were initiated to align climate research with water management and spatial planning (Werners et al., 2003). My role could be described as a peripheral member (Adler & Adler, 1987) of the (national) water management community in the Netherlands.

The programme officers from the climate research programs (CcSP and KfC) were, from the beginning, involved with the National Delta Program. In addition, I became involved with the regional policy team of the Delta programme that is responsible for drafting the long-term policy for freshwater resources management and coastal safety of the Southwest Delta (team SWD). In 2011, I became a member of this team with the task to formulate an annual knowledge agenda. From then onwards my role could be described as participant observation (Atkinson & Hammersley, 1994) with an active membership role (Adler & Adler, 1987). The role of uncertainties was also explored by literature research (Veraart &

Klostermann, 2013) and interviews regarding the Environmental Impact Assessment procedure (EIA) for lake Volkerak-Zoom (2000-2012). The interviews were deliberately done by another researcher (Klostermann et al., 2013). This choice was made to allow for an unbiased comparison between the observations within the regional policy team and the stakeholder interviews. The interviewer was not involved in the formulation of the regional climate adaptation strategy, which enabled an interpretation of the interview results, free from preconceived notions or strategic alignment. The results of both interviews and participant observation are described in Chapter 5 and Annex B.



***Picture**: Part of the CcSP-Programme Council and Programme Office (September 2005).*

The study about freshwater supply at farm level (Chapter 6) was conducted between 2011 and 2014. I was a member of a research team that consisted of technical experts, farmers, civil servants, and students. To elicit farmers' perceptions of drought risks and attitudes towards adaptive measures, a survey was conducted among members of a Dutch agricultural organization (division South, ZLTO) by Deltares in collaboration with TNS-NIPO during January and February of 2013 (Annex A).

Water-related problems caused by climate change threaten the future of food systems in both the Netherlands and Ghana (Chapter 7). In this chapter the results of a comparative case study analysis are presented. The objective is to identify similarities in the use of spatial information by experts and stakeholders in their attempts to remove barriers or enable the uptake of Nature-based Solutions (NbS) in view of climate change. I was leader of the research team that conducted the comparative case study analysis. In the Netherlands, stakeholder participation focused on improving feasibility maps for wastewater reuse with available national water, soil, and land use models. The research approach could be described as a scientific assessment enriched with stakeholder consultation (Termeer et al., 2015; Wardenaar, 2015).

1.4.2 ANALYTICAL APPROACH

Data on the following aspects were collected the involved stakeholders, policy makers and scientists that work at the interface between climate adaptation research, water management and water use:

- The types of uncertainties addressed;
- The degree of consensus about the uncertainties;
- Their narratives/lines of reasoning regarding climate impacts and solutions;
- Whether they posed denial claims about climate change?;
- The role of boundary objects across spatial scales (where considered or present);
- The strategies proposed to address uncertainties.

Based on this analysis, the prevailing uncertainties during specific time periods were assessed (Research Question 1); the use of boundary objects across different spatial scales was examined (Research Question 2); and the strategies employed at interfaces to address uncertainties were evaluated (Research Question 3).

Typifying and assessing the prevailing uncertainties: a consensus approach
To evaluate which types of uncertainties, propagate at the interface, it was studied to what extent water managers, climate researchers and water users:

- use the same line of reasoning;
- pose/state denial claims;
- use the same boundary objects with the same interpretation.

Accordingly, their degree of consensus was labelled as *consensus, disputed* and *unclassifiable (uncertain)*[1].

In this dissertation the label '*consensus'* is used when the collected data for each qualitative criterion underpin that the actors involved agree upon the (scientific) validity of a problem–solution combination (de Boer et al., 2010; Hommes et al., 2009) and the significance and meaning of the associated knowledge base (Koppenjan & Klijn, 2004). In this case study, the 'problem' is the availability of freshwater resources in view of climate change and the 'solutions' are the considered climate adaptation strategies. We speak about consensus when climate adaptation researchers, water managers and water users have almost the same line of reasoning and use similar terminology. Denial claims and heterodox ideas are

[1] In the papers that formed the basis for this dissertation, the term 'negotiated knowledge' (chapter 4) is used. In the synthesis this has been replaced by the term consensus. In chapter 4, the term uncertain is used to qualify uncertain consensus on uncertainties. This has been replaced in the synthesis by unclassifiable (uncertain).

considered to be absent or to have little influence on decision making. Boundary objects are, in general, understood in a similar way.

In this dissertation 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 repeated frequently (McLean, 2013). The heterodox ideas also are underpinned with reason and logic (Verweij et al., 2006). Those narratives define what sort of evidence from climate adaptation research counts as a legitimate fact at the science-policy interface (Verweij et al., 2006). Although scientific facts are not negotiable in climate research, this may occur in the policy domain among different actors (Putnam & Holmer, 1992).

In this dissertation, knowledge is viewed as *unclassifiable (uncertain)* when discussion exists about the seriousness of a problem and/or the feasibility of a solution. Involved actors have doubts about the available knowledge; however, denial claims do not occur. The line of reasoning (narrative) between actors is comparable regarding epistemic uncertainties but may differ regarding ontic uncertainties. Ontic uncertainties are more important than epistemic uncertainties or ambiguity. When knowledge is unclassifiable, there are more lines of reasoning present at the science-policy interface, but denial claims, and heterodox ideas are still rare.

Table 1-2 illustrates how types of uncertainties (ambiguity, ontic & epistemic uncertainty) can be ranked to assess prevailing uncertainties and how they are linked to the degree of consensus about the uncertainties.

***Table 1-2**, Assessment approach of the research questions. CR=Climate (Adaptation) Research, WM = Water Management, WU = Water Users.*

Degree of consensus about uncertainties	Narrative characteristics			Prevailing uncertainty
	Line of reasoning (CR, WM, WU)	*Denial claims/ heterodox ideas*	*Boundary objects (CR, WM, WU)*	
Consensus	Only a few often-similar lines of reasoning exist	Extinct/ little influence on WM	Similar interpretations	Epistemic uncertainty
Unclassifiable *(uncertain)*	More lines of reasoning exist which sometimes differ from each other.	Rare/ not common	Different interpretations	Epistemic and ontic uncertainty are equally important
Disputed	Many opposing lines of reasoning exist	Are present	Not shared or explained by heterodox ideas.	Ambiguity

Boundary objects

Boundary objects are artefacts - such as concepts, discourses, processes, models or language - that can simultaneously project disparate interpretations (section 1.3.1). In water management and climate adaptation research, boundary objects often share similar terminology in narratives yet may be interpreted differently depending on context. Examples of terms that serve as a boundary object between environmental sciences and policy makers are *resilience* and *sustainability*. Both terms are widely used at science-policy interfaces, but they are often explained differently. In climate adaptation research, *resilience* may refer to ecological robustness, while in water management, it might mean infrastructure redundancy (Kumar et al., 2025).

This research will focus on use of the following boundary objects at the studied interfaces:

- *Terms and concepts related to climate adaptation,*
- *Interpretation and use of scenarios and related tools, terminology and concepts.*

It is investigated whether the interpretation of these concepts is comparable in water management and climate adaptation research and whether the explanation of the concepts and scenarios change over time. In this dissertation, boundary objects were not predefined as a fixed set of terms. Instead, they were identified inductively, based on terms that appeared in practice within climate adaptation research and water management.

Addressing uncertainties

The synthesis (Chapter 9) reflects on how uncertainties were addressed per unit of analysis and studied interface. This was done in an inductive manner, i.e. without a checklist of known ways to address uncertainties.

Table 1-3 categorizes the studied units of analysis (figure 1-2) and chapters by the elements of the presented theoretical framework and involved actors (figure 1-1). Table 1-3 illustrates that not all elements of the theoretical framework could be analysed in every unit of analysis of the nested case study. However, every element from the theoretical framework was, at least once, investigated in-depth. Table 1–3 shows that, for addressing research questions 1 and 3, most of the empirical evidence in this study has been collected and published (Chapter 2-8). The role of boundary objects and boundary organisations, as theoretical concepts, is mentioned only in Chapter 2 and 4. The discussion of research question 2 is therefore primarily based on a retrospective reflection on the research conducted (Chapter 2-8).

***Table 1-3**, The relationship between the elements of the theoretical framework (rows) and the chapters of this thesis (columns). A coloured cell accentuates that this element was the explicit subject of research. Solely a check mark indicates that the element plays a contextual role in the chapter.*

Element	Chapter 2	3	4	5	6	7	8
Units of analysis							
NRP CC	√	√					√
DWC			√				
CcSP	√	√	√				√
KfC	√			√	√		√
National Delta programme	√	√		√			√
Programme Office Southwest Delta				√			
Water resources at farm (GOFRESH)					√		
Water reuse in food chains and drinking water production						√	
Stakeholders (as part of the study)							
Climate Adaptation Research	√	√	√	√	√	√	√
Water Management	√	√	√	√	√	√	√
Water users	√			√	√	√	
Contextual stakeholders (not part of the framework)							
Policy (other than water management, such as spatial planning)	√	√	√	√		√	√
Society	√		√				
Other sectors that used climate research (excl. water use)	√	√				√	√
Addressed uncertainties (research question 1)							
Ambiguity (incl. stakeholder perceptions)	√			√			√
Epistemic uncertainty	√	√	√	√	√	√	√
Ontic uncertainty	√		√	√	√		√
Conclusions degree of consensus	√	√		√	√		√
Use of boundary objects at spatial scales (research question 2)							
Boundary object/organisation	√		√				
Concept for climate adaptation	√	√	√	√	√	√	√
Scenarios	√	√	√			√	√
Models	√		√	√	√	√	√
Strategies to address uncertainties (research question 3)							
Narratives/line of reasoning	√		√	√			
Denial Claims/heterodox ideas	√			√	√		
Strategies to address uncertainties	√	√	√	√		√	√

1.5 STRUCTURE OF THE DISSERTATION

The dissertation comprises an introduction (Chapter 1), a case study description (Chapter 2), and six chapters detailing the research (Chapter 3-8), all of which have been previously published in peer-reviewed literature. It concludes with a synthesis (Chapter 9). The substantive Chapters (2-8) are briefly described below:

Chapter 2: *Longitudinal reconstruction of the nested case study of climate adaptation research and water management in the Netherlands*

This chapter describes and reconstructs the longitudinal nested case study. This chapter is not published as a paper. Both the analysis beyond this chapter (the longitudinal reconstruction) and writing were conducted by me.

Chapter 3: *Climate change impacts on water management and adaptation strategies in the Netherlands: stakeholder and scientific expert judgments*

This chapter was originally published as a research paper in a peer reviewed scientific journal. I have contributed to the analytical framework together with the co-authors from Wageningen University, Wageningen Research and Maastricht University (ICIS). I was lead-author and developed the structure of the paper, the analysis of the results and the formulation of the conclusions. The underlying research was performed in a multi-disciplinary team where I had a final responsibility for the data analysis for the topic water management.

Chapter 4*: Climate proofing*

This chapter was a section (chapter) in the book *Climate change adaptation in the water sector* (Ludwig et al., 2009). I was lead-author of this section and developed the structure of the chapter and the formulation of the conclusions. Co-author Marloes Bakker has ensured that the chapter was aligned with the other chapters of this book, she also contributed to the conclusions. The book was reviewed by the publisher, and this chapter has been internally reviewed by the editors of this book.

Chapter 5: *Scientific knowledge use and addressing uncertainties about climate change and ecosystem functioning in the Rhine-Meuse-Scheldt Estuaries*

This chapter was originally published as a research paper in a peer reviewed scientific journal. I have developed the analytical framework together with the co-authors and I coordinated the formulation of the conclusions. The data collection and analysis were a shared task with one of the co-authors (Judith Klostermann).

Chapter 6: *Evaluation of socio-economic factors that determine adoption of climate compatible freshwater supply measures at farm level: a case study in the southwest Netherlands.*

This chapter was originally published as a research paper in a peer reviewed scientific journal. I have developed the analytical framework together with the co-authors and I coordinated the formulation of the conclusions. The data collection and analysis were a shared task with the co-authors from Wageningen Research (Jan Vreke) and Deltares (Rianne van Duinen).

Chapter 7: *Using spatial information to remove barriers and foster enablers: the uptake of nature-based solutions for food production and water resource management in Ghana and the Netherlands.*

This chapter was originally published as a research paper in a peer-reviewed scientific journal. I developed the analytical framework together with the co-authors and I coordinated the formulation of the conclusions. I did the data collection and analysis for the Dutch case study in collaboration with Confidence Duku (Wageningen Research) and Ilse Voskamp (Wageningen University).

Chapter 8: *From climate research to climate compatible development: experiences and progress in the Netherlands.*

Chapter 8 was a synthesis-paper of the results of the CcSP and KfC research programmes which was part of a special issue of a peer reviewed scientific journal. The structure of this paper and the formulation of conclusions and recommendations were a co-creation of all involved co-authors (Kim van Nieuwaal, Pavel Kabat, Peter Driessen) with also significant contributions from myself. I conducted the synthesis of the different research projects that were part of these programs.

Chapter 9*: Analysis, conclusions and recommendations*

This chapter was written by myself under the supervision of my promotors (Pavel Kabat and Ilse Voskamp).

Chapters 4, 7 and 8 include research results beyond the main scope of this dissertation. The specific chapters have their own internal logic but all of them analyse the interface between climate adaptation research and water management, albeit in different contextual conditions.

2



***Picture**: Reconstruction of a timeline at the office of water authority Noorderzijlvest (2024).*

Longitudinal reconstruction of the nested case of climate adaptation research and water management in the Netherlands

Abstract – This chapter presents a temporal analysis of the evolving interface between climate adaptation research and water management policy across spatial scales. It traces the trajectory of developments from the inception of Dutch climate research in the 1960s, the formulation of climate adaptation strategies between 2000 and 2014 and what happened afterwards (2014-2025). It is explored how uncertainties were addressed in this period and what the boundary role of climate scenarios and climate adaptation was. Across three decades of Dutch climate-water governance, climate scenarios and the policy concept of climate adaptation have repeatedly functioned as boundary objects, but their roles have evolved in line with institutional shifts, scientific developments, and changing governance priorities. The Netherlands' first major national research program, NRP-GC, linked climate change with air pollution but had limited engagement with water management. A shift occurred in the early 2000s as climate adaptation began to gain prominence in environmental policies and spatial planning. Research programs like "Climate changes Spatial Planning" (CcSP, 2004–2012) were initiated which introduced boundary concepts like "climate-proofing". From 2005 onward, institutional structures were established to operationalize climate adaptation in policy such as the creation of the National Delta Programme. Despite progress in the water sector, cross-sectoral integration remained a challenge. Efforts to bridge the gap between research and practice continued through Knowledge for Climate (KfC), a follow-up to CcSP. NGOs developed also climate adaptation strategies via initiatives like the Coalition for Natural Climate Buffers. After 2014, institutional responsibility for climate adaptation in the water sector shifted back toward water management agencies. Despite formal mechanisms for climate scenario updates and climate adaptation strategy reviews to address uncertainties, the interface reverted partially to a sectoral structure. The emergence of the Sea Level Rise Knowledge Programme (KP-SLR) in 2019 highlighted renewed urgency in face of ontic uncertainties.

The chapter concludes that, although the exchange of knowledge between the domains of water management and climate adaptation research has strengthened over time, significant challenges remain in formulating cross-sectoral climate adaptation strategies. Furthermore, the current approaches to address epistemic and ontic uncertainties, as well as ambiguity within nested interfaces, could be improved.

2 LONGITUDINAL RECONSTRUCTION OF THE NESTED CASE OF CLIMATE ADAPTATION RESEARCH AND WATER MANAGEMENT IN THE NETHERLANDS

2.1 INTRODUCTION

This chapter aims to reconstruct the historical relationships between the units of analysis (table 1-1). It provides a descriptive account of the interactions between water management and climate adaptation research through the studied interfaces. In this way, the addressed uncertainties, used boundary objects and the relationships between the various units of analysis are reconstructed. Subsequent Chapters 3 up to 8 offer more detailed analyses of specific components and timeframes within the nested longitudinal case study covering the period 2000–2014.

The primary focus of Chapter 2 lies on the period 2000–2014 (Section 2.3). However, the analysis also briefly reflects on developments preceding this timeframe (Section 2.2) and considers subsequent changes after 2014 at the interface between climate adaptation research and water management (Section 2.4).

Figure 2-1 illustrates the operational timelines of the examined science–policy interfaces. It distinguishes between water management (blue), other environmental and land-use policies such as spatial planning (green), and climate adaptation research (yellow). Flags mark contextual events—such as media coverage and extreme weather—that, while not directly studied, help situate the temporal narrative within a broader societal context.

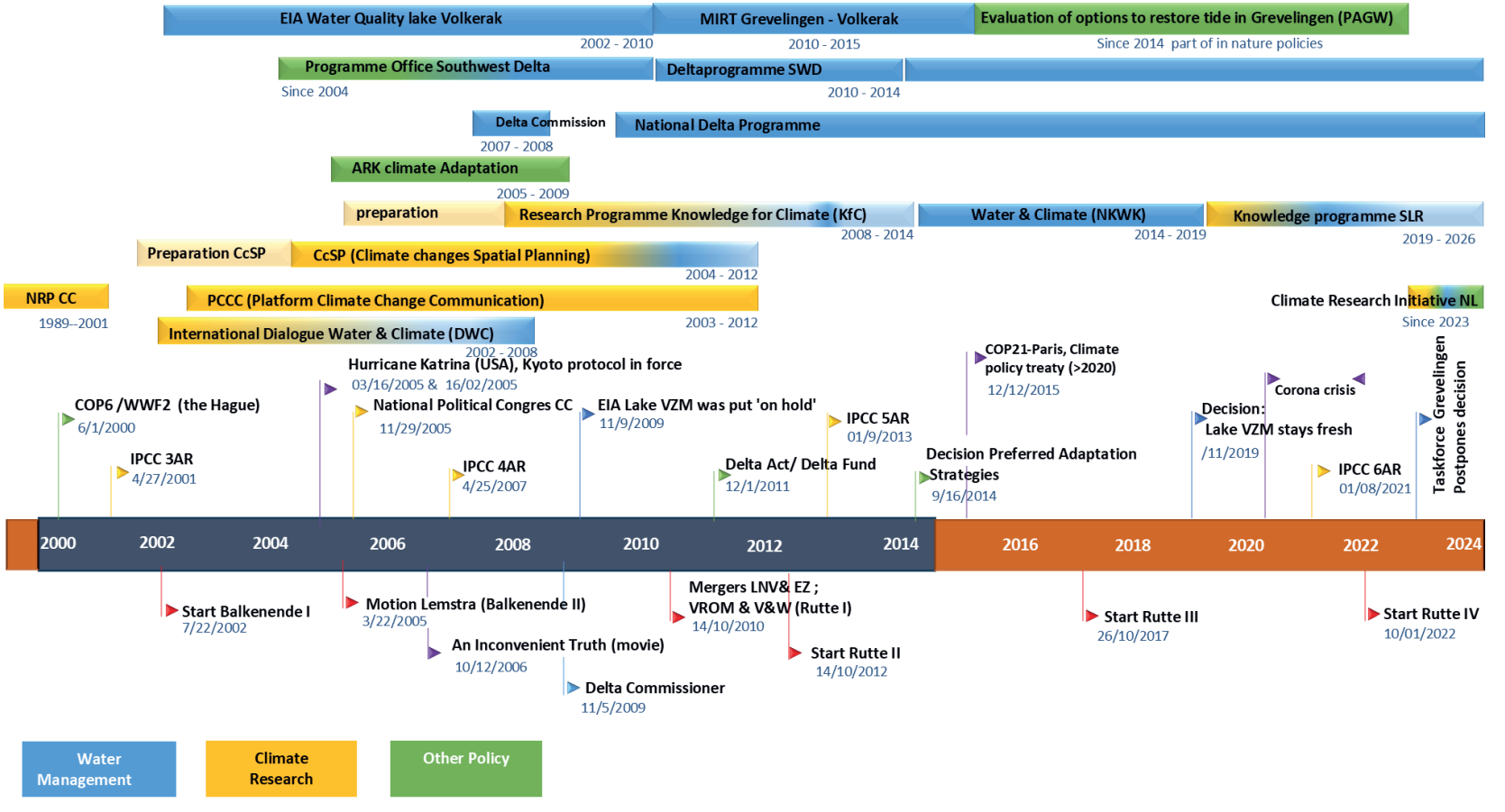


***Figure 2-1**, Gantt chart of the studied interfaces between climate research, policy, and water management.*

2.2 CLIMATE RESEARCH AND WATER MANAGEMENT BEFORE 2000

Climate research in the Netherlands before the start of IPCC

The Netherlands has a long-standing tradition of climate research, beginning in the 1960s (Baede & Schuurmans, 2008; Schuurmans & Baede, 2008). Early studies, such as the 1967 Dutch paper on the relationship between CO_2 and climate change (van Genderen, 1967), had little societal impact. By 1986, the Royal Netherlands Meteorological Institute (KNMI) formally included climate as a research area, reflecting growing global interest in climate change (KNMI, 2023). The 1970s saw significant developments through the Club of Rome, which utilized quantitative models to highlight the impact of fossil fuel combustion on rising atmospheric CO_2 levels (Meadows, 1992; Meadows et al., 1972). The Club of Rome primarily described the modelled atmospheric CO_2-concentration increase, from 293 ppm in 1860 up to a projected 380 ppm in 2000, as an environmental issue rather than human-induced climate change. Ppotential thermal effects of the CO_2-concentration increase were only mentioned in a footnote. The Club of Rome compared the modelled CO_2-increase with CO_2-measurements on the island of Manou Loa (Meadows et al., 1972). The modelled CO_2-concentrations were based on scenarios for, amongst others, population growth and the use of natural resources.

The Club of Rome conducted a systematic approach with models and expert judgment. An approach that addresses *epistemic uncertainty*, while the Club of Rome must also have encountered countless ontic uncertainties and ambiguity.

The start of IPCC

In 1988, the United Nations established the Intergovernmental Panel on Climate Change (IPCC) to assess the scientific understanding, economic impacts, and response strategies for climate change. Response strategies were meant to delay, limit or mitigate the impact of adverse climate change. The assessment included the identification of relevant existing international legal instruments having a bearing on climate and the identification of elements for inclusion in a possible future international convention on climate (IPCC, 1990). An important reason to start IPCC was the uncertainty whether climate change was a result of human agency or a result of a natural cause. This question was also raised because *ambiguity* played a role regarding the urgency for climate mitigation policies (Duineveld et al., 2024). The first IPCC-assignment did not include climate adaptation yet.

In the executive summary uncertainties are described as follows (IPCC, 1990): *"We are certain about the following", "We calculate with confidence that", "based on current models we predict", "there are many uncertainties in our predictions particularly with regard to the*

timing, magnitude and regional patterns of climate change due our incomplete understanding of", "Our judgment is that", "to improve our predictive capability, we need…". The first IPCC report (1990) categorized uncertainties: epistemic uncertainties, based on incomplete knowledge, and ontic uncertainties related to unknown physical processes. The report omitted ambiguity, which arises from differing interpretations and perspectives (IPCC, 1990).

The boundary role of climate scenarios before 2000 - The first IPCC report developed multiple emissions scenarios to explore how different socioeconomic pathways could affect future greenhouse gas concentrations. These scenarios were used to estimate future climate change and sea-level rise, and to express the range of uncertainty in projections. In the Netherlands, the IPCC-1990 scenarios were not used in water management because they lacked the detail needed for hydrological modelling. The scenarios functioned as a boundary object for climate scientists to build a bridge towards climate policy and economic development (Lidskog, 2024), but they did not yet have that function for Dutch water management.

Climate research in the Netherlands since the start of IPCC

In the Netherlands, climate change research and policies were, initially, linked with research and policies regarding air pollution. The 1989 Ministerial Conference on Atmospheric Pollution and Climatic Change (Vellinga et al., 1989) led to the establishment of the National Research Programme on Climate Change and Air Pollution (NRP-GC), active until 2001 (Kok et al., 2002). No explicit interface existed between climate change research and water management in the Netherlands at that time.



Picture: *Ministerial Conference on atmospheric pollution and climate change in 1989. Chairman Minister Ed Nijpels, flanked by Pier Vellinga (left), C. Zoeteman and mrs J. Waller.* Source:(Vellinga et al., 1989).

Climate policies and land use

A new dimension of climate research emerged with investigations into climate mitigation strategies, such as land-use changes (RIVM, 1987), renewable energy (Oikonomou & Jepma, 2008) , and biosphere feedback mechanisms (de Gier & Schuurmans, 1998; van der Laan & de Kort, 1998). Global research programmes like the International Geosphere-Biosphere Programme (IGBP) addressed uncertainties surrounding these complex feedback loops and showed that land-use changes impact not only the biosphere but also global climate patterns (Pielke et al., 1998; Pielke & Avissar, 1990; Steffen, 2001). There was a growing awareness that land use change affects not only the hydrological cycle and biosphere but also the global climate (Kabat et al., 2004).

The scientific understanding of these feedbacks were incomplete (*ontic uncertainty*) and between 1986 and 2015 many research projects were initiated by IGBP to address these uncertainties, also with contributions of NRP-GC (P. Kabat et al., 2002). IGBP's initial thinking was very much guided by the Bretherton diagram as developed by NASA in 1986, where the sun and humans were external factors (Steffen et al., 2020).

Climate science, global change, and climate policy (early 1990s)

The early 1990s marked an increase in global awareness of climate change. The second IPCC assessment report (1995) cautiously suggested a *"discernible human influence"* on climate, but uncertainties about natural climate variability, the magnitude and pattern of climate change and the scale of human impact persisted (IPCC, 1995). For IPCC-researchers this was *ontic uncertainty*, while for some other scholars this uncertainty was reason to question whether the climate is changing due to human influence, also resulting in denial claims (Lewandowsky et al., 2015; Porter et al., 2017), indicating *ambiguity*.

This ontic uncertainty, combined with ambiguity, fueled climate change skepticism in the Netherlands and slowed policy implementation (Dewulf et al., 2017). In response, the Netherlands set modest emission reduction targets (3-5% by 2000) within its second national environmental policy plan (VROM, 1993).

Climate science, global change, and climate policy (late 1990s)

During the Global Change Open Science Conference (Amsterdam, 2001) the *"Amsterdam Declaration"* was published, stating that anthropogenic forces were *"equal to some of the great forces of nature in their extent and impact"* (Moore et al., 2001). The International Human Dimensions Programme on Global Environmental Change (IHDP) was an indication that uncertainties associated with *ambiguity* were, at least, recognized. IGBP was followed up by the research network Future Earth (UNESCO et al., 2024).

Water management and climate change research before 2000

Since the 1950s, water managers have relied on scenarios as a tool to address uncertainties and prepare for future water management. However, climate scenarios derived from models were not incorporated into this practice until the 1990s (Haasnoot & Middelkoop, 2012). Examples of scenario-based applications in water management in the period 1950-1990 include, among others, the PAWN framework (Policy Analysis of Water Management for the Netherlands) (Veen & Baarse, 1982), as well as the various strategies to reduce the coastline length that have been carefully considered within the context of the Delta Works. Although assumptions were made regarding future climatic conditions, climate scenarios and underlying climate models were not employed. Instead, the scenarios primarily served to evaluate various interventions in coastal defence, freshwater supply, and land use (Veraart et al., 2014b).

Water managers became more involved in the second term of NRP-GC (1995-2001). For example, NRP-GC initiated research about the impact of changing precipitation patterns on the discharge of the Rhine (Middelkoop et al., 2001) and what the effects of sea level rise and land subsidence would have on the salinity levels in regional water systems (Vermulst et al., 1998), also using the first Dutch climate scenarios developed by KNMI. These climate scenarios were originally developed for the preparation of the Fourth National Water Plan commissioned by the Ministry of Transport, Public Works, and Water Management and Rijkswaterstaat (Klein Tank et al., 1995; Können et al., 1997).

Water management and climate change research since 2000

The 21st Century Water Management Committee (WB21), established in 2000, aimed to adapt Dutch water systems to climate risks, including increased river discharges, soil subsidence, and sea-level rise (Commissie Waterbeheer 21e eeuw, 2000). While the committee comprised water managers and land-use experts, climate researchers played an advisory role. WB21's recommendations included enhancing water retention and accommodating higher river discharges, but conflicts emerged with land use interests, highlighting ambiguity and competing spatial priorities (During et al., 2016). An *ambiguity* that arose, for example, is that not every farmer in the Netherlands in 1998 endorsed measures to minimize drainage. Intense precipitation events, in combination with reduced drainage capacity resulting from water retention measures, exacerbate the risk of pluvial flooding and water nuisance, with adverse consequences for agricultural productivity and urban infrastructure (Stuyt et al., 2012). Interventions to accommodate increasing river discharge also have implications for land use in the floodplain area (During et al., 2016). The WB21-committee was aware that regional development and climate adaptation would

lead to competing spatial claims. The committee advised the government to align water management with spatial planning.

The boundary role of climate scenarios since 2000 - The first KNMI scenarios (Klein Tank et al., 1995) used in the WB21 for, among other things, Rhine discharge projections (Middelkoop et al., 2001; Middelkoop & Parmet, 1998), could perhaps be defined as a boundary object for experts from climate research and water management. They also provided the level of detail that was lacking in the 1990 IPCC scenarios from a water management perspective (Haasnoot & Middelkoop, 2012).



Picture: *Anders omgaan met water – Waterbeleid in de 21e eeuw.*

2.3 TIME PERIOD 2000-2014

Climate adaptation is shaping climate research (2000-2005)

In preparation for the third IPCC report more focus is given to adaptation to climate change compared to previous IPCC assessments (IPCC, 2001a). In the third IPCC report, climate change was not only predicted by model results and scenario projections. It was also identified by the statistical analysis of time series of global air temperature. The signal of climate change came above the so-called statistical noise.

Before 2005 the term 'adaptation' was common vocabulary for climate researchers instead of the term 'climate adaptation' by IPCC but also in the Netherlands, exemplified by the climate impact assessment study in the Netherlands (Chapter 3) and the underlying report (van Ierland et al., 2001). Dutch climate scientists and the IPCC put more emphasis on the need for adaptation to climate change towards policy makers since 2001, often with the following argumentation:

- *'Reductions of greenhouse gas emissions, even stabilization of their concentrations in the atmosphere at a low level, will neither altogether prevent climate change or sea-level rise nor altogether prevent their impacts.' (IPCC, 2001b);*
- *'…Consensus has been achieved about the Kyoto-protocol (July 2001, Bonn). However, such a protocol and reduction would only be a start as emission reduction targets from the Kyoto protocol are insufficient to mitigate climate changes as expected to occur over the next 50 years….' (van Ierland et al., 2001).*

At the same time, climate researchers argue that adaptation and mitigation strategies to climate change cannot be seen separately from each other:

- *'The development of planned adaptation strategies to address risks and utilize opportunities can complement mitigation actions to lessen climate change impacts. However, adaptation would entail costs and cannot prevent all damages. The costs of adaptation can be lessened by mitigation actions that will reduce and slow the climate changes to which systems would otherwise be exposed' (IPCC, 2001b).*

Climate change and environmental policies in the Netherlands (2000-2005)

In the fourth National Environmental Policy Plan, abbreviated NMP4, climate change was presented as one of the seven major environmental problems (VROM, 2001). The other mentioned environmental problems were *loss of biodiversity, overexploitation of natural resources, health risks, external safety risks, damage to the living environment and potential unmanageable risks*. NMP4 concluded that Dutch CO_2-emissions must be halved by 50% by 2030 compared to 1990. The NMP4 did not use the phrase *(climate) adaptation*, but stated that measures were being developed to cope with the effects of climate change in water management (Commissie Waterbeheer 21e eeuw, 2000).

Sectoral policies and institutional shortcomings were mentioned by NMP4 as the main barriers that prevented integrated solutions for the environmental problems at hand (VROM, 2001). The authors of NMP4 were aware that each ministry and knowledge infrastructure tended to develop its own line of reasoning for environmental problems, potentially creating *ambiguity.*

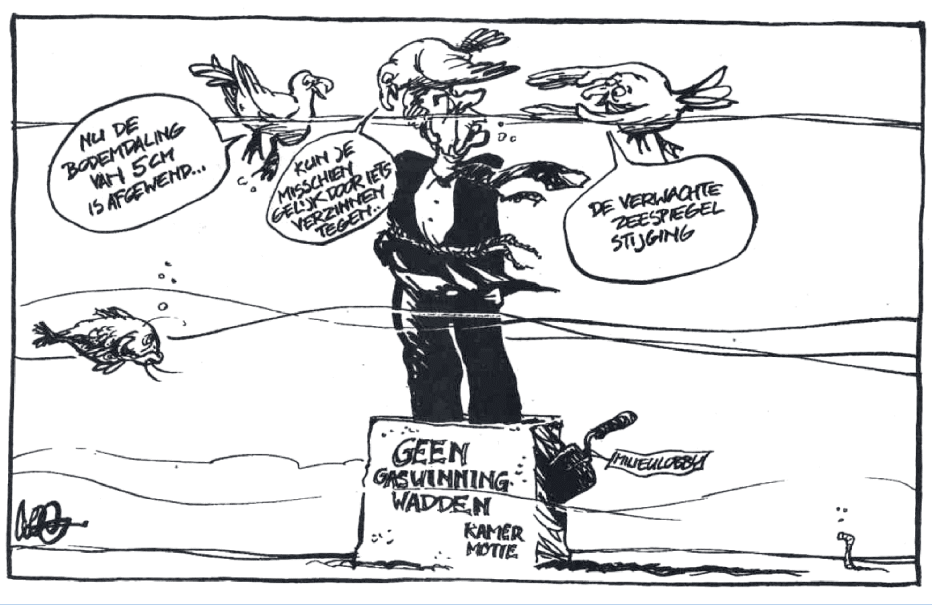


Picture: *United Nations Climate Change Conference of the Parties (COP) in 2000 chaired by minister Jan Pronk (Ministry of Housing, Spatial Planning and the Environment).*

In 2001, a competitive call for expressions of interest for large research programmes was issued by the national government followed by a call for proposals (Ministry of Economic Affairs, 2002b). The government's objective was to strengthen the Dutch economic infrastructure by improving the Dutch knowledge infrastructure through knowledge transfer and valorisation of knowledge between science, policy, and private sectors (Box 2-1). The call resulted in 37 research & innovation programmes in the field of environmental sciences and technology (CPB et al., 2003).

Members of the Dutch climate research community were able to set up a national research programme entitled *Climate changes Spatial Planning* (CcSP) that ran from 2004 to 2012 (Kabat et al., 2005). The CcSP programme was organised in five main themes: climate scenarios, mitigation, adaptation, integration and communication (Programme Office CcSP, 2012 (expired); Veraart et al., 2007). This structure was chosen in consultation with the ministries involved and regional policy makers beforehand (2000-2004). Previous Climate Research programmes were fully funded with public resources. However, within this call a maximum of 50% of the total budget of research programmes was subsidized. Applicants were encouraged to seek additional financial resources and partners from other sectors. The objective of the call was also to realize collaboration between research institutes and the private sector.

Box 2-1, *Political debate about necessity of changes in Dutch research funding strategies around 2000.*



Cartoon: *The cartoon illustrates uncertainties in knowledge that were faced during decision making about future gas exploitation in the Wadden Sea in kabinet Kok-II. "Now that 5 cm of soil subsidence has been averted, you may be able to do something about the expected sea level rise." (Jos Colignon, 1998)*

PvdA, VVD and D66 had agreed in their coalition agreement (cabinet Kok II, 1998) to allocate approximately 1.1 billion guilders (≈ 0.5 billion euros) for the period 2000-2010 to strengthen the Dutch Knowledge Infrastructure. Ironically, this budget came from the annual gas revenues (fossil fuel, CO_2). These investments should result into a structural annual national economic growth of three per cent. An important prerequisite was that an improved knowledge infrastructure should lead to future proof and sustainable infrastructural investments. The VROM Council (Advisory Council Ministry of VROM, 1998) endorsed this necessity, but also recommended that budget should be allocated for fundamental (academic) research.

At a later stage (March 2005), the motion Lemstra asked the government to evaluate long-term (climate) risks and benefits of considered spatial and infrastructural investments by developing a national vision, and exploration of long-term scenarios (>2050). The motion was also discussed between policy makers and climate researchers during a high-level Climate Conference in Scheveningen in presence of minister-president Balkenende and responsible ministers for water management and environment.



(Picture: © Michelle Muus, 2005)

Different views on the relationship between climate adaptation and mitigation policies

The Netherlands Bureau for Policy Analysis (CPB) (CPB et al., 2003) was critical about the proposed climate mitigation research within the CcSP-programme proposal. They argued that in face of the expected ratification of the Kyoto protocol (2004), mitigation policies to reduce greenhouse gas emissions and energy use were in their final stage of development and new research was not necessary. In addition, the CPB indicated that socio-economic instruments such as pricing of energy use or greenhouse gas emissions would be more efficient compared to planned land use change to reduce greenhouse gasses (CPB Netherlands Bureau for Economic Policy Analysis, 1998). As a result, only monitoring of emissions of land use based greenhouse gases was included in CcSP-programme (Veraart et al., 2008).





Picture: *Data regarding land use bound greenhouse gas emissions (Hutjes et al., 2010) were collected with instruments such as Eddy-Covariance flux- towers and an airplane (photo). This airplane is still used to measure greenhouse gas emissions from the Dutch peatlands (Hutjes et al., 2022).*

The set-up of climate adaptation research within the CcSP programme was comparable with IPCC working group II and designed from both a sectoral and regional perspective. The projects under the CcSP-theme 'Integration' were meant to integrate activities within the other themes and to develop decision support frameworks for policy making. Some scholars argued that the CCSP-research strategy to address uncertainties and to develop adaptation strategies was predominantly defined by life sciences, while spatial planning expertise was lacking (Driessen et al., 2009; Wardenaar, 2015; Wardenaar et al., 2014). Those experts in spatial planning had organized themselves within other research programmes such as Habiforum and Leven met Water (Wardenaar, 2015).

Climate change is shaping water management via spatial planning in 2000-2005.

In the fourth national water management plan (Rijkswaterstaat, 1998) a start was made with thinking about water management in the 21st century (Commissie Waterbeheer 21e eeuw, 2000), abbreviated WB21. The plan aimed for measures between 1998 to 2006 and mentioned uncertainties for water management related to soil subsidence and climate change, referring to IPCC and scientific insights regarding soil subsidence (Vermulst et al., 1998). WB21 recommended prioritizing water retention measures in the following sequence: first, maximize retention within the soil; second, retain as much as possible in surface water; and third, once these two strategies have reached their limits, discharge the remaining freshwater to the sea (figure 2-2). The extensive rainfall in 1998, which led to widespread water nuisance, highlighted a critical uncertainty: measures aimed at retaining water longer to mitigate drought under climate change also reduce the capacity to drain excess water during extreme precipitation events. To address this dilemma, an additional committee was convened to provide advice on crisis management (van Duijn & Crisis Onderzoek team, 1999).

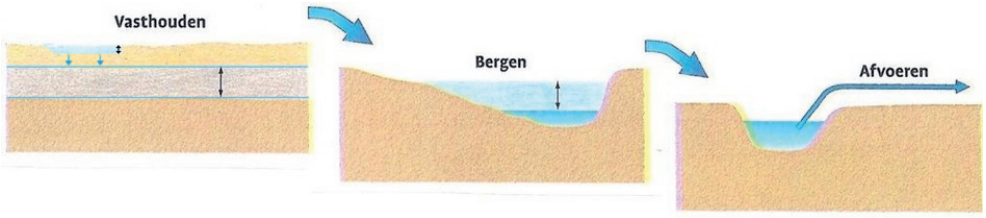


***Figure 2-2**, The proposed strategy of water management in the 21st century: (1) improve water retention (left) in the soil, then store water in surface water bodies and finally (3) develop strategies for water drainage. Source: (Kaandorp et al., 2024), adapted from Commission Water Management 21th century.*

Spatial planning and Water management in 2005

The fifth national Spatial Planning Policy Plan (2005) outlined the development perspectives for spatial planning in the Netherlands up to 2020- 2030 (Ministry of Housing Spatial planning and the Environment, 2005). This plan addressed the consequences of climate change for water management, sustainable energy, and the development of the Dutch Ecological Network as a spatial adaptation option for animal species. Water management was mentioned as a guiding principle for spatial planning in view of climate change. However, in this policy plan the need for climate adaptation was only included in the long-term perspectives (2030) for the Dutch coast and the southwestern delta. Climate adaptation was not mentioned for the low lying urban areas of the Netherlands or the rural peat areas (Veraart & Kabat, 2005). Before the plan came into effect, it was evaluated by the Senate (in Dutch: Eerste Kamer). The CcSP-research program stated that it was

necessary to evaluate how climate proof the proposed investments in the low-lying areas of the Randstad were. In addition, the CcSP-researchers indicated that the current water management in peatlands resulted in significant greenhouse gas emissions (Kabat & Veraart, 2005). If water was the guiding principle for spatial planning as stated by the plan, then the reduction of greenhouse gas emissions from peatland should also have been an objective for spatial planning according to the CcSP-researchers. One of the outcomes was the 'Motie Lemstra' in which the Dutch government was asked to invest in the development of a long-term vision for spatial development and investments in infrastructure. This 'Motie Lemstra' was also a reason to organize a conference on climate adaptation in the Netherlands for policy makers in the Netherlands (Box 2-1).





Picture: *The national conference 'Omgaan met klimaatverandering in Bestuurlijk Nederland'.* ***Left:*** *Professor Pavel Kabat talking about climate change impacts.* ***Right:*** *professor Wolter Lemstra (CDA) elaborating about the long-term sustainability of investments in Dutch infrastructure (Pictures © Michelle Muus, 2005).*

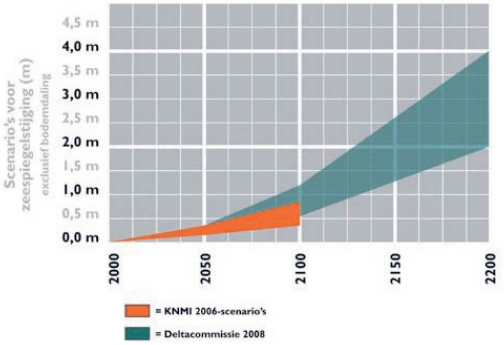
Developments in water management 2005-2010

The elaboration of the WB21-strategy was published in the next national water plan (2009-2015) (Ministry of public transport and water management, 2009). To cope with increasing water nuisance risk, a strategy was developed by the regional water authorities entitled in Dutch: 'Nationaal Bestuursakkoord Water' (I&W et al., 2018; Unie van Waterschappen et al., 2011).

In 2007, the Dutch government installed a Delta State Commission that formulated recommendations about flood risk reduction strategies and long-term freshwater supply in view of climate change (Deltacommissie, 2008). Afterwards the national Delta Programme (2009) was initiated along with a Delta commissioner (2010), an Delta act (2011), and a Delta investment fund (2011) (Vink et al., 2013). The investment fund, amounting to approximately €1 billion yr^{-1} until 2100, was established for investments in adaptive water management (Restemeyer et al., 2016). Decisions about new standards for flood risk

management, guidelines for allocation of freshwater, and 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 concept called 'adaptive delta management' (Dewulf & Termeer, 2015).





***Picture, Left**: Delta Commission Veerman. Members: C.P. Veerman (chair), I.M. Bakker, J.J. van Duijn, A.P. Heidema, P. Kabat, T. Metz, J.G. van Oord, M.J.F. Stive and B.W.A.H. Parmet and L.O. Fresco. **Right**: Sea level rise scenarios for the Dutch coast as developed by KNMI (orange) and Delta commission (blue).*

The National Water Plan 2009-2015 (NWP 2009-2015) paid a lot of attention to climate adaptation. It not only elaborated on the WB21-advice, but also on the advice of the Delta State Commission. The term climate adaptation was also introduced by NWP2009-2015 instead of the term adaptation. The plan summarized the second generation KNMI scenarios (van den Hurk et al., 2006), introduced the concept of climate proofing and stated that climate adaptation should be climate neutral, i.e. without additional greenhouse gas emissions. The plan had a separate chapter that described how water management would address uncertainties from climate research. The following advice and strategies were mentioned to address uncertainties in NWP2009-2015:

- It was formalized that the KNMI climate scenarios must be updated periodically (this is a way to address epistemic uncertainty).
- Decision makers in water management were urged to use the latest scientific understanding about climate change (a way to address ontic uncertainty).
- It was acknowledged that due to the proposed periodical updates of the KNMI-climate scenarios, uncertainty could arise about recently implemented policies, particularly the national flood risk reduction strategy (in Dutch: HWBP).
- This rise in uncertainty also occurred after the publication of the State Commission's advice, which contained other scenarios for sea level rise than those of the KNMI-

2006 scenario's (ontic uncertainty but also a risk for ambiguity)[2]. The Dutch Cabinet therefore decided to conduct a Quick Scan to assess what the consequences of the State Commission's advice were for envisaged interventions in relation to flood protection and freshwater supply.

- A preference was expressed for working with 'flexible measures' when adapting water management, unless the climate risk could only be solved with hard infrastructure. The *terms 'moving along with climate change'* (*in Dutch: Landgebruik laten meebewegen met klimaatverandering*), *'resisting climate change' (In Dutch: weerstand bieden met waterbeheer en daarmee huidig landgebruik vasthouden onder klimaatverandering)* and *'realisation of robustness to climate change in water management'* were mentioned as strategies to address the uncertainties in the climate scenarios. The strategy 'moving along with climate change' could be described as managed realignment of coasts in international literature (Doody, 2013; Esteves, 2014; Kraan et al., 2025);
- Guidelines for Rijkswaterstaat and regional water authorities were provided which of the four KNMI-climate scenarios (van den Hurk et al., 2006) could be used for specific themes (such as water nuisance, flood risk or drought). The KNMI was also asked to define a plausible upper limit for the next generation of climate scenarios and sea level rise.

The boundary role of climate scenarios - By this point, the KNMI climate scenarios got a formalized role - effectively a boundary object - between climate science and Dutch water management. The KNMI scenarios were used simultaneously by climate researchers (who produced and updated them), national policymakers (who set strategic directions), Rijkswaterstaat and regional water authorities (responsible to implement measures) and advisory bodies like the Delta State Commission.

National Programme on Adaptation, Spatial Planning and Climate (ARK, 2005-2009)

The response to the Lemstra motion (2005) from the government was the initiation of the National Programme on Adaptation, Spatial Planning and Climate (ARK). ARK ran from 2005 to 2009 (van Alphen & Bloemen, 2024), and was coordinated by the ministry of Housing, Spatial Planning and Environment (VROM) with contributions from the Ministries of Public transport and water management (VenW), Agriculture, Nature and Food Security (LNV), Economic Affairs (EZ) and by the umbrella organisations of the provinces (IPO), municipalities (VNG) and water authorities (UvW). The objective was to develop a national adaptation strategy, including an implementation programme and budget for taking

[2] It also appears that by formalizing the updating of KNMI climate scenarios, the Ministry of Infrastructure and Water Management also tried to reduce the risk of publishing untimed scientific insights.

measures. The echo of the IPCC's two-track approach of climate change adaptation and mitigation policies sounded much stronger in the messages via national Platform on Climate Communication (PCCC) (Box 2-2) than in ARK.

At the start of ARK, CcSP was closely involved, for example the national conference in Scheveningen (November 2005), entitled *"Omgaan met klimaatverandering in Bestuurlijk Nederland"* was organised jointly by CCSP and the ministry of VROM (de Pater & Dorland, 2006). The science-policy interface between this policy programme and climate research was strengthened through the initiation of a new public-private research programme (Knowledge for Climate, KfC) linked to the existing research CcSP-programme (see also Chapter 4, box 4-2).

***Box 2-2**, Platform for Climate Change Communication (PCCC; 2003-2012).*

The Platform Communication on Climate Change (PCCC) was established in 2003 by the Netherlands Environmental Assessment Agency (MNP) and the Royal Netherlands Meteorological Institute (KNMI). The PCCC network was launched in October 2003 in the presence the Minister of Transport, Public Works and Water Management and the press, followed by a briefing of the Parliament.



The PCCC objective was to improve the quality, efficiency, and effectiveness of the communication of climate research. PCCC was a collaboration of MNP, KNMI, Wageningen UR, VU University Amsterdam, Utrecht University and NWO. ECN (2006), TNO (2010) and Deltares (2010) became also involved. PCCC organized meetings for policy makers, governors, and researchers when climate change was an important item in the media, for example when the Kyoto Protocol was ratified (2004) or when IPCC reports were published (2007). PCCC published in the period 2006-2010 on an annual basis the brochure, entitled 'The State of the Climate' and maintained the website www.klimaatportaal.nl (no longer active), based on Dutch climate research. PCCC was sponsored by the Ministry of Housing, Spatial Planning, and the Environment (VROM) and the Climate changes Spatial Planning programme until 2012. Dutch climate change sceptics (Kroonenberg, 2012; Lewis & Crok, 2014; Rorsch et al., 2008) frequently were in dialogue with the PCCC network to give a critical reflection regarding conclusions from climate research. Since 2009 this dialogue between climate scientists and sceptics moved towards websites such as www.climategate.nl (Dewulf et al., 2017). The Climate Dialogue weblog (2012-2014) (Crok et al., 2015), could be seen as follow-up for PCCC activities, following a request by Dutch Parliament (Nepperus, 2010) to involve sceptics more in the climate debate. The website was set up by the Royal Netherlands Meteorological Institute (KNMI), PBL Netherlands Environmental Assessment Agency, and Dutch science journalist Marcel Crok.

Picture: *Frontpage of one of the annual brochures of PCCC, entitled 'De Staat van het Klimaat'.*

Developments in terms about climate adaptation - The evolution of the term climate adaptation in Dutch policy in this time period also reflects the emergence of a boundary

object. The use of 'Climate adaptation' instead of 'Adaptation' was introduced by ARK. This term is also used in European climate policies for coastal zones and marine ecosystems (European Commission, 2013, 2009). The term climate adaptation seems vocabulary that is specifically used in the Netherlands. The IPCC continued to use the term 'adaptation' until the latest assessment report (AR6, 2023). AR6 adds the terms *'adaptation planning', 'incremental adaptation'* and *'adaptation response'* to the climate research vocabulary (Intergovernmental Panel on Climate Change, 2023).

ARK approached climate adaptation as a spatial and intra-sectoral societal challenge for sectors such as water management, agriculture, industry, nature and health (Ministerie van VROM et al., 2007). However, ARK was never completed. The mandate to develop climate adaptation strategies for water management quietly shifted from the Ministry of Housing, Spatial Planning and Environment to the ministry of Transport, Public Works, and Water Management when the advice of the State Commission was published in 2007 (Box 2-3). This shift resulted in reduced complexity of climate adaptation governance, because priorities regarding climate adaptation were restricted to water management (Biesbroek et al., 2014). Yet the term climate adaptation itself remained stable and continued to coordinate action across institutions. This combination of interpretive flexibility (Pinch & Bijker, 1984), cross-sectoral usability, and institutional durability strongly suggests that climate adaptation functioned as a boundary object in the Dutch governance context.

***Box 2-3**, Summary of advice 2nd Delta Committee 'Samen Werken met water – Een land dat leeft, bouwt aan zijn toekomst' (Delta Commission, 2008).*

In the advice, 'water safety' plays a crucial role. This concerns protection against flooding and securing the freshwater supply. Ensuring water safety prevents victims and social disruption, it prevents damage to the economy, landscape, nature, culture and the climate of investment. The advice assumes that ensuring water safety is a collective social interest. It was advice to change the flood risk norm method and standards in view of climate change. The committee's recommendations to develop adaptation strategies that are cost-effective and have added social value. Climate adaptation strategies should be flexible, can be realised gradually and contain a perspective for action in the short term. The proposed interventions in the advice must be sustainable: during their implementation they must make efficient use of water, energy and other raw materials, so that the quality of the living environment is not only maintained but even improved. It was advice to start a national Delta Programme to develop a climate-proof design of the Netherlands. This programme is financially (Delta Fund) and politically and administratively anchored in a renewed Delta Act.



Interface with water users

Around 2006/2007, the same time that ARK was founded, the term Natural Climate Buffers was introduced in a study commissioned by a number of Dutch environmental NGO's (Andriesse L.A. et al., 2007). The study was the basis for the establishment of the Coalition for Natural Climate Buffers, a joint effort of Dutch organisations working in the field of nature and environmental protection, aiming to make the Netherlands climate proof while restoring and improving landscape and biodiversity (Zingstra & Vertegaal, 2021). In 2010, the Ministry of Housing Spatial Planning and Housing granted a subsidy to develop this approach. The NGOs started already in an earlier stage to develop the natural climate buffers with a subsidy from the Postcode Loterij (postal code lottery). In the second phase (since 2016) the projects were additionally funded by European subsidies such as LIFE and INTERREG. Under the umbrella of the Coalition for Natural Climate Buffers (abbreviated as CNK) a variety of development projects were planned or have been carried out. The climate buffer projects can be seen as local interfaces between water management and water users (nature). The interaction with climate research differed per climate buffer project (Veraart et al., 2019). The financing was primarily intended for the realization of climate adaptation and for research.

After 2018, cooperation between CNK with climate research became more intensive and was partially financed with resources from the Dutch climate agreement (Klimaatberaad, 2019; Vertegaal et al., 2019). For peatlands, the Climate Agreement set out a 1.0 Mton reduction in annual emissions by 2030 (Klimaatberaad, 2019). CO_2 and CH_4 emissions have therefore been measured in Climate Buffers projects in Drenthe (Onlanden) and Overijssel (Wieden-Weerribben) since 2020 with CcSP- expertise (Kruijt et al., 2023). Similar research is being conducted on peatland in agricultural use since 2019 (Erkens et al., 2022; NOBV, 2020).



Picture: *measuring CO_2 and CH_4 emissions in the nature reserve area Onlanden, a joint effort of climate researchers and nature developers to explore uncertainties (2021).*

The NGOs explored the complexity of combining environmental policy objectives and have remained very close to the definition of climate proofing as drawn up by Kabat et al. (2005), contrary to the Delta Program where climate adaptation and mitigation policies were kept

separate to reduce complexity (e.g. a way to address uncertainties). The NGOs were committed to implementing climate adaptation in 2007 and accepted scientific uncertainties about its effectiveness (also a way to address uncertainties). However, when they explored financing the development of Climate Buffers within the Climate Agreement (climate mitigation) and the National Delta Program (climate adaptation), the scientific uncertainties became more important. The relevant authorities wanted to have more certainty about effectiveness of the natural climate buffers regarding the set objectives (Hekkenberg, 2019; Hekkenberg & Koelemeijer 2018).

In general, there is scientific consensus that peatland rewetting will lead to reduction of CO_2 emissions, and with sufficient rewetting a peatland can become a sink for carbon (Boonman et al., 2022; Evans et al., 2021; Koch et al., 2023). There are uncertainties about the order/magnitude of possible emission reduction/sink capacity (epistemic uncertainty) and the influence of regional differences in soil and vegetation (ontic uncertainty) (Hu et al., 2024; Robroek et al., 2024). Knowledge about methane emissions and N_2O is much more incomplete (ontic uncertainty), although not all underlying mechanisms have yet been understood. In addition, methods to assess the collective impacts of CH_4, N_2O and CO_2 from peatlands on the climate systems are debated amongst climate scientists (Meinshausen & Nicholls, 2022; Van Huissteden, 2022). Furthermore, due to the different interests of agriculture and nature, ambiguity also plays a major role in the rewetting of peat areas (van den Ende et al., 2023). The Delta Program questions whether there will always be sufficient freshwater water supply to rewet the Dutch peat areas when the summers become drier due to climate change and sea level rise (Delsman et al., 2023; Mens et al., 2022).

Climate research (KfC, CcSP) operates at two (nested) interfaces about climate adaptation: NAS and the National Delta programme (since 2010)

In 2010, the ministry of Housing, Spatial Planning, and the Environment (VROM) merged with the ministry of Public Transport, Infrastructure and Water Management (V&W). From that moment on, one minister was responsible for spatial planning and water management instead of two. Also, in other sectors than water management a need remained for policy making about climate adaptation. In 2010, the government started developing a national climate adaptation strategy, abbreviated as NAS (Ministry of Infrastructure and Water management, 2016). The NAS was published in 2016, in response to the European Commission's call for all member states to draw up a climate adaptation strategy by 2017 (European Commission, 2013, 2009). The National Court of Audits (in Dutch: Algemene Rekenkamer) advised the government to ensure the development of climate adaptation strategies for all sectors (Roenhorst & Van der Geest, 2012). This was also an incentive for the government to develop a climate adaptation strategy outside the water sector. However, the government did not allocate budget for climate adaptation in sectors other than water

management in 2016. When developing this national adaptation strategy, the interface between climate research and the ministry of Infrastructure and Water was established via the Knowledge for Climate research program (KfC), but also via KNMI and PBL Netherlands Environmental Assessment Agency.

From climate adaptation to climate-proofing (2005-2010; Chapter 4 and 8)

Between 2000 and 2006, research results about the economical dimension of responses to climate change was brought forward by climate adaptation research but these results were often disputed at interfaces between climate adaptation research and water management (Chapter 5, 6). Similar reactions are observed internationally (Stern, 2006; Tol, 2012; Yohe & Tol, 2007).

In addition, knowledge valorisation and creating incentives via research for innovation in the private sector were important evaluation criteria for the government to measure the impact to the climate research programmes KfC and CcSP (Wardenaar, 2015; Wardenaar et al., 2014).

These were reasons for Kabat et al. (2005) to introduce the concept 'climate-proofing', defined as a decision-making process in which both risks and opportunities of climate change are considered to reduce risks to a quantified level, accepted by society, with room for innovation (technological, institutional and societal), regulatory measures and changes in infrastructure.

Climate-proofing (in Dutch: Klimaatbestendig maken) was initially also adopted in Dutch policy (2005-2011), and was frequently used in the Delta Commission's advice (Delta Commission, 2008). Between 2011 and 2014, we observe that the phrase 'climate-proofing' was often replaced by 'future proofing' in the communication by the national Delta programme but also in associated research reports (Box 2-4).

***Box 2-4**, Examples of government documents and research report titles that use the phrase 'future proof' (In Dutch: toekomstbestendig)*

De Vries, I., Termaat, J., Van Velzen, E.H., (2012). Toekomstbestendigheid besluit Volkerak-Zoommeer: een robuuste beslissing? Deltares, Delft.

Ministry of Infrastructure and Environment, (2015). Toekomstbestendige en duurzame financiering van het Nederlandse waterbeheer - fase 1a: Huidige financiering - fase 1b: Trends en ontwikkelingen

Probably the term "climate-proofing" was too politically sensitive in view of the elections in 2012 and a new rise of climate change sceptics in the media as a result of discovered errors in IPCC publications (Dewulf et al., 2017; Hajer, 2012). By using "future proofing" instead of "climate-proofing" the narrative about climate change adaptation was subtly reframed as

a socio-economic issue rather than an environmental issue. The use of the phrase 'future proofing' refers, for example, also to the long-term manageability of water management costs (Ministry of Infrastructure and the Environment et al., 2015; OECD, 2014).

The DWC dialogues (Chapter 4) revealed that institutional flexibility is important for successful climate-proof water management, and this is supported in more recent literature (Driessen et al., 2012; Lemos, 2015; Plummer et al., 2013). The national Delta Programme also identified institutional flexibility as a key aspect of "adaptive delta management "(Vlieg & Zandvoort, 2014; Werners et al., 2015). Again, a new concept was introduced with a lot of similarities to 'climate-proofing'. This reflects not only adoption of the ideas of climate research, but it also reflects ownership.

From climate-proofing to climate compatible development (2010-2014)

In 2010 the United Nation expressed (COP16, Calcun, Mexico) the ambition to hold *"the increase in the global average temperature below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels.* This was later laid down in the Paris climate agreement (2015). By naming this ambition, international climate research also focused more attention on the relationship between climate mitigation, climate adaptation, and sustainable development.

'Climate compatible development' is mostly used in the international science-policy arena, which can be described as a development that minimises the harm caused by climate impacts while maximising the many social and economic opportunities that result from low carbon urban developments and more resilient pathways (Mitchell & Maxwell, 2010). In this concept, climate change adaptation and mitigation are both addressed.

The research programmes KfC and CcSP attempted to combine climate research, climate policies and economic development to achieve 'climate compatible development' rather than 'climate adaptation' or 'climate-proofing' in the narrow sense (Chapter 7). However, the term 'climate compatible development' was not really adopted in Dutch water management. In the agricultural science-policy domain, the term is used in the Netherlands, although slightly reframed as 'climate smart' and 'climate friendly' (FAO, 2015a; Verhagen et al., 2014).

Water management: lessons learnt from Programme Office Southwest Delta (Chapter 4)

Between 2004 and 2014, a steering group in the Rhine-Meuse Scheldt estuary was installed to discuss proposed interventions in water management, to align those with regional economic development strategies (Programmebureau Zuidwestelijke Delta, 2017) and to facilitate long-term vision building for this region (Adriaanse & Hoekstra, 2009). This steering group consisted of decision makers from Provinces, Water authorities,

Rijkswaterstaat, the former[3] 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).

In 2009, this programme office took responsibility for the formulation of a climate adaptation strategy for the Southwest Delta before 2014 (Staf Deltacommissaris, 2014) The Programme Office SWD also had a role in stakeholder consultation and participation for Environmental Impact procedures regarding the water quality in lake Volkerak-Zoom (Rijkswaterstaat directie Zeeland et al., 2009), Lake Grevelingen (Witteveen en Bos, 2012) and the creation of additional water retention areas to accommodate high river discharges and to reduce flood risks (Deltaprogramma | Zuidwestelijke Delta, 2012; Programmabureau Zuidwestelijke Delta, 2012; Projectbureau Ruimte voor de Rivier, 2006; Slootjes & Tijssen, 2013; Stone & van der Doef, 2013; van Rhee, 2014).

In this case, the Knowledge for Climate program (KfC) was one of the interfaces between water management and climate research. There were also other sectoral interfaces, however, KfC provided a multidisciplinary interface for researchers with different backgrounds in public administration, hydrology, ecology and water management.

The interface with water users in Zeeland - Within the multidisciplinary organisational structure of the CcSP and KfC research programmes it was possible to combine insights from climate adaptation research with expertise from different water users (such as agriculture, nature management and drinking water production). These insights were used to develop regional and local climate adaptation strategies for urban areas below sea level (Groot-Reichwein et al., 2013; Moel et al., 2013; Veraart & Van Gerven, 2012), in rural areas in Zeeland (Landsman, 2012), and for specific landscapes such as peatland (Kwakernaak et al., 2013) and the sandy soils. The research strategy of CcSP and KfC was not only focussed on climate adaptation strategies but also on the development of tailored climate scenarios and regional specific information about climate impacts for a wide range of users. In this way, epistemic uncertainties were addressed as experienced by the users of climate information.

Relationship between climate adaptation and mitigation in 2010-2014

Since 2010 and in view of the Climate Agreement in Paris (2015), the relationship between climate adaptation and mitigation was brought up again in water management. Research was commissioned by the national Delta program to evaluate what the Climate Agreement

[3] 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). Also, the ministry Agriculture, Nature Conservation and Food security (LNV) and the ministry of Economic Affairs (EZ) merged, currently called the Ministry of Economic Affairs (EZ).

of Paris (2015) meant for the scenarios used within the Delta Program (Bruggeman et al., 2016), and how new ontic uncertainties in the projections for greenhouse gas emissions could be addressed in national climate scenarios. Bruggeman et al (2016) concluded that: "*the bandwidth of the used scenarios (Bruggeman et al., 2013; Klein Tank et al., 2014) within the national Delta Program also includes the limited warming (ΔT (average) <2°, 2100 compared to 1990) that the climate agreement of Paris (December 2015) aims to achieve with greenhouse gas emission reductions. The climatic and hydrological outlook, as used by the Delta Program for the period until 2050 is hardly influenced by the Paris Agreement.*"

The outcome did not differ much from the scientific discussion and outcome between PBL and KNMI around 2006 about the coherence between the KNMI climate scenarios, the IPCC emission scenarios, and socio-economic scenarios for the Netherlands (Berkhout et al., 2013). This conclusion meant for the national Delta Program that the scenarios used in water management still were legitimate to use in developing climate adaptation strategies in water management.

During a national Climate Conference in 2016, the Delta Commissioner stated (Kuijken, 2016): *"In the Netherlands, we started in 2010 to prepare ourselves for climate change, within water management and spatial planning. The national Delta Program covers a large part of climate policy. Mitigation to climate change is more an international task and more complicated compared to adaptation to climate change. However, we must quickly address mitigation as well, otherwise the Netherlands is trying to dry while the leak continues. Mitigation and adaptation are the two sides of the same coin. […] Ladies and gentlemen, it is our joint assignment to ensure that 'Amersfoort at sea' never becomes a reality. The method which was developed by the national Delta Program to address climate adaptation has useful components, which we also can use the to address mitigation. Take advantage of it."*

Interpretation: Although the Delta Commissioner talks about one coin, he advises to draw up two parallel policy paths for climate adaptation and mitigation policies. Combining these two policies creates additional uncertainty in view of the Delta Commissioner. Keeping climate adaptation and mitigation policies separate is a form of addressing uncertainties from a policy makers perspective.

2.4 SINCE 2014

The interfaces between water management and climate research

The research programmes (KfC and CcSP) ceased to exist in 2014, as agreed in advance. The national water and climate knowledge and innovation program, abbreviated NKWK, was presented in 2014/2015 by the Delta Program, Rijkswaterstaat and STOWA as a follow-up of the climate research programmes (Staff Delta Commisioner et al., 2017).

A foundation called ' Climate Adaptation Services (abbreviated as CAS) was founded in 2014 to provide continued access to the knowledge and climate information from the two climate programs and to further develop it in the form of climate services in cooperation with WUR, KNMI and Deltares (CAS, 2024). These climate services were meant to support the development of spatially explicit climate adaptation strategies in the Netherlands but also elsewhere (Goosen et al., 2013).



Picture: *National Congress Water and Climate (Wageningen, 2018). Organised by the National Delta Programme and hosted by Wageningen Environmental Research.*

In addition, KNMI and PBL have formal tasks for climate research and evaluation of water and climate policies as prescribed by law. That was the case in 2001 and that is still the case in 2024. The KNMI Act (2001) describes the tasks of the Dutch Royal Meteorological Institute (KNMI) and its position. KNMI conducts research under the responsibility of the minister of Infrastructure and Water Management. Primary tasks, as described by this law, are weather monitoring, weather forecasting, climate research, air quality forecasts and monitoring of seismic activity. KNMI is also appointed by law as the national research and information centre for these subjects. Climate scientists from applied research institutions such as Wageningen UR and Deltares have maintained their relationship with water management and land use but partly fell back to the traditional (sectoral) division of tasks and Dutch research finance mechanisms between government, policy, applied research and fundamental research.

A reversal in the management of the Water and Climate interface can also be observed: CcSP and KfC were coordinated by the knowledge institutions involved, and NKWK was managed by representatives from water management, such as Rijkswaterstaat and STOWA. Participation by scientists and policy makers was more on a voluntary basis compared to CcSP and KfC. Each commissioner of climate research remained in charge regarding funding and research contracts and NKWK was used to align the research agendas of the ministries. This can be seen as a partial return to a sectoral knowledge infrastructure, which was identified by the government in 2001 as the main reason why the development of integrated solutions to tackle climate change did not fly. The national Delta Program was the most important representative of policy and water management in this NKWK-network. The focus therefore remained on water safety and freshwater supply. The themes of spatial adaptation in urban areas, soil management and the ecology of the Delta, rivers and lakes were added as research themes. Between 2015 and 2019, a national Water and Climate conference was organized on an annual basis. Various participants from the network were given the opportunity to act as hosts. The COVID pandemic interrupted these annual conferences and the NKWK network quietly ended. Only those involved in the topic of a climate-resilient cities still use the NKWK acronym (2024).

Since 2010, another network was created by the national Delta programme that was meant for knowledge exchange between the different regional and thematic policy networks of the national Delta programme (in Dutch: Kennisnetwerk Deltaprogramma). Between 2010 and 2014, this network had a supporting task in identifying knowledge gaps related to climate adaptation and water management. After 2015, the knowledge network was meant for knowledge exchange. Participants in this knowledge network had no role in commissioning research, except for the representatives of the Delta Commissioner. The network still exists (2024).

The COVID pandemic was not the only reason the NKWK disappeared. The signals from climate science that sea level rise is accelerating (Huismans et al., 2022; Katsman et al., 2011 ; Le Bars et al., 2017; van Alphen et al., 2022; van den Hurk & Geertsema, 2020) led to the establishment of the sea level rise knowledge program in 2019, with a duration from 2019 to 2026 (Nationaal Deltaprogramma, 2024), abbreviated as KP-SLR. In 2008, the upper limits of the estimated sea level rise of the Delta Commission were quite controversial within water management (ambiguity) because they differed from the KNMI scenarios. Within KP-SLR, it was possible to investigate climate adaptation strategies that consider the plausible upper limit of sea level rise.



Picture: *Frontpage Website Knowledge Programme Sea level rise.*
https://english.deltaprogramma.nl/delta-programme/knowledge-development/sea-level-rise-knowledge-programme

KP-SLR developed three climate adaptation scenarios , taking into account accelerated sea level rise: (1) maintaining water safety, current coastline and freshwater supply, (2) shifting the coastline seawards and (3) managed realignment (adaptation with spatial planning) (Haasnoot et al., 2022; van den Hurk et al., 2022). The third scenario (managed realignment) still causes a lot of controversy in water management among both experts and stakeholders (Kraan et al., 2025). This is also observed in spatial planning policies in the Netherlands.

Spatial planning and climate adaptation policies since 2022

The principle of spatial planning that follows natural dynamics in water and soil, as also mentioned around 2005 (Veraart & Kabat, 2005), re-appeared in national spatial planning policies in 2022 (Minister van Infrastructuur en Waterstaat, 2022). However, to some experts this principle is too rigid for regional development (de Zeeuw & Rijcken, 2024), while other experts embrace it (Baptist et al., 2019). The opponents are confident that climate resilient spatial development can be achieved with innovation and technical solutions. Also the old contradiction between the foundational water management paradigm and adaptive water management (Chapter 4) is becoming relevant again (Mooyaart et al., 2023).

Developments in water management regarding climate adaptation since 2014

The regional climate adaptation strategies of the national Delta programme were reviewed in 2014 by scientists from the KfC program (Vellinga & Driessen, 2014), in line with the philosophy of adaptive delta management (van Alphen et al., 2022). The practice of a periodic review was formalized in the National Water Plan 2016-2022, like the formalisation of the periodical actualisations of the KNMI-scenarios in an earlier stage. The first actualisation of the climate adaptation strategies was published in 2020 and adopted by the Dutch government (van Alphen & Bloemen, 2024). The first formal scientific review of these actualised scenarios was carried out by the CAS foundation and the international Delta

Alliance (Nationaal Deltaprogramma, 2020; van Alphen & Bloemen, 2024). As we speak, the second actualisation is conducted, and publication and adoption are scheduled in 2026. It is important to notice that the actualisation of the climate adaptation strategy is also evaluated by the national Environmental Impact Committee (in Dutch: commissie m.e.r.). In 2020, the Environmental Impact Committee had concluded that international nature legislation increasingly sets preconditions for the implementation of climate adaptation aimed at freshwater supply and water safety. The actualisation of the regional climate adaptation strategies also describes how the national Delta Program implements the guiding principle 'Water and Soil as a basis for spatial planning' (Minister van Infrastructuur en Waterstaat, 2022; Nationaal Deltaprogramma, 2020).

The role of boundary objects since 2014 - Both climate scenarios (especially KNMI scenarios and later KP-SLR scenarios) and the policy concept of climate adaptation have continued to function as boundary objects in Dutch climate-water governance - but their roles have changed in important ways. At first (2014-2020) they became boundary objects primarily within the water domain, rather than across multiple sectors. The re-emergence of "Water and Soil as a basis for spatial planning" (2022) broadened the term climate adaptation again, linking adaptation to spatial planning and ecological considerations. Climate scenarios became more technically authoritative but more sector-specific, serving primarily as boundary objects within water management—until KP-SLR re-expanded their cross-sectoral relevance. The KP-SLR scenarios regained also a broader boundary-object function by structuring national debate on extreme futures. Climate adaptation remained since 2014 a broad, flexible policy concept that different actors could interpret in different ways, enabling coordination across shifting institutional landscapes.

Climate adaptation science and water management became more intertwined in the Netherlands since 2009 with the start of the National Delta Programme, particularly the research institutions involved in applied science. The intertwining between science and policy can be seen as an indicator of social relevant research, but there is also a risk that climate adaptation research can be subject of public scrutiny in the media (Dewulf et al., 2017; Hajer, 2012) and regional policy making (During et al., 2016; Wesselink, 2008; Zegwaard et al., 2015; Zegwaard & Wester, 2014). This could be seen as a scientific authority paradox (Kunseler & Tuinstra, 2017).

Water and climate research in a public-private setting

KFC and CcSP were funded from a national fund called 'Enforcement National Economic Structure (abbreviated as FES). FES, established in 1995, was funded with revenues from natural gas exploitation by the Netherlands. FES was meant for investments in infrastructure as well as for research and innovation. The fund was managed by the Ministry of Economic

Affairs and the Ministry of Finance. The fund was terminated in 2011. In 2012, the Ministry of Economic Affairs started with public-private knowledge & innovation programmes in Dutch entitled "Topsectoren beleid", including a knowledge and innovation programme about water. The public resources are allocated by annually returning competitive calls with the precondition that private parties also co-finance the research. In this way, examples of water and climate adaptation research projects have been developed in a PPS-construction between government, private partners and applied research institutes. It is often difficult for universities to participate in these calls, although the National Scientific Research Council (NWO) became co-commissioner in PPS-calls more often. In these cases, it is easier for universities to participate.

PPS-projects led to research projects on very specific topics, which is a strength to realize usability of research. However, for complex issues like climate change adaptation this is a weakness as many partners are needed to design cross-sectoral climate adaptation strategies.

National Growth fund

Partly for this reason, the Rutte III cabinet (2017-2022) initiated a national growth fund, which can be seen as a successor to FES. The current government (Schoof I) decided in 2024 to end this new fund again, but the awarded projects can continue. A research program called, "The Netherlands in 2120, the green revenue model", was awarded by the national growth fund in 2023 and started in 2024 with a duration of 10 years with an annual budget comparable to CcSP and KFC (Nationaal Groefonds, 2024). This research program will also work on climate adaptation by exploring solutions that are based on natural processes (Nature-based solutions) and for which revenue models can then be developed (Calliari et al., 2022; Gómez Martín et al., 2021; Somarakis et al., 2019). The line of reasoning of this research programme combines economic and ecological arguments to cope with climate change. NL2120 will have to deal with ambiguity and uncertainties of a similar epistemic and ontic nature as CcSP and KfC.

Dutch Climate research Initiative (since 2022)

NWO founded in 2022 the Dutch Climate Research Initiative (KIN). KIN has the objective to make a substantial contribution to accelerating the necessary climate transformations in society to reach the goal of a sustainable, climate-neutral society by 2050 (NWO & KNAW, 2024).

2.5 PRELIMINARY CONCLUSIONS

Governance of climate adaptation research at the interface with water management

In this longitudinal case study analysis, we identified the following realized changes in the governance of the interface of water management and climate adaptation research:

- The role of the national Delta Program, the Delta Commissioner and the Delta fund in policy and water management at national level is arranged for an indefinite period by law (Vink et al., 2013). Adaptation strategies for sectors other than water management are established in the national adaptation strategy.
- The formalisation of periodically updating the KNMI-scenarios and the periodic review of the climate adaptation strategy of the national Delta programme by law is a realized change in the knowledge infrastructure between water management and climate research.
- Combining KNMI climate scenarios with socio-economic scenarios and land use scenarios is not a formalized task, although it happened in 2017 and 2023. The latest Delta Scenarios (van der Brugge & de Winter, 2024) also describe how climate mitigation and climate adaptation are related with each other.
- Climate adaptation science and water management became more intertwined in the Netherlands since 2009 with the start of the National Delta Programme, particularly the research institutions involved in applied science. The intertwining between science and policy can be seen as an indicator of social relevant research, but there is also a risk that climate adaptation research can be subject of public scrutiny in the media and regional policy.

Shifting roles of climate scenarios and climate adaptation as boundary objects

Across three decades of Dutch climate-water governance, climate scenarios and the policy concept of climate adaptation have repeatedly functioned as boundary objects, but their roles have evolved in line with institutional shifts, scientific developments, and changing governance priorities. Since 1990, climate scenarios and since 2000 the concept of climate adaptation have repeatedly acted as boundary objects in the Netherlands, but their bridging roles have shifted over time. Before 2000, IPCC scenarios linked climate (adaptation) research to international climate policies but were too coarse for Dutch water management; the first KNMI scenarios (1998) became a boundary object for experts working in between climate research and water management, but not yet for policy makers. Between 2000 and 2014, KNMI scenarios became formally embedded in national water policy, and "climate adaptation" emerged as a flexible policy term that enabled

coordination across sectors, in particular water management. After 2014, both concepts remained boundary objects, but their cross-sectoral function weakened as the organisation of climate adaptation research became more sectoral again. Climate scenarios became more water-focused, while climate adaptation remained a cross sectoral policy concept but became less important. New developments such as KP-SLR and the return of *Water and Soil principle* as a basis for spatial planning partially restored the cross-sectoral boundary role of climate adaptation outside the water sector. The way climate adaptation research is organized today (2025) is different from the organisational structure in 2000. However, the differences are not as substantial as the initiators (scientists) and the Dutch government had in mind in 2000. The sectoral organisational structure of research programming changed but it still exists and limits the potential boundary-object function of climate adaptation between water management and other sectors.

3



***Picture**: Bridge over the Scheldt-Rhine Canal (Jeroen Veraart, 2016).*

Climate change impacts on water management and adaptation strategies in the Netherlands: stakeholder and scientific expert judgments

Abstract – This chapter presents the results of a survey of stakeholder and scientific expert judgments regarding the impacts of climate change on water management in the Netherlands in 2001. The main methodological findings were put into broader perspective during the initiation and start of the national research programme "Climate changes Spatial Planning" (CcSP) in the period 2001-2007. We focus on the impacts of climate change on water management and related adaptation strategies because they were mentioned most in the 2001 survey: these include flood risks and impacts on freshwater resources. For the flood risks, a high degree of consensus amongst stakeholders and scientific experts was discovered about knowledge, values and aims involved. This was not the case for the impacts of climate change on freshwater resources. The approach, chosen in 2001, enabled the researchers to explore the different opinions regarding the impacts of climate change. It appeared, however, very difficult to prioritize available adaptation options and to formulate cross-sectoral adaptation strategies. Within the CcSP-programme, initiated after the 2001 survey, a changing approach by scientists of stakeholders in water management and spatial planning can be observed. The approach of climate scientists in the Netherlands is gradually shifting from a collaborative/consultative approach towards a real participatory approach in the research and design process of combined regional and sectoral adaptation strategies.

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3 CLIMATE CHANGE IMPACTS ON WATER MANAGEMENT AND ADAPTATION STRATEGIES IN THE NETHERLANDS: STAKEHOLDER AND SCIENTIFIC EXPERT JUDGMENTS

3.1 INTRODUCTION

Water management in the Netherlands has a long tradition and involves a complex array of public and private decision making. The hydrological system is highly engineered. However, the two near-flood situations along the river Rhine in 1993 and 1995 and the impacts of droughts in the summer of 2003 show that the Dutch water system is vulnerable to hydro-meteorological extremes. The first policy response to this near-flood disaster (1995) was to mobilize all necessary resources and to side line opposition (by drafting specific legislation) in order to heighten and strengthen the dikes and dams (de Vries, 2006). By the late 1990s, however, the short-term fear of flooding was replaced by a long-term consciousness of the possible consequences of climate change.

Doubts were raised about the appropriateness of traditional technological interventions into water management, such as heightening dikes or pumping water out of low-lying polders (de Vries, 2006). A government commission was established to advice on water management in the 21st Century (Commissie Waterbeheer 21e eeuw, 2000). One of the core recommendations of this commission was to develop a closer relationship between water management and spatial planning. Since 2000 spatial flood risk reduction measures (i.e. by planning restrictions on human activities within the watershed and by allocating specific retention areas) are prioritized over technical measures. This process of reconsidering water management strategies and land use zoning plans in the Netherlands has accelerated since the call for a climate-proofing approach (Kabat et al., 2005) for long term investments by the senate of the Dutch parliament in 2005 (motie Lemstra). In 2007 the government installed a new commission that included scientists and politicians with the request to formulate recommendations on protecting the coast and the entire low lying part of the Netherlands against the consequences of climate change (Delta Commission, 2008).

Several of the measures proposed in the last decade will require special allocation of land, which is a scarce resource in a small, densely populated and highly industrialized country such as the Netherlands. More pressure on the use of water and land may also add strains that increase vulnerability to climate change.

The ability of water resource managers to cope with a changing climate is also limited by the fact that they have to respond to changes in the governance of water resources, such as the democratisation of the decision making process, legislation by the European Union and integration with other policy domains (Tol et al., 2003; Tol et al., 2001). This gradual shift from government to governance of water resources involves turning away from vertical steering mechanisms, such as rules and regulation, towards horizontal steering through complex systems and networks in which other actors – private organisations, non-governmental organisations, and citizens – fulfil a more prominent role (Kickert et al., 1997; Marsh & Rhodes, 1998; Sorenson & Torfing, 2007). Furthermore, it will be difficult to take expensive adaptive measures to climate change well-before stakeholders recognize the risks or directly experience damage.

In general, risks, or climate impacts, are perceived and assessed in various ways, both by scientific experts and stakeholders. Individuals interpret their environment and the related risks in terms of their own personal set of constructs (Kelly, 1955). This set of constructs can be seen as attributes that individuals use to distinguish between similar and different elements in their environment. In case of risks, important attributes include the degree of harm/fatality, the amount of damage, the probability of undesired consequences, the voluntariness of exposure, and the distribution of risks and benefits (Meertens et al., 1994). Risk and vulnerability assessments for climate change in water management are complicated because the cause – effect relationships are complex, full of feedback and at different spatial and temporal scales. In addition, both stakeholder and scientific expert judgments must be considered in decision making. However, in contrast to scientific expert judgment (Pahl-Wostl, 2002; Wetenschappelijke raad voor het regeringsbeleid, 2003), stakeholder perceptions are often based upon a rather undefined hypothetical problem sketch of climate change. This does, however, not imply that stakeholder perceptions are less rational than expert judgments (Meijnders, 1998).

Objective

The initial aim of the research project (van Ierland et al., 2001) was to carry out an integrated assessment of impacts of climate change and adaptation options for the Netherlands in order to:

- provide an overview of expert judgments and stakeholder perceptions about current and future impacts of climate change for economic sectors, public health, and natural systems based on given climate and socio-economic scenarios.
- explore~~,~~ through a participatory process with the main stakeholders, sectoral and cross-sectoral adaptation measures and identify the main actors involved.

In this paper, we compare the stakeholder and scientific expert judgments regarding impacts of climate change and possible adaptation strategies in water management. To put the results of the 2001 survey in a broader perspective, we also discuss the (changing) role of stakeholder and scientific expert judgment in the context of the Dutch national research programme "Climate changes Spatial Planning" (CcSP) in the period 2001-2007.

The mission of the CcSP-programme is to introduce climate change and climate variability as one of the guiding principles for spatial planning in the Netherlands by providing a knowledge base that interactively supports practitioners in spatial planning as well as in land-, water- and nature management. The CcSP-programme aims to engage a dialogue between stakeholders and scientists about adaptation and mitigation measures in spatial planning (Veraart et al., 2007; Werners et al., 2003).

Understanding differences between stakeholder and scientific expert judgment regarding the impacts of climate change and the effectiveness of possible adaptation strategies is crucial to develop climate policies and associated research programmes, such as CcSP, with broad support in society. Furthermore, the process of problem defining, embedding climate policies into spatial planning and research programmes may benefit from these insights. This is in line with the experiences about the framing of the climate change issue itself and the status of knowledge, science and the evidence base for policy in respectively Norway (Lindseth, 2005) and the United Kingdom (Wilson, 2006), as raised by Lindseth (2005) and Wilson (2006). The insights from our study may also help to (re)define and to negotiate boundaries between science and policy (Janasoff, 2004; Tuinstra, 2006; Turton et al., 2007) and to transfer knowledge between climate scientists and stakeholders involved in spatial planning and water management.

The structure of this paper is as follows: first, the methodology of the stakeholder analysis and the assessment of scientific expert judgments are explained (section 3.2). In section 2.3 the stakeholder and scientific expert judgments about climate change impacts on water management (subsection 3.3.1) and adaptation strategies (subsection 3.3.2) are discussed. Section 3.4 starts with a summary of the key findings from the 2001 survey (subsection 3.4.1). Those are put into a broader perspective by discussing use of expert judgment in climate adaptation research in the Netherlands after 2001 (subsection 3.4.2). Finally, conclusions are drawn about the contribution of this analysis to the academic debate on the role of scientific expert judgment in climate adaptation research, spatial planning, and water management (section 3.5).

3.2 METHODOLOGY

Stakeholder and scientific expert judgments about the seriousness of climate change and related impacts were assessed to define the main issues at stake and to identify leading opinions within the following sectors and domains: water management, soils, ecosystems, agriculture, forestry, fisheries, transport, energy (supply and demand), insurance, recreation, tourism and human health (table 3-1). The aim was to use the obtained insights as a starting point for further research. The study was exploratory in nature: it was explicitly not aimed at designing a representative sample for the Netherlands or to design and plan adaptation strategies in a participatory setting. Consultation of scientific experts and stakeholders was done with questionnaires for each sector, followed by 2 workshops.

Table 3-1, *Sectors and issues included in the study (van Ierland et al., 2001) clustered in 4 groups, indicating the number of questionnaires sent out to both experts and stakeholders.*

Group 1: Natural systems (300 questionnaires)	**Group 2: Land use and fisheries** (500 questionnaires)
Ecosystems (flora, fauna, landscapes) **Soil** (erosion, shrinkage, saltwater intrusion) **Hydrology** (hydrology, water quality)	**Agriculture** (productivity, crop selection) **Fisheries** (productivity, recreation, diversity) **Forestry** (productivity, recreation, diversity)
Group 3: Economic sectors (250 questionnaires)	**Group 4: Human health and recreation** (250 questionnaires)
Energy (energy demand and supply) **Insurance** (domestic property, companies) **Transportation** (road, water, air, and rail)	**Human health** (Lyme disease, air pollution) **Recreation and Tourism** (national and international)

The sectors and domains were chosen by the project team in consultation with the commissioners of research of the Netherlands Research Programme on Climate Change (NOP) and the Ministry of Agriculture, Nature, and Food Quality (LNV). The 11 sectors were clustered in 4 groups: natural systems (Group 1), land use and fisheries (Group 2), economic sectors (Group 3), and human health and recreation (Group 4).

Recipients of the questionnaire and workshop participants were selected to create a set of respondents and participants in which, in all 4 groups, i.e. scientists, policy makers and societal organisations, were present in sufficient numbers.

The category 'policy makers' included civil servants from national and regional governments (provinces and water boards). Representatives from societal organisations included people from nature conservation organisations, the private sector (energy, insurance, and transport) and agricultural interest groups. In this analysis both are assumed to be

stakeholders. The scientists involved were experts in the field of hydrology, ecology, environmental management, fisheries, agriculture, forestry, public health and environmental economy from different universities and knowledge institutions from the Netherlands.

In February 2001, approximately 1300 questionnaires were sent out, distributed over the 4 groups (table 3-1). The recipients were derived from address databases from Wageningen University and Research Centre, LNV, the National Research programme office (NOP) and the International Centre of Integrative Studies from Maastricht University. The mailing included fact sheets about the climate scenarios used and an inventory of the possible impact of climate change on the sector in question. The questionnaires and fact sheets were available on the internet too to give recipients the opportunity to also complete questionnaires for other sectors.

3.2.1 SOCIO-ECONOMIC AND CLIMATE SCENARIOS

A set of existing scenarios for the Netherlands, based on the scientific insights in 2000, were used to create a coherent and consistent starting point of assumptions about recent trends and plausible future scenarios for (1) climate change and (2) socio-economic and environmental trends described in factsheets. The scenarios were used to facilitate the judgments of both stakeholders and experts. Using both long-term (2100, 2050) and short-term scenarios (2020, 2030) from different sources enabled us to express scientific uncertainty about future developments.

Climate scenarios

The variation in model projections of regional climate change, i.e. for Western Europe or the Netherlands, based upon regional and global climate models, was still large in 2001. In order to sketch these uncertainties, 2 sets of regional climate scenarios were used, which had been prepared by the Royal Netherlands Meteorological Institute (Können et al., 1997; Verweij & Viner, 2001) and the Hadley Centre (Viner & Hulme, 1998) respectively. Various projections were used within these scenarios (e.g. 'high – medium – low'). The KNMI scenarios projected a temperature increase of 1-2°C by 2050 and a maximum temperature increase of 4°C by 2100. The Hadley scenarios projected a temperature increase of 0.5°C by 2020 to 1.5°C by 2050 and 2.5°C by 2100. The climate scenarios used did not include thresholds or unexpected sudden events.

Socio-economic and environmental scenarios

The Netherlands Bureau for Economic Policy Analysis (CPB) provided baseline projections for economic growth for the period 1990-2020 according to three scenarios: Divided Europe, European Co-ordination and Global Competition (CPB Netherlands Bureau for Economic Policy Analysis, 1999, 1998). Assumptions for the scenarios differed with respect to (global) economic development, demographic development, political viewpoints, and technological development. The 5th National Environmental Assessment (CPB Netherlands Bureau for Economic Policy Analysis & RIVM, 2000) complemented the socio-economic scenarios 'European Co-ordination' and 'Global Competition' with projections of future greenhouse gas emissions, indicators for air pollution, acidification and eutrophication for the target years 2020 and 2030. CPB judged that it was impossible to make similar projections for 2050 and 2100. Therefore 4 scenario projections for 2050 and 2100 were also added, which were derived from the IMAGE-Worldscan integrated assessment model (Geurts et al., 1997) that was used by IPCC during the development of the emission scenarios.

3.2.2 CONSULTATION WITH QUESTIONNAIRES AND WORKSHOPS

Questionnaires were developed for the identified economic sectors and natural systems (table 3-1) to gain insight into stakeholder and scientific expert judgments regarding:

- the vulnerability to climate change of each sector for impacts such as floods or droughts.
- identification and effectiveness of possible adaptation options.
- the most important cross-sectoral interactions.

Separate questionnaires were developed for each sector in Groups 1, 2 and 4. Respondents were asked to indicate the seriousness of the sectoral impacts on a scale of 1 (not serious) to 5 (very serious). Within each questionnaire a number of adaptation options were given while, in addition, respondents were asked to add adaptation options, ranking them in order of importance, and to identify possible cross-sectoral interactions between adaptation options and sectors. Qualitative argumentation was also asked after each question about impacts, adaptation, and vulnerability of the sector in question to discuss the use of risk attributes by stakeholders and experts. The general set up and some questions of the questionnaires in Group 1 are shown in Box 3-1 as an example.

Workshops

The survey results were the starting point for a two-day workshop, divided in 4 parallel groups (table 3-1). The participants (total of 56) were invited in such a way that there was a balance between stakeholders and scientific experts for all the 11 identified sectors. For each group three sessions were organised. In the first session attention was given to the possible effects of climate change tailored for the sectors in question. The second session focused on cross-sectoral interactions. Adaptation options were discussed in the third session. Participants were encouraged to express their opinions about the relative importance (probability and seriousness) of impacts of climate change and effectiveness of adaptation options.

Box 3-1, *Examples of questions used in Group 1 (Natural systems, sector Water).*

B. Questions on impacts of climate change

B1. In which of the mentioned water systems in the Netherlands are, according to your opinion, obvious impacts of climate change to be prospected? (you may select more than 1 system)

Step 1) Select a water system	**Step 2)** Which climate factor is the most important cause for this sensitivity according to you? You may select more than 1 variable.				**Step 3)** Explanation or other factor
	Tempe-rature	**Precipitation**	**Extreme events**	**Sea level rise**	
√ Marsh (fictive example)	☐	√	☐	☐	More frequent summer droughts may result into extinction of certain aquatic macrophytes
☐ Rivers	☐	☐	☐	☐	
☐ Etc....	☐	☐	☐	☐	

B2. Which water system do you think is most sensitive to climate change?

B3. The next questions you answer for your selected most sensitive water system (question B2), or you answer it for the water system for which have a high expertise. I answer question B2 in for the following water system: _____ because:

☐ I think this is the most sensitive water system and/or
☐ I do have a lot of expertise about this water system.
☐ Other reason, _____

Impact climate change:	**Seriousness effect** Not serious --> Very serious 1 2 3 4 5	Not important	Don't know	Explanation/or reference:
Example low summer discharge in the Rhine	☐ ☐ ☐ √ ☐	☐	☐	Navigation will be difficult
A) River discharge	☐ ☐ ☐ ☐ ☐	☐	☐	
B) Floods	☐ ☐ ☐ ☐ ☐	☐	☐	
C) Groundwater table	☐ ☐ ☐ ☐ ☐	☐	☐	
D) Surface water table	☐ ☐ ☐ ☐ ☐	☐	☐	
Other, _____				

B4. Which effect do you consider MOST important for this water system?

C. Adaptation strategies

C1. Some announced adaptation strategies within Dutch vision for water management in the 21st century are summarized in the next table. Do you think these adaptation strategies will be effective for the system that you have selected (question B2)
Step 1) Which adaptation options you would like to add?
Step 2) Which 3 options do you consider the most effective? Please rank them from 1(the best one) to 3
Step 3) Can you explain your choices?

Step 1) Selection of adaptation strategies	**Step 2)** Ranking	**Step 3)** explanation
A) retention of water upstream		
B) development of emergency plans		
C) Other, _____		

D CROSS-SECTORAL INTERACTIONS BY ADAPTATION

D1. Your selected most effective adaptation option may also have impact on other natural systems and sectors. This can be a positive or negative impact. Please indicate in the table below how you think that these interactions can be valued for your selected adaptation option (question C1)

Other sectors:	Explanation	Judgement Impact of interaction (negative of positive) -2 -1 0 1 2	Don't know	Not important
Agriculture (example)	Less area for cultivation	√ ☐ ☐ ☐ ☐	☐	☐
Recreation (example)	More area for cycling	☐ ☐ ☐ ☐ √	☐	☐
Other, _____				

D2. Which interaction do you think is most important?

3.3 EVALUATION OF STAKEHOLDER AND EXPERT PERCEPTIONS

Out of 1300 questionnaires 177 were returned (response rate=14%). Response was relatively evenly distributed over policy makers (26%), scientists (34%) and representatives from various interest-groups (e.g. NGOs, entrepreneurs) (40%). Of the total number of questionnaires returned, 25% were by Group 1 (Natural Systems), 49% by Group 2 (Land use and fisheries), 12% by Group 3 (Economic sectors) and 14% by Group 4 (Human health and recreation) (figure 3-1). The workshop (March 29-30, 2001) was attended by a total of 56 participants (including 8 project team members). A selection of invitees attended the workshop on both days and participated in various groups. This paper focuses on the results derived from the questionnaires from Group 1 and 2.

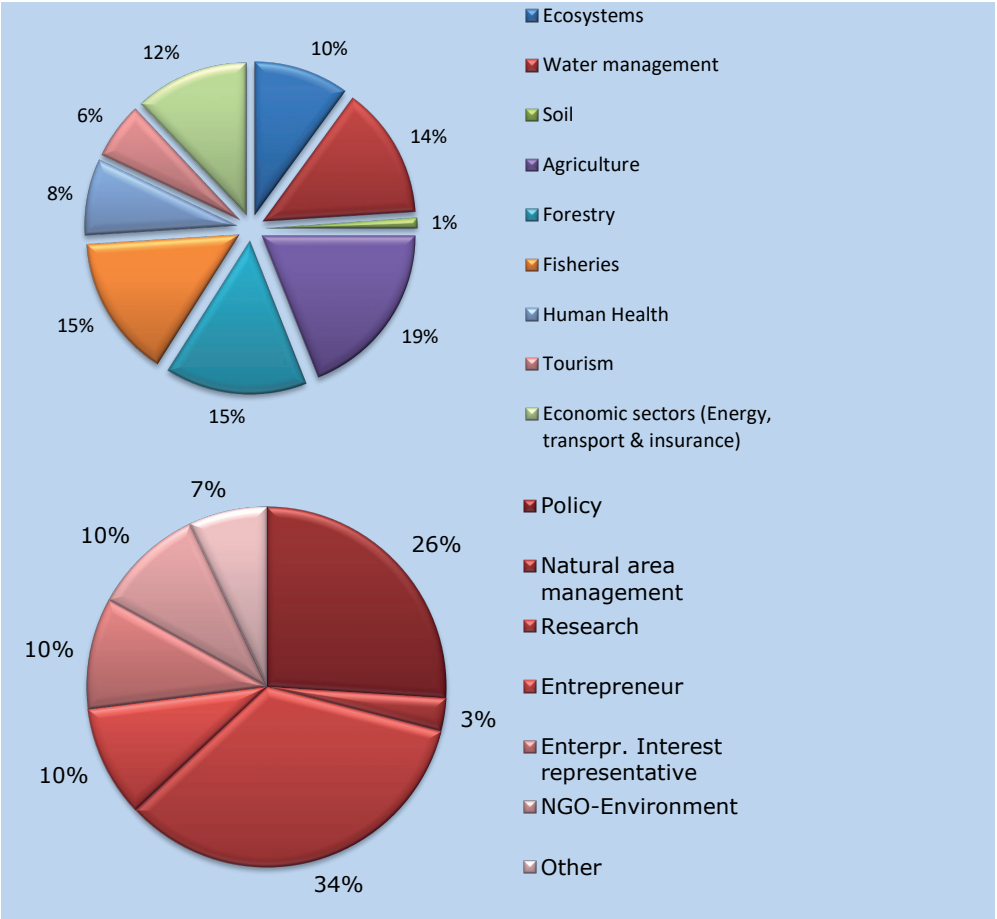

***Figure 3-1**, **top:** background of people who responded to the questionnaire (total reply =177, response rate=15%); **bottom:** relative distribution of the response over the sectors.*

3.3.1 IMPACTS OF CLIMATE CHANGE ON WATER MANAGEMENT

The identified impacts of climate change on water management in the Netherlands, derived from the questionnaires and workshops, are listed in table 3-2. Impacts with an overall average score >2 in the questionnaire are further discussed regarding differences in risk judgment between scientific experts and stakeholders. The arguments that have played a role in the judgment regarding the seriousness of climate impacts on water management in the survey, are derived from the qualitative argumentation of all respondents (n=177) and workshop participants (n=56) and are discussed in table 3-2.

***Table 3-2**, Overview of mentioned impacts regarding water management. Seriousness was scored between 1 and 5 by both stakeholders and experts in the questionnaire (average and standard deviation are given). Hypothesis about the risk perception derived from the qualitative argumentation from this survey (total survey, n= 177; workshop n=56) is marked as follows: high (+), low (-), diverse (+/-), i.e. some experts/stakeholders perceive high risks while others don't or do not know.*

Impact	**Risk perception**		
	Average Perceived Seriousness (n=24)	Experts (n=8)	Stakeholders (n=16)
(1) Increased flood risk along rivers and coast (property and safety) (n=24)	3.6 ± 1.2	3.6 ± 1.5 **(+)**	3.6 ± 1.2 **(+)**
(2) Changes in water quality (oxygen, nutrients, temperature, sediment) and biotic processes in aquatic ecosystems with consequences for biodiversity, inclusive fish migration (n=24)	2.3 ± 1.1	1.9 ± 1.1 **(+/-)**	2.6 ± 1.1 **(+/-)**
(3) Changing groundwater tables; (n=24) • lower in summer, • higher in spring/autumn/winter	3.2 ± 1.3	3.0 ± 1.2 **(+/-)** **(+/-)**	3.5 ± 1.4 **(-)** **(+)**
(4) Increased saline water intrusion in low areas with consequences for agriculture & natural values (n=24; workshop group 2)	2.9 ± 1.4	2.3 ± 1.5 **(+/-)**	3.0 ± 1.4 **(+/-)**
The following impacts are not discussed (often mentioned but low average perceived seriousness)			
• The impact on fish production in coastal and estuarine ecosystems and especially the production of mussels (group 1,2)			
• Reduced arable farming – wetter spring and autumn reduce possibilities for soil management and mechanical work on the land; this limits the positive effect of a longer growing season (workshop group 2; discussed under (3))			
• Marine fish production capacity depends on the Gulf stream (for nutrients) and change, and impact thereof is unclear for fisheries (workshop group 2)			
• The sea-level rise will lead to an increase of water to be drained, and for this purpose a lot of energy will be needed. (workshop group 1)			
• Low water levels can hamper navigation in summer, while in winter high water levels may, for instance, cause collisions with bridges. This will lead to economic damage. (workshop group 3)			
• Respondents mentioned impacts on tourism (temperature change, water quality & sea level rise. However, the same respondents argue that the tourist sector can adapt (workshop group 4).			

(1) Flood risk

The scientific experts and stakeholders involved in water management (group 2, n=24) within this questionnaire perceive increased flood risk as the most serious impact of climate change. During the workshop there was a high consensus about the importance of flood risks not only in Group 1 but also in other groups. The associated damage (property at risk) and safety (lives at risk) could be assessed by the involved individuals in our survey, probably because of their experiences with the risks of the near-floods in 1993/1995 and the damage caused by extreme rainfall in 1998 in the Netherlands (Rooijers et al., 2004). The results of the questionnaire also show that both experts and stakeholders are familiar with scenarios on climate change, sea level rise and river discharge as presented in the vision on water management for the 21st century for the Netherlands (Commissie Waterbeheer 21e eeuw, 2000).

(2) Water quality and aquatic biota

Scientific expert judgments in this survey regarding the seriousness of the impact of climate change on aquatic ecosystems are much more diverse compared to the consensus by experts regarding riverine flood risks (de Wit et al., 2001; Hooijer et al., 2004; Middelkoop et al., 2001). There is scientific consensus that temporal variation in precipitation and temperature play an important role in wet ecosystems like wetlands, rivers, marine and coastal ecosystems (Covich et al., 1997; Kabat et al., 2003a,b) and determine processes such as species-species interactions, primary productivity, microbiological activity, nutrient cycles, habitats quality and phenology (van Vliet & Schwartz, 2002). Theoretical model studies have shown that sudden changes may occur in ecosystems that are exposed to gradual climate change (Scheffer et al., 2003; Scheffer et al., 2001). The interactions between climate and ecosystems are often studied by experimental research and field observations, but in 2001 few research results were available regarding the complex interplay among climate change and trophic levels in aquatic ecosystems.

Knowledge of the impacts of climate change on aquatic ecology was not reported in the report of the Committee on Water management in the 21st Century (Commissie Waterbeheer 21ste Eeuw, 2000), the mayor information resource for the stakeholders involved in the 2001 survey. As a result, stakeholder judgments about the impacts of climate change on aquatic ecosystems are rather speculative and diverse. Within this survey, environmental interest groups assumed serious impacts, while other interest groups and policy makers regarded this impact as much less serious.

In the questionnaire on fisheries (group 2), the most serious impact of climate change was expected to be observed in the Dutch estuaries, both in terms of production (mussels) and

natural values. The estuaries, the transition zone between freshwater and seawater, must deal with both sea level rise and higher winter fluvial discharge. The latter may cause mortality of the local fauna, including mussels. For fish stocks there was broad agreement amongst the scientific respondents that the effects of climate change on fish stocks in the North Sea were unpredictable and could easily be masked by the immediate effects of over-fishing (Daan, 1994).

(3) Changing groundwater tables, lower in summer, higher in winter/spring

Several stakeholders, but also some scientific experts, assume that both agricultural and natural areas will have to cope with an increased risk of groundwater depletion during summer as a result of climate change (RIZA, 2002; van Ierland et al., 2001). However, in 2001, many scientific experts doubted whether climate change would have a significant impact compared to other driving forces, like autonomously increasing demand for drinking water and for irrigation water in agriculture.

In general, two scientific expert points of views could be distinguished in 2001, both of which had been reported to national policy makers before. A multidisciplinary research project team, installed by the ministry of V&W (Projectteam Klimaatverandering NW4, 1997) concluded that natural values may profit from climate change-induced increased groundwater tables in spring (which is the most crucial period for groundwater-dependent vegetation), because of more precipitation in winter (Können et al., 1997). On the other hand (RIZA, 2002) concluded that this potential positive impact of increased water availability in spring on natural values is insignificant compared to the negative impacts of more frequent dry summers and more intense precipitation events.

The participants from water boards and environmental interest groups regarded increasing groundwater tables due to climate change in spring as a serious problem (damage) for both urban and natural areas (if the groundwater level exceeds surface level), while representatives from agriculture argued that higher ground water levels in spring and autumn would reduce possibilities for soil management and mechanical work on agricultural land. Increased water scarcity induced by climate change was not seen as a serious problem by stakeholders in 2001, probably since by then the last extreme dry summer was in 1976[4].

(4) Increased saltwater intrusion

Scientific experts and stakeholders from Group 1 and 2 (table 3-1) agreed that saltwater intrusion of ground- and surface water will increase due to climate change (sea level rise,

[4] In 2003 a very serious drought hit Europe, and this has changed drought risk perceptions.

changing precipitation patterns). Scientific experts identified autonomous soil subsidence and dryer summers as the explaining drivers for increased saltwater intrusion in the lower parts of the Netherlands, whereas in 2001 many stakeholders assumed that sea level rise was a major cause. Some stakeholders mentioned that climate change induced increased freshwater seepage in spring will negatively impact saltwater habitats, despite the fact that the available scenarios for 2050 (Projectteam Klimaatverandering NW4, 1997) indicate that increasing saltwater seepage is dominant in the lower parts of the Netherlands.

Some ecologists (both scientists and stakeholders) assumed a loss of (freshwater) species due to saltwater intrusion, while others assumed loss of saltwater habitat due to increased freshwater seepage. Agricultural interest groups and regional water boards were aware of the negative impacts on crop yields in the lower parts of the Netherlands. Other respondents, however, state that agriculture is able to cope with increased saline seepage because adaptation options are available such as inlet of freshwater from the central lake IJssel (figure 3-2) or a shift to more salt tolerant crops.



Figure 3-2, *Overview of the mentioned regions in this paper.*

3.3.2 ADAPTATION OPTIONS FOR WATER MANAGEMENT

Stakeholder perceptions and expert judgments regarding the effectiveness, necessity and priority of the adaptation strategies identified, were very diverse compared to their judgment regarding the impacts (table 3-2). For this analysis we grouped the results by using the following four categories of measures:

- Regulatory instruments (e.g. land use planning, legal instruments);
- Technical measures (e.g. dikes and river regulation);
- Financial instruments (e.g. financial compensation and insurance);
- Preparatory measures (e.g. evacuation plans, communicative measures; forecasting and monitoring (e.g. flood forecasting).

Regulatory measures

Regulatory measures were mentioned in particular by participants involved in group 1 (water management) and were mainly aimed to reduce increased flood risks due to climate change. The measures are aimed at restricting economic activities and housing in floodplain areas and at implementation of water buffering areas. Many respondents argued that, with the help of restrictive regulatory measures within spatial planning, extra surface area for water storage can be combined with the re-establishment of cultural landscapes, natural values, recreation, extensive agriculture, the exploitation of clay and gravel in the riverine region, collectively termed multifunctional land use see also (Wiggering et al., 2003). Some respondents stated that multi-functional land use will result in a more attractive landscape for the general public, which may lead to increased public support for water management measures to adapt to climate change. However, agricultural interest groups feared that agriculture will lose fertile productive areas and income at the expense of natural areas and recreational functions, see also (van Tatenhove, 1996). This conflict of public flood risk alleviation strategies and private agricultural interests, often results in inertia in the stage of decision making regarding multifunctional land use (Teisman et al., 2009).

Some respondents from environmental interest groups point out that, if water quality is not improved, more frequent (controlled) inundation of the riverine floodplains may also have negative consequences for nature conservation within the floodplains. Experts (De Nooij et al., 2001) state that large scale reconstruction of floodplains can indeed endanger biodiversity values of the river systems through bad water quality. On the other hand, these controlled inundations could lead to an increase of legislation aimed at conserving and increasing the diversity of ecotypes.

Technical measures to optimize use and supply of freshwater resources

Stakeholders from Group 1 and 2 called for measures to increase the water retention capacity of soil-water systems in the catchment areas where flood risks and the availability of freshwater resources are an issue. A management approach of this kind will result in more dynamic groundwater level as compared to the situation in 2000. In order to optimize agricultural crop yields, the conventional approach generally does not allow fluctuations in groundwater tables. A sophisticated drainage system is needed to optimize groundwater level management for both agriculture and nature conservation. Some experts emphasize, however, that this strategy may result in higher flooding risks, due to possible saturation of regional soil and water systems during extreme events (de Wit et al., 2001; Hooijer et al., 2004).

Agricultural production in the coastal zone depends on the availability of sufficient freshwater from Lake IJssel for irrigation and flushing out saline water. Agricultural interest groups supported the increase of the pumping capacity to flush out saline water by letting in freshwater. Alternatively, some experts mentioned that structural investments might be necessary on the long term to reduce the freshwater demand, beside above-mentioned water supply measures such as research on the introduction and implementation of drought-resistant and salt-tolerant crop varieties. A number of decisions at different scales (farm level, research and policy) about investments and policies need to be made in order to achieve such a long-term structural reduction in freshwater demand. For example, choices need to be made regarding investments in irrigation and drainage systems, freshwater pricing policies and investments in plant breeding research. Stakeholders involved in nature conservation and water management stated that a local strategy to flush out salt water with fresh water may result into water supply problems for adjacent regions with consequences for ecological values, drinking water availability and other agricultural sectors. The debate about the choice between freshwater supply and water demand policies is still continuing, for example in the process of formulation of the National Water Policy plan in the period 2008-2009. Many experts and policy makers involved in Dutch water management currently argue that water supply policies are more robust, resilient and reliable based on the uncertainties as compared to water demand policies (Delta Commission, 2008; van Beek, 2009). However, this is also contested by other experts and stakeholders. For example, the concept national water plan (Ministry of public transport and water management, 2009) describes a combination of water supply and water demand policies to climate proof freshwater resources.

Technical measures to reduce flood risks in the coastal zone

Nature conservation stakeholders involved in the survey argue that the disappearance of the estuarine characteristics of the coastal areas after the closure of the Scheldt-Rhine estuary (section 3.3.1) supports the plea for the restoration of interconnection between the arms of the southern delta (figure 3-2) and the sea. A mentioned trade-off is the increase of the ecological resilience that may help to cope with the projected precipitation changes and perceived increased freshwater seepage due to climate change (section 3.3.1). Other stakeholders were against this strategy, because it implies major investments and negative economic impacts for regional agriculture (freshwater availability).

Financial instruments

The insurance companies involved in this survey indicated that they were not directly involved in the consequences of flood damages, because, in 1965 (in view of the enormous loss potential) they negotiated a market agreement to exclude flooding as an insurable risk, and this agreement was still in force in 2001. The Netherlands has no state insurance for the risk of flooding either, but there is the possibility of disaster relief through ad-hoc compensation of disaster damages, including the damages of flooding. The floods in 1993 and 1995 near some rivers in the Southern part of the Netherlands started a new debate between the insurance sector and policy makers on the lack of insurance protection (Tol & Langen, 2000). However, public/private insurance coverage against flood damage is still not generally available in the Netherlands (Botzen & van den Bergh, 2008). For extreme weather events some damage compensation and insurance exist, such as the Harvest Damage Act (OSR) and the "Contribution at Disasters and Severe Accidents Act" (WTS) (Botzen & van den Bergh, 2008). Private insurance companies provide hail and windstorm insurance schemes for field crops (Langeveld et al., 2003; van Asseldonk et al., 2000).

Preparatory emergency measures

Neither the questionnaire respondents nor the workshop participants explicitly mentioned these types of measures. Only the need for long-term environmental monitoring (ecosystems, water quality) was expressed in this survey. Climate and flood forecasting were not explicitly mentioned. This seems in line with the conclusion of Bates (2002) that, in water management, the usefulness of seasonal climate forecasting still has to be demonstrated more convincingly (Bates, 2002). A number of factors are responsible for this, such as limited training in/or experience with climate science in the water management community. On the other hand the scientific tools to work with, for example, seasonal flood and climate forecasts, are too complex for practical use (Kabat et al, 2003b).

In the Netherlands disaster planning, -management and -response are outlined in the Disaster Act (Rampenwet) of 1985 (Olsthoorn & Tol, 2001) and are characterised by different levels of government being involved (Rosenthal & Hart, 2012). In principle, evacuation decisions are made by the mayor, but the Minister of Interior Affairs may take over the competence to evacuate, if deemed necessary (Olsthoorn & Tol, 2001). These types of stakeholders were not part of the survey.

3.4 THE MAIN FINDINGS FROM THE 2001 SURVEY IN A BROADER PERSPECTIVE

3.4.1 SYNOPSIS OF THE MAIN FINDINGS

The initial aims of the 2001 survey were to provide an overview of stakeholder perceptions and expert judgments about the impacts of climate change based on given scenarios, as summarized in table 3-2, and to explore sectoral and cross-sectoral adaptation measures. The following main findings can be drawn when the results in this table are compared to the initial objectives of the 2001 survey:

Use of scenarios and cross-sectoral approaches

The scenarios used are aimed at representing the relationships of climate and economic variables in three different alternative futures. However, neither the involved stakeholders nor the invited scientific experts did express specific and distinct views on the impacts they expected in relation to the three different alternative futures.

The approach chosen in 2001 enabled us to explore the different opinions regarding the impacts of climate change. It was, however, very difficult to prioritize the identified adaptation strategies and to evaluate their effectiveness from a cross-sectoral point of view. We presume that the approach chosen in our 2001 survey essentially amounted to exploring uncertain future risk and opportunity assessments of individuals rather than of organisations or institutions.

Differences between stakeholder and scientific expert judgment

In case of increased flood risks, stakeholders and experts generally used the same argumentation in order to assess the seriousness of the problem. This argumentation included risk attributes such as the extent and amount of potential harm and damage. The possible consequences were imaginary for the involved experts and stakeholders and during the workshops often compared with the relatively recent extreme hydro-meteorological

weather events in 1995 and 1998. In the period of the survey, scientific experts and policy makers also intensively exchanged resources of knowledge and information on flood risks because many of them where involved with the preparation of the vision on Dutch water management for the 21st century (Commissie Waterbeheer 21e eeuw, 2000).

The uncertainty in the judgments about the impacts of climate change on the freshwater availability, saltwater intrusion, water quality and aquatic ecology was high for both scientific experts and stakeholders in 2001, despite available and communicated drought risk assessment studies (Projectteam Klimaatverandering NW4, 1997; RIZA, 2002). They used similar attributes to assess the vulnerability of freshwater resources due to climate change, such as potential damage, the level of controllability and manageability of the impacts and the identification of potential benefits. However, their opinions differed regarding the probability and the potential damage or benefits of the climate impact on freshwater resources, in particular exemplified by the discussion about the climate impacts in the South-western Delta.

3.4.2 EXPERT JUDGMENT IN CLIMATE ADAPTATION RESEARCH AFTER 2001

In this section the main findings of the 2001 survey are put into a broader perspective by comparison with documented discussions between climate scientists, policy makers and decision makers[5] in the Netherlands during the initiation and start of the national *"Climate changes Spatial Planning research programme"* (CcSP) in the period 2000-2007 (Veraart et al., 2007). The CcSP-programme officially started in November 2004. However, in consultation with stakeholders (Werners et al., 2003), the framework of the research programme had already been designed in the period 2000-2003.

The search for cross-sectoral adaptation strategies continued after 2001 in both the policy domain, the academic world (van Ierland et al., 2007) and in the interplay between these worlds in the Netherlands (de Bruin et al., 2009; Delta Commission, 2008; Programme Office Knowledge for Climate, 2008 (expired); van Drunen, 2007).

Prioritisation of adaptation strategies

As a follow-up on the 2001 survey within the CcSP-programme De Bruin et al. (2009) used a multi-level multi-criteria analysis (MCA) (Janssen & van Herwijnen, 2006) to categorize and rank adaptation options, based on stakeholder analysis and expert judgment. Similar to the 2001 survey the analysis was done on the basis of a sectoral approach, and

[5] A difference between the 2001 survey and the CcSP-programme is that not only policy makers are involved but also decision makers.

comparable stakeholders and scientists were involved as in the 2001 survey. However, not only scientists but also individuals from the policy community were regarded as experts. The MCA, followed after the stakeholder analysis, was solely based on expert judgment. Priority ranking based on a weighted sum of criteria reveals that integrated nature and water management and risk-based policies ranked high, followed by policies aiming at 'climate proof' housing and infrastructure.

The search and evaluation of cross-sectoral adaptation strategies since 2001

Also, regional science-policy dialogues were initiated by the CCsP-programme in a selected number of case studies, called 'Hotspots'. Those hotspots are used as a node for designing cross-sectoral adaptation strategies by experts in spatial planning, urban development, and water management in dialogue or in consultation with the CcSP science community. The selected hotspots are, within the CcSP philosophy, preferably areas where climate-proofing planned investments or activities create potential high social or economic opportunities (Kabat et al., 2009), in addition to the risk assessment approach (Willows & Connell, 2003), as used in the 2001 survey and many other studies about climate adaptation in water management and spatial planning (Ludwig et al., 2009). The regional approach of CcSP has some drawbacks too; proposed regional adaptation strategies could generate some negative side effects, like the transfer of problems or burdens from one region to the other. This is one of the main challenges for the CcSP-programme in the second phase (2007-2011).

The increased awareness about flood risks resulted in attempts to institutionalize the link between water management and land use planning (Woltjer & Al, 2007), exemplified by legislation such as the water impact assessment in land use planning, compulsory since 2003 (Ministry of Housing Spatial planning and the Environment, 2005; RIZA, 2004). In the same period regional policy makers received more freedom from the national government to develop land use plans tailored to the local circumstances (J. Gupta et al., 2010). However, the call for flood risk reduction measures and other adaptation strategies in order to climate proof the Rhine/Meuse delta and North sea coastline by the Delta Commission (2008) tend to complicate this process of widening governance (Driessen et al., 2008), also shown in the United Kingdom (Bulkeley, 2006). The impact of climate change on freshwater availability on freshwater resources was also discussed between scientists and policy makers since 2001 but didn't yield yet into new legislation.

The use of scenarios with stakeholders in the Netherlands

The recognition by Dutch climate scientists that, within the 2001 survey, stakeholders do not perceive differences in impacts under different climate scenarios, has led to development of tailored sector- and local specific climate scenarios within the climate changes spatial

planning programme (CcSP). Yet, contrary to the climate scenarios used in 2001 (Können et al., 1997), the scenarios were developed by consultation and in close co-operation with Dutch regional water boards and knowledge institutions in the field of water management and spatial planning (van den Hurk et al., 2007; van den Hurk et al., 2006). This process of tailoring climate information encompasses a wide range of procedures. For example, it can be the outcome of a joint stakeholder and scientific expert judgment on the choice for the most relevant scenario for a given sector from an available set of scenarios, but also a quantitative translation from available time series of a certain climate variable into a quantity that is better related to the concerned sector (Jacob & Van den Hurk, 2009). Also, a so-called climate effects atlas was constructed for regional policy makers by CcSP in order to visualise climate change effects on variables such as groundwater, water quality and biodiversity (Jacob and Van den Hurk, 2009). In the philosophy of CcSP tailoring climate information comes down to the evaluation of multiple scenarios within the range of sensitivity of the specific sector or region. However, practice learned that in the regional policy domain this is often a though ambition for scientists because policy makers still prefer to stick to one single climate change scenario. The drawback of tailoring climate information for regions and sectors is, again, that it becomes difficult to upscale the regional and sectoral impact assessments in order to identify national adaptation strategies.

3.5 CONCLUSIONS AND RECOMMENDATIONS

3.5.1 CONCLUSIONS

The 2001 survey, as well as the follow-up by De Bruin et al. (2009) was based on an exploratory multidisciplinary philosophy with transdisciplinary elements, e.g. the recognition of the role of values and stakes in the selected sectors. The set-up of the 11 questionnaires in 2001 was a result of different disciplinary frames of reference on values and assumptions (Wesselink, 2008) on assessing cross-sectoral adaptation strategies. The use of multi-criteria analysis (MCA) in combination with expert judgment and stakeholder analysis conducted after the 2001 survey provided a ranking of adaptation options; however, also with this approach it was not possible to formulate cross-sectoral adaptation strategies. The approach struggles with the increased complexity of the design process as a consequence of the involvement of increasing number of societal groups and knowledge institutions within the climate adaptation policy domain (Cash et al., 2006a; Cash et al., 2003).

The 2001 approach did initiate a slow but steady and on-going learning process about the role of climate scientists and climate information in water management and spatial planning. The approach of climate scientists in the CcSP-programme is gradually shifting from a collaborative/consultative approach towards a real participatory approach in the research and design process of combined regional and sectoral adaptation strategies. Some researchers and institutions are moving faster in this transition than others within the CcSP-programme. Furthermore, the consultative approach is for some of the CcSP objectives also effective, exemplified by the success of tailoring climate information to regional or sectoral circumstances and requirements. The combination of both sectoral and regional science-policy interfaces within the CcSP-programme is a promising approach that may result in new insights about the co-production of knowledge. Upscaling results from regional science-policy dialogues and sectoral research results remains a challenge for the second phase of the CcSP-research programme.

3.5.2 RECOMMENDATIONS

Differences in stakeholder and expert judgment regarding climate change are an expression of both scientific and societal uncertainties. Lack of awareness of these differences is one of the reasons why it often appears to be difficult to make firm decisions in water management and spatial planning. A structured approach to assess the uncertainties involved might help to improve the design process regarding cross-sectoral adaptation strategies to climate

change. The designers, but also the decision makers involved not only have to agree on the measures but also on the uncertainties. This concerns the differences in world views of individual scientists and stakeholders when they meet each other in a science-policy interface with the intention to solve regional problems. This could be seen as a negotiation process (Fisher et al., 1981). Exploring these different world views can be done by mapping the patterns of certainties and uncertainties both qualitatively, through analysis of cultural concepts (Klostermann & Cramer, 2007), and quantitatively, by statistical analysis (Cofino et al., 2005). Such an analysis of the fundamental perceptions of the various aspects of climate change will contribute to a better understanding of the issues at stake and to well-informed decision making.

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4



Picture: *Professor Ainun Nishat (BRAC University, Bangladesh) was interviewed during the fifth World Water forum in Kyoto, Japan (Jeroen Veraart, 2002).*

Climate-proofing

Abstract - This chapter explores how water management strategies can be adapted to address climate change and variability. Climate proofing is used in different ways: as a policy objective, a decision-support framework, or a planning paradigm integrating risk thresholds, uncertainty, and long-term resilience. The chapter situates climate proofing within two dominant paradigms of water management: the foundational paradigm and adaptive management. The foundational paradigm, grounded in the stationarity principle, assumes that hydrological variability remains within a fixed range and emphasizes structural measures (such as reservoirs) and incremental no-regret policies. In contrast, adaptive management rejects stationarity, acknowledging that climate change may induce unprecedented hydrological conditions that may require precautionary decision-making under uncertainty. Climate proofing is best understood as a decision-making process that integrates both risks and opportunities of climate change while incorporating sustainability goals. The approach emphasizes three steps: (1) vision building through scenarios and participatory methods based on both scientific expertise and societal values; (2) learning by doing through practical adaptation experiments; and (3) evaluation using decision-support tools such as climate scenarios, forecasts, risk assessments, and cost-benefit analyses. The chapter stresses that climate proofing requires transparency, recognition of uncertainty, and plural expert judgment. Boundary organizations—intermediary institutions connecting science, policy, and society—are identified as crucial in facilitating dialogue, managing uncertainty, and fostering co-production of knowledge. In conclusion, climate proofing is a synthesis of adaptive management principles tailored to climate uncertainty. Ultimately, climate proofing is presented as a joint learning process requiring investment in education, interdisciplinary collaboration, and flexible governance. Its success depends on balancing scientific rigor with societal values, while embedding decision-making in credible boundary organizations that enhance resilience against climate change.

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4 CLIMATE-PROOFING

4.1 INTRODUCTION

Every day, key decisions are being made about future (infrastructural) investments related to water management and land use across the globe. Expected changes in climate and socio-economic water demands require that water managers reconsider their strategies that aim to minimize flood risks and optimize water supply. Coping with climate variability has been part of water resources management for ages; but the use of systematically collected climate information and daily weather forecasts stems from more recent date. The usefulness of daily weather forecasts is widely acknowledged in various sectors. However, the operational use of (seasonal) climatic forecasts (Ludwig, 2009) and climate change scenario's (Jacob & Van den Hurk, 2009) in water management is still limited.

Since the 1970s, several governments have proposed programs and technologies designed to weather-proof or drought-proof their countries in order to cope with climate variability (box 4-1). These programs can be regarded as the earliest forms of 'climate-proofing', a term currently becoming a buzz phrase. The phrase started to appear in Australian and American policy documents about ten years ago. In the scientific literature it was probably first described by Glantz (2003) followed by elaborations and alternative interpretations by, for example, Kabat et al. (2005) and Hay et al. (2005). The concept of 'climate-proofing' could be interpreted in three different ways:

- A policy objective or an additional standard, a set of risk thresholds or criteria for (sustainable) water management and land use;
- A decision support system for interventions in water management and land use focused on climate change and climate variability, taking into account the uncertainties that come with a changing climate; or
- A new planning paradigm for water management, natural resources management and spatial planning taking into account the future claims on natural resources, risks, opportunities and associated uncertainties.

Moreover, assessing and dealing with future uncertain risks (Aerts & Droogers, 2009) is central to all interpretations of climate-proofing.

***Box 4-1**, Drought & weather proofing: The precursors of climate-proofing. Source: (Glantz, 2006).*

The history of successful agriculture in the Canadian prairies has been punctuated by episodes of drought. During the 1970s, following the recurrence of severe drought in the Canadian prairies, the government launched a program to 'drought-proof' the prairies. Drought-proofing measures included changes in land-use practices such as leaving stubble and crop residue in the ground after harvest. Expectations for successfully drought-proofing this region, however, were soon undermined by nature, as droughts and crop losses continued to reappear in the region. Today, Canadians in the region are more specific in their activities - for example, in calling for the drought-proofing of farm water supplies. Different interpretations still surround the concept of drought-proofing; however, it is still being proposed by U.N. agencies as well as by various national governments such as recently in Australia and India.

In late 1999, the U.S. Weather Research Programme launched a national computing system for forecasting purposes, in order to weather-proof economic activities. But within a matter of days, a forecast of light snow for the Washington D.C. area proved wrong, when a major winter storm developed, depositing 30cm of snow in the metropolitan area. In March 2001, a storm of major proportions - referred to by some forecasters as a potential 'storm of the century'- had been forecast for the lower half of the north-eastern US. The forecast prompted people and government to take precautionary measures. Stores were emptied of shovels, salts, mechanical snow-removing devices, and the like. The track of the storm unexpectedly shifted more than 160km to the north. Afterwards the Governor of New Jersey threatened to sue the National Weather Service for the adverse costly impacts of what he viewed as a grossly 'erroneous' forecast.

4.2 CLIMATE-PROOFING IN WATER MANAGEMENT: DEBATES & PARADIGMS

This book discusses, in detail, two planning paradigms. The approach described van Beek (2009) will in the remainder of this chapter be referred to as the Foundational *water management paradigm*, while *Adaptive management* is discussed by Aerts and Droogers (2009). Both book chapters mention the paradigm of *Integrated Water Resource Management* (IWRM). Next to these named planning paradigms, many others exist within policy sciences and spatial planning, such as the distinction between state-led systems and multi-layered governance of water resources, or the division of tasks between public and private sector. Keeping this in mind, climate-proofing will placed in the context of the *'foundational water management paradigm'* and *adaptive management* in this book section. Van Beek (2009) describes how climate-proofing could be conceptualized in water management and spatial planning and summarizes the main conclusions and explains the difficulties of the conceptualization of climate-proofing (van Beek, 2009).

The foundational water management paradigm and climate-proofing

Many expert communities involved in water management tend to construct, assess and approach climate risks based upon the stationarity principle (van Beek, 2009). The basic assumption underlying this stationarity principle is that natural systems fluctuate within a fixed range of variability and that this range does not change (Milly et al., 2008). Water

managers supporting this paradigm favour the formulation and revision of design rules and management criteria based upon statistical analysis of monitoring data and the methodology of stochastic (synthetic) hydrology. Several experts (Fiering & Matalas, 1990; Matalas, 1997) within this paradigm, notably Fiering and Matalas (1990) and particularly Matalas (1997) state that this approach can also accommodate the uncertainties in water management induced by global warming with the operational assumption that stationarity is as meaningful as the assumption of non-stationarity.

Nearly all land-use and water management decisions related to climate variability within this paradigm will result in a trade-off between maximizing water supply and/or economic income and the risk of failure (van Beek, 2009). Water managers who use this paradigm in their daily activities tend to favour structural adaptation measures over non-structural measures. The rationale behind this is that they perceive these measures as more robust, resilient, and reliable based on the uncertainties as compared to structural measures.

Usually, (incremental) no-regret decisions (i.e. measures whose benefits equal or exceed their cost to society) are taken into consideration within this paradigm. These decisions do not suffer from errors of caution and their implementation improves welfare relative to the reference case. In adaptation policies to climate change the 'error of precaution' could be seen as welfare consequences (Smith & Lenhart, 1996); see also the Berg River Basin case study (Callaway et al., 2009). For example, reservoirs are the preferred measure to cope with drought, rather than water demand policies (Bates & Hughes, 2009; van Beek, 2009).

Design floods (van Beek, 2009) are calculated based on a maximum of accepted probability, and if the maximum accepted probability is exceeded, engineering solutions are largely sought, such as constructing or heightening dykes. The occurrence of such a flood is derived from historical and/or synthetic time series analyses. In order to take unknown flood risk into account, safety margins are added to design rules for infrastructural measures. Should evidence of increased variability continues (non-stationarity) to become more substantial; water managers have the option to increase the safety margin. In this paradigm, water managers recognize increased vulnerability to extreme weather events by acknowledging the fact that the population living in flood and drought prone areas and associated economic capital will increase. This is the main argument used that legitimizes the consideration of coping strategies to climate variability. In addition, but of less importance within this paradigm, water managers have to cope with the uncertainties linked to possible changes in climate.

The adaptive management paradigm and climate-proofing

Alternatively, other experts state that climate changes are likely to produce – in some places and at sometimes – hydrologic conditions and extremes of a different nature than current systems were designed to manage (Aerts & Droogers, 2009; Gleick, 1998). In addition, social scientists call for more institutional flexibility and stakeholder participation within water management with a central role in an iterative 'social learning process as a strategy in complex problem situations, such as climate change (Folke et al., 2002; Pahl-Wostl & Hare, 2004). Because the first ideas about adaptive management were developed by ecologists in the 1970s (Holling, 1978), it is often also reviewed as a paradigm that addresses a widely perceived need to give more prominence to ecological imperatives, such as the used concept of 'living with floods' in river basins. In addition, the notion of possible discontinuities and turning points, caused by disturbances and surprises in ecology and society is further emphasized. These discontinuities are frequently caused by small incremental changes in the drivers that trigger a rapid and large response. The dissolution of the Soviet Union, the Berlin Wall coming down, and putting a man on the moon are examples of rapid non-linear surprises within society (Costanza, 2000). Water systems and ecosystems are also exposed to gradual changes in climate, nutrient-loading, habitat fragmentation or biotic exploitation. One might assume that these systems respond to gradual change in a smooth way. However, studies on lakes, coral reefs, oceans, forests and arid lands have shown that smooth changes can be interrupted by sudden switches to a contrasting state, such as shallow lakes suddenly turning from a 'clear water state' into a 'turbid state' or rapid irreversible coral bleaching (Scheffer et al., 2001).

Within this paradigm attempts are sought to improve the management of scientific uncertainty and ignorance (unknown bounds of the set of potential outcomes and unknown probabilities) in situations where both regulatory action and inaction can have costly but unforeseeable impacts or surprises (Pahl-Wostl, 2002; van der Sluijs, 2007). For example, if one forgets to maintain a dyke system or work with fixed risk thresholds, the cost of respectively inaction and, respectively regulatory action could be an unforeseeable flood.

Scientific experts and stakeholders who approach water management from the adaptive management paradigm tend to prioritize non-structural measures, such as institutional changes (for example flood risk zoning in spatial planning) or behavioural change (e.g. via water demand policies) and argue that structural measures are far less flexible and often result in irreversible environmental impacts. Within this paradigm more decisions are taken based upon the precautionary principle (i.e. the absence of full scientific certainty is not used as an argument to postpone decisions that could prevent unproven threat of serious or irreversible harm).

4.3 CONCEPTUALIZING CLIMATE-PROOFING

As said before, the process of conceptualizing weather and climate-proofing started in the 1970s (box 4-1). Recent programmes initiated in Europe include initiatives in the Netherlands (box 4-2), the United Kingdom and in Sweden, but also in other continents, for example initiatives by the World Bank in Asia (Hay et al., 2005). It is clear that no society, rich or poor, is able to fully insulate its people and human activities from climate- and weather-related anomalies (Glantz, 2006; Kabat et al., 2005). However, the alternative is less clear, resulting in policy makers searching for design rules, climate risk thresholds and management criteria.

Here, we view 'climate-proofing' as a decision-making process (figure 4.1) in land and water management in which both risks and opportunities of climate change are taken into account, in line with the definition of Kabat et al. (2005). The opportunities involve, but are not limited to technological, institutional, and societal innovations. In order to meet sustainability objectives as well, the adaptation strategies should not lead to additional greenhouse gas emissions compared to the business-as-usual scenario. The concept of climate-proofing uses a combination of infrastructural and institutional measures in order to adapt to future climate change. Within the climate-proofing approach risk is seen as a social construct which is not only determined by the probability of exposure and the potential amount of damage (Aerts & Droogers, 2009), but also by elements such as the voluntariness of exposure, the expected benefits of taking the risk and the imaginableness of the consequences. Risk experience, and as a result, the determination of (risk) thresholds are also influenced by factors such as personal experience, access to scientific information and media attention. As a result, in addition to the definition of Kabat et al. (2005), we state that climate-proofing is a policy objective that should not be presented in a set of fixed risk threshold(s) derived from science nor supported with a single decision support system. It also poses the question who is responsible for determining climate risk thresholds. Crucial steps in the evaluation of adaptation policies and associated risks and opportunities are:

- exploring the future by vision building on climate-proofing;
- learning adaptation to climate change by doing; and
- the design of tailor-made interfaces between science, society, and policy.

These steps will be explained in the sections below.

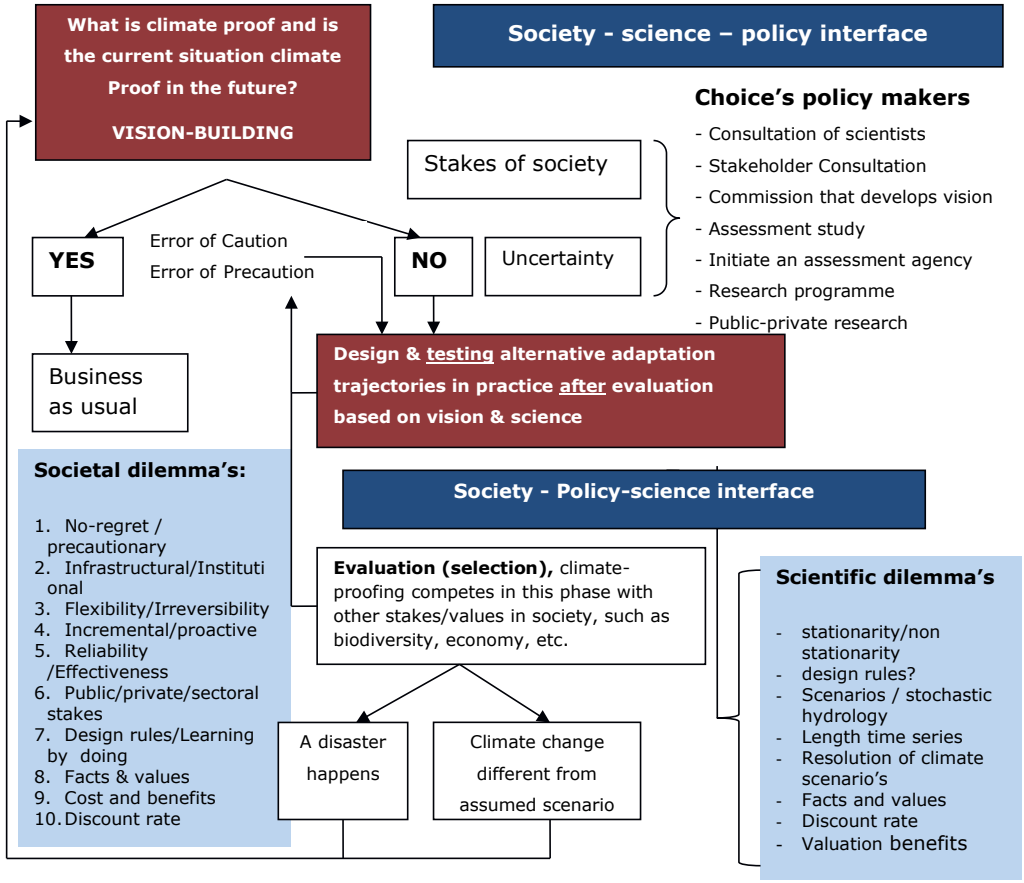

***Figure 4-1**, Presentation of the decision-making process regarding climate change adaptation strategies.*

Exploring the future by vision-building in Climate-proofing

The future is a moving target: divining its characteristics is always tough. Methodologies to explore the impact of policies on the future have a long history, going back as far as the Greeks and their Oracle of Delphi (Ruijgh-van der Ploeg & Verhallen, 2002). Systematic studies, like vision building and scenario analysis, are applied on a large scale applied in policy making ever since World War II, but also by private companies, for example in strategic management for oil exploration and refinery by Shell (Ruijgh-van der Ploeg & Verhallen, 2002). In the 1970s the Club of Rome started using newly developed quantitative modelling tools for trend analysis to assess the extent of future environmental problems (Meadows, 1992). Currently, a wide array of methods is available to explore the future.

Distinctions can be made between(Ruijgh-van der Ploeg & Verhallen, 2002):

- formal methods based on a mathematical (global) approach; and
- normative methods based on expert knowledge, including (local) stakeholder participation.

Formal scenarios provide plausible descriptions of how the future could develop, based on coherent and internally consistent set of assumptions ('scenario logic') about key relationships and driving forces, such as economic growth, energy consumption or emission of greenhouse gases. A scenario is part of a set of scenarios, which together span the range of likely future developments. This is also the approach followed by the Intergovernmental Panel on Climate Change (IPCC). Normative methods go one step further and aim to create a shared vision of a sustainable and desirable society, thereby involving values. The development of these scenarios relies much more on qualitative information and personal perceptions than on analytical methods (Ruijgh-van der Ploeg & Verhallen, 2002).

The 'climate-proofing approach' should start with vision building by scientists, policy makers and other representatives of the stakeholders in the involved catchment or region. Vision building could be done by formulating narrative stories for the future or designing maps of the future. The desired future could also be visualized or described by architects, movie makers, journalists, and product designers. At this stage a normative method is preferred because in designing adaptation strategies practical knowledge is equal to scientific knowledge in judging how effective and desirable adaptation options are. In addition, the preferred future is, by definition, a societal value. Experience shows also that the use of pre-described 'formal' socio-economic scenarios, in particular, is frequently debated in political charged atmospheres and hampers the process of designing adaptation trajectories in dialogue with scientists. On the other hand, quantified information about future climate change and related impacts on natural resources and economic sectors are also often requested by decision makers. Questions such as: 'What is climate proof?' or 'Is our region vulnerable to climate change?' are often posed at this stage. Within the climate-proofing approach, the aim is to develop a vision which is a co-production of policy, societal values, and scientific expertise. The design of the process is complex and requires delicate tuning between these three entities, and preferable chaired by someone from the society or policy domain. Expert judgment derived from formal climate scenario methods and impact assessment can be included but should not dominate the process of vision building. At a later stage, when societal preferences for the future are clear, the identified adaptation trajectories should be evaluated using formal scientific methods in order to assess the impact of the designed adaptation trajectory compared to the business-as-usual scenario.

Evaluation of Adaptation Trajectories

The most important difference between the climate-proofing decision-making pathway (figure 4-1) and the 'foundational water management paradigm' is that the (scientific) evaluation phase of alternative adaptation options is done later in the process after the initiations of practical pilots (learning adaptation by doing). These 'adaptation trajectories' consist of a set of cross-sectoral (structural and non-structural) measures for a defined system - for example a catchment, river delta or country. This approach has many components that fall within the scope of Integrated Water Resources Management (IWRM,(van Beek, 2009)). The difference is the way knowledge transfer (society-policy-science interfaces), future risks (partly unknown) and current uncertainties are treated within the decision-making process.

This book describes a selected number of scientific tools that can be used within the interface of climate science and water management, in particular climate forecasts, climate scenarios, time series analysis and risk assessments (table 4-1). In addition, some socio-economic decision support models were discussed within the case study Berg River Basin (South Africa). For additional reading, we refer the reader to (Toth & Mwandosya, 2001) and (Dessai & van der Sluijs, 2007).

***Table 4-1**, Scientific tools addressed in this book.*

Tool	Remarks regarding application in Water management (cons and pro's)
Time series analysis climate variables (Jacob & Van den Hurk, 2009) **Stochastic (synthetic) hydrology** (van Beek, 2009) **Extreme Value Analysis** (van Beek, 2009)	• Predictability, nature, and amplitude of climate variability strongly varies on spatial and temporal scales • Trend detection: signal to noise ratio determine detectability of a trend. In addition, the availability of (long term) homogeneous observational records
Climate scenario's (Jacob & Van den Hurk, 2009)	• Climate projections: first 50 years uncertainties in the initial conditions are more important than uncertainties in external forcings (GHG emissions) • Different approach of using climate scenarios in transboundary rivers (i.e. Rhine) • Tailoring climate information, lessons learned from Climate Effect Atlas
Climate forecasts (Jacob & Van den Hurk, 2009; Ludwig, 2009; van den Hurk & Jacob, 2009)	• Correlations between Sea Surface Temperatures and ENSO, PDO, NAO, IOD as a basis for seasonal forecasts (ENSO is the best) • Land Atmosphere Interactions, in particular soil moisture, as a basis for seasonal forecasts • Developments in Decadal forecasts (10-15 years)
Climate models (GCM/RCM) (Jacob & Van den Hurk, 2009)	• Predictability is determined by initial conditions and external forcings. • Model Scenario projections: from GCM to ESM (Earth System Models) • Uncertainty associated with imperfect modelling systems: can be covered with multi-models.
Risk assessments (Aerts & Droogers, 2009) Case study Thailand (Lebel et al., 2009)	• Empirical found correlations between water management and (mitigated) impacts are based on current (climatic) conditions. • Learn from other risks (for example nuclear power) • Risk = P x potential damage, whereas perceived risk = f (P. damage, media attention, conceivability of a disaster, risk distribution, voluntariness of exposure, etc.) • How to deal/assess impacts of adaptation measures outside the water management arena? • Case study "Flood and disaster management in Thailand" describes societal uncertainties regarding mitigating flood risks.
Cost Benefit Analysis Case study Berg River Basin (Callaway et al., 2009)	• Deterministic scenario's instead of stochastic scenario's • Identification of parameter values based upon empirical data. • coupling of Climate scenarios with hydrological models & (b) economic models • The principles of "caution" and "precaution" are defined by mathematical expressions. • Use of 4 different possible future water supply and demand scenario's (dam, markets) • Discount rate 6%

Transparency

Since the evaluation of adaptation trajectories is inevitably a normative process 'transparency' is an important criterion in the selection of and/or the design of decision support tools for climate policies. Scientific information on climate risks (and opportunities) is not always consistently used within the internal decision-making process due to conflicting stakes. Decision makers and stakeholders may have a tendency to rank adaptation options to cope with, for instance, drought risks, solely with reference to one of the stakes, for example agriculture, ignoring all other differences between different adaptation options (Van der Heide et al., 2008). Hence, lexicographic preferences are defined as preferences without trade-offs, because of the respondents attitudes or fundamental beliefs and are an indication of strategic behaviour of the respondent (Van der Heide et al., 2008).

An element of subjectivity cannot be excluded in scientific expert judgment regarding the presentation of uncertainties. For example, water and climate scientists may have dilemmas in accounting uncertainties in making climate scenarios and related impacts spatial explicit on local (provincial) level (Jacob & Van den Hurk, 2009). If water and climate scientists refuse to make climate risk maps for zoning on a provincial level, they may lose credibility. But if they do not communicate uncertainties and simply make the risk zoning maps, they may lose legitimacy as well. It is therefore important to give special attention to disclaimers and develop benchmarks that provide some indication of the amount of associated uncertainty. In the reporting and presentation phase of the evaluation it is also important to give attention to the linguistic aspects of expressing probabilities and risks. For example, IPCC has developed verbal equivalents for probability intervals: in the sentence 'Drought-affected areas will likely increase in extent.' *likely* means with a 66 to 90 per cent probability'.

In order to visualise the uncertainty in expert judgment, particularly if those judgments that are not supported by empirical observations or model analyse, we propose to involve several experts of each discipline during the evaluation of adaptation strategies. Often, due to financial and time constraints, this is not done. However, it is worthwhile to investigate alternative methods to get multiple expert judgments, for example by internet questionnaires. The expert could be asked about the uncertainty range in his/her judgment and his/her perception of the probability that his/her expert judgment might be wrong. For example, the question: 'What will be the necessary safety margin for dike heights in order to cope with future sea-level rise' is given to a group of 20 scientific experts. One expert will say a safety margin of 50 cm with an upper and lower bound of 25cm and 100cm and the probability that he or she will be wrong is less than 10 per cent. Another expert estimates a safety margin of 25 cm with a lower and upper bound of 10 and 45 cm with a probability estimation of 50 per cent. Following a Bayesian data analysis, prior beliefs in the form of the

probability statements are multiplied with likelihood functions to obtain a joint probability distribution function (PDF). The entropy measure of a PDF is maximum if all estimated safety margins are equally likely mentioned by the experts (= maximum uncertainty). The entropy could be seen as a benchmark of uncertainty or degree of disagreement among experts about the effectiveness of a certain adaptation strategy.

Boundary organizations (science-policy-society interfaces)

Climate-proofing requires, like other environmental problems, clearly (re)defined and negotiated boundaries between science and policy (Janasoff, 2004; Tuinstra, 2006). Problem defining, policies and research agendas need to be mutually constructed in boundary organizations, which may also lie outside the traditional domain of water resources management. Boundary organisations between science and policy as such are not new. Examples exist in the field of air quality policies (Tuinstra, 2006) and the field of integrated water resource management and climate change (e.g. the Co-operative Programme on Water and Climate or CPWC). Other examples of boundary organizations are national environmental/economical assessment agencies, public-private research programmes, a participatory research project or a temporary installed commission by the government (box 4-2). Boundary organizations that also include representatives from society, next to science and policy are not as common (Turton et al., 2007). The Trialogue Model from Turton et al. (2007) assumes three interfaces (processes) - namely society and science; government and society; and (c) government and science. Knowledge transfer within the interfaces can be supported by decision support tools but usually contain also other communication strategies, including media and internet.

***Box 4-2**, Boundary organizations mentioned in this book (Ludwig et al., 2009).*

Climate change and spatial planning in the Netherlands

In the Netherlands many key decisions about future (infrastructural) investments are being taken in the field of spatial planning and water management, the senate of the Dutch parliament called for incorporating climate change risks and opportunities into these decisions in 2005 (motie Lemstra). In response policy developed a boundary organization, called ARK (Adaptation Programme for Spatial Planning and Climate) that included two interfaces:

- National Policy- Regional policy/Society.
- National Policy – Science.

The management of the boundary organization falls under the ministry of Environment and Spatial Planning (VROM), supported by an interdepartmental steering group and national associations for the provinces and municipalities. The science-policy interface is developed through the initiation of a new public-private research programme (Knowledge for Climate) linked to an existing public-private research programme (Climate changes Spatial Planning). Both platforms are managed by scientific institutes. Parallel to these more long-term interfaces also commissions are installed in the Netherlands, such as the Delta Commission (2007). This commission consisted of both scientists and policy makers and has got the task to develop a new vision for future water management up to 2200 within one year. This is an example of knowledge management in practice, which does not necessarily follow the proposed scheme as presented in figure 4.1. This exemplifies how difficult knowledge management is. Due to the power of existing networks in policy and science it is not easy to design the desired science-policy-society interfaces, necessary to be fully equipped for adaptive management approaches such as 'Climate-proofing'. However, designing science-policy-society interfaces is also 'Learning by Doing'.

Drought management in Australia

The development of the Indian Ocean Climate Initiative (IOCI) could be seen as an institutionalization of the science-policy interface between water managers and climate scientists in Australia. Overall, the research outputs such as climate risk assessments and climate scenarios from this partnership have provided acknowledged guidance for the State Water Strategy and the State Greenhouse Strategy. However, underpinning decision making with information obtained from the latest developments in climate science is still in its infancy. The sequence of debating decisions by the Water Corporation and its predecessors was largely driven by observed dam inflow reductions due to multi-decadal droughts.

The use of 'science', 'society' and 'government' in three entities, is, of course, an over-simplification. While designing interfaces between these entities it is therefore important to take into account the historical context and user characteristics of existing policy and scientific networks already in place that need to co-operate within the boundary organisation. The individuals (or institutes) that take leadership within the policy-science interface will strongly influence the choices in response to the mentioned dilemmas (figure 4-1).

Not only the national government, but all levels of policy institutions such as water boards or municipalities, are often routinely engaged in the process of climate-proofing water management and land use. Water managers are typically considered to be formally trained

professionals and involved in some institutionally organized component of water development, delivery or regulation, with the responsibility and accountability for the decisions that are made (Kabat et al, 2003a,b). In state-led planning systems interfaces between the three entities are less complex; one boundary organization might be enough. However, in multi-layered water management governance systems you have to deal with national, regional and local levels of government. In these circumstances co-operation between many regional boundary organizations in combination with a national or a transboundary river catchment boundary organization is necessary. This will increase complexity due to upscaling and downscaling issues on both the scientific level and societal levels (problem shifting).

The scientists working on this subject are from a myriad of disciplines: climate sciences, hydrology, and governance studies to name but a few. Within the same discipline different paradigms may exist. In addition, each country has its own design of scientific networks that may include universities, research programmes, applied research institutes and bodies that take care of review and scientific quality. Cultural aspects and even law determine the character of these networks and the attitude of scientists towards policy makers and their willingness to participate in these type of boundary organisations.

Each individual is an element of society; however, it is clear that it is impossible that each individual can participate in a boundary organisation. Selection of societal representatives within a boundary organisation is therefore an important but also difficult step within the design phase due to the political dimension, especially in state-led planning systems. This is, for example, exemplified in the case study of Thailand (Lebel et al., 2009), where the empowerment of local communities in water management and disaster reduction policies is called for.

It is therefore important to take into account the historical context and user characteristics of existing policy institutions, societal governance networks and scientific infrastructure that are already in place and need to co-operate within the boundary organisation. The designer should be aware of the initial objectives of the involved institutions, how these organizations currently deal with uncertainty, how they frame climate-proofing, how they deal with dissent opinions and their familiarity with stakeholder participation. These initial settings will differ from region to region. In African countries, water management is more organised in informal institutions than in Europe or USA. In addition, economical settings, and the influence of economic sectors (agriculture, multi-nationals, services, etc.) on policies and their climate sensitivity differ.

4.4 CONCLUSIONS

Climate-proofing can be seen as adaptation trajectories, (cyclic) operational steps towards achieving a progressively more and more protected society by increasing the resilience and adaptive capacity of both the physical and societal system in question. Developing visions on climate-proofing and 'adaptation trajectories' to respond to climate change is strongly recommended. Within the climate-proofing approach - primarily, though not exclusively - normative methodologies for exploring the future are used in the phase of vision building. After vision building practical test cases (learning by doing) are initiated, followed by an evaluation phase. This evaluation phase of adaptation strategies is supported by formal quantitative scenario methods and decision support systems. The use of formal scenario methods in a later stage of the decision-making process is different from the current approach in water management and climate policy.

In most cases, the dilemmas for scientists and policy makers (figure 4.1) within the decision-making pathway of water management can be boiled down to choices between the 'adaptive management paradigm' and the 'foundational water management paradigm'. In practice a mixture of individual scientists and policy makers is involved in the decision-making process. As a result, a mixture of proactive and conservative arguments from both paradigms is used, relevant to each region, country, or catchment. The individuals (or institutes) that take leadership within the policy-science interface will strongly influence the choices in response to the described dilemmas (figure 4.1). The definition of climate-proofing depends on whether the local or national situation of the decision-making process is dominated by people using the 'adaptive management paradigm' or the 'foundational water management paradigm'. The need for climate-proofing is acknowledged in both existing paradigms but will lead to different risk thresholds.

Our described preferred climate-proofing approach is mostly in line with the adaptive management paradigm and can be seen as an explicit example of this paradigm. While it is not a new planning paradigm, it does build upon existing theories regarding decision making under uncertainty.

The conceptualization of 'climate-proofing' is a process of joint-learning, where some expert and policy communities are taking the lead in this process, while others are still struggling. Training and educating both scientists and water professionals is therefore important in order to select and use the most appropriate decision support tools, such as (tailored) climate scenarios (Jacob & Van den Hurk, 2009; van den Hurk & Jacob, 2009) . In addition, training of water professionals, scientists, and other representatives of society with the intention to design tailor-made boundary organisations is vital. However, it should be kept in mind that no blueprint exists for a catchment or a region. The successes of boundary

organisations are usually judged upon credibility, legitimacy and social relevancy (Tuinstra, 2006). It is therefore important to take the historical context and user characteristics of existing policy and scientific networks already in place into account. Finally, it is important to design a knowledge transfer procedure and decision support tools where water managers can identify the effectiveness of adaptation strategies for themselves in dialogue with climate scientists, rather than providing information on costs and benefits beforehand. The entity that is responsible for the evaluation and the selection of the decision support tools is preferably a boundary organisation between science, policy, and society.

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5



Picture: Kreekrak Sluices in the Rhine-Scheldt Canal (Jeroen Veraart, 2010).

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

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).The online version of this article contains supplementary material in this dissertation this material is presented in Annex B.

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5 SCIENTIFIC KNOWLEDGE USE AND ADDRESSING UNCERTAINTIES ABOUT CLIMATE CHANGE AND ECOSYSTEM FUNCTIONING IN THE RHINE-MEUSE-SCHELDT ESTUARIES

5.1 INTRODUCTION

The impacts of climate change on freshwater resources are becoming noticeable in many parts of the world (IPCC, 2014c). 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 & Termeer, 2015; Kabat et al., 2009; Kabat et al., 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 & 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 & 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 (Berkhout et al., 2013; Jeuken et al., 2015; 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 ask who should be involved in research, decision making, financing and implementation (Gupta et al., 2010; Termeer et al., 2012; Veraart et al., 2014a). 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 & 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 among 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.

5.2 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 & 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 & Wolf, 2010; O'Brien et al., 2007). Research usability also depends on the context of potential use and on the process of scientific knowledge production itself.

Methodology

The presented analysis is mostly based on qualitative research methods but also has quantitative elements. The methodological design of this research (figure 5-1) builds on a case study approach (Flyvbjerg, 2006; Ford et al., 2010; Yin, 2012, 2009). 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).

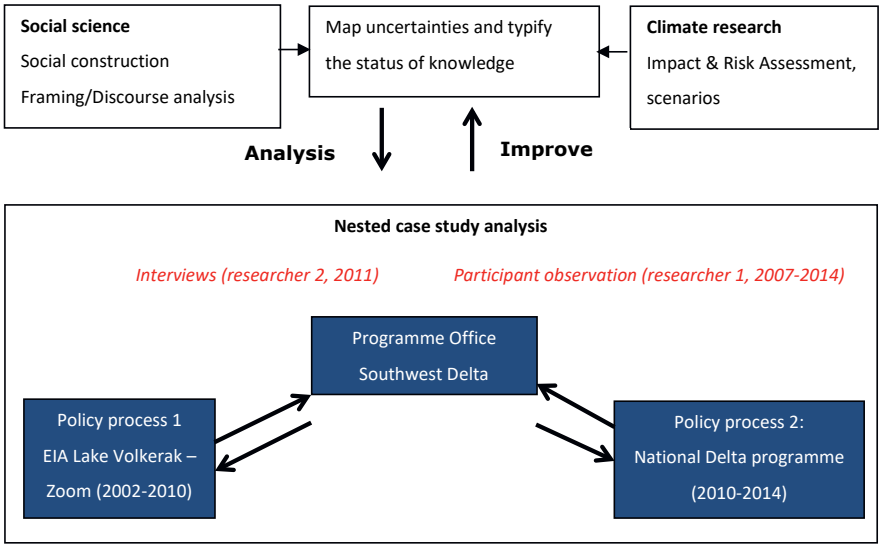


***Figure 5-1**, overall methodological design of this study.*

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 Southwest Delta was involved (figure 5-1).

Participant observation in Programme Office Southwest Delta (Data collection)

The principal investigator participated in 20 stakeholder meetings (2007-2011) organized by the Programme Office Southwest Delta (programme office SWD), and his role could be described as peripheral 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 freshwater resources management and coastal safety. In this period his role could be described as participant observant (Atkinson & Hammersley, 1994) with an active membership role (Adler & 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 & 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[6].

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 5-1). The respondents were selected from participant lists of public consultation evenings and stakeholder meetings in which the programme office SWD was involved.

[6] See also supplementary material (Annex B).

Table 5-1, *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

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 (figure 5.1). 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.

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 (Klostermann et al., 2013), analysis of policy and research reports (Veraart & 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 5-2) 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.

***Table 5-2**, 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*
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
Saltwater 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

* This was answered by every respondent as it was a specific interview question (see Annex B)

Classifying knowledge (analysis)

Subsequently we explored how the status of the scientific knowledge could be characterized for each theme (table 5-2). The following labels are used: **negotiated, disputed** and **uncertain** (table 5-3). 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 & Bos-Gorter, 2006; Klostermann et al., 2013)

***Table 5-3**, 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)

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 & Klijn, 2004). We explore problem-solution combinations because it is difficult to debate a wicked problem without judging the possible solutions (de Bruijn & ten Heuvelhof, 1999).

Knowledge can also be *disputed* between or among 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 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; Te 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 & Cramer, 2007). We are interested in how people respond to these broad qualifications regarding the status of knowledge.

5.3 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 figure 5-1.

Rhine-Meuse-Scheldt Estuaries

In the case study area (figure 5-2), 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 & Broekhans, 2015; Maris et al., 1956; Stuvel H.J., 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 & 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).

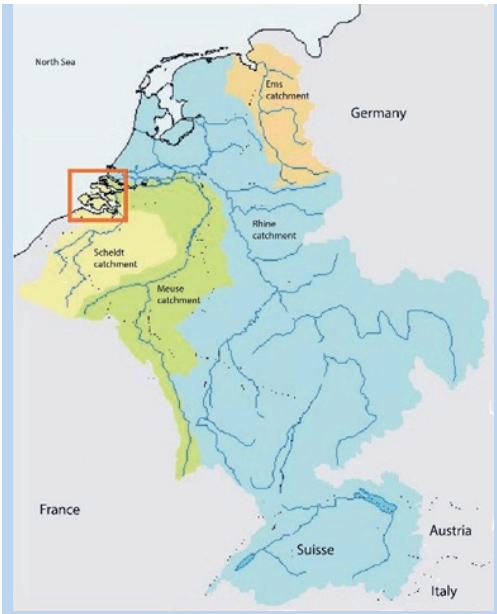
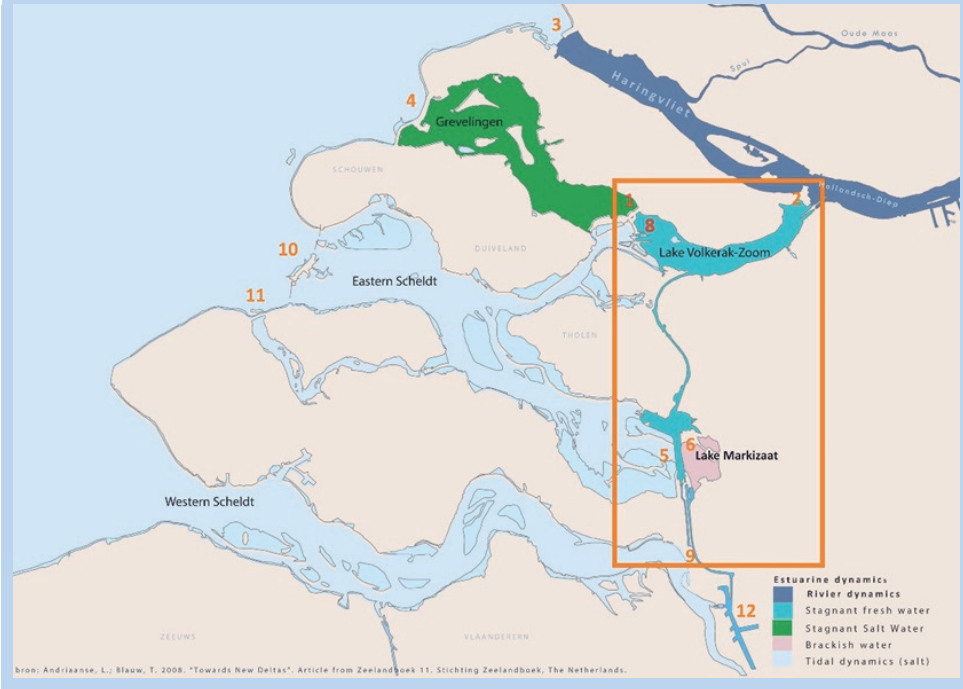


Figure 5-2, *Rhine-Meuse-Scheldt Catchments (left) with a cutout of the estuaries in the southwestern part of the Netherlands (below). Numbers: 1. Grevelingendam, 2. Volkerakdam, 3. Haringvlietsluizen, 4. Brouwersdam, 5. Oesterdam, 6. Markiezaatkade, 7. Zandkreekdam, 8. Philipsdam, 9. Bathse Spuisluis,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



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 & 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 & Boute, 1997). Several measures were taken to combat the algal blooms (Meijer & 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 (figure 5-3).

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[7] 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 & 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

[7] 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).

strategy (Staf Deltacommissaris, 2014). The program 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).

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 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 & Termeer, 2015), inspired by national climate research programmes (Veraart et al., 2014a) 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).

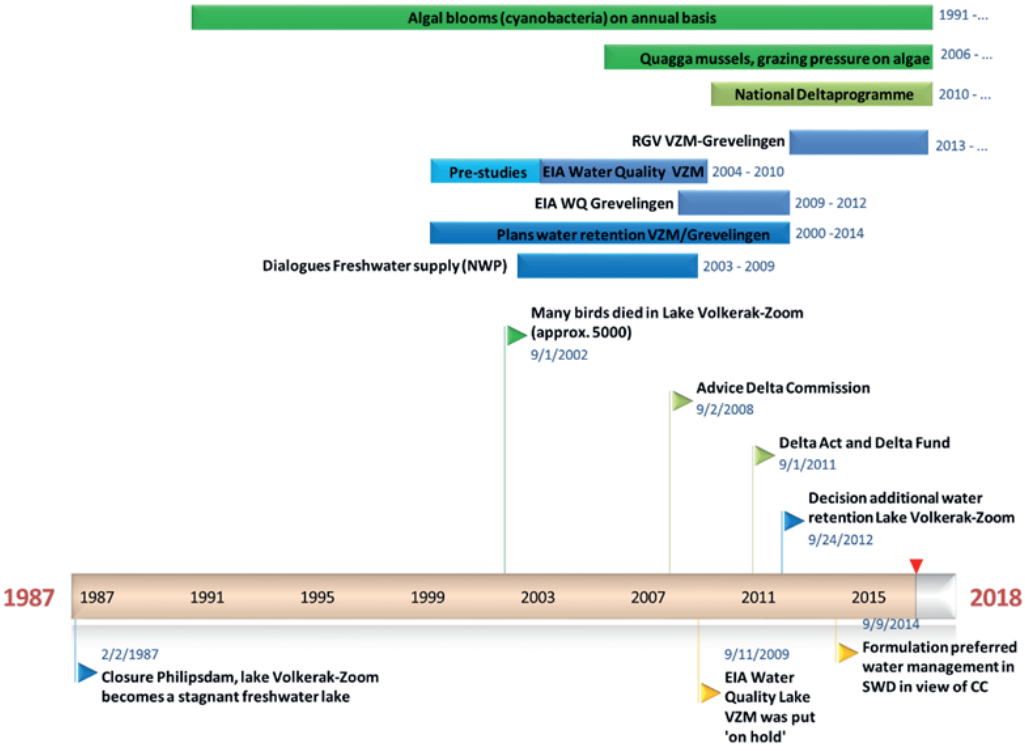


***Figure 5-3**, Timeline of analysed planning processes. The dark green rows are ecological changes within Lake Volkerak-Zoom, while the blue rows describe the responses in planning and policy processes, the light green rows represent the response to climate adaptation. The two yellow flags represent 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.*

5.4 MAPPING UNCERTAINTIES: RESULTS

5.4.1 ADDRESSED UNCERTAINTIES AND CLASSIFICATION OF KNOWLEDGE

Table 5-4 presents the knowledge status per theme per period. The text below explains the basis for this qualification.

***Table 5-4**, 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
Saltwater 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

Respondents' definitions for freshwater and saline water

Because of the frequent use of the term's '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 5-5). 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.

***Table 5-5**, 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 (Klostermann et al., 2013).*

Used expressions and comparisons to qualify fresh and salt water	Water management/policy	Water users (agri & drink.)	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

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 to 600 mg/l. Four respondents define 'saline water' as sea water with a chloride concentration of 18000 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).

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 [8]*: "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 et al., 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 & van Tuinen, 2011; de Vries et al., 2009; de Vries et al., 2010; Witteveen en Bos, 2010, 2005) and associated costs (Rijk et al., 2009). The outcomes were frequently disputed in 2009-2010.

[8] 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.

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[9] 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)"

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).

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 [10] 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 5-5). 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; de Vries et al., 2012; Schipper et al., 2014a; Schipper et al., 2014b). The research findings were discussed within the network of the SWD programme office. Similar uncertainties were raised as during

[9] This interview was done in the summer of 2011.
[10] 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.

the EIA procedure (table 5-5). 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 5-3). Table 5-6 illustrates that on sub-topics or specific research issues nuances exist.

***Table 5-6**, 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:(Klijn et al., 2012; Klijn et al., 2011)
Model assessments regarding saltwater intrusion to bordering water systems (Δ Chloride concentration in surface water)	disputed	uncertain	Disputed: (Beijk, 2008; de Vries et al., 2008; van Pagee et al., 2009) Uncertain: (Spijker & van den Brink, 2013; Uittenbogaard et al., 2015)
Chloride requirements water users near lake Volkerak-Zoom	disputed	uncertain	Disputed:(Stuyt et al., 2005) Uncertain: (Schipper et al., 2014a; Schipper et al., 2014b)
Estimations of current regional freshwater demand, in particular for irrigation (mm in growing season)	disputed	uncertain	Disputed: (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 & Van Tuinen, 2012; Visser & Van Hoorn, 2012) Negotiated: (Baltissen et al., 2014)
Significance of impact of climate change on (agricultural) water demand around lake Volkerak-Zoom	Disputed	uncertain	Disputed:(de Vries et al., 2009) Uncertain: (Schipper et al., 2014a; Schipper et al., 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; Schipper et al., 2014b; van Rhee, 2012)
Overall conclusion	**Disputed**	**Uncertain**	

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 (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.

Saltwater 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 Antwerp's 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 & 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 saltwater 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 5-3). 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.

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 saltwater system with a proper tide, fluctuations in salinity and dynamic water tables" (8:6).

However, discussion continued amongst national and local NGOs 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 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 & 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 & Ministerie van Landbouw Natuur en Voedselkwaliteit, 2014; Spaargaren, 2014).

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 et al., 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, figure 5-2) and Lake Volkerak-Zoom (Grevelingendam, figure 5-2) (Bestuurscommissie MIRT Verkenning Grevelingen, 2010).

The EIA-VZM (2010) concluded that the creation of an inlet in the Philipsdam (figure 5-2) 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.

5.4.2 ADDRESSING UNCERTAINTIES

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 5-7). 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.

***Table 5-7**, 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	+

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 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.

5.5 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 a 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.

5.6 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 4-7) 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 & 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 5-8).

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 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 & van Buuren, 2015; Vink et al., 2013; Zandvoort, 2017).

Table 5-8, *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 with regard to scientific knowledge 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 (saltwater dynamics), (b) ontic uncertainties (climate variability and change) and (c) ambiguity play a role.	(1) 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 5-6) 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	(2) Commissioning research whereby temporarily a protected environment is created to allow research without political interference (example: saltwater 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 policy making.	Most of the mentioned uncertainties within the negotiation arena could be qualified as epistemic.	(3) A monitoring and research programme before and after implementation (example: ecosystem functioning of Lake Volkerak)

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6



Picture: Water pump for irrigation in a ditch at an unknown location in Zeeland (Maurice Veraart, 2015).

Evaluation of Socio-Economic Factors that Determine Adoption of Climate Compatible Freshwater Supply Measures at Farm Level: a Case Study in the Southwest Netherlands

Abstract - The availability of freshwater resources in soil and groundwater bodies in the southwestern part of The Netherlands is expected to decrease during the agricultural growing season because of an expected increase of freshwater demands and a changing climate. This expected shortage of fresh water might negatively affect agricultural production. To cope with this problem, three pilots were initiated aimed at increasing freshwater supply at farm-level. The objective of this paper is to evaluate the socio-economic factors that determine the wider use of the measures investigated in these pilots. Therefore, the results of a feasibility study and a survey about drought risks were compared. The survey indicates that respondents do not make distinction between a dry and extremely dry year in their estimation of the return period. The results of a feasibility study illustrate that confidence and the level of common understanding regarding the reliability of these innovative measures has increased amongst project participants since 2012. The survey respondents were less optimistic about the wider implementation of the investigated technologies. A reliable freshwater supply and supportive legislation are the most decisive socio-economic factors for a future investment in additional freshwater supply for farmers in this region. Both studies illustrate that the impact of additional freshwater supply on farm economics strongly depends on farm type and crop cultivation plan. These insights may support the wider use of these innovations and may help to improve agro-hydrological models.

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6 EVALUATION OF SOCIO-ECONOMIC FACTORS THAT DETERMINE ADOPTION OF CLIMATE COMPATIBLE FRESHWATER SUPPLY MEASURES AT FARM LEVEL: A CASE STUDY IN THE SOUTHWEST NETHERLANDS

6.1 INTRODUCTION

Under average climatic conditions, freshwater supply for Dutch agriculture is excellent. A large part of Dutch agricultural areas can be supplied with water from the rivers (figure 6-1). However, in situations with a low river discharge and a high precipitation deficit, it is possible that the freshwater supply cannot meet agricultural freshwater demand during the growing season. This is particularly true for the rain-fed agricultural areas in the southwestern part of the Netherlands (figure 6-1) that have no access to river water. These agricultural areas, situated below sea level, are also sensitive to saltwater intrusion (Cominelli et al., 2013; de Louw, 2013; de Louw et al., 2011; van Bakel et al., 2009).

The Netherlands usually has a precipitation deficit in summer (average 100mm) and a precipitation surplus in winter. In the coastal zone, the precipitation deficit in spring and early summer is usually larger than in the rest of the country, whereas the situation is reversed in late summer and autumn (van Minnen & Ligtvoet, 2012). The annual cumulative maximum precipitation deficit occurs during the summer half-year from April to September (Beersma & Buishand, 2004).

In the southwest of the Netherlands there are about 5500-6000 farms, of which 50% perform arable farming, 12% horticulture and 6% greenhouse horticulture (CBS & LEI 2014). In 2012, total turnover amounted to some 1.3 billion euro (Visser & Van Tuinen 2012).

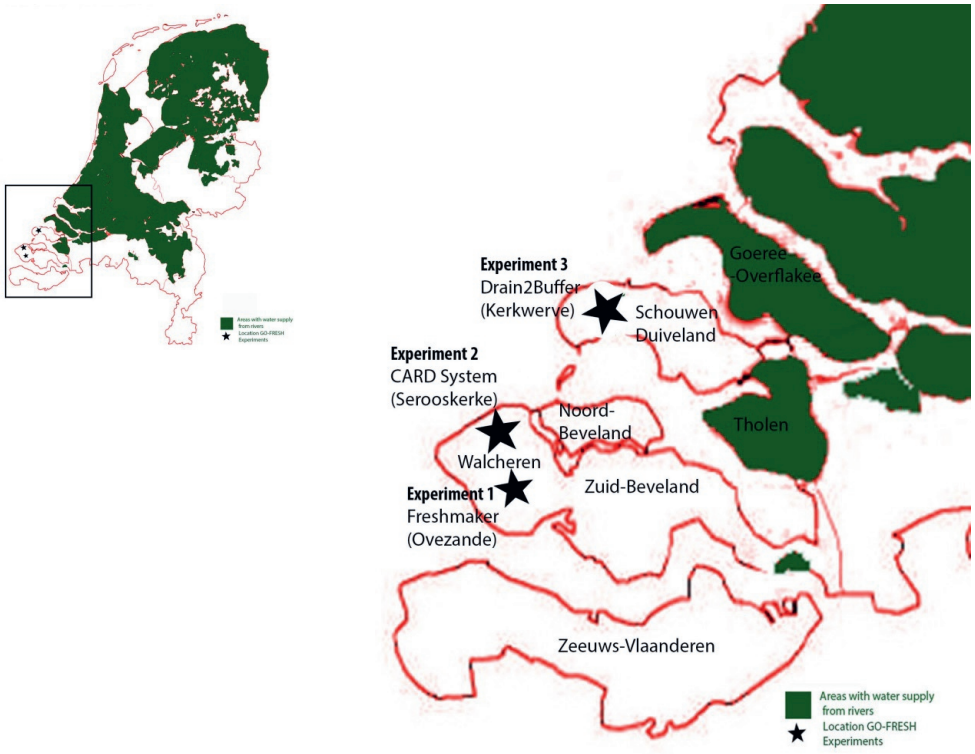

***Figure 6-1**, Freshwater supply areas in the Netherlands (van Minnen & Ligtvoet, 2012). The white areas are dependent on precipitation and groundwater resources and/or artificial water supply (Zeeuws-Vlaanderen). The black stars represent the GO-FRESH experiments.*

The probability of agricultural yield reduction and loss of farm income due to water shortage and salinization in these rain-fed areas is therefore larger than the probability in other regions with an external fresh water supply from rivers. The availability of freshwater resources in soil and groundwater bodies will most likely decrease in southwest Netherlands due to prospective climate change and increasing water demand (Oude Essink et al., 2010).

Other reasons to improve freshwater supply at the farm-level, in this part of the Netherlands, are the expected impact of climate change (Kabat et al., 2009) and of the partial recovery of estuarine dynamics in this region (Hommes et al., 2009; Vinke-de Kruijf et al., 2010).

In practice, the application of a technology to improve freshwater supply at a farm depends on its socio-economic feasibility and the behaviour of the farmer. Within the research program 'Knowledge for Climate' (Jeuken et al. 2012a; Oude Essink et al. 2014) these aspects were investigated in two projects:

The GO-FRESH project, which stands for Geo-hydrological Opportunities Fresh Water Supply consists of three pilots (2011 - 2014) with new technologies to improve freshwater supply at farm level (table 6-1).

***Table 6-1**, Description of the three GO-FRESH experiments.*

Experiment 1 (Freshmaker): This technology is based upon aquifer storage and recovery (ASR) which involves injection and recovery of freshwater in aquifers via vertical abstraction wells. Although ASR is a proven technology(Pyne, 2005), the technique is not yet often used in aquifers in a brackish to saline environment as exemplified in this experiment at a fruit orchard in Ovezande (K.G. Zuurbier et al., 2014; K.G. Zuurbier et al., 2014).
Experiment 2 (**CARD system**, *Controlled Artificial Recharge and Drainage system*) concerns storage and infiltration of freshwater in creek deposits with controlled drainage systems at two farms in Serooskerke (horticulture and arable farming). Also, controlled drainage systems and sub-irrigation are a proven technology (Madramootoo et al., 2007; Stuyt & Dierickx, 2006) but have never been used to infiltrate fresh water into a saline groundwater environment (Pauw et al., 2015).
Experiment 3 (Drains2buffer) involves increasing shallow rainwater lenses with controlled drainage and has been applied at a farm in Schouwen-Duiveland, Kerkwerve (arable farming). The rainwater storage capacity of the subsurface is increased by drainage of brackish to saline groundwater. This is achieved by positioning the drainage pipes deeper and closer to each other as compared to conventional drainage designs (Oude Essink et al., 2014). The technology is also applied in the North of the Netherlands within the project Spaarwater (ACACIA Water, 2014; Velstra et al., 2011).

Moreover, the project also contains a so-called feasibility study to select criteria for the socio-economic feasibility of the kind of technologies applied in the pilots. It concerns technologies that buffer winter precipitation surplus in soil and groundwater bodies to be used in summer. By applying this technology, farms become better equipped to cope with precipitation deficits in summer. In each pilot, drainage, infiltration, and abstraction technologies, known from geo-hydrological and agricultural engineering, are combined. The pilots are currently still in an experimental stage. The GO-FRESH project participants have worked together for three years (2011-2014).

Within the project 'Balancing supply and demand of freshwater', a survey was conducted in the southwest of the Netherlands to elicit farmers 'risk perceptions and adaptive behaviour to drought (van Duinen et al., 2015; van Duinen et al., 2014). The survey analyses the attitude of potential users of the new technologies with respect to the feasibility of drought mitigation measures over time at a certain moment (Spring 2013). The survey was conducted amongst agricultural entrepreneurs in the same region where the pilots were initiated (southwest Netherlands).

This paper focuses on socio-economic feasibility. Results of both studies are compared to assess how experts, farmers and policy makers evaluate environmental, socioeconomic, and behavioural factors that determine the wider use of water supply technologies at farm level.

6.2 THEORETICAL FRAMEWORK

Adoption of technologies

New technologies spread gradually, reflecting heterogeneity among potential adopters, processes of learning, technological improvement and socio-economic conditions (Rogers, 2003; Vreugdenhil et al., 2012). Several studies stemming from various scientific disciplines (Bouma et al., 2011; Kiparsky et al., 2013; Ortt et al., 2008) highlight the importance of economic, behavioural, institutional, and social factors in the adoption of innovations in various sectors, including the water management (Nji & Fonteh, 2002; Vreugdenhil et al., 2012; Vreugdenhil et al., 2010a; Vreugdenhil et al., 2010b) and climate adaptation science (Bolson & Broad, 2013; Zilberman et al., 2012).

Adaptation to climate change can be defined in many ways (Fankhauser & Schmidt-Traub, 2011; IPCC, 2007; Nelson et al., 2007). We choose a definition suggested by Zilberman et al. (2012) where adaptation is defined as a response of economic agents and societies to environmental (climate adaptation) or political and socio-economic changes. Given the inherent uncertainties (Swart et al., 2009), decision making at farm level about adaptation strategies could be defined as a risk management strategy.

Application of micro-economic theory to study the adoption of farm technology, suggests that expected costs and benefits as well as risk aversion are important drivers of farmers' decision-making when facing risks (Just & Zilberman, 1983; Liu, 2013; Serra et al., 2008; van Duinen et al., 2014).

Typically, these studies assume perfectly rational decision-making in which agents form expectations based on perfect information on the probabilities and potential damages related to extreme weather conditions.

While economic factors are important, it becomes increasingly recognized that decision-making in a risk context is seldom perfectly rational and that behavioural factors such as risk perception along with perceived costs, benefits and self-efficacy affect individual adaptive decision-making (Dang et al., 2014; Gebrehiwot & van der Veen, 2015; Grothmann & Patt, 2005; Liu, 2013; Pidgeon & Fischhoff, 2011; Schwarz & Ernst, 2009). Research shows, for example, that farmers' drought risk perceptions are biased due to drought risk

experience, perceived behavioural control and social networks (Tang J. et al., 2013; van Duinen et al., 2015; Wheeler et al., 2013). Biased risk perceptions could give rise to risky behaviour or excessively protective behaviour.

Due to these behavioural factors and imperfect knowledge, farmers, water managers and the developers of a technology might perceive the socio-economic feasibility of an innovative technology differently (de Boer et al., 2010). Also, differences in perceptions regarding crop yield reduction risks may play a role in choices of farmers (Lavee, 2010; van Duinen et al., 2012) regarding investments in local freshwater supply technologies. Biases in the perceptions of risks (de Boer et al., 2010), costs (Klostermann et al., 2013) and uncertainties about the effectiveness of measures to improve freshwater supply (Lavee, 2010), may hamper the adoption and diffusion of these technologies.

6.3 RESEARCH APPROACH

Results from the feasibility and survey studies are combined and compared. Both studies tried to assess attitudes towards innovations in fresh water supply at the farm-level in the southwestern Netherlands in view of climate change, in absence of sufficient empirical data on hydrological efficiency and crop yield of the applied technologies. The quantification of some of the socio-economic factors was meant to discuss the impact of assumptions. It was not the objective to compare the feasibility of the three technologies.

As the study subject and its context are similar, a case study approach (Flyvbjerg, 2006; Yin, 2012, 2009) is chosen to synthesize the results. It has to be taken into account that the studies were conducted in different ways.

6.3.1 APPROACH FEASIBILITY STUDY

The feasibility study was conducted between 2011 and 2014 and included active membership (Adler & Adler, 1987; Atkinson & Hammersley, 1994) within a project team of about 20 people that consisted of technical experts, farmers, civil servants and some students (table 6-2).

Selection of feasibility criteria

A wide array of criteria can be typified as relevant for the evaluation of the socio-economic feasibility of the investigated technologies. The criteria were identified through discussions with the project participants (table 6-2) in workshops and interviews (Oude Essink et al., 2014).

***Table 6-2**, actors directly involved in the experiments.*

Funding bodies / regional authorities	Technical Experts	Target group for the innovation	Knowledge transfer / socio-economic conditions
Province of Zeeland	Deltares	Meeuwse Trading	HZ University of Applied Sciences
STOWA (Acronym for Foundation for Applied Water Research, founded by Dutch Water boards)	KWR Water	Fruit Cultivation firm (user technology 1)	ZLTO (Dutch agricultural interests association)
Water Board Scheldestromen	ACACIA Water	Arable farmer (user technology 2)	Alterra
Foundation "Knowledge for Climate"		Horticulture (user technology 2)	
Municipality Schouwen-Duiveland		Arable farmer (user technology 3)	
ZLTO (Dutch agricultural interests association)			

All selected criteria were evaluated in a qualitative way. In addition, for all three experiments, the criteria directly related to the profitability at farm level were evaluated quantitatively.

6.3.2 ASSESSMENT OF COSTS AND BENEFITS OF THE TECHNOLOGY AT FARM LEVEL

For each technology (CARD, Drain2buffer, FRESHMAKER), the expected net revenue of additional fresh water supply was estimated for two scenarios (table 6-3). In the first scenario, the crop production plan has remained unchanged, while in the second scenario the crop production plan also has been altered to include more profitable crops. In the examples of arable farming, sugar beets were replaced by cauliflower. At the fruit company, on 25% of the plots apples were replaced by pears (table 6-3).

***Table 6-3**, Farm properties used in the calculations.*

Farm properties	Fruit farm	Arable farm 1 (Sanderse)	Arable farm 2 (Van den Hoek)
Applied technology	FRESMAKER	CARD	DRAIN2BUFFER
Farm size (ha)	15	25	75
Scenario 1: additional freshwater supply	75% Elstar Apples, 25% Conference Pears	Potatoes (25%), unions (25%), sugar beets (25%), winter wheat (25%)	
Scenario 2: Additional freshwater supply and an altered crop production plan	50% Elstar Apples, 50% Conference Pears	Potatoes (25%), unions (25%), winter wheat (25% and 25% cauliflower	

The estimated net revenue reflects the difference between the scenario and the reference situation, i.e. the situation without additional freshwater supply and baseline crop production plan. In the calculations no distinction is made between crop yield reduction caused by drought or by salinity. It is assumed that water nuisance damage is similar and minimized in all scenarios. Moreover (expected) long-term developments on the agricultural market and dynamics in market prices are not taken into account.

The applied farm sizes were the actual farm sizes where the experiments were applied. The applied crop production plans (arable farm 1, fruit farm) are representative for arable farming and fruit cultivation in this area in the Netherlands. The crop production plan of the farm in the DRAIN2BUFFER experiment was not applied because it included crops for which the required data were not available (spinach seed, grass seed).

Assumptions to address agro-hydrological uncertainties

It was assumed that application of a technology results in an additional freshwater supply of 100mm, available for irrigation (FRESHMAKER, CARD) or as soil moisture (DRAINS2BUFFER). This irrigation gift quantity is representative for an average (moderately) dry year (table 6-4). It is assumed that the three technologies have an equal and modest hydrological performance.

Table 6-4, *Characteristics of drought years that are used in national hydrological studies in the Netherlands (Klijn et al., 2010).*

	Precipitation deficit	Return period (as used in Dutch models)(Klijn et al., 2011; Klijn et al., 2010)	Relative yield reduction (as used in Dutch models) (Jeuken et al., 2012)	Irrigation gift (as used in Dutch models)(Massop et al., 2013; Stuyt et al., 2005)
Average dry year (1967)	151	2.5	6%	100
Moderately dry year (1996)	199	6.7	?	?
Dry year (1949)	220	10	10%	144
Extremely dry year (1976)	360	100	24%	>200

Yield calculations: arable farms

For the reference situation (without additional freshwater supply), the figures of the gross production and the gross revenue per hectare for a specific crop were based upon the average yields (kg) and average prices (€/kg, VAT included) in the period 2007-2011 in the Netherlands (PPO Wageningen UR, 2012). The gross revenue per hectare was calculated by subtracting material costs (fertilizers, pesticides, energy use, etc.) and the costs of hired labour from the gross production multiplied by the weighted average price/kg (table 6-5). The gross revenue is the reward for the input of capital, land and (the farmers own) labour.

With respect to the supply of additional fresh water, it is assumed that, for all selected crops, a supply of 100 mm water increases the yield between 6% and 10% as compared to the reference situation (in the current Dutch climatic conditions). The assumed sensitivity to drought, therefore, is relatively small. Among the most drought-sensitive crops are summer vegetables, leafy vegetables, flower bulbs, fruit, and tree crops. The potential gross yield of these crops might decrease by 9 to 38% due to drought stress (Brouwer & Huinink, 2002; Stuyt et al., 2005).

The difference between the reference situation and the situation with additional freshwater supply (scenario 1) and/or changed production plan (scenario 2), represents drought damage for up to a moderate dry year (table 6-4).

Yield calculations: fruit firms

The difference between the measured averages of the 5-year physical yields (Heijerman-Peppelman & Roelofs, 2010) of Elstar Apples (16%) and Conference Pears (22%) with and without irrigation was used to estimate the effect of an additional freshwater supply of 100 mm (table 6-5). The net revenue of additional freshwater supply was calculated for the situation in which fruit trees are fully established and at full production. Apples and pears need respectively 4 and 6 years to achieve full production (table 6-5) (Kipp, 1992).

***Table 6-5**, Estimated gross revenue per hectare of the crops within the crop rotation plans as used in the scenario's regarding (additional) water supply and changes in crop rotation.*

	No additional water supply	With additional water supply			
Assumed yield increase	**0%**	**6%**	**10%**	**16 %**	**22%**
Source: (PPO Wageningen UR, 2012)				(Heijerman-Peppelman & Roelofs, 2010)	
	Gross revenue (€ ha^{-1})				
Potatoes (consumption)	4011	4277	4573		
Winter wheat	1147	1112	1198		
Cauliflower	5216	5541	5893		
Sugar beet	1729	1770	1912		
Sowing union	3801	4050	4346		
Elstar apple	1444			2379	
Conference pear	7329				10972

Cost calculations (fruit and arable farming)

The investment costs were estimated from the costs incurred during the construction of the experimental sites. The technical lifetime for all techniques used is set at 15 years to assess the annual depreciation.

Annual maintenance, energy and legislation costs are an important uncertainty, as the evaluated techniques have not yet been applied at a large scale. Estimations were made based upon a recent inventory of costs within the Netherlands (Tolk, 2013) and cost estimations that were made during the course of the experiments by involved actors.

Net revenue

In both cases the net revenue is determined as the product of the gross revenue for each crop and the corresponding crop surfaces minus the annual costs of the innovation. The annual costs of an innovation consist of the investment, maintenance, and legislation costs. The costs of water supply (i.e. the use of the innovation) are accounted for in the yield calculations.

At present, the uncertainties in the costs and benefits for these three new technologies are still too large to calculate a net present value in a meaningful way with a discount rate. The cost calculations take into account an average inflation of 2.5% over the entire lifespan of the investment.

6.3.3 RESEARCH APPROACH SURVEY STUDY

To elicit farmers' perceptions of drought risks and attitudes towards adaptive measures, a survey was conducted among 1474 members of a Dutch agricultural organization (division South, ZLTO) during January and February of 2013. TNS-NIPO, a professional organization in the Netherlands specializing in data collection using questionnaires (TNS-NIPO, 2014), supported the survey design, web-application, and communication with respondents.

Some of the survey results (van Duinen et al., 2015) are further explored to examine how the results agree with or differ from the experiences in the GO-FRESH project.

The survey was pre-tested in 12 interviews. After the pre-test, redundant questions were removed, and unclear questions were reformulated. Survey requests and reminders were sent by email and by mail (Goeree Overflakkee) with the invitation to participate (online or by post). The 1474 survey requests, elicited 142 replies (response rate 9%) (van Duinen et al., 2015).

With small samples, response bias may pose a danger. To check the representativeness of the sample, age, education, farm size, farm type and access to an external water supply of the respondents were compared to those of the population in general using data from CBS Statistics Netherlands.

On average, farmers in the sample were slightly younger and better educated than the overall population they were thought to represent, but the differences were found to be small (van Duinen et al., 2015). In the survey, arable farmers (81% compared to 70%) and those growing fruit and flowers were over-represented compared to farmers growing grass and corn (12% compared to 26% of the actual population). Consequently, the response rate was higher for those farms that are more susceptible for drought.

6.4 FEASIBILITY STUDY: RESULTS AND DISCUSSION

Table 6-6 illustrates the socio-economic factors, which were considered to be important for the feasibility by the GO-FRESH participants.

***Table 6-6**, Overview of identified socio-economic factors within the GO-FRESH project team.*

	Involved Technical Experts	Involved Farmers & Drainage constructors	Regional authorities in water management & policy
Hydrological performance (additional water m^3 for irrigation)	Important, assumed to be significant, quantification is subject of research	Important, promising	Important, but also an uncertainty
Reliability & risk reduction	- Minimizing drought & salt damage risks - climate proof	- reliable water supply - climate proof	- Food security - Self-sufficient Freshwater supply - climate proof
Legislation	Minimize complexity	Minimize complexity	Necessary, but complexity is acknowledged.
Farm economics	- cost-benefit analysis at farm level (Δ€ ha^{-1} yr^{-1}) - Revenue analysis (Δ€ ha-1 yr-1) - Cost effectiveness (€ m^{-3}) - Investment return (yr)	Cost effectiveness (€ m^{-3})	cost-benefit analysis for agricultural sector (Δ€ ha^{-1} yr^{-1})
Ease of use	Not mentioned	Important	Not mentioned
Regional Environmental Impact	Water quality	What legislation permits	Water quality Ecology
Regional Economic Impact	Cost-benefit analysis for agricultural sector	Competitive advantages / co-operative freshwater supply	Fair distribution of cost & benefits of water supply

Discussion of hydrological performance

All participants involved (table 6-2) were convinced that the hydrological performance of additional freshwater supply at the farm level is an important criterion for the adoption of the three studied technologies at a larger scale. The actors use the same indicator (additional freshwater supply expressed in m^3 or mm).

In the initial phase, regional authorities had doubts about the hydrological performance of the three experiments. This was because of their experiences with previous comparable experiments (Projectgroep Zoetwateronderzoek, 1986; van Meerten, 1986; Vermaas, 1987) with disappointing results. However, during the implementation of the results of the

experiments, the farmers, researchers, and policy makers involved became more convinced that the technologies are promising, despite uncertainties regarding their hydrological performance.

Field measurements also indicate that a significant and promising amount of freshwater was buffered in the subsurface in all three experiments (table 6-7). This is also partly explained by the high winter precipitation surplus of 2013 (345 mm). Follow-up research (2015-2016) is scheduled for all 3 experiments to assess how the technologies perform under different weather conditions.

***Table 6-7**, Hydrological performance in the three pilot areas.*

	Irrigation requirement in a moderate dry year (100 mm)	Estimated hydrological performance	Development time of subsurface water buffer
CARD System Serooskerke (25 ha) (Pauw et al., 2015)	25.000 m3	190000 M^3 Recharge after 10 years	10 years
Drains2Buffer Kerkwerve (75 ha)(Oude Essink et al., 2014)	75.000 m3	300000 M^3	4-5 years
FRESHMAKER Ovezande Fruit Farm (15 ha)(K.G. Zuurbier et al., 2014)	15.000 m^3	1700 – 3000 m^3 successfully infiltrated and recovered for irrigation in one season.	1 season

To implement the CARD-system, a 7-ha area was used and the development of the freshwater lens below this farm concerned (25ha) and the neighbouring farm (11 ha) was monitored from May 2013 to May 2014. The application of the technology is beneficial to the increase of the size of the entire freshwater lens under both farms.

Both farms have facilities (deep drains) to extract (irrigation) water from the lens.

The models applied predicted a total volumetric increase of the freshwater lens of about 190,000 m^3 after 10 years (Pauw et al., 2015). This implicates that after 1-2 years enough water is present in the sub-surface for 100 mm irrigation gift as assumed in the feasibility study. For the Freshmaker technology, model calculations showed that after 2 years it becomes possible to annually recover 4200 m^3 from the subsurface (K.G. Zuurbier et al., 2014). For this specific fruit farm in Ovezande the additional freshwater supply created is sufficient for a moderate dry summer.

At first glance the additional water supply (4000 m3) does not meet the water demand (15000 m3). However, in addition to sub surface storage (Freshmaker), this farm has a

water basin (4500 m3). Rainwater is collected in winter. In case of water scarcity in spring or summer the basin can be re-filled with surface water, provided that the salinity is not too high. In case the salinity of the surface water is too high (summer), the basin can be re-filled with the additional water from the Freshmaker. In this specific example, the feasibility of the Freshwater technology benefitted from the presence of surface water and a water basin.

For the DRAIN2BUFFER technology, the first field measurements show that the drainage system performs better than the old drainage system. However, it was not yet possible to determine whether the freshwater lens in the field had increased significantly. Model calculations indicate that a maximum equilibrium of the freshwater lens can be reached in 4-5 years (Oude Essink et al., 2014). If the technology would be applied to the surface area of the farm, it would result in an increase of 300.000 m^3 freshwater. In theory, this will be sufficient to present an irrigation gift of 100 mm in the growing season in a moderate dry summer.

Reliability & risk reduction

The technical experts involved frequently used the reduction of drought and salt damage risks as an argument to apply the technologies. The farmers involved on the other hand, stressed the importance of reliability of freshwater supply. Only secondly, drought or salt damage risks were mentioned by the farmers. The farmers also asked the experts for guarantees on the hydrological performance of the technologies.

Legislation

The current legislation aims to reduce the environmental impact of large-scale withdrawals and infiltration of fresh water on the supplies of drinking water. All GO-FRESH participants agree that current legislation is not suited for small-scale applications of the three experiments.

Different regional authorities are in charge of the implementation (water board, municipality, province), while national authorities are responsible for the formulation of the quality standards for the water to be infiltrated. The regional authorities are cautious granting licenses in this early stage of technology development because the environmental impact of large-scale application at more farms in a region is unknown to them.

The level of juridical complexity is different for each technology. The use of the Freshmaker, for example, requires 5 licences for construction (bore holes), infiltration, withdrawal, discharge of brackish water into surface water and withdrawal of freshwater for irrigation. In addition, water quality monitoring is required for infiltration of freshwater and discharges

of brackish groundwater into surface water. The application of the CARD and Drains2Buffer require less legislation and associated costs (Zuurbier et al., 2015).

Licenses include water quality standards and limits regarding the volume that is infiltrated or extracted. Monitoring activities are costs for the farmer. Permissions are an agreement between water manager and a farmer that a certain activity is allowed (no costs involved).

Farm economics

All actors involved agree that the application of the technologies should, in the end, result in a benefit for the agricultural firm involved. However, different socio-economic indicators are used to assess the added value. Socio-economic indicators mentioned are the net revenue for farmers (Δ€ $ha^{-1}yr^{-1}$) based upon the enumeration of costs and benefits at farm level, cost effectiveness (€ m^{-3}) and the investment return time (years). There was no agreement about what indicator to use preferentially. Although identical terms were used for the identified indicators, sometimes for the participants definitions implicitly are slightly different. For example, the cost-effectiveness of various technologies has been often discussed without information about the hydrological performance of each of the three technologies.

Table 6-8 presents the calculated economic indicators for the hypothetical firms with arable farming, horticulture, and fruit cultivation for different scenarios regarding technology use and crop choice.

***Table 6-8**, Economic impacts of additional freshwater supply with applied new technologies (scenario 1) and changed crop rotation (scenario 2).*

Socio-economic indicators	Fruit Farm (15 ha)	Arable farm (25 ha)	Arable farm (75 ha)
Applied technology	**Aquifer storage & recovery (ASR) / Fresh maker**	**Storage in creek deposits**	**Storage in rainwater lenses**
Investment costs *(euro)* *(derived from pilot costs)*	56250	50000	187500
Annual costs technology* (euro)	6050 – 12.200	6500 - 7400	16600-16800
Annual cost/ha technology *(€ ha^{-1})*	400-800	260-300	220-225
Scenario 1: additional freshwater supply (technology use)			
Net revenue farmer *(Δ 10^3 € ha^{-1} yr^{-1})*	0.8-1.2	-0.10 – 0.17 (6%) 0.03 - 0.07 (10%)	-0.1 (6%) 0.1 (10%)
Scenario 2: additional freshwater supply and changed crop rotation			
Net revenue farmer *(Δ 10^3 € ha^{-1} yr^{-1})*	3.0-3.4	0.07-0.08 (6%) 1.0 -1.1 (10%)	0.9 (6%) 1.1 (10%)

* Based upon a technical lifetime of 15 years.

Discussion of addressed cost indicators

The calculated cost indicators for the DRAIN2BUFFER and CARD are within the same range as mentioned in other studies (50-500 € ha^{-1}), while the estimated costs for Freshmaker application are relatively low compared to other studies (700 – 2400 € ha^{-1}) (Tolk, 2013). Maintenance, energy use and legislation costs remain important uncertainties.

Differences in assumptions about investment costs have a low impact on the calculation of the net revenue because they are spread out over a 15-year period in the annual costs (depreciation). It should also be taken into account that farmers will compare the annual costs of additional freshwater supply with other investment options that may increase or maintain yield or farm income, such as crop management, pest management or harvest technologies (Kanellopoulos et al., 2014; Schaap et al., 2013).

Discussion of net revenues in arable farming

The results indicate that the application of additional fresh water supply (scenario 1) mitigates drought damage (net revenue ≈ 0) in moderate dry years, given the selected crop production plans for arable farming. At the fruit farm, additional the freshwater supply results into a modest revenue increase.

Scenario 2 illustrates that the net revenue of additional water supply can increase when the crop cultivation plan is simultaneously adapted towards more profitable crops for both type of farms. It should be noted that the design of the crop production plan does not only depend on freshwater availability. For example, pears are also very susceptible to pests and diseases. This risk also has an effect on the decision of a farmer regarding his crop production plan choice.

Ease of use

The participating farmers and ZLTO expressed that the ease of use is an important factor when deciding whether to apply a certain technology or not. More experience is needed before concise statements can be made for a larger group of farmers.

Regional Environmental Impact

Water quality standards for groundwater and surface water are recognized criteria by technical experts, farmers, and policy makers, as reflected in existent monitoring protocols for water supply and storage (table 6-8). In particular, this is true for the Freshmaker project, where it was also subject of research. The Province of Zeeland also stressed the importance of ecological and landscape impacts when the technologies are applied at larger scale.

Regional economic impact

The application of the techniques can increase competitiveness of the agricultural sector in the southwestern Netherlands. However, additional freshwater supplies may also boost freshwater demand at regional level with implications for other water users. The distribution of costs was also brought up as a point of concern. If one farm invests in freshwater storage, the neighbouring farms may profit without sharing costs. Therefore, a regulated freshwater supply with cost sharing via farm co-operations was also considered. This may accelerate the adoption of these technologies and reduce the legislation costs (cost sharing).

6.5 THE SURVEY: RESULTS AND DISCUSSION

Drought risk perceptions about yield reductions in a dry and very dry year

The survey contained two questions that were designed to reveal farmers' drought risk perceptions. Respondents were asked to give a quantitative estimate of the return period (figure 6-2) and farm income reduction (figure 6-3) for a dry year and an extreme dry year.

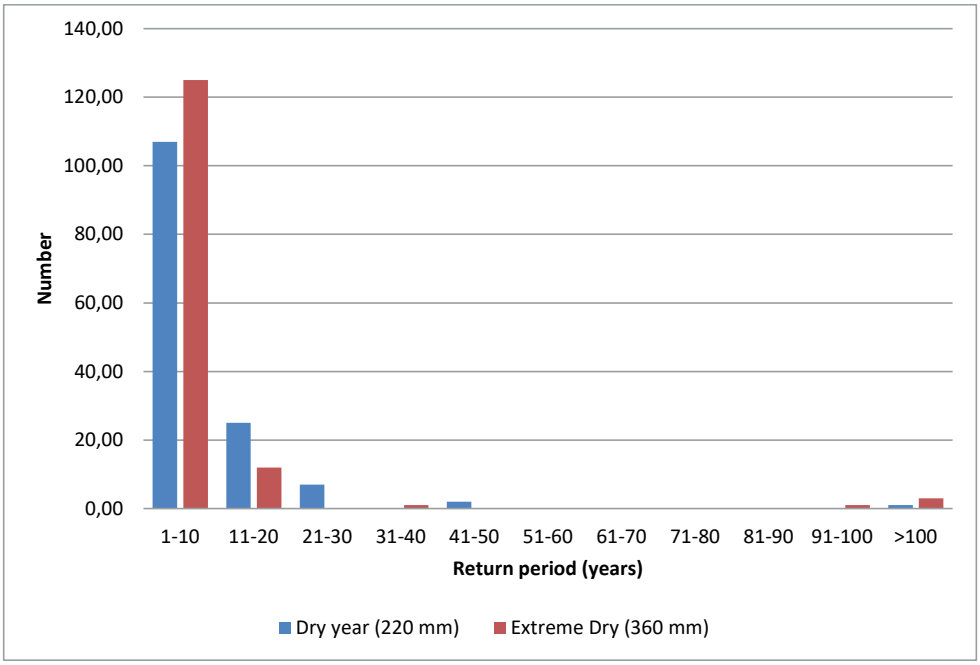

***Figure 6-2**, Frequency distribution of farmers' estimation of the return time of a dry year and an extreme dry year (perceived probabilities).*

Figure 6-2 shows that respondents did not make a distinction between a dry and extremely dry year in their estimation of the return period. For both meteorological conditions similar

estimations were given that ranged between 2 and 15 years (figure 6-3). In hydrological studies (table 6-4), a difference of a factor of 10 is assumed regarding years that are characteristic for the return period for a dry and a very dry year, respectively. This assumption is based upon time series analysis of climate data. It can be concluded that respondents tended to overestimate the probability of an extremely dry summer.

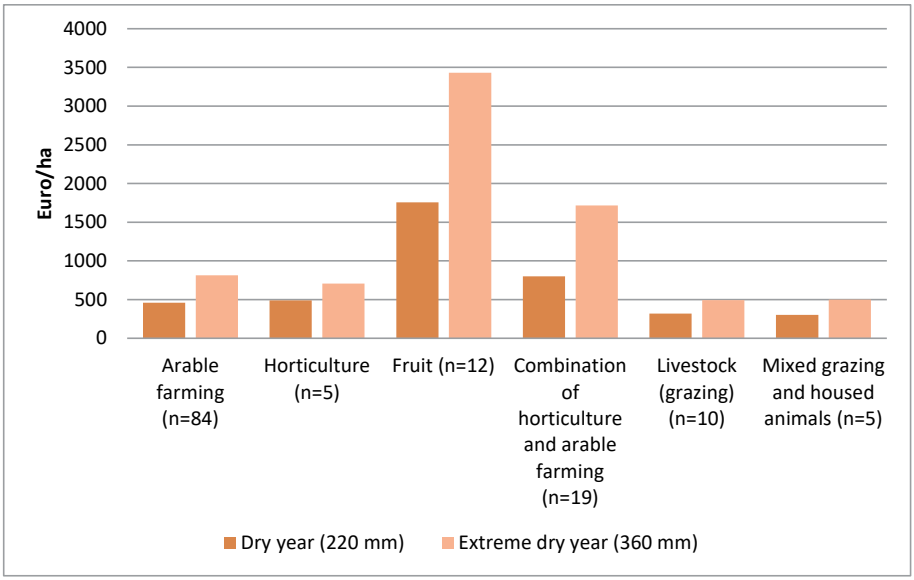

Figure 6-3, *Estimation of perceived damage by farmers in a dry and extremely dry year (expressed in euro ha^{-1} for different farm types.*

The survey respondents estimated an average production loss ranging from 750 euro per ha (arable farmers) up to 3500 euro per ha (fruit farms) in a very dry year (figure 3). The average income was ± 3000 - 6000 € ha^{-1} (arable farming) and 15000-19000 € ha^{-1} (fruit) (LEI Wageningen UR, 2014).

On average, farmers expect to suffer approximately €39,000 damage in a dry year compared to €78,000 in an extremely dry year. The average annual turnover of the respondents is in the order of €200,000 to €250,000. Consequently, income losses amount to some 16-20% in a dry year and 30-40% in an extremely dry year.

Estimated income losses in period 2003-2012

Respondents were also asked to estimate income losses as a result of drought for each year from 2003 to 2012 (table 6-9).

***Table 6-9**, Annual summer deficit in growing season in the Netherlands (KMNI) and average estimated production loss in survey.*

year	Summer deficit (KNMI)	# resp.	Avg est. production loss	Sd
2003	227 mm	24	18.0	7.0
2004	12 mm	10	15.0	8.4
2005	52 mm	8	13.8	8.7
2006	117 mm	32	19.2	11.5
2007	0 mm	11	17.1	8.4
2008	109 mm	11	12.4	7.0
2009	**197 mm**	**19**	**17.1**	**12.9**
2010	45 mm	30	19.5	10.8
2011	17 mm	43	16.5	12.0
2012	13 mm	11	11.5	8.8

There seems no correlation between annual cumulative summer deficit (April-September) and the estimated average production loss by the respondents (table 6-9). An alternative indicator for drought is the standardised drought indicator (SPI) (McKee et al., 1993). The SPI is the deviation of the amount of precipitation from the mean for a specified period.

In figure 6-4 the monthly SPI values are presented for the period 2000-2014 from the KNMI weather station in Vlissingen that is situated in the neighbourhood of where the experiments are performed. The mean and standard deviation were derived from the data for the 1962-2014 period.

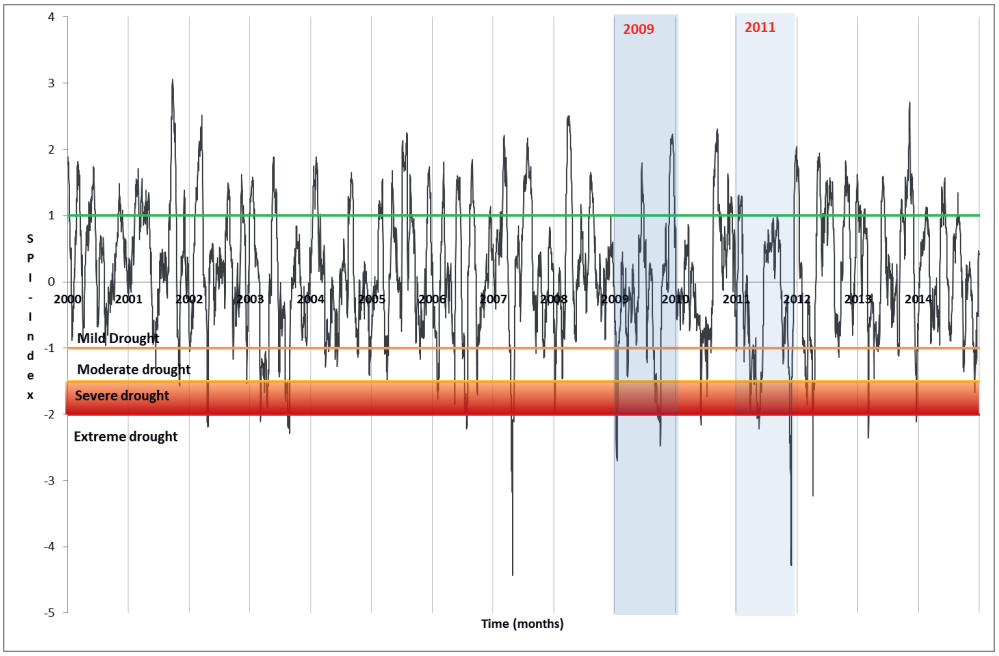

***Figure 6-4**, SPI time series for the Weather station at Vlissingen in the period 2000-2014 (Alterra et al., 2015; Wesseling et al., 2011).*

In 2003, 2006, 2009 and 2011, spring (March-May) was dry (figure 6-4). In these years the number of respondents that reported production loss nearly doubled. However, the average perceived yield reduction (± 18%) did not differ significantly compared to other years.

Based on the cumulative summer deficit of 200 mm, 2009 can be typified as a 'moderately dry year'. About 19 respondents reported drought damage. This is a low response rate compared to years with similar or higher summer deficits (table 6-9). The SPI time series (figure 6-4) indicate a mild drought (0<SPI<-1) in the beginning of the growing season (March-June), while in July and August severe to extreme drought was measured (-1.5<SPI<-3). The low number of farmers that reported drought damage despite a summer deficit of 200 mm is therefore probably explained by the fact that mostly fruit growers experienced drought damage in late summer. Most arable farmers within this sample experienced little or no drought damage in spring 2009.

The year 2011 (cumulative summer deficit = 11 mm) can be classified as an average dry/wet year. Intuitively, one would expect a low number of respondents that report drought damage. Surprisingly, however, the response rate was high (43 respondents). The SPI-time series indicate a period of severe drought (-1.5<SPI<-2) in the first part of growing season (March-May).

Attitudes towards the innovative measures

In the survey, famers indicated their level of familiarity with the adaptation measures, including the three studied GO-FRESH technologies, by multiple choices with six options (figure 6-5).

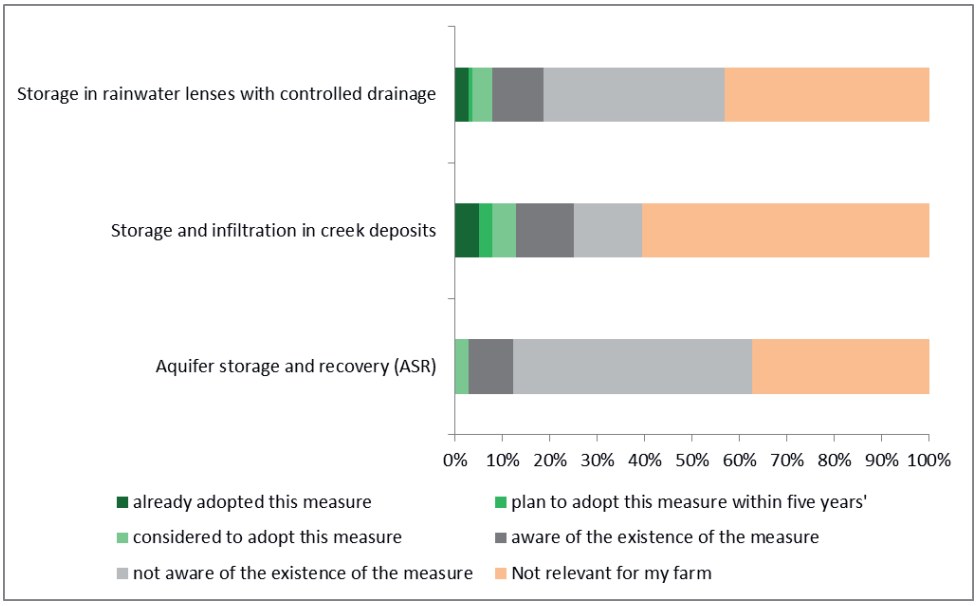

***Figure 6-5**, Indicated level of familiarity for Aquifer storage and recovery (FRESHMAKER), Storage and infiltration of freshwater in creek deposits (CARD SYSTEM) and Freshwater storage in rainwater lenses with controlled drainage (DRAIN2BUFFER) (n=139).*

On a 7-point scale (1=low; 7=high) the farmers were asked to indicate the effectiveness and the costs of each the two measures. Based on these answers, a cost-effectiveness (CE)-score was calculated for each of the three measures. This is the ratio between perceived effectiveness and perceived costs. The value of the CE lies between 1/7 and 7.

Aquifer storage and recovery (FRESHMAKER)

About 50% of the farmers are not aware of the existence of this measure. Approximately 40% of the respondents conclude that this measure is not applicable to their farm (figure 6-5). The CE-ratio is below 1 for the majority of the respondents, indicating that they perceive the costs to be higher than the effectiveness of the measures. Perceptions were not found to differ between arable farming, fruit cultivation and horticulture.

Storage and infiltration of freshwater in creek deposits (CARD SYSTEM)

Of the respondents, 85% was aware of the possibility to store and infiltrate fresh water in creek deposits (figure 6-5). The majority of farmers indicate that this measure is not applicable to their farm, probably because they are not located in the vicinity of a creek or sand ridge. The measure is perceived to be more cost-effective than FRESHMAKER and DRAIN2BUFFER. The cost-effectiveness ratio (CE) is above 1 for the majority of the respondents.

Freshwater storage in rainwater lenses with controlled drainage (DRAIN2BUFFER)

A large part of the farm sample is unfamiliar with this type of measure and thinks it is not applicable to their farm (figure 6-5). Furthermore, the perceived cost-effectiveness of this type of measure is low (<1).

6.6 CONCLUSIONS

The feasibility study and the survey were compared to analyse how experts, farmers and policy makers evaluate environmental, socioeconomic, and behavioural factors that determine the wider use of climate compatible water supply technologies at farm level.

For the participants involved in the feasibility study and the respondents of the survey, it was difficult to quantify yield reduction risks in terms of probability, expected yield reduction and causes of yield reduction. This also applies to the involved scientists.

The respondents did not make a distinction in terms of drought damage between 'dry' or 'moderately dry years. In contrast to agro-hydrological models, in the period 2003-2012 the estimated average yearly drought damage (12-17%) was more or less similar among respondents. The number of respondents reporting drought damage is a more reliable indicator of agricultural drought impact than the cumulative precipitation deficit, in particular when it is combined with the standardized precipitation index (SPI).

Furthermore, the survey reveals that farmers do not make a significant distinction between the probability of occurrence of a dry and extremely dry year. The survey respondents overestimate the risks of an extremely dry year by a factor 10.

These observations illustrate differences in understanding between the indicated drought damage risks by farmers compared to the used risk values in water management and research.

In the feasibility study it appeared to be difficult to select a single economic indicator for cost(-effectiveness) all involved actors agreed upon (low level of common understanding). In the survey 'costs' and 'effectiveness' were assessed separately in qualitative terms. This approach avoids this discussion, and it is recommended to use this approach in feasibility studies.

The costs, and hence the cost-effectiveness, depend also on the existing water supply facilities at farm level. It is therefore difficult to identify generic cost estimates in both approaches. For example, if farms already have a controlled drainage system in place, the investment costs to apply CARD and DRAINS2BUFFER will be lower compared to the presented examples. On the other hand, within the pilot with the CARD system, costs were also reduced because the controlled drainage system was designed for two farms.

In the pilot with the FRESHMAKER, cost savings were possible because a sufficiently large water basin was present at the location studied. However, not all companies in this region have a water basin with the desired capacity. It is therefore recommended to add uncertainty ranges to cost estimates in feasibility studies in combination with cost saving opportunities.

The calculated CE ratios for the three technologies were low (<1) because most survey respondents were unfamiliar with the technologies in contrast to the farmers that participated in the GO-FRESH experiments. The level of common understanding of and confidence in the technical and socio-economic feasibility increased amongst the farmers, policy makers and experts that were involved in GO-FRESH. However, for farmers reliable freshwater supply and supportive legislation are the most decisive socio-economic criteria for a future investment.

Both the survey and the feasibility study illustrate that a positive impact of additional freshwater supply on the net revenue of an agricultural farm strongly depends on the type of farm (fruit, arable farming, and horticulture) and the crop cultivation plan. This insight offers opportunities to increase the positive impact of additional freshwater supply by simultaneously adapting the crop cultivation plan.

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7



Picture: the use of spatial information during a workshop in Borselle, Province of Zeeland (Jeroen Veraart, 2022).

Using spatial information to remove barriers and foster enablers: the uptake of nature-based solutions for food production and water resource management in Ghana and the Netherlands

Abstract - Water-related problems caused by climate change threaten the future of food systems in both the Netherlands and Ghana. In this paper, we present the results of a comparative case study analysis. The objective is to identify similarities in the use of spatial information by experts and stakeholders in their attempts to remove barriers or foster the enablers of the uptake of Nature-based Solutions (NbS) in view of climate change. Experiences in this field have been assessed, by using the Food System Approach (FSA), in the Rhine-Scheldt Estuaries (the Netherlands) and the Bono East Region (Ghana) in relation to rainwater harvesting (RWH) and the reuse of wastewater, which are considered as hybrid nature-based solutions. Both rainwater harvesting and wastewater treatment techniques are available, and ready to be accepted and applied by farmers and the food processing industry. Their uptake, however, is hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers. We conclude that spatial information can be an enabler for the adoption of nature-based solutions if that information is applicable for the assessment of a wide range of possible solutions for water scarcity in the frame of food production – either nature-based solutions or technologies. In both case studies, we observe a struggle to make the future spatially explicit due to the availability of spatial information of all relevant factors. The involvement of stakeholders in the process of creating spatially explicit information for the suitability of NbS was valuable in both case studies, in terms of identifying driving factors, and improving the adequacy of the suitability maps.

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7 USING SPATIAL INFORMATION TO REMOVE BARRIERS AND FOSTER ENABLERS: THE UPTAKE OF NATURE-BASED SOLUTIONS FOR FOOD PRODUCTION AND WATER RESOURCE MANAGEMENT IN GHANA AND THE NETHERLANDS

7.1 INTRODUCTION

In this paper, we present the results of a comparative case study analysis. The objective is to identify similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers or foster the enablers of the uptake of Nature-Based Solutions (NbS). NbS use and deploy the properties of natural ecosystems and the services that they provide in a smart and in some cases an "engineered" way. The uptake, or upscaling of NbS, is often hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers. The uptake or adoption of NbS differs from the adoption of technology as NbS will be spatially specific, as the basic design principle is based on the properties of natural ecosystems. In addition, some scholars in water management (Janssen et al., 2019; Smit et al., 2014) state that stakeholders may argue that NbS must become evidence-based before they can replace conventional ways of water management strategies (the innovation dilemma). In this study, we focus on the role of NbS in agriculture and water management. The paper also considers that enablers and barriers can also occur elsewhere in the food chain.

Experiences in this field have been assessed in the Rhine-Scheldt Estuaries (the Netherlands) and the Bono East Region (Ghana) about the reuse of wastewater and rainwater harvesting. The analysis focuses on identifying similarities in the use of spatial information by stakeholders in their attempts to remove the barriers or foster the enablers of NbS uptake. The paper evaluates the essential requirements in developing spatially explicit scenarios for NbS in view of climate change, in a participatory setting. The lessons learnt in both countries provide guidance for embedding NBS in their socio-spatial and biophysical context.

First, we describe the water-related problems that are encountered in relation to climate change, for which rainwater harvesting and water reuse may provide a nature-based solution. Secondly, we present recent research on the adoption of NbS, and the challenges

which are generally encountered regarding their uptake. Thirdly, we focus on barriers and enablers that are relevant for both case studies and where the availability of spatially explicit information may play a role in the decision to adopt NbS, considering the differences of the different food systems.

Food security and climate proof water supply

The world's population is predicted to rise to 9.7 billion by 2050 (United Nations, 2019). This prospect puts a strain on the global food security and water supply. In future, more water will be needed to produce enough food for a growing world population, but also for the maintenance of water resources, and the maintenance of those economic activities that rely on the available water resources. The availability of freshwater resources for food production is at risk due to climate change and the increasing water demand by multiple users in many parts of the world (IPCC, 2021, 2018, 2014c; Shukla et al., 2019; World Water Council, 2000). Reduced and erratic rainfall, reduced streamflow and groundwater recharge, coupled with increased domestic, industrial, and crop water demand pose major climate-related risks to agriculture, water utilities, and hydropower production (Immerzeel et al., 2020). FAO estimates that at least 25% of the costs of damage and loss from climate-related disasters are absorbed by agricultural sectors (FAO, 2015b).

Policymakers, scientists, and social actors are therefore working on strategies to ensure food security and water supply in the long-term. Not only for securing a long term food security, but also to reduce the risks to investors, and to maintain their interest in continuously investing in the production of food (Chiriac et al., 2020; Verdegaal et al., 2018). As risks rise, the discussion as to which sector is responsible for taking the risks rises as well (Mauelshagen et al., 2014), leading to a call for innovative public-private financial arrangements or otherwise blended finance. Across the globe, new pathways are explored to ensure that all people have access to affordable, sufficient, and nutritious food all year round, and to ensure the sustainable use of water resources to support this. There are also studies that explore how resilient these pathways are under different climate scenarios (Achterbosch et al., 2014; FAO, 2018; Haasnoot et al., 2020b; Mens et al., 2022). In general, it can be stated that in delta areas and river catchments, water availability for food production comes under increasing pressure due to climate change, sea level rise, and related increased salt water intrusion (Thorslund et al., 2021). Especially in regions where the water supply is mainly dependent on rainwater (Iglesias & Garrote, 2015).

In many parts of the world, boosting local economic development is key to achieving food security and a better quality of life. To combat rural poverty, food security must increase in terms of quantity, but also in terms of food quality, income, and in terms of resilience to increasing weather extremes induced by climate change. Addressing these multiple goals

simultaneously, however, requires more efficient use of natural resources such as water. The challenge herein is to increase the availability of water through temporal storage or otherwise use less water while producing more food with less impact on biodiversity. To do so, there is a growing recognition for the need to change our current linear ways of producing food and feeds into circular systems by closing water, nutrient, and carbon cycles, and consequently minimizing resource loss and mitigating climate change impacts.

Nature-based solutions

Increasing awareness that nature can be a source of inspiration in providing viable contributions to reduce the impact of anticipated negative effects of climate change (Sonneveld et al., 2018). These so-called 'nature-based solutions (NbS),' or interventions use and deploy the properties of natural ecosystems and the services that they provide. The term NbS is derived from environmental sciences, water engineering, and agricultural sciences. Its first appearance in mainstream scientific literature was in the early 2000s, amongst others in integrated pest management and the use of (constructed) wetlands for wastewater treatment (Potschin et al., 2016). In NbS, there are gradations in the use of natural processes, the level and type of engineering applied to ecosystems and the number of ecosystem services delivered (Cohen-Shacham et al., 2016; Eggermont et al., 2015; Somarakis et al., 2019). Also, in the field of water engineering, experience has been gained with NbS in the last decade. For example, in the Netherlands pilots, research projects and also real-life interventions along the coast have been initiated (Bouw et al., 2020; de Vriend et al., 2015; Slinger & Vreugdenhil, 2020; Willems et al., 2021).

Different definitions for NbS are in use, while in this paper we use the following definition from the EU Research and Innovation policy agenda as a starting point: *". . . measures that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions contribute to more biodiversity and other natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient, and systemic interventions*." (European Commission, 2015). With this definition of NbS, we can link the impact of NbS to biodiversity as well as the food system (Keesstra et al., 2023). We realize that opponents of this definition argue that its emphasis on cost-effectiveness may lead to NbS that prefer economic, rather than social and environmental outcomes. We do believe, however, that including the cost-effectiveness of NbS is appropriate, as it secures their sustainability towards nature-inclusive activities. Moreover, Keesstra et al. (2023) provided a typology of NbS: *i)* intrinsic NbS which make use of existing ecosystems; *ii)* hybrid NbS which manage and adapt ecosystems; and *iii)* inspired NbS which consist of newly constructed ecosystems. RWH and water reuse are examples of the hybrid NbS according

to the typology of Keesstra et al. (2023).

NbS for food and water security – i.e., hybrid NbS – can be implemented on different scales (e.g., farm, watershed, landscape, and region) and require multi-level governance support. Examples at the farm level are mixed cultivation, biological pest control, agroforestry, water treatment, and harvesting. On the landscape level, nature-based interventions may be more complex and partly nested, responding to the multiple landscape functions and services provided at the landscape level. For example, nested NbS may address the reuse of production water and nutrient flows from the food processing industry, while at the same time constructed wetlands can be used to purify wastewater for irrigation in agricultural areas. NbS, on the landscape level, usually aim to make better use of natural dynamics in land, water, and sediment fluxes, and combine these with the socio-economic, political, and cultural dynamics at stake and different scales (Vreugdenhil et al., 2010a).

Enablers and barriers for adoption of nature-based solutions

Enablers and barriers that determine the adoption of a new technology or policy strategy at the interface of the environment, climate, and food supply have been frequently researched (Abdallah et al., 2014; Bolson & Broad, 2013; Liu, 2013; Veraart et al., 2017). This also applies to the NbS that are central to this comparative case study analysis (Calliari et al., 2022). The success or failure of adopting a NbS or changing operational management at farm level will also depend on enablers and barriers elsewhere in the food chain and in water management. It seems evident that a food system approach could add value, as it facilitates assessing the multiple enablers and barriers that are relevant to different components of a specific food system (Alarcon et al., 2021; Ingram, 2011; van Berkum et al., 2018). In this study, the Food System Approach is used to select indicators (section 7.2).

Embedding NbS in agricultural practice, food processing, and water management in view of climate change will require *major changes* in their necessary skills. The change may require more than an adaptation in business operations or adaptive management (Terwisscha van Scheltinga & Timmerman, 2020). In order to embed NbS, the required change can also mean that the agricultural entrepreneur has to completely transform his or her production system, which requires completely different skills and technologies (Wojtynia et al., 2021). The question is sometimes raised whether this *change process* can be managed, often qualified as 'transition management' (Köhler et al., 2019; van der Brugge et al., 2020).

The role of spatial explicit data and information in adopting nature-based solutions

On all spatial scales, decisions are taken by public and private actors about the use of natural resources (water) and the adoption of NbS. Many barriers and enablers are caused by often

unpredictable feedback stemming from decisions between these different scales. In addition, the actors involved may have an uncertainty-reducing behaviour in decision-making (enablers), while others continuously pose new questions and uncertainties (barriers) (Veraart et al., 2018). The availability of scenarios for solutions and climate change applicable on different spatial scales is also mentioned as a barrier in various studies (Kanellopoulos et al., 2014; van den Hurk et al., 2013).

Spatial data and information play a vital role in adopting NbS. They are essential in identifying the potential locations, types, and configurations of NbS that can maximise their effectiveness and co-benefits, while minimising their costs and trade-offs (Mubeen et al., 2021; Sarabi et al., 2022). They are also essential in simulating the hydrological and ecological effects of NbS under different scenarios and conditions, such as climate change, land use change, human interventions, and uncertainty (Gómez Martín et al., 2021). In addition, spatial data are important in facilitating the participation and collaboration of different stakeholders and sectors in the design and management of NbS, such as water managers, policymakers, researchers, and practitioners (Verweij et al., 2016). Finally, spatial data allows for the quantification of the ecosystem services and human well-being benefits of NbS (Gómez Martín et al., 2021; Paulin et al., 2020). In general, spatial data and information are key enablers and drivers of NbS adoption, as they can provide valuable insight, evidence, and guidance for decision-making and planning processes. However, spatial information also faces some challenges and limitations, such as data availability, quality, and interoperability, as well as ethical, legal, and social issues.

Increasing the usability of spatial information about NbS for decision-making in water management and food systems is challenging because this has to be done simultaneously on different scales, each often with its own science-policy interface or disparate knowledge systems (O'Toole & Coffey, 2013).

The structure of the study is as follows. In Section 7.2, a methodological approach and the data collection are presented. Section 7.3 discusses two case studies on NbS, one in the Netherlands, and one in Ghana, which will be compared. In Section 7.4, the results of the comparison are discussed, and Section 7.5 presents our conclusions.

7.2 OUR METHODOLOGICAL APPROACH AND DATA COLLECTION

7.2.1 APPROACH

Case study analysis is an accepted qualitative research method to unravel complex knowledge systems where rationality, power, and intuition shape each other in decision-making (Flyvbjerg, 2006). The methodological design of this study builds upon a comparative case study approach (Yin, 2009).

The phenomenon of study is the role of spatial information in stakeholder processes that have the objective to assess the feasibility of adopting NbS, as exemplified by Rainwater Harvesting and Wastewater Reuse. This is done by identifying similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers or foster the enablers of the uptake of Nature-Based Solutions (NbS) in view of climate change.

First, the following contextual conditions are described for each case study (table 7-1): (a) Water supply conditions, (b) Food supply conditions, (c) Environmental conditions, (d) Socio-economic Institutions, and (e) Available alternatives for NbS. The conditions and potential indicators were selected from, amongst others, the Food System Approach (Alarcon et al., 2021; van Berkum et al., 2018).

***Table 7-1**, General set up of the comparative case study analysis.*

Contextual conditions	Possible indicators	Ghana *current*	Ghana *future*	Netherlands
Water supply (Spatial explicit)	• Water Gap Risk (supply < demand) • Adaptive capacity to climate change	Mapping contextual conditions (spatial & non-spatial) in current situation to support dialogue about NbS		
Food Supply	• Food Gap Risk (Supply < Demand)			
Environment	• Biodiversity • Soil			
Socio-economic & institutional	• Land tenure. • Policy incentives and support	***assess*** ↓	↑ **use**	
Alternatives for NbS (Rainwater Harvesting & Water reuse)	• Available alternatives • Added value NbS for Food System • Income Effect for Farmer from NbS	enablers and barriers that determine future NbS uptake that are dependent on spatial information		

The choice for case studies in Netherlands and Ghana may seem a far stretch. However, there are reasons why the authors decided for these cases. Comparing case studies in both Ghana and the Netherlands is relevant because, despite different contextual conditions, both case study areas experience increased pressure on water resources, especially in relation to food production because of climate change. In addition, both case studies share the barrier of enablers for implementing NbS differently perceived by stakeholders on the landscape level and on a landowner's plot. The usability of spatial information in both case studies was compared to the aim of identifying the essential requirements that this information must meet to be relevant for decision-making on multiple levels (food system, landscape, farm). Figure 7-1 presents the enablers of both case studies using the dots at the bottom of figure 7-1. In Ghana, farmers and the stakeholders involved in the landscape are the key enablers. In the Netherlands, farmers and wastewater collectors are the key enablers.

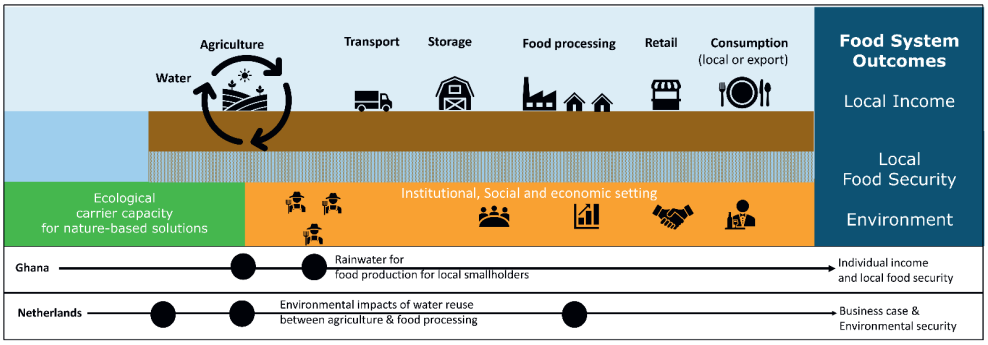

Figure 7-1 - *The case studies (Ghana & the Netherlands) were framed in the perspective of the (Water & Food System Approach. The black circles indicate by case study which part of the food system has been studied in this comparative case study.*

In addition, for more than four centuries, the food systems of the Netherlands and Ghana have been highly interrelated. Imports by the Netherlands from Ghana in 2021 amounted to more than 700 million USD, of which almost $600,000,000 reflect agricultural products (UN COMTRADE database on international trade, 2022).

7.2.2 STAKEHOLDER PARTICIPATION IN THE NETHERLANDS AND GHANA

The case studies in the Netherlands and Ghana share a commonality that spatial information was used about the water supply and agricultural water demand to develop feasibility maps. However, the tailoring of spatial environmental data has been done in different ways (section 7.4.1 & 7.4.2), which is inherent to the chosen strategy to develop feasibility maps with local stakeholders from both countries. Also, differences in the availability of spatial data in the case studies played a role. Feasibility maps concerned the reuse of wastewater in the Netherlands and rainwater harvesting in Ghana, respectively.

Stakeholders that contributed to this analysis in both case studies originated from the national science policy networks in which the authors are active, we are aware of the bias this can entail. Examples of those science-policy networks are, amongst others, the Dutch national Delta programme (Staf Deltacommissaris, 2019), the Dutch Knowledge, the Innovation programme "Agriculture – Water and Food" (Topsector Agro&Food et al., 2022), Solidaridad West Africa (Solidaridad, 2022), and the Forestry Commission of Ghana. Table 7-2 gives an overview of the stakeholders who actively participated in workshops, field trips, or were interviewed.

The researchers in Ghana already had a coordinating role in arranging stakeholder meetings within the Forestry Commission of Ghana and Solidaridad West Africa before the start of the study. This allowed for stakeholder workshops to be embedded in ongoing activities. In the Dutch case study, a start was made with bringing together stakeholders who are active in either national science policy networks concerning water management or wastewater treatment technology. Different networks needed to be bridged. The research was implemented during the global COVID-19 pandemic, which made it hard to consult with stakeholders directly in both case studies.

In the Netherlands, the approach could be described as a stakeholder consultation, while in Ghana the process was more collaborative (Termeer et al., 2015; Wardenaar, 2015) . In the Netherlands, the stakeholder participation focused on improving feasibility maps for wastewater reuse with available national water, soil, and land use models. Like the Netherlands, in Ghana, stakeholder participation also focused on improved suitability maps of rainwater harvesting which had been initially produced solely because of literature reviews. Table 7-2 illustrates that in Ghana mainly stakeholders from the agricultural sector were involved, while in the Netherlands the focus was on involving the food processing industry.

***Table 7-2**, Overview of consulted stakeholders in the Netherlands and Ghana.*

The Netherlands	
Stakeholder	*Consultation method*
Drinking water supply factory (PWN, EVIDES)	Bilateral meetings (December 2021)
Food processing Factory (pre-fried fries)	Bilateral meeting (May & June 2021)
Food processing Factory (potatoes)	Workshop (December 2020)
Regional Water Authority (Scheldestromen)	Workshop (December 2020)
Province (Zeeland)	Workshop (December 2020)
Consultants & Experts	Workshop (December 2020)
Brewer (beer)	Interview
Ghana	
Stakeholder	*Consultation method*
Agricultural department (Techiman North District)	Three-day field trip meeting (December 2020)
Farmer associations	
Community leaders	
Farmers (n=34)	Interviews with farmers from Adutwie, Kyiridiagya, Ofuman, Bonya and Tanoboase (communities)
Department of Environmental Management	Three-day field trip meeting (December 2020)
Extension officers (n=5)	
Solidaridad West Africa	Existing stakeholder network, co-researcher
Forestry Commission Ghana	Existing stakeholder network, co-researcher

Stakeholder participation in the Netherlands

The feasibility map for the Southwestern part of the Netherlands was developed, step by step, whereby the map was adapted in dialogue with policymakers and practitioners by means of a workshop, bilateral meetings, and interviews (table 7-2). In this way, the assumptions beyond the map were also validated by stakeholders, and knowledge needs were identified. Subsequently, the workshop examined which combinations of NbS, and water technologies could be used in the future to use this potential water source as climate adaptation in this part of the Netherlands. Based on the stakeholder consultations, enablers and barriers were identified for applying NbS as a measure to increase climate resilience of landscapes and food production chains by expert judgment.

Stakeholder participation in Ghana

In Ghana, the approach to developing suitability maps for rainwater harvesting was iterative and dynamic. Initially, these maps were created based on a comprehensive literature review, without direct stakeholder engagement – but with the expertise of the research team. Subsequently, field work was conducted to check the accurateness of the maps which took place in the terrain in the Bono East Region. The field team visited the Techiman North District at the end of 2021, and they took georeferenced photos which were later integrated into the suitability map. During the field trip, interviews were conducted with 34 farmers

and five extension officers (Derkyi et al., 2021). The maps were updated utilising the fieldwork. The preliminary results were presented at a workshop with diverse stakeholders, whose feedback, particularly regarding adoption drivers and enablers, was invaluable. This stakeholder feedback was integrated into the Bayesian network model to the extent permitted by data availability, leading to the production of an updated and more refined suitability map.

7.3 CASE STUDY DESCRIPTIONS

7.3.1 RHINE-MEUSE-SCHELDT ESTUARY (NETHERLANDS)

The case study analysis is focused to the southwestern part of the Netherlands, where the Rhine, Scheldt, and Meuse flow into the North Sea (figure 7-2). In Dutch water policies, this area is often referred to as the Southwest Delta (van Alphen, 2016). Food production outside the selected area also depends on water management in these spurs of the Rhine-Meuse-Scheldt delta.

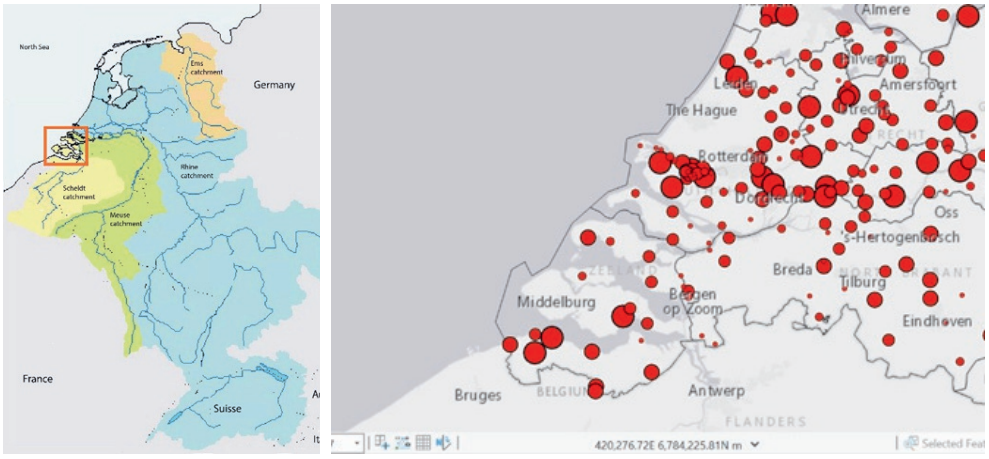

***Figure 7-2**, Rhine-Meuse-Scheldt Catchments (left) with a cutout of the estuaries in the southwestern part of the Netherlands including wastewater resources derived from E-PTR data.*

Water supply – The Netherlands usually has a precipitation deficit in summer (average 100mm) and a precipitation surplus in winter. In the coastal zone, the precipitation deficit in spring and early summer is usually larger than in the rest of the country, whereas the situation is reversed in late summer and autumn (van Minnen & Ligtvoet, 2012). The annual

cumulative maximum precipitation deficit occurs during the summer half-year from April to September (Beersma & Buishand, 2004).

Under average climatic conditions, the freshwater supply for Dutch agriculture is excellent. However, in situations with a low river discharge and a high precipitation deficit, the freshwater supply cannot meet agricultural freshwater demand during the growing season, as we experienced in 2018, 2019, and 2022. This is particularly true for the rainfed agricultural areas in the southwestern part of the Netherlands that have no access to river water.

Reuse of effluent water could, potentially, reduce the gap between water supply and water demand. However, not only is the reduced gap in volume important, but also the water quality if the water is reused for food production or is discharged in nature areas (Pronk et al., 2021). Natural processes are explored in policymaking to solve this, such as the use of constructed wetlands to realise additional water for food production or drinking water production by purifying used water. However, competing land claims in the Netherlands are a barrier to realize these type of landscapes (Gupta et al., 2016). That is why in this study combinations of nature-based solutions with wastewater treatment technology are explored. Food processing industries in the Netherlands are also exploring how water use per unit of produced product can be reduced. Some consider whether residual water streams can be re-used within the factory or by neighbouring landowners such as farmers. Also, food processing industries investigate whether substances dissolved in the water can be re-used.

Food Supply – Agriculture in this area contributes to Dutch economy by food production for consumption in the Netherlands and the export of agricultural products. The physical yields in arable farming have increased enormously over the past century. In an economic sense, the contribution of Dutch Agro- and Food sector was near 7% of the GDP in 2020, of which 30% can be attributed to the primary sector (WECR, 2022). In 2021, the annual export of agricultural products had a value of approximately €105 billion (Jukema et al., 2022). In the case study area, there are about 5,500–6,000 agricultural entrepreneurs of which 50% perform arable farming, 12% horticulture, and 6% greenhouse horticulture (CBS & LEI, 2014). This is about 10% of the total number of farms in the Netherlands.

Environment – In the case study area, the rivers Rhine, Meuse, and Scheldt come together. The interplay between sea and rivers is controlled by a comprehensive system of protective dikes and storm surge barriers developed between 1953 and 1997 to reduce flood risks. These measures have caused water quality problems and unforeseen ecological shifts. The result is that the water bodies in this region still do not comply with Natura 2000 and Water Framework Directive, despite environmental policies (van Gaalen et al., 2020; Veraart et al., 2021). European environmental regulation also requires that the treatment process in a

constructed wetland, if it is part of a wastewater treatment unit, continuously functions, despite extreme events or natural dynamics. When the food processing industry and farming activities become less dependent on freshwater (surface water) from the delta, more water resources are left for nature, which in delta areas creates options to restore or protect estuarine dynamics.

Socio-economic institutions – In the Netherlands, there are subsidies for the agricultural sector and food industry aimed at making food production more sustainable, such as VAMIL (depreciation of environmental investment), and the more efficient use of natural resources such as water and rural development. There are subsidies from the government (e.g., Delta Fund), the European Commission (CAP), and regional authorities sometimes have funds. The subsidies often cover only part of the investment and entrepreneurs must make it clear that they are making the investment for the benefit of the public interest (environment), not for profit. A subsidy can act as an enabler, but also as a barrier when the application procedure is too complex or the private benefit for the entrepreneur is too small.

Reuse of wastewater (NbS) and available alternatives – Food processing industries in the Netherlands are increasingly exploring how water use per unit of a produced product can be reduced in both raw materials supplying farming systems and within the factory. Some industries are considering whether residual water streams can be reused within the factory or by neighbouring landowners (e.g., horticulture, livestock, onshore aquaculture, cattle). Also, valuable substances dissolved like nutrients in the water can be re-used. In turn, the food processing industry can also use residual flows from other sectors. Natural processes can also be the basis for wastewater treatment, such as constructed wetlands. Wastewater purification can consciously utilise ecological nutrient uptake processes and sedimentation of suspended solids that can observed in aquatic ecosystems. In constructed wetlands, these uptake processes can be optimised (Saaltink et al., 2016; Wagner et al., 2018). It depends on the design whether regional biodiversity can also benefit of these constructed wetlands. The flipside is that the competition for land is high in the Netherlands, making it more difficult to realise constructed wetlands. In the case study area, there are alternative freshwater resources available. The climate resilience of those freshwater resources are the subjects of research (Mens et al., 2022), including re-use of water (Pronk et al., 2021). Currently, there is a choice between precipitation (winter surplus), river supply, and groundwater sources in the case study area (figure 7-5), except for the southern part of Zeeland where no river supply is possible and limited access to groundwater.

7.3.2 CASE STUDY BONO EAST REGION (GHANA)

The Bono East region is a part of the former Brong Ahafo region in Ghana (figure 7-3). The region lies in the transitional zone from Savanna to temperate climate and the green vegetated belt in Ghana. The Northern and Northeastern regions are Guinea savannah woodlands, transitioning to semi-deciduous forest in the South-West area. The Techniman North District is one of the districts of Bono East Region, which is favourable for applying rainwater harvesting techniques for farming.

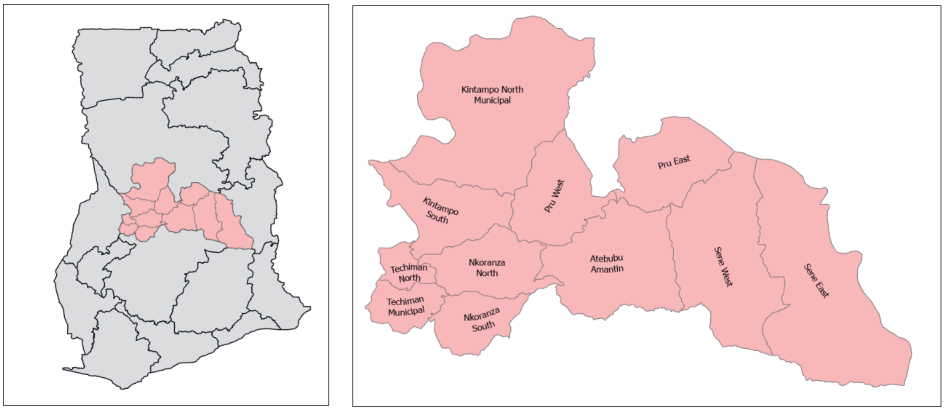

***Figure 7-3**, Ghana (left) emphasizing Bono East Region and a cutout of the Bono-East Region showing its districts.*

Food Supply – The Bono East Region in central Ghana represents a rural region which is known for its food production. The region is commonly referred to as one of the major 'food baskets' of the country which provides a large proportion of food consumed in Ghana's major cities Kumasi and Accra, as well as its neighbouring countries. Its dependence on agricultural production is its strength, yet at the same time also its weakness, as the mounting pressure on arable land is increasingly leading to disclosure of forested areas, with deforestation and land degradation as a result. Global climate change is even acerbating this situation, as it leads to unpredictable crop yields, endangering livelihoods within the region and food security in Ghana as a whole (Läderach et al., 2011; Ministry of Foreign Affairs of the Netherlands, 2018). The Ghana National Climate Change Adaptation Strategy (NCCAS) has the primary goal of *"enhancing Ghana's current and future development to climate change impacts by strengthening its adaptive capacity and building resilience of society and ecosystems"(Government of Ghana, 2021).* It is expected that agriculture, which is the largest employer in Ghana, will be heavily affected by the increased variability of rainfall, with devastating impact on crop yields, productivity, and farm income. Besides increased

variability of rainfall, the average temperature is also on the increase, causing prolonged droughts and more frequent incidence of bush fires, with environmental degradation as a result (Government of Ghana, 2021, 2012). Vulnerability to climate change in Ghana is spatially and socially differentiated whole (Läderach et al., 2011; Ministry of Foreign Affairs of the Netherlands, 2018). In the transition zones, the variability of rainfall has serious consequences for farmers and the remaining forests, as the changing weather conditions affect the production of cocoa and fruit, such as pineapples, mangos, papaya, etc. (Government of Ghana, 2012).

Water supply – Over the past few years, water supply in Bono East Region has become irregular and unpredictable. It is becoming harder to predict the onset of the rainy season, while erratic rainfall and prolonged dry spells have turned agriculture into an unreliable and unprofitable activity. In the adjacent Northern Region, the rainfall patterns have changed even more dramatically, putting pressure on Northern animal husbandry practice. Herders are therefore moving southward, putting more pressure on the increasingly scarce resources in Bono East. The resulting heat stress, periodic lack of water, pests, and diseases are on the increase. To cope with these climate-induced challenges, farmers have become even more dependent on the natural resources they have, not only through intensifying their agricultural and animal husbandry activities, but also by increasing their use of naturally occurring trees for timber, house construction, and charcoal production. Illegal chainsaw operations in forest reserves and otherwise encroachment into forest reserves is increasingly leading to conflict between farmers, pastoralists, and forest dependent communities.

Solutions & alternatives – There are several techniques that would help farmers to adapt their management practice to the changing weather conditions, but so far, in Bono East these techniques are hardly practiced. One example of this is rainwater harvesting for irrigation, which is frequently practiced in the North, where it has provenly enhanced the climate-resilience of the food system future (Boelee et al., 2013; Stockholm Environment Institute & United Nations Environment Programme, 2009). However, rainwater harvesting is not yet common practice in the Bono East variability (Amankwah & Napoleon, 2019; Antwi-Aygei, 2012). This may be explained that the effects of climate change are not yet fully perceived or practically experienced, leading to a low sense of urgency among producers and policymakers. Climate projections however show that this situation will change very soon. This may however change in future, as rainwater harvesting is a good option for rural communities to get safe water for domestic use given the limited access to public water supply (Antwi-Aygei, 2012; Owusu & Asante, 2020). It allows for the collection of run-off water, storage of it, and making it available where and when it is needed, as it is stored and kept for a later moment in time (Kiggundu et al., 2018; Qadir et al., 2007). Moreover, RWH can be part of soil and water conservation measures to increase agricultural

productivity (Abdallah et al., 2014). In 2011, the National Rainwater Harvesting Strategy for Ghana was published (Ministry of Water Resource, 2011). One of the statements in this strategy was that the Ministry of Food and Agriculture (MoFA) and Ghana Irrigation Development Authority (GIDA) are responsible for developing irrigation reservoirs that harvest rainwater for agriculture (Ministry of Water Resource, 2011). Since 2011, the MoFA has worked on RWH for irrigation through irrigation schemes, but despite the potential, little of these investments have been made in Bono East (Amankwah & Napoleon, 2019; Hari, 2019; Linderhof et al., 2022).There are multiple techniques that are available for rainwater harvesting, adapted to the context. Depending on slope and soil texture and structure, run-off of rainwater can be harvested from a catchment area into a reservoir created by micro-dams (Biazin et al., 2012; Kiggundu et al., 2018). Alternative techniques consist of rooftop collectors, underground tanks, wells, and ponds (Hagos et al., 2013). The different techniques require different levels of infrastructure and herewith different levels of investment. The choice for a specific technique depends on the feasibility, applicability, and financial possibility of the farmer or owner of the land. Figure 7-4 provides an overview of multiple techniques applied in Bono East.



***Figure 7-4**, Three different techniques of rainwater harvesting for agricultural production. Source: (Linderhof et al., 2022).*

7.4 RESULTS AND DISCUSSION

7.4.1 DEVELOPMENT AND USE OF SPATIAL INFORMATION IN THE NETHERLANDS

Development of spatial information

Initially, a water availability map (prototype) and a technology portfolio for wastewater reuse was developed for the southwestern part of the Netherlands. First, the agricultural water demand was calculated for each municipality in the region. The agricultural water demand is based on the potential transpiration, actual transpiration, and irrigation based on the current climate for the period 2009–2018 with outcomes for 10-day periods for 250x250 meter grids. To calculate the agricultural water demand, data is also required about the available surface area per crop type. For this purpose, the Land Use Database of the Netherlands (LGN7) was used (Hazeu, 2014). Based on the E-PRTR data (EEA, 2020), an estimate has been made of the yearly potential supply of water (in m^3) from industry and sewage treatment, using the reported phosphorus load as a proxy. In figure 7-5 the water supply (effluent) and water demand are superimposed with an outcome for each municipality in this region.

To get a first impression, we consider if reusable water resources are an option for an additional water supply in view of climate change in the current situation. It was explored in which areas the potential new water resource remains greater than the current water demand from agriculture. This provides a first picture in which municipalities the potential additional water supply in view of climate change is present or not. In the future, agricultural water demand (increasing evaporation and changed precipitation patterns), the crop choice, land use, and farm management and irrigation will also change. The scenario for the future were not available during the stakeholder consultations. Instead, the stakeholder consultations provided insights about the strategies to make use of the additional water supply in view of climate change. Ultimately, a map was made showing practical examples, mentioned by stakeholders, where water reuse is already taking place.

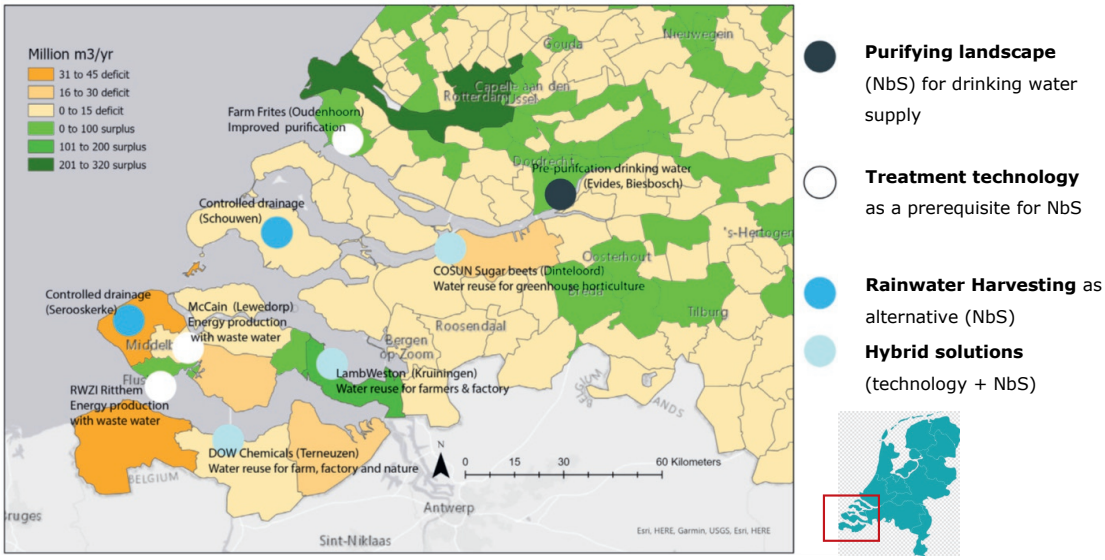

***Figure 7-5**, Comparing wastewater availability with agricultural water demand in the southwestern part of the Netherlands at the municipal level (current climate), including practical examples (circles).*

The used spatial information

The green areas on the feasibility map of the Netherlands (figure 7-5) are municipalities where the potential water supply from industry and sewage treatment exceeds the water demand from agriculture in the current situation. In these areas, it is interesting to explore whether this unused water resource can be an addition to the current available water resources (surface water, precipitation, groundwater). This potential water resource can be used within and outside the municipality in question.

The circles include examples where reuse of effluent is already practice, as mentioned by the consulted stakeholders. The stakeholders provided arguments as to why the example presented qualified as NbS. In our analysis, we grouped the examples (table 7-4) and projected them on the map (figure 7-5). In addition, we identified which technology or NbS could be considered for each cluster. It should be noted that the arguments, as mentioned by both stakeholders and experts, do not always match the definition we use for NbS.

***Table 7-4**, Overview of the clustered examples from the stakeholder dialogue coupled with identified technologies.*

Cluster 1: Treatment technology is a prerequisite for NbS (micropollutants)	Cluster 2: Purifying Landscape: ecological processes as basis with optional technological support	Cluster 3: rainwater harvesting as an alternative for wastewater reuse in agriculture	Cluster 4: Hybrid solutions, combinations of (1,2,3) at regional level as a climate adaptation strategy
Technologies • Filtration (membranes) • (Reversed) Osmosis • UV-treatment • Thermal disinfection • Electrochemical treatment • Ion-exchange	**Technologies** • (constructed) wetlands. • Soil Infiltration Areas • Benthos/worms/macrofauna	**Technologies** • Controlled drainage • Aquifer recharge • Dune and Creek ridge conservation (NBS) • Subirrigation	**Technologies** • Reuse water sugar beet factory COSUN

Treatment technology as a prerequisite for nature-based solutions (cluster 1)

Water Treatment processes, based on natural processes (e.g., uptake by vegetation or sedimentation), could be an effective measure to re-use water and nutrients. However, to reduce the emissions of micro-pollutants such as crop protecting agents (CPAs), PFAS, and pharmaceuticals and medicine residues these processes in (constructed) wetlands are not suited. So called 'polishing technologies' are needed, however, the disadvantage of these technologies, based on oxidation and/or ozonation processes is that they are not selective. Also, the natural occurring organic material (NOMs) in the effluent are oxidized. This organic material is important for the food web of wetlands, degradation has consequences for biodiversity when the treated water is intended for nature areas (Overbeek et al., 2018). Our hypothesis is that by establishing hybrid solutions consisting of both NBS and technology best of both worlds is reached and quality and quantity can be guaranteed.

Purifying Landscape, a nature-based solution with optional support of technology (cluster 2)
Organic matter and nutrients can be removed by ecological processes, but not always in the desired quality for economic use. Technology can lend a hand if the purified water must be of constant quality for people and/or nature. Pre-purification (five months) of water from the river Meuse in water reservoirs was identified as a NbS by Evides, one of the participating drinking water companies. Those water reservoirs, located in the Biesbosch, are in use since the seventies of previous century. Pilots are currently conducted at other drinking water plants to improve those systems (Caltran et al., 2020).

Rainwater Harvesting as an alternative for water reuse (cluster 3)

Several workshop participants have mentioned Rainwater Harvesting as an alternative for wastewater reuse, while in Ghana the stakeholders identified mainly barriers for adopting this solution. Those participants referred to research pilots based on infiltration of rainwater into soils or aquifers (Pyne, 2005) in arable farming, fruit cultivation, and horticulture in Zeeland (figure 7-5). Those research pilots make use of technologies such as controlled drainage, storage, and infiltration of freshwater in creek deposits with controlled drainage systems (Pauw et al., 2015) and aquifer storage and recovery (ASR) technology (Pyne, 2005; K.G. Zuurbier et al., 2014; K.G. Zuurbier et al., 2014).

Hybrid solutions (cluster 4)

We also identified examples, that are combinations of cluster 1, 2, and 3. Those examples, already in practice, concerned cooperation between different parties involved in food production (e.g., farmers and food processing industry). It concerns several private parties that have made agreements on a regional scale about the exchange and storage of used water. One of these examples concerned a sugar beet factory in Dinteloord (figure 7-5). Wastewater from this factory is used as irrigation water for nearby greenhouse horticulture. The treatment is done by Reversed Osmosis. Sugar beets are processed in autumn and winter, while Greenhouse horticulture needs irrigation water in spring/summer. Since 2016, the purified waste water is stored within the aquifer during winter and the water can be recovered in spring and summer by ASR technology (K.G. Zuurbier et al., 2014).

Discussion

- We observed that the provided spatial information about water supply was confirmed or disputed by participating policymakers, while the involved entrepreneurs took it for granted. For example, policymakers were concerned that in regions with creek ridges the agricultural water demand (irrigation) was overestimated in this map. In reality, the climate resilience of agricultural water demand is higher than modelled, explained by the natural phenomenon of rainwater lenses (de Louw et al., 2011).
- The geographically defined borders to compare water supply and demand based on maximum acceptable transport costs of water (pipes), as initially used, was difficult to grasp for stakeholders. Therefore, we have scaled up these units to the areas of the municipalities.
- Security of supply is more important to private parties than the underlying principle (nature-based, technical, etc.), while the consulted policymakers consider a nature-based solution as an important added value. NBS solutions are also initially considered in the Netherlands, but finally not implemented. For example, the

Heineken brewery considered biological wastewater treatment (Helophyte filter). However, it was decided to postpone the project, because it appeared difficult to guarantee the desired discharge water quality towards the authorities.

- Not only water is a recyclable resource from wastewater, also the reuse of the dissolved substances has an economic value was brought forward by the consulted entrepreneurs. For policymakers, this was more seen as a side effect.

7.4.2 DEVELOPMENT AND USE OF SPATIAL INFORMATION IN GHANA

Development of spatial information

Uptake and scaling the multiple types of rainwater harvesting not only depend on the potentially suitable areas available within a specific landscape, but also on the biophysical, climatic, and socioeconomic drivers at hand (Duku et al., 2021). Identifying these different drivers in Bono East was done with the aim to develop a suitability map for rainwater harvesting by building a Bayesian belief network, based on a combination of criteria defined in the literature (Adham et al., 2016; FAO, 2003; Haile & Suryabhagavan, 2019), and feedback from stakeholders in a workshop setting. The outcome of this exercise shows that rainwater harvesting for irrigation in Bono East is often randomly implemented, without considering the wider ecological, socio-economic, and institutional context. This leads to sub-maximum use of Bono East's potential, and poor performance of investments made. Identifying the potentially promising areas where rainwater harvesting for irrigation could be successfully implemented as a function of bioclimatic, terrain, hydrologic, and edaphic factors, hence well-embedded in its spatial context would be an effective pathway to enhance climate resilience, more efficient water use, and stronger circularity of food systems.

Used spatial information

Figure 7-6 shows the feasibility map which reflects the probability that an area is suitable for RWH for irrigation in Bono East. Suitability was computed using Bayesian belief networks as a function of slope, soil hydrologic properties, mean annual rainfall, tree cover, land cover, and distance to farms.

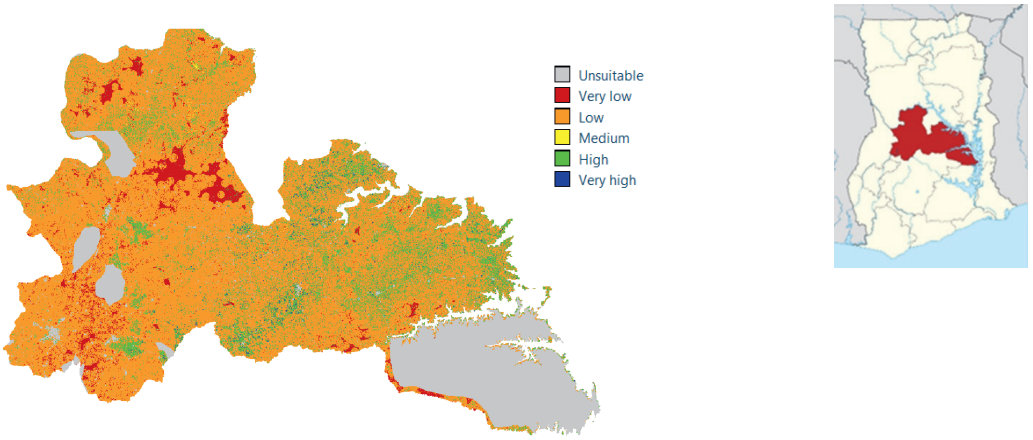

***Figure 7-6**, Suitability map of RWH for irrigation in the Bono East Region (Duku et al., 2021).*

Discussion

We found that whereas awareness on climate change is mounting, the sense of urgency in Ghana's Bono East remains relatively low. Currently, there are few examples of rainwater harvesting for irrigation in the region, while the potential of it is high. But, even if the sense of urgency would increase, there still are several barriers to the uptake of rainwater harvesting that hamper this NBS to be applied. These barriers may be categorised in the following manner:

- Biophysical barriers: inaccessibility of the terrain; steep slopes; erosion and run-off; more pronounced seasonality of rains.
- Technical barriers: poor availability of technical solutions; poor availability of knowledge to apply technical solutions.
- Socio-economic barriers: low motivation of farmers to invest; lack of financial means to invest; low-income level of farmers; unclear ownership of land, which is a disincentive to invest; low level of farmers' organisation, making it hard for farmers to invest collectively; stakeholder conflicts related to access to and control over resources such as water and land; pastoralists using water sources for drinking.
- Institutional barriers: available means for RWH are channelled through the Ministry of Social Services taking care of water and sanitation in town; not through the Ministry of Agriculture that takes care of agricultural production and irrigation; poor policy alignment; lack of farmers' participation in sectoral and spatial planning; poor access to spatial information and lack of participatory spatial planning methodologies.

Despite all these barriers, stakeholders believe that there is the need for RWH for irrigation, and the potential for it in Bono East is high. Through interviews, focus group discussions, and stakeholder dialogue, there was created a theory of change of the social, economic, and environmental impacts of RWH for irrigation implementation in Bono East,

the impact on the food system using the food system framework and the stakeholders were listed (Linderhof et al., 2023). The following enablers were recognised:

- Biophysical enablers: the strongest enabler is the climate itself. It is increasingly acknowledged that rain events are getting increasingly erratic, which is increasingly affecting agricultural yields. This increased awareness raises the sense of urgency, which is a great enabler for actors to develop the agency to respond.
- Technical enablers: There is technical knowledge available in Ghana, as the results show that rainwater harvesting is commonly practiced in the northern part of the country, which is much drier than the Bono East Region. Scaling the northern experience towards the south is very feasible, but needs to be supported by agricultural extension services, governmental or non-governmental support agencies, farmers' associations, and farmers themselves.
- Socio-economic enablers: investment in rainwater harvesting requires financial means which are typically low. Nevertheless, as Bono East Region is the food basket of Ghana, which will only increase under future climate conditions, leading to higher prices of food. It can be expected that this will lead to higher prices, which theoretically enables farmers to intensify commercial food production, earn more, and invest more. The issue of land ownership, however, remains a challenge, as unclarity on property rights are a disincentive to invest. Therefore, strengthening tenure security, land certification and cadastral developments will stimulate commercialisation and herewith increase the uptake of RWH for irrigation.
- Institutional enablers: integrating RWH for irrigation in the various sectoral policies can only be possible within a framework of stronger policy integration, and intersectoral spatial planning. Aligning Social Services policies with agricultural policies would help bringing RWH for irrigation infrastructure closer to the farm areas, to reduce investment costs. Enhancing urban water supply could reduce the pressure on surface water and enable farmers to get access to rainwater harvesting investments and support. Moreover, increased access to spatial information and participatory spatial planning methodologies would increase farmers' participation in spatial planning, bringing their needs and interests to the fore.

7.4.3 DIFFERENCES AND SIMILARITIES IN THE SPATIAL APPROACH

Our observations on the use of spatial information in Ghana and the Netherlands are summarised in table 7-5.

***Table 7-5**, Difference and similarities between the Netherlands and Ghana regarding the use of spatial information in this research project for the identified contextual conditions (table 7-1).*

Contextual conditions	Spatial information about:	Netherlands	Ghana
Water supply	• Water Gap Risk (supply < demand) • Adaptive capacity to climate change	• Assessed for the current climate and spatial information was improved in consultation with stakeholders	• Assessed for the current and future climate and used in stakeholder participation
Food Supply	• Food Gap Risk (Supply < Demand) •	• No spatial information was provided and involved stakeholders did not express spatial explicit information need on this subject.	• No spatial information was provided; however, stakeholders did emphasize the need for spatial explicit information need on this subject.
Environment	• Biodiversity • Soil	• Spatial information about the soil was implicitly provided/available as it was used to calculate the water demand. Involved stakeholders were concerned about the soil health and have access to soil information. • Spatial information about the impacts of biodiversity was not provided. Involved stakeholders did not express needs on this subject. However, from other studies in the Netherlands it is known that this need exists (Pronk et al., 2021; Zuurbier et al., 2018).	• Spatial information about the soil was implicitly provided/available as it was used to calculate the water demand. Involved stakeholders did also express knowledge needs that require spatial information on soils. • Spatial information about the impacts of biodiversity was not provided. Involved stakeholders did not express needs on this subject.
Socio-economic & institutional	• Land tenure • Policy incentives and support	• Spatial information on land tenure is not publicly available but can be made available on request (cadaster). This information was not used. Involved stakeholders did not express spatial information needs about land tenure, but the involved organisations use information about land tenure when granting permits for irrigation and drainage, for example.	• Land ownership was an important criterion of constructing the suitability maps. However, this information was not publicly available. • Although RWH is stimulated by Ghanian Government, this policy is not yet applied at Bono East Region since the lack of water availability during growing season has not yet

		• Spatial explicit information on policy incentives is publicly available but was not explicitly provided in this study. Stakeholders expressed information needs but those were not spatial explicit.	reached a critical level. Spatial information on suitable places for RWH would be beneficial for RWH policy in Bono East Region.
Alternatives for NbS (Rainwater Harvesting & Water reuse)	• Available alternatives • Added value NbS for Food System • Income Effect for Farmer from NbS	• Examples of alternatives, derived from the stakeholder consultation, were provided on a map (figure 7-5) for future stakeholder processes. The involved participants expressed needs for spatial explicit information on this subject but also provided information.	• Alternatives for NbS could be changing cropping patterns towards more drought-resilient crops. However, giving the fact that Bono East Region supplies food to urban areas (Accra and Kumasi, for instance). Current food supply consists of stable crops contributing to food security of low-income people in the urban areas. The consequences of changing cropping patterns are uncertain for people in Bono East Region and in urban areas.

Discussion

Ghana -The actual choice for specific technical options were in Ghana not explained by technical and contextual factors alone, but also by the availability of spatial information to make a well-informed choice, as well as the way in which spatial information was communicated and used by a variety of stakeholders in the form of participatory spatial planning. The case study used online and offline stakeholder dialogue and scenario modelling to assess suitability based on biophysical data, as well as socio-economic and institutional data, both types of data being key in mapping suitability and making well-informed choices. Both the online and offline dialogue offered a safe space to raise awareness on the necessity for NbS, discuss the different alternative solutions, and share insights on how best spatial data can be made available, to serve stakeholders to make a well-informed choice.

The Netherlands - In the Netherlands, the spatial information about additional water supply and demand provided insights for stakeholders to discuss also alternative solutions to combat the impact of climate change on water supply. Spatial information was initially used in the Netherlands to identify the best places for the application of the NBS at stake (reuse of wastewater).

Similarities in use of spatial information

In both cases, the use of geo-spatial information was considered as a stimulus to adopt and apply NBS, making the researchers realise that the role of geo-spatial information in the adoption and application of NBS is important. It helps to analyse the impact of climate change and present the NBS as an effective measure to adapt and raise the awareness on the potential of this.

In both case studies, the effect on biodiversity of respectively reuse of effluent water and RWH did not play a direct role in the stakeholder dialogue. Attention was rather paid to the economical use of natural resources (water, soil, nutrients in both case studies). Spatial information about the soil was used in both case studies, but no spatial information about biodiversity was available nor used.

7.5 CONCLUSIONS

Water-related problems connected to climate change are threatening the future of food systems in both the Netherlands and Ghana. The studied NbS offer opportunities for adapting to the impacts of climate change and increase the efficiency of water use in food systems. We studied two ways in which this can be done: making better use of rainwater by harvesting rainwater and reusing water through wastewater treatment. The first solution, as applied in Ghana, directly relates to rainfall, it collects the water whenever it falls, and requires relatively low investment costs, which need to be covered by increased crop yields. It increases a one-off efficiency in water use and does not allow for re-use. It also responds to climate change through adaptation, but it is less relevant for circularity, which is not yet an issue in Bono East. It requires relatively low investment costs, which suits the context which allows for small investments only, based on low rentability, low farmer incomes, and low levels of industrialisation involved.

The second solution, wastewater treatment, is focusing on recycling water, by using it more than once. This solution also responds to climate change by adapting, but it also allows for a more circular food system to emerge and is much more dependent on technology and

associated investment costs. It does, however, depend on technological innovation and requires considerable investment costs. It is, therefore, more likely that this NbS is adopted within a high value food system context, where food production and processing is industrialised and has high economic returns.

Both types of NbS respond to the challenge of climate change and farmers to adapt. Both rainwater harvesting and wastewater treatment techniques are available, and ready to be accepted and applied by farmers and food processing industry. Their uptake, however, is hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers.

In both cases, the availability of spatially explicit information, in combination with sectoral policy integration and more participatory spatial planning is considered key in adopting the available technology. The objective of this analysis was to identify differences and similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers or foster the enablers of NbS uptake. We conclude that the following requirements are essential to develop spatial explicit scenarios for NbS for climate resilient and circular food systems:

- Spatial information can be an enabler for adoption of nature-based solutions, if the spatial information is applicable for the assessment of a wide range of possible solutions for water scarcity considering food production, either nature-based solutions or technologies.
- In both case studies, we observe a struggle to make the future spatially explicit. In the Dutch example, it helped to discuss the future with existing examples (enabler), but the test of whether the potential water supply is climate-proof remains essential for existing subsidy regulations and is still missing (barrier).
- In both case studies, the effect on biodiversity of respectively reuse of effluent water and RWH did not play a direct role in the stakeholder dialogue. We were not able to identify whether this is an enabler or barrier for adoption of RWH for irrigation and wastewater reuse in food production and water management respectively. However, it is recommended to investigate this. Furthermore, biodiversity, in particular soil biodiversity, can also be a factor that determines the suitability of an area for both.

8



Picture: *Hondsbossche en Pettemer zeewering (Jeroen Veraart, 2015).*

From climate research to climate compatible development: experiences and progress in the Netherlands

Abstract - Over the past decades significant experience has been gained in demand-driven research on climate change in many countries. In the Netherlands a competitive call for proposals for large research programmes at the interface between policy, science and private sector was issued in 2001. Members of the Dutch climate research community proved they were able to develop two large research programme proposals which were funded: '*Climate changes Spatial Planning'* and its successor '*Knowledge for Climate'*. The programmes ran from 2004 to 2012 and from 2008 to 2014 respectively. Both programmes can be considered as a 10-year research programme experiment to develop knowledge about both the climate system and climate compatible development by crossing disciplines, institutions, and national research funding strategies. Within this 10-year period a trend can be observed in which a 'top-down' climate impact assessment approach is increasingly combined with a 'bottom-up' approach. Based on the 15 articles presented in this special issue (and others) we argue that this development has enriched both fundamental and applied research on climate adaptation. Despite the predominantly Dutch-oriented scope of the presented research we believe that such experiences can be of international interest. Climate adaptation research finds itself in between global systems knowledge on the one hand and practical needs and experiences at the local, regional, and national level on the other. This demands the utmost from all actors involved to enable an efficient and constructive flow and use of knowledge and expertise.

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8 From Climate research to climate compatible development: experiences and progress in the Netherlands

8.1 Introduction

Over the past few decades significant experience has been gained in demand-driven research on climate change. Various accounts and historical reconstructions can be found in the literature that describe the development of climate change research at the global level (Doherty et al., 2009; Pielke, 2010), at the European level (Biesbroek et al., 2010; Termeer et al., 2012) and at national level in different countries (Bauer et al., 2012; Greiving & Fleischhauer, 2012). Studies at the national level are generally characterised by a thematic approach, such as spatial planning (Wilson, 2006), agriculture and national resources (Meinke et al., 2009; Pearson et al., 2011; Steffen et al., 2011), flood risk management (Rosenzweig & Solecki, 2010; Rosenzweig & Wilbanks, 2010) or the governance of climate research (Pielke, 2009; Sarewitz & Pielke, 2007; Schneider, 2009; Storbjörk, 2007; Termeer et al., 2011).

The Netherlands has a tradition of research on climate change which goes back to the 1960s (Baede & Schuurmans, 2008; RIVM, 1987; RMNO, 2001; Schuurmans & Baede, 2008). Like in many other countries, research on the climate itself, as a system, goes back much earlier of course, with its origins in natural science and meteorology. According to the Royal Netherlands Meteorological Institute (KNMI) the first article in Dutch literature (van Genderen, 1967) on the relationship between CO_2 and climate change appeared in 1967 and had very little societal impact. It was not until the early 1980s that Dutch climate policy began to take shape, parallel to the developing stage of the IPCC as an international intermediary (Driessen et al., 2009; Schuurmans & Baede, 2008).

Looking back at those last 30 years, we make a distinction between three successive periods that characterise the development of climate research in the Netherlands:

Climate science and climate change (early 1980s – 1990)

Is climate change caused by human agency? The hypothesis underlying this question was the scientific and social trigger for increasing the level of research on climate and climate change, with the implicit assumption of the oceans, ice, the hydrological cycle, and the atmosphere being the major components of the climate system.

Climate science and climate policy (early 1990s – 2001)

Which measures are needed to prevent or to mitigate climate change? An additional dimension of climate change research became the investigation of possibilities to lower the emission of greenhouse gases by mitigation policies through the alternative deployment of natural resources, land use change (RIVM, 1987) and encouraging the use of sustainable energy resources (wind, solar, water, biofuels) (Klostermann et al., 2009; Oikonomou & Jepma, 2008). The feedback loops between the biosphere and land-use on the one hand and other components of the climate system were increasingly taken into consideration (de Gier & Schuurmans, 1998; van der Laan & de Kort, 1998), also internationally (Steffen, 2001). While the notion of land and land-use as an intrinsic part of the climate system was not new (Pielke et al., 1998; Pielke et al., 1991; Pielke & Avissar, 1990) it was not until the late 1990s that it was acknowledged by a wider range of scientific disciplines.

Climate science, adaptation, and climate compatible development (2001 – present)

What are the effects of climate change, to what extent are they acceptable (Dessai et al., 2004; Paavola & Adger, 2006), and if they are not acceptable, which societal agents should incorporate climate adaptation (Glantz, 2003; Kabat et al., 2005) into their long-term strategies? Climate change had become recognised as a two-sided coin, with not only a mitigation-side to it but also entailing an assignment for adaptation (Termeer et al., 2011; van Nieuwaal et al., 2009). Furthermore, extra emphasis was put on the question: what kind of science-society and science-policy relationships do we need in order to translate climate change into social change (Driessen et al., 2010)?

In the Netherlands this discussion encompassed not only climate change, mitigation, and adaptation. Around 2000 the economical dimension of responses to climate change was also brought forward. In this period, funding programmes for climate research in the Netherlands were coupled with the policy objectives of the ministry of Public Transport & Water Management (V&W), the ministry of Agriculture, Nature, and Food Quality (LNV), the ministry of Housing, Spatial Planning, and the Environment (VROM) and the ministry of Economic Affairs (EZ). In 2001, a competitive call for proposals for large research programmes was issued by the national government. The government's objective was to strengthen the Dutch economic infrastructure by improving the Dutch knowledge infrastructure through knowledge transfer and valorisation of knowledge between science, policy, and private sectors. The funding, which was € 802,000,000, came from national gas revenues (Ministry of Economic Affairs, 2002a, 2002c). A maximum of 50% of the total budget of these research programmes was funded in this way and the participating organisations were obliged to bring in the rest. This research funding philosophy resulted in 37 research & innovation programmes in the field of environmental sciences (Bouma et al.,

2011; Kabat et al., 2005; Zegveld, 2003, 1988), and technology (Cramer & Zegveld, 1991; Zegveld, 1988). In many of these research programmes the objective was to make use of multiple scientific disciplines and to address environmental and socio-economic issues in a cross-sectoral way. This required a transdisciplinary research approach, while the conventional public research funding approach in the Netherlands, and in Europe, were still mostly geared to maintain and reinforce disciplinarity (Vasbinder et al., 2010). In addition, this called for a shift from focus on the production of disciplinary knowledge to more attention being given to interdisciplinary research approaches, the involvement of stakeholders in developing research agendas and research projects, and knowledge dissemination and application.

Members of the Dutch climate research community proved that they were able to develop two large research programme proposals which were funded within a competitive context: *Climate changes Spatial Planning* (CcSP) and its successor *Knowledge for Climate* (KfC)(Kabat et al., 2005; van Nieuwaal et al., 2009). These programmes ran from 2004 to 2012 and from 2008 to 2014 respectively.

In both cases, one could speak of an attempt to combine research, climate policies and economic development in order to achieve 'climate compatible development' (Mitchell & Maxwell, 2010) rather than 'climate adaptation' or 'climate-proofing' (Adger & Barnett, 2009; IPCC, 2007) in the narrow sense. 'Climate compatible development' is a development that minimises the harm caused by climate impacts while maximising the many social and economic opportunities that result from low carbon urban developments and more resilient pathways (Mitchell & Maxwell, 2010). Dwelling on the experiences from the programme management of both national research programmes we observe a tendency from a more 'top down' climate impact assessment approach to a more 'bottom up' approach to the climate change issue within the Netherlands. By a top-down approach we mean scenario-induced climate adaptation, in which impact-assessments guide research and policy. By a bottom-up approach we mean processes aimed at climate adaptation that hinge on the vulnerability and resilience of specific regions and urban agglomerations, and this emphasises the importance of close science-policy interactions. We argue that both approaches are necessary to translate insights from international climate change research to regional initiatives and experiences with climate compatible development and vice versa.

The objective of this editorial is to position the presented research results contained in this special issue in the context of the shifts that have been detected in the above. The articles themselves mainly originate from the Dutch national research programme CcSP, but many authors are also involved in the KfC programme. Figure 8-1 shows a tag cloud based on the 15 abstracts of the papers in this special issue. It reflects the themes addressed in this special issue.

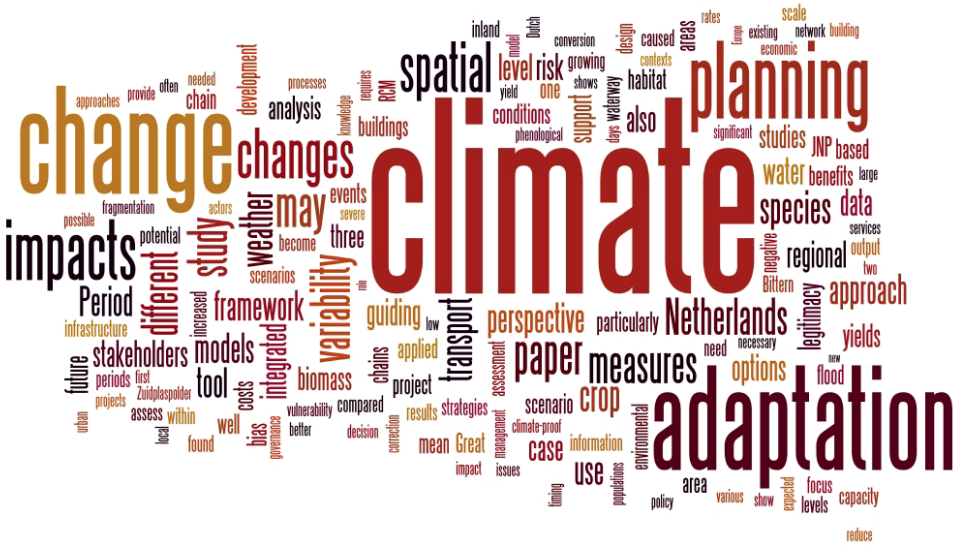

***Figure 8-1**, A tag cloud (Feinberg, 2011) based on the 15 abstracts in this special issue. The figure gives greater prominence to words that appear more frequently in the source text.*

A fair defence can be put forward to consider both programmes as a 10-year research programme experiment to develop knowledge about both the climate system and climate compatible development by crossing disciplines, institutions, and national research funding strategies. The research programmes share the objective to generate internationally competitive scientific results and to provide a knowledge base that interactively supports practitioners on how to cope with climate change at the national, regional, and local scale. The CcSP research programme having finished and the KfC research programme actively elaborating on the legacy of its predecessor provides a golden opportunity for the joint effort to produce this special issue. All four editors invited to work on this special issue were actively involved in managing the two research programmes.

The scope of this special issue, including the limited selection of articles (table 8-1), does not allow our ambition to position the research results in the context of shifts in climate change research to be sustained by strong causalities and generalisation within an international context. However, reflections in Europe on climate research funding strategies are scarce, contrary to those in other research fields (Arnold, 2004; Spaapen et al., 2007), and this encouraged us in our modest attempt to share the thinking in the Netherlands. In addition, the responsible climate research funding agencies, and leading scientists of the

two programmes not only evaluate scientific output but also frequently discuss the extent to which research within CcSP and KfC is relevant and applicable for actual decision-making processes on investments aiming to improve climate-compatible development based on the criteria presented in table 8-2. Also, from this perspective is it considered interesting to reflect on this issue.

To focus and structure our analysis three domains were selected. Although the two research programmes are independent, separately funded programmes it is these three domains that CcSP and KfC share as the main column for the research being carried out and they were found to be the drivers for collaboration between the two programmes. These three domains also touch upon the core of development we aim to investigate:

- climate model research and scenario development;
- climate adaptation and scenario use;
- development and evaluation of climate adaptation policies.

It must be noted that these three domains do no justice to the variety and depth of research on climate adaptation in the two programmes. The papers presented in this special issue are a selection of the most relevant research outcomes so far. An exhaustive overview of research projects and associated results can be found on the website of both programmes [11] .

The analysis is carried out based on documented accounts from both programmes, including articles and reports from the projects and the articles presented in this special issue. Special attention is given to the existence of features of 'top down' as well as 'bottom up' approaches (Adger et al., 2005a, 2005c) and features of interdisciplinary and transdisciplinary research (Wesselink, 2009; Wesselink, 2008) at both project and programme level. Experiences from the follow-up programme KfC supplied additional sources to reflect upon our findings.

[11] http://www.climateresearchnetherlands.nl

***Table 8-1**, Overview of the papers contained in this special issue.*

Climate model research and scenario development				
Abbreviated title and authors	*Top-down/ Bottom-up*	*Disciplinary fields*	*Scale*	*Sector*
Exploring the efficiency of bias corrections of regional climate model output for the assessment of future crop yields in Europe (*Bakker et al.)*	Top-down	Crop science, Climatology, Software engineering	Europe	Agriculture
Framing climate uncertainty: using socio-economic and climate scenarios in assessing climate vulnerability and adaptation *(Berkhout et al.)*	Top-down and bottom-up	Climatology, Social psychology, environmental sciences	Global (IPCC), national (the Netherlands), local (the North)	IPCC, Water management, Wind energy
Climate adaptation and scenario use				
Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, the Netherlands *(De Moel et al.)*	Top-down	Hydrology, Economics, Climatology, Public administration	Rhine catchment, Rotterdam area	Water management, Insurance, Building construction
Climate-proofing the Zuidplaspolder: a guiding model approach to climate adaptation *(Reichwein et al.)*	Bottom-up	Environmental Sciences, Landscape architecture	Local, regional	Spatial planning
Climate adaptation of interconnected infrastructures: a framework for supporting governance (*Bollinger et al.)*	Top-down and bottom-up	Civil engineering, Economics, Logistics, Geosciences, Public administration	Local, regional	Urban planning, Road, Electricity, Drinking water
Synthesis of ecosystem vulnerability to climate change in the Netherlands shows the need to consider environmental fluctuations in adaptation measures *(Van Bodegom et al.).*	Top-down	Landscape ecology, Soil science, Eco hydrology	National	Nature, the Netherlands Environmental Assessment Agency
Population dynamics of Great Bittern (Botaurus stellaris) in the Netherlands: interaction effects of winter weather and habitat fragmentation *(Cormont et al.)*	Bottom-up	Landscape ecology, Population ecology, Statistics	National	Nature conservation
Climate change and economic consequences for inland waterway transport in Europe *(Jonkeren et al.)*	Top-down	Transport economics, Spatial economics, Hydrology	Rhine catchment, National	Navigation, Transport, Water management

Development and evaluation of climate policies				
An integrated computer-based tool to assess economic and environmental implications of biomass delivery chains *(Elbersen et al.)*	Bottom-up and top-down	Landscape architecture, Environmental sciences, Plant production science, biotechnology	Europe, national, regional level	Agroforestry, Energy and Agriculture
Climate-proof planning for flood-prone areas: assessing the adaptive capacity of planning institutions in the Netherlands (*Van den Brink, et al.)*	Bottom-up	Public administration, Environmental sciences,	Local level	Spatial planning, water management
Observed climate-induced changes in plant phenology in the Netherlands *(Van Vliet et al.)*	Bottom-up	Phenology, Ecology	Local and national level	Phenological networks, Citizen science
Costs and benefits of adapting spatial planning to climate change: lessons learned from a large-scale urban development project in the Netherlands *(De Bruijn et al.)*	Top-down	Economics, Environmental sciences	Local and national level;	Water management, Spatial planning
Towards legitimate governance strategies for climate adaptation in the Netherlands: combining insights from a legal, planning, and network perspective *(Van Buuren et al.)*	Top-down and bottom-up	Environmental sciences, public administration; Legal sciences	Regional level	Spatial planning and Water management
Climate Adaptation Services for the Netherlands: an operational approach to support spatial adaptation planning *(Goossen et al.)*	Top-down and bottom-up	Environmental sciences, Climatology, Architecture, Geography, Hydrology, Plant science, Geoscience, GIS	Regional level	Spatial planning and Water management.
Toward design principles for joint knowledge production projects: lessons from the deepest polder of the Netherlands *(Hegger et al.)*	Bottom-up	Environmental sciences, public administration	Local level	Spatial planning

8.2 THE CCSP & KFC RESEARCH PROGRAMMES

The CcSP programme was originally organised in four main themes: climate scenarios, mitigation, adaptation, and integration. This structure was chosen in consultation with the ministries involved and regional policy makers during the proposal development phase (2000-2004). This structure seems comparable with the three working groups of IPCC in 2001 but there are some subtle distinctions and different accents due to the national context.

The research theme 'Climate Scenarios' covered not only research into the climate system (IPCC working Group 1) but also focused on tailoring climate information to support water managers and spatial planners. The Dutch Government was critical about mitigation research in 2000-2004 because in face of the ratification of the Kyoto protocol (2004) mitigation policies to reduce greenhouse gas emissions and energy use were in their final stage of development. As a result it was decided to narrow down research into mitigation to quantify greenhouse gas emissions related to land use (Hutjes et al., 2010; Lauvaux et al., 2009), full carbon accounting (Hutjes et al., 2008; Nabuurs et al., 2006) and bio-energy chains (Cuppen et al., 2010; Elbersen et al., 2014). IPCC working group III (mitigation) has a much broader scope. The set-up of adaptation research was comparable with IPCC working group II and designed from both a sectoral and regional perspective. The projects under the theme 'Integration' were meant to integrate activities within the former three themes with the aim of generating comprehensive decision support frameworks for policy making, while within the international climate research community 'integration' is often described as mainstreaming climate policies in other policy domains (Brouwer et al., 2013; Buuren et al., 2013; Halsnaes & Traerup, 2009; Uittenbroek et al., 2013; Yamin, 2005) or described as the interplay between adaptation and mitigation (Jordan et al., 2010). During the programme, it was decided to introduce a fifth separate theme for communication projects. The objective of the communication theme was to allow stakeholders to interact with the research agenda by informing them about projects at an early stage to increase the practical usefulness of the research results, also for stakeholders that were not involved in a particular project.

Climate (adaptation) research and practice became a 'booming business' in the Netherlands after 2005, and it turned out that the CcSP programme alone could not meet the rapidly increased demand and societal need for applied knowledge on climate adaptation. As a result, a new and complementary research programme, Knowledge for Climate (KfC; 2008-2013), was developed which was approved by the Dutch Government for funding in 2007. The KfC programme consists of two research lines: (a) fundamental research on eight adaptation themes; (b) applied research on adaptation strategies for eight vulnerable areas in the Netherlands (so called 'hotspots'). The KfC themes were flood risk management, freshwater supply, rural areas, cities, infrastructure and networks, climate projections, governance of adaptation and decision-support tools. The research themes were selected in dialogue with representatives of the relevant ministries and the regional hotspots teams. An important selection criterion was that the research results could be applied in climate adaptation measures and strategies at local, regional and/or national scale. The hotspots served as intermediary platforms to align knowledge needs and scientific research during the entire course of the programme.

Table 8-2, *Some general characteristics of the CcSP and KfC programmes (data derived from societal and scientific synthesis reports that were written for review in 2012 (Kabat et al., 2011))*

Characteristics	CcSP	KfC	Total
Research projects	53	>60*	>100
Scientific characteristics			
Initiated PhD trajectories	59	55	114
Scientific papers in international journals			>600
Socio-economic characteristics			
Co-financing partners	97	>100*	>100
Realised co-funding	44 million (€)	32 million (€)	76 million (€)
Programme funding (FES, BSIK)	40 million	46 million	86 million
Knowledge dissemination			
Unique Visitors www.klimaatonderzoeknederland.nl (2012)			27,987**
Total downloaded publications (2012)			316,919**

* Projects are still being initiated

** Personal communication: Fokke de Jong, web manager CcSP/KfC website

Together, both programmes have initiated more than 100 research and knowledge dissemination projects (table 8-2). Cooperation between scientific disciplines and policy-making was organised at programme and project level by research consortia. The project duration ranged from a few months to 5 years (projects involving PhD research). Coherence between the projects was emphasised and promoted through programme management by defining shared objectives, products and by organising programme-wide activities - programme meetings for instance - and international conferences, such as Deltas in times of climate change I (CcSP et al., 2010) and II (2014).

Many of the co-financing partners have participated in both programmes and include national financial resources which were primary allocated for universities and applied research institutes. In addition, co-funding was derived from governmental bodies at regional, national, and international level (EU research programmes). Contributions from the business community were relatively small in both programmes.

Together, both programmes so far have published more than 600 scientific papers in international scientific journals in the field of hydrology, climatology, ecology, environmental sciences, climate science, public administration, economics, governance, and planning. In conjunction with these scientific publications, knowledge was also disseminated by means of special issues in Dutch public magazines, contributions in media (newspapers, etc.), the Internet and social media.

8.2.1 CLIMATE MODEL RESEARCH AND SCENARIO DEVELOPMENT

Apart from providing society with estimates of future climate conditions it is necessary to remain alert about the many unknowns in the models, the observations, and the generated scenarios for temperature (van den Hurk et al., 2007), precipitation (van Haren et al., 2012) and sea level rise (Katsman et al., 2011). To give emphasis to this awareness, CcSP (and to a lesser extent KfC) followed a dual-course strategy in climate scenario research: one track aimed at generating tailored climate scenarios for a wide range of users, as exemplified by the paper about bias correction (Bakker et al., 2014) in this special issue. The other track focused on an increased understanding of the system and improved observational records, adequately merged into a regional climate model (RACMO) and a global model (EC-Earth).

Climate model developments

The RACMO climate model was revised (van Meijgaard et al., 2012) and refined with new knowledge about the boundary layer (Baas et al., 2008), aerosols (Ten Brink et al., 2009; Weijers et al., 2011), soil hydrology parameters (de Jong van Lier et al., 2008), cloud formation (Bouniol et al., 2010; Schutgens & Roebeling, 2009) and evaluated with European remote sensing data (Wipfler et al., 2011). This was done in a multidisciplinary approach in which insights from physics, soil science and hydrology (Brauer et al., 2009), derived from monitoring projects (Russchenberg et al., 2011), were combined with meteorology.

CcSP cooperated with international observation campaigns in the north-western North Atlantic (Hendry et al., 2007; Kohl et al., 2003). Hydrographic properties of the pre-industrial run of eight Coupled Climate Models, used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), were compared with observations from the World Ocean Circulation Experiment in the north-western North Atlantic (de Jong et al., 2009). The simulations with these coupled climate models differ significantly from regional observations of ocean thermal stratification in the north-western North Atlantic. The subsurface temperatures in the climate models that were used are higher compared to the observations in the North Atlantic (de Jong et al., 2009). A large natural variability at all water mass horizons could be described from daily to multi-decadal time scales (van Aken et al., 2011). Because of that natural variability, one may expect that the West European climate that depends on heat flux from the Atlantic Ocean will be more variable than currently assumed in climate models used for climate scenarios simulations. These new insights are taken into account within the next generation of Dutch climate scenario's (KNMI-next), and the development of EC-Earth (Hazeleger et al., 2010). Within EC-Earth it has been recognised that biogeochemical and human processes interact with the physical climate system.

Scenario development

The paper of Bakker et al. and Berkhout et al. in this special issue (Berkhout et al., 2013) demonstrate which steps are necessary to make tailored general climate scenarios for water management, agriculture and the energy sector. In addition, Berkhout and co-authors argue that scenario approaches need to be matched to the frames of stakeholders who are situated in specific decision contexts. Bakker et al. exemplifies how data from Regional Climate Models (RCMs) could be corrected for bias in observations, in order to improve crop yield simulations with the crop model WOFOST(Boogaard et al., 2013).

Socio-economic and land use scenarios were not developed but in most research projects adopted from the national environmental and socio-economic agencies (van Drunen & Berkhout, 2009). The use of these socio-economic scenarios is exemplified in this special issue at national level for water transport (Jonkeren et al., 2013) and flood risk management (Moel et al., 2013), while experiences at regional level are described for case studies in the area of Rotterdam (Goosen et al., 2013; Moel et al., 2013). In CcSP/KfC studies for agriculture (Hermans et al., 2010; Reidsma & Van Ittersum, 2012; Reidsma, 2010; Schaap et al., 2011) and bio-energy chains (Elbersen et al., 2014) the IPCC-SRES scenarios were used as the basis (Nakicenovic et al., 2000).

The dual course strategy enabled climate scientists to identify uncertainties at the level of the climate system while also the needs for knowledge from stakeholders and other scientific disciplines were identified within the tailoring process. An important challenge for climate compatible development is to co-produce knowledge (Cash et al., 2006a; Edelenbos et al., 2011) about vulnerability and resilience to climate change of society based on both 'global' climate change scenario's and regional determined socio-economic scenario's (bottom-up).

8.2.2 CLIMATE ADAPTATION AND SCENARIO USE IN THE NETHERLANDS

The papers in this special issue illustrate the diversity in how scenarios were used in Dutch practice in spatial planning, water management, nature conservation and infrastructure policy. Scenarios were used regarding Flood risk reduction measures at the national level (Kabat et al., 2009; Te Linde et al., 2011; Vellinga et al., 2009; Vellinga et al., 2008) and at the level of regional water systems in urban areas situated both below (Groot-Reichwein et al., 2013; Moel et al., 2013; van den Brink et al., 2013) and above sea level (Buuren et al., 2013). Many of these research projects were inspired by the risk approach (Hall et al., 2006; Vlek, 2010) which is also a characteristic of climate compatible development and climate-proofing. The risk approach is also adopted by the national Delta programme. One

of the implicit objectives of the National Delta programme (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs Agriculture and Innovation, 2011) is to embed knowledge about risk analysis, scenario use and tipping points analysis (Kwadijk et al., 2010; Werners et al., 2013) into flood risk management and to a lesser extent into water supply management.

The assignment for spatial planning is of a kaleidoscopic nature. The vulnerability of urban areas to prospected flood risks and heat stress has found its way to the policy making agenda of the Netherlands. The framework of multi-layered safety (Ministry of Infrastructure and the Environment, 2009) in the national water plan is also inspired by the risk approach and climate adaptation. Within this framework investments have been made not only in the prevention of floods, but also in the prevention of damage in the unlikely case of an emergency, by taking adaptive measures in spatial development and in evacuation potential. However, at regional policy-making level this concept is recognised as an adaptation option, such as in the Rotterdam region (Moel et al., 2013), but is not yet common practice or even doubted as is the case in the Province of Zeeland (Broekhans & Correljé, 2008). Current research in the Netherlands elaborates on the paradigm shift that 100% safety can never be guaranteed, and therefore residual risks and subsequent damages should not be ignored. This opens new opportunities for research and innovation.

Surprising to some, climate change also implies issues of water shortage in the Netherlands. Fresh water supply is recognised as one of the main concerns in that respect, but low water levels in the Rhine will also cause significant welfare losses due to increased transport prices if waterway transport becomes more and more congested (Jonkeren et al., 2013). The vulnerability of infrastructure and networks in general is increasingly recognised as an indispensable part of the climate adaptation research agenda (Bollinger et al., 2013). Amidst issues within our built environment, we must not forget the ecological structures with which they are, and should be, connected (Groot-Reichwein et al., 2013). Climate adaptation research in the Netherlands is building up a strong curriculum on research into the impact of climate change on the interactions between the abiotic (water, soil, atmosphere) and biotic components (species) of ecosystems (Bodegom et al., 2013; Vliet et al., 2013). The paper on the great bittern (Cormont et al., 2013) is one of a very specific kind, but it does illustrate how specialised the field has become.

With the support of both research programmes significant progress has been made on using the risk approach in water policy making and climate science at different scales in the Netherlands. This is one step forwards towards climate compatible development. Knowledge about climate risks and adaptation strategies in Dutch water management is also being increasingly co-produced by combining knowledge from the different sectors involved

(Hegger et al., 2012b; Verkerk & Van Buuren, 2013). However, it remains a challenge to do this, from other policy perspectives too, and to combine the insights gained.

8.2.3 DEVELOPMENT AND EVALUATION OF CLIMATE POLICIES

Adaptation to climate change entails the quest for balancing short-term agency and long-term horizons. Many studies in the field of climate policies (Adger et al., 2009; Davoudi et al., 2010; Termeer et al., 2011; Wilson, 2006), natural resources management (Adger et al., 2005b) and disaster risk reduction have shown that it is difficult to effectively use these inter-linkages, even if they are obvious, because investment costs, benefits and side effects of national adaptation strategies are, for example, not equally distributed between different geographical scales, different regions and between socio-economic groups, also exemplified in the study about the Zuidplaspolder (de Bruin et al., 2013).

Therefore, not surprisingly, climate adaptation requires the development, implementation and evaluation of policy strategies and policy measures. Not acting is not an option; yet investing too much in the wrong direction is a pitfall everybody would want to avoid. Developing the adequate policies is not only crucial for effective climate compatible development, there is also an increasing awareness that there is much more to gain in terms of efficiency. We argue that because of all the uncertainty, climate adaptation is to a large extent learning by doing and evaluation and monitoring should be part of all climate policies. The interaction with stakeholders throughout the entire process appears to pay off (Buuren et al., 2013; Goosen et al., 2013; Hegger et al., 2012a; Hegger et al., 2012b; van den Brink et al., 2013). Modelling and monitoring tools (Goosen et al., 2013) can be instrumental in drawing the bigger picture in which the various stakeholders not only recognise themselves, and *feel* that they are recognised; it also enables a true dialogue on the wicked problem at stake. More flexible institutional arrangements are proposed to put those insights into practice (van den Brink et al., 2013). Particularly pilots and experiments at the regional and local scale can be of value in taking knowledge production further. This special issue incorporates three papers on such a case, the Zuidplaspolder (de Bruin et al., 2013; Groot-Reichwein et al., 2013; van den Brink et al., 2013).

The papers in this special issue illustrate how knowledge to underpin adaptation and mitigation policies can be developed at different scales – ranging from national to local, and for different sectors. However, it remains a challenge how to interlink top-down and bottom-up research at different scales.

8.3 CONCLUSIONS

Experiences from climate adaptation research in the Netherlands indicate a shift from what we have labelled a 'top-down approach' to the inclusion of more 'bottom-up approaches' to climate adaptation research. Based on the articles presented in this special issue, among other things we argue that this development has enriched both fundamental research and applied research on climate adaptation, finding its way particularly towards climate compatible development at the national, regional, and local scales.

Despite the predominantly Dutch oriented scope of the research, we believe that such experiences can be of international interest. Hence, we encourage subsequent initiatives from elsewhere in order to accommodate and stimulate international comparison. We firmly believe that the crossing of scales from a geographical, temporal, and sectoral perspective will become more and more important in conducting research on climate adaptation. Alternating top-down *and* bottom-up approaches will be one of the major challenges in that respect. Climate adaptation research finds itself in between IPCC level global systems knowledge on the one hand, and practical needs and experiences at the local, regional, and national level on the other. This demands the utmost from all actors involved to enable an efficient and constructive flow and use of knowledge and expertise.

Acknowledgements

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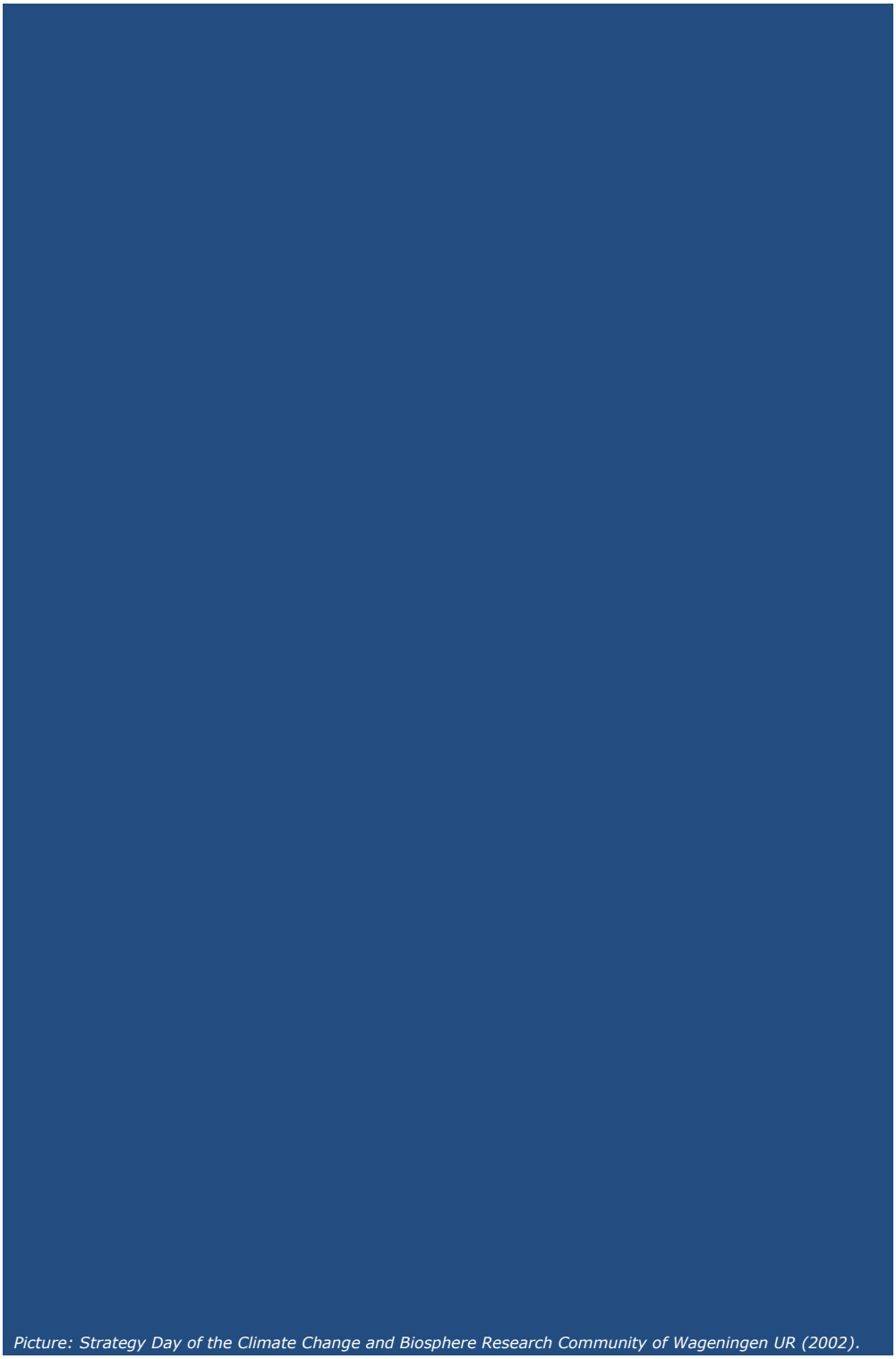
9





Picture: Strategy Day of the Climate Change and Biosphere Research Community of Wageningen UR (2002).

9 ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS

9.1 INTRODUCTION

The objective of this thesis is to explore how uncertainties are addressed between climate adaptation research and water management in situations where science-policy interfaces co-exist at different geographical scales.

The following research questions were formulated:

- **Q1:** *What are the type and role of uncertainties at the interface between climate adaptation research and Dutch water management?*
- ***Q2:*** *What is the role of boundary objects in knowledge exchange between climate adaptation research and water management across spatial scales?*
- **Q3:** *What are strategies to address uncertainties from the perspectives of research and practice respectively, and how to enhance the usability of climate adaptation research in water management?*

The insights gained from this dissertation aim to contribute to the improvement of existing approaches for addressing uncertainties in climate change adaptation at the interface between climate research and water management, including applications beyond the Dutch context.

These research questions were assessed with a nested longitudinal case study research approach (section 1.4, Chapter 2). By exploring this process in the Netherlands across multiple geographical scales, in detail for the period 2000–2014 and with a forward-looking perspective extending to 2025, this study aims to offer guidance for enhancing knowledge exchange between climate adaptation research and water management. A nested case study approach was chosen to capture interactions across scales between climate adaptation research and Dutch water management.

Interfaces were examined at the national level, such as the *National Delta Programme* and the research programme *Climate changes Spatial Planning*. At the regional level riverine and estuarine dynamics shape both climate adaptation strategies about freshwater availability and flood risks. The focus was on the estuaries of the Rhine, Meuse, and Scheldt in the southern part of the country. At the local level, individual farms in this region exemplify how these regional adaptation strategies as well as climate change impacts translate into challenges for freshwater supply, crop choices and soil management. By linking these scales, the case study highlights how regional water safety strategies and local freshwater management are interdependent. Science-policy interfaces partially coexisted in a nested

configuration. The longitudinal analysis focused on the period from 2000 to 2014, mainly based on the research findings presented in Chapters 3 through 8.

In this final chapter, as well as in Chapters 2 and 8, attention was also given to the periods preceding 2000 and following 2014, accordingly distinguishing three distinct time periods: *"before 2000"*, *"2000-2014"* and *"2014-2025"*. Between 2000 and 2025, four IPCC assessment reports were published, and the impacts of climate change became increasingly apparent across the globe and within the Netherlands. During this period, considerable efforts were undertaken in the Dutch water sector to formulate climate adaptation strategies, establish long-term financing and governance arrangements, and debate the necessity of spatial planning reforms alongside the climate-resilient transformation of water infrastructure. Climate adaptation scientists contributed to these developments through their involvement in science-policy interfaces at multiple spatial scales.

The key findings regarding research questions 1, 2, and 3 are discussed in section 9.2 through 9.4. Each of these sections starts with a brief introduction to the research questions. Then the key findings are presented. Finally, the reasoning that provides the basis for the findings, derived from Chapter 2-8 is discussed. Finally, Chapters 9.5 and 9.6 summarise the conclusions and recommendations, respectively, in a concise, point-by-point manner.

9.2 THE TYPE AND ROLE OF PREVAILING UNCERTAINTIES (RQ 1)

Research question 1 concerns the type and role of uncertainties that effect knowledge exchange between climate adaptation research at the interface(s) with Dutch water management over time. This dissertation applied a typology of uncertainty - ontic, epistemic, and ambiguity - alongside classifications of consensus (disputed, unclassifiable, consensus). This framework, based on Zandvoort (2017), has not previously been applied over a longitudinal period of 14 years (with outlook towards 2025) and offers a novel contribution to the field.

Key findings have been assessed regarding the (changing) role and characterization of uncertainties that played a role in the units of analysis that represent:

- Interfaces at regional level (Rhine-Meuse-Scheldt Estuary) and local level (farm level in Zeeland).
- Interfaces at national and regional level such as the studied climate research programs (NRP-CC, CcSP, KfC) and the national Delta program during the studied time period (2000-2014), prior and after.

The available longitudinal information from the nested case study analysis is smaller for these nested scale levels compared to the nested national and regional interfaces. Consequently, the majority of key findings are based on the nested interfaces at the national and regional scales. To assess these key findings, the role and characteristics of the uncertainties are first summarized per time period.

Key finding 1: *Between 2000 and 2014, ambiguous, epistemic, and ontic uncertainties were observed across the various units of analysis in this case study and progress has been observed in understanding and addressing those. However, the prevailing uncertainties were often not aligned in time across national scale (Delta Programme), regional scale (Southwest Delta) (Chapter 5), and local scale (freshwater supply at farm level in Zeeland) (Chapter 6). In each unit of analysis, the typification and identification of prevailing uncertainty categories and degree of consensus did not consistently evolve in time. Rather, it exhibited a dynamic pattern, shifting back and forth among the domains of water management, climate adaptation research, and water user perspectives, including interactions over time.*

Several European case studies support and enrich this observation. For example, in the Guadalquivir Basin it was observed that strategies to address epistemic uncertainty in the context of the Water Framework Directive were compounded by narrative pluralism (conflicting views on water supply and demand) which evolved unevenly over time and across the regional and local scale (Cabello et al., 2018). In Germany, local coastal defense strategies were developed in response to sea-level rise projections at national level, while regional and national planning frameworks lagged behind in integrating ontic uncertainties, such as storm surge unpredictability (Martinez et al., 2020). Unlike these two international case studies, this dissertation illustrates that consensus on climate adaptation strategies is not necessarily enduring (Chapter 2,5). It can unravel when new ontic uncertainties arise, for example, stemming from inherently unpredictable changes in the physical system, challenging previously shared understandings and agreements.

This key finding is based on the insights from Chapters 2, 5 and 6, that describe, respectively, regional and local interfaces between climate adaptation research and water management. New ontic uncertainties frequently emerged, introduced either by environmental research or climate adaptation research. At the same time, water users and stakeholders developed new lines of reasoning, often drawing on scientific knowledge from outside the climate adaptation research field, which also changed the prevailing uncertainties in decision making. For instance, unexplained ecological phenomena, such as

the changes in algal blooms observed in Lake Volkerak-Zoom (Chapter 5), have prompted alternative interpretations regarding regional environmental issues (water quality, biodiversity, climate change impacts) and economic issues at local level. At regional level, increasing ontic uncertainty emerged among researchers and water managers regarding the causes (water quality), consequences (algal blooms), and the proposed solution, namely, the restoration of estuarine dynamics. Simultaneously, ambiguity arose as water managers began reframing the issue in the political discourse. Initially, partial restoration of estuarine dynamics in lake Volker-Zoom was presented by water management as a solution for a water quality problem (2000), with the proposition that this would also contribute to climate adaptation objectives (2014). Eventually, however, the proposed measures were reassessed in response to economic concerns. Questions arose regarding the desirability of restoring estuarine dynamics, given the risk that climate change could increase freshwater scarcity at both the regional and national levels. This shift in perspectives challenged the previously established consensus not only on the appropriate climate adaptation measures but also on the underlying framing of the problem itself.

Changing roles of uncertainties in the different time periods

To evaluate which type of uncertainties prevailed in each of the three time periods at the interface of the national and regional cases, it was studied to what extent water managers, climate researchers and water users:

- used the same line of reasoning;
- posed denial claims;
- used the same boundary objects with the same interpretation.

Accordingly, the degree of consensus was labelled as *consensus, disputed* and *unclassifiable (uncertain)* in table 9-1, 9-2, 9-3 and 9-4. For the purposes of the analysis, the period from 2000 to 2014 was subdivided into two intervals: 2000-2005 and 2005-2014. Such a more nuanced temporal delineation was feasible because sufficient insights had been obtained.

The role of uncertainties before 2000

As described in Chapter 2, before 2000, *ontic uncertainties* were prevailing and shaping climate research and earth system science at the international level (table 9-1). Little research was done on adaptation to climate change, except for research how to cope with weather extremes and climate variability in water management.

Table 9-1, *Prevailing uncertainty about climate change and freshwater resources before 2000.*

Units in interface	Degree of consensus	Prevalence of (addressing) uncertainties		
		Prevailing	**Second**	**Third**
Climate Research	Unclassifiable	Ontic	Ambiguity	Epistemic
National Water Management	Not investigated	-	-	-
Interface (not organized)	-	-	-	-

Indicative for ontic uncertainties - The first IPCC report (1990) highlighted incomplete understanding of climate systems, emphasizing the need for improved models to enhance predictive capability. Significant gaps persisted in understanding natural climate variability and feedback mechanisms, as can be seen in the first generation of KNMI scenarios (Chapter 2).

Indicative for ambiguity – Globally, public debate on human-induced climate change fueled skepticism and denial, delaying climate mitigation policy actions (Duineveld et al., 2024), also in the Netherlands (Chapter 2). Competing views emerged between scientists advocating evidence of human influence and critical scientists questioning the role of anthropogenic activities. However, ambiguity related to climate risks was less prominent in water management before 2000 (Chapter 2,4).

Indicative for epistemic uncertainty - Early climate studies (e.g., Club of Rome in the 1970s) addressed uncertainties through systematic modelling and expert judgment, identifying gaps in knowledge about CO_2 effects and environmental interactions (Chapter 2).

Key finding 2: *Prior to 2000, discussions on climate change impacts in water management were scattered across individual projects and institutions, without a coordinated platform to consolidate knowledge or foster systematic debate (Chapter 2). The debate on uncertainties was conducted within other science–policy interfaces (outside the domain of water management), concerning the predictability of climate change and the usefulness and necessity of climate mitigation policies. Climate research during this period was shaped primarily by ontic uncertainties, reflecting the inherent unpredictability of the climate system. While ambiguity also influenced climate science, it was most evident at the interface with climate mitigation policies and less present in the domain of water management.*

The lack of a coordinated network of climate adaptation researchers in the Netherlands prior to 2000 is underlined by other Dutch scholars (KNMI, 2023; van Bree & van der Sluijs, 2014). This dissertation finds that ambiguity, defined as the existence of multiple legitimate

interpretations of climate risks, played a minor role in water management prior to 2000. Instead, ambiguity was more pronounced in the realm of climate mitigation policy, where competing values, political interests, and divergent scientific framings created a high interpretive complexity (Chapter 2).

The role of uncertainties between 2000-2014

In the period 2000-2005, the development of interfaces, such as CcSP and DWC, contributed to consensus between climate scientists, land use experts, hydrologists and water managers about the need to conduct systematic climate adaptation research (Chapter 2,8), i.e. addressing epistemic uncertainties (table 9-2).

Table 9-2, *Prevailing uncertainty about climate change and freshwater resources in period 2000 – 2005.*

Units in interface	Degree of consensus	Prevalence of (addressing) uncertainties		
		Prevailing	**Second**	**Third**
Climate Adaptation Research	Consensus	Epistemic/Ontic	Ambiguity	
National Water Management	Unclassifiable	Epistemic	Ontic	Ambiguity
Interface (national)	Unclassifiable	Epistemic	Ontic	Ambiguity

Indicative for ontic and epistemic uncertainties - Water managers were stressing to climate researchers that long-term climate projections were too uncertain to meet the requirements to develop a climate adaptation strategy (Chapter 3). The proposition 'too uncertain' by both stakeholders and experts implicitly involved a combination of ontic and epistemic uncertainties.

Indicative for ambiguity - Parallel to this discussion at the interface between water management and climate adaptation research, climate sceptics embraced ontic uncertainties related to the long-term climate projections. They continued to communicate heterodox ideas (also existent before 2000) about the relationship between increased greenhouse gas emissions and climate change (Chapter 2). Landowners and water users started developing alternative ways of reasoning by underlining the economic 'risk of regret' if climate adaptation measures would be implemented in water management (Chapter 2,5). This resulted in ambiguity at regional level (table 9-3).

The role of uncertainties between 2005-2014

In the years that followed (2005-2014), various methods were developed to reduce epistemic uncertainties between climate adaptation research and water management at different spatial scales (table 9-3). Progress was made at the interface between climate

research and national water management since 2005 in making long-term climate scenarios operational for different sectors and different spatial scales.

Climate adaptation researchers and water managers developed a narrative that climate adaptation required land for increasing water safety and for a better distribution of fresh water across the Netherlands at national level (Chapter 2). At the strategic level, adaptation strategies were completed at national and regional level (consensus) under supervision of the national Delta Programme.

Table 9-3, *Prevailing uncertainty about climate change and freshwater resources in period 2005 – 2014.*

Units in interface	Degree of consensus	Prevalence of (addressing) uncertainties		
		Prevailing	**Second**	**Third**
Climate Adaptation Research	Consensus	Epistemic	Ontic	Ambiguity
National Water Management	Consensus	Epistemic	Ontic	Ambiguity
Regional water management	Unclassifiable	Ontic	Ambiguity	Epistemic
Water Users	Unclassifiable	Ambiguity	Ontic	Epistemic
Interface (national)	Consensus	Epistemic	Ontic	Ambiguity

Indicative for epistemic uncertainty - Methods to address epistemic uncertainties in water management shaped the interface with climate adaptation research in the Netherlands between 2005-2014, while ambiguity persisted in the public discussions about climate change and water management. The CcSP-programme (2004-2012) and KNMI made significant progress in the development of tailored climate scenario's that could be used at national and regional scale (Chapter 2,8). The periodic and structured updates of the KNMI scenarios since 2006, embedded in law and national water policies, indicate that addressing epistemic uncertainties prevailed in both climate adaptation research and water management at national level. The periodic updates of the KNMI scenarios reflect a strategy to continually address and incorporate emerging insights in climate modelling about, for example, regional variations in cloud formation (Teuling et al., 2017).

Indicative for ontic uncertainties - CcSP-Research addressed gaps in understanding feedback mechanisms and future climate impacts. In climate science, feedback mechanisms refer to processes that can either amplify or suppress climate change impacts. Hydrological feedbacks were discussed, such as land-atmosphere coupling (Chapter 2) and soil-moisture-precipitation feedbacks (Chapter 8). The conclusion was that ontic uncertainties in hydrological and precipitation patterns persisted (Chapter 2), in line with feedback on the latest IPCC assessment report (Douville et al., 2022).

The Delta Programme's concept of adaptive delta management (Chapter 2,5) was an approach to address ontic uncertainties, such as extreme sea-level rise scenarios. Climate

sceptics continued to raise primarily ontic uncertainties in relation to national climate mitigation policies and its economic consequences (Chapter 2). Some of these ontic uncertainties concerned the variability of the hydrological cycle and the indeterminate effects of land cover change on climate dynamics. Such uncertainties complicated the assessment of climate mitigation policies, since their impacts on greenhouse gas fluxes and regional climate feedbacks could not be predicted with confidence. At the same time, these considerations needed to be explicitly incorporated into the design of climate adaptation measures in water management, as already emphasized by climate adaptation scholars at the time (Berkhout et al., 2013; Jordan et al., 2010) and reaffirmed in more recent research (Peeters et al., 2022). However, during this period, water managers generally preferred to treat climate adaptation and climate mitigation as separate policy domains (Chapter 2). As a result, opportunities to develop synergies between adaptation strategies and mitigation policies remained limited, including in areas such as peatland water management (Chapter 2).

Indicative for ambiguity – In this period, tensions arose between water management strategies (e.g., water retention versus drainage) and stakeholder priorities (e.g., agriculture versus flood management). The introduction of concepts such as "natural climate buffers" revealed ambiguity in balancing multiple objectives, including biodiversity conservation, flood risk reduction, and greenhouse gas dynamics. This conclusion is illustrated in Chapter 2 (section 2.3) with the case of the Onlanden nature reserve (peatland). In its initial phase, improvement of biodiversity and the realization of increased water retention were mutually reinforcing. However, the rewetting of peatland further raised questions by some stakeholders about the availability of sufficient freshwater to sustain such measures in view of climate change. Moreover, while rewetting enhanced carbon sequestration, it simultaneously led to higher methane emissions, underscoring the complex trade-offs inherent in climate adaptation strategies. Scientific assessments about costs and benefits regarding additional freshwater supply for agriculture (water users) in view of climate change were debated, by some actors even disputed (Chapter 5,6,7).

Key finding 3: *In the period 2000-2014 a noteworthy observation emerges at the co-existing interfaces between climate adaptation research and water management: most efforts were directed towards the structured reduction of uncertainty (see Chapters 2, 5, 6, and 8). This approach aligns with contexts in which epistemic uncertainties are prevailing. Simultaneously, ontic uncertainties and ambiguity continue to exert considerable influence within climate adaptation research and climate policy in and beyond the water sector. Notably, the application of epistemic methods to address ontic uncertainty raised concerns among climate adaptation researchers with backgrounds in the life sciences. Meanwhile, social scientists in the field were actively seeking methodologies that would more effectively engage with ambiguity in decision-making processes.*

Key finding 3 is exemplified by the dual-track strategy employed in climate scenario research under the Climate Changes Spatial Planning (CcSP) programme (Chapter 8). One track focused on producing tailored climate scenarios - an effort to reduce epistemic uncertainty - while the other track aimed to deepen understanding of the climate system through observational data and modelling, thereby addressing ontic uncertainty. CcSP researchers maintained both tracks, whereas water managers primarily engaged with the first, more practical track (Chapter 2). At a later stage, when CcSP was finalized (2012) and the research programme Knowledge for Climate (KfC) continued, this two-track approach became less prominent (Chapter 2). Other scholars have also noted an implicit preference for epistemic strategies at the science-policy interface, often aimed at reducing all forms of uncertainty. For instance, Taebi, Kwakkel et al. (2020) argue that technical climate risk governance is dominated by epistemic uncertainty reduction, while deeper ontic and normative uncertainties are frequently overlooked (Taebi et al., 2020). Observations and modelling reduce epistemic uncertainty about processes, while ontic uncertainty (such as natural variability) can be delineated, in terms of its possible range, but not reduced.

The role of uncertainties since 2014

In 2014, the national climate adaptation strategy for Dutch water management was formalized by decisions on water safety standards and the allocation of freshwater resources, in combination with regional climate adaptation strategies. This formalization reflects a consensus regarding climate adaptation strategies and their associated uncertainties (Chapters 2 and 5). Since 2014, the urgency surrounding climate adaptation in Dutch water management has intensified, driven by the increasing frequency and severity of weather extremes such as the prolonged droughts in 2003 (Chapter 3), 2018 and 2019 and the high river discharge events affecting Germany, Belgium, and the Netherlands in 2022 (Chapter 2). These developments prompted a growing concern at national and regional

levels regarding the adequacy of incremental adaptation strategies. As a result, more transformative approaches (Dampha et al., 2025; Harding et al., 2024) such as managed realignment of coastal zones and shifts in land use have been more reconsidered.

Table 9-4, *Prevailing uncertainty about climate change and freshwater resources since 2014.*

Units in interface	Degree of consensus	Prevalence of (addressing) uncertainties		
		Prevailing	**Second**	**Third**
Climate Adaptation Research	Unclassifiable	Ontic/Epistemic		Ambiguity
National Water Management	Consensus	Epistemic/Ontic	Ambiguity	
Regional Water Management	Unclassifiable	Ontic	Ambiguity	Epistemic
Water Users	Unclassifiable	Ambiguity	Epistemic	Ontic
Interface (national)	Unclassifiable			

Indicative of ontic and epistemic uncertainty (table 9-4) – new ontic uncertainties arose during the operational implementation of the regional climate adaptation strategies of the Dutch Delta programme after 2014, such as uncertainties about the rate of the sea level rise (Le Bars et al., 2017; van Alphen et al., 2022; van Alphen et al., 2024) as described in Chapter 2. The establishment of the Sea Level Rise Knowledge Programme (KP-SLR) exemplifies institutional efforts by the national Delta programme to address persistent ontic uncertainties in sea-level rise projections (Chapter 2). By refining upper-bound scenarios through structured scientific inquiry, KP-SLR adopted an epistemic approach to better understand and anticipate long-term risks (see table 9-4; Chapter 2). Notably, both ontic and epistemic uncertainties received comparable attention at the science–policy interface, making it difficult to hierarchize their prevalence. While KP-SLR explores strategic responses to accelerated sea-level rise, the presence of unknown physical processes - such as ice-sheet dynamics (Le Bars et al., 2017; Ran et al., 2024) continued to pose significant challenges for water management and spatial planning.

Indicative for ambiguity - Ambiguity is evident in the contested discourse surrounding managed realignment in view of sea level rise in the Netherlands (Bax et al., 2023; Zegwaard et al., 2015). Chapter 2 illustrates that, since 2014, diverging views between proponents of nature-based solutions (Boelee et al., 2017; Slinger et al., 2021) and advocates of the traditional water management paradigm (Mooyaart & Jonkman, 2017) (Chapter 4) can be observed at the interface between water management and climate adaptation research. This is, for example, illustrated by the evolving debate around the Dutch government's 2022 policy principle, *"Water and Soil as Guiding Principles for Spatial Planning."* On one hand, this principle has received growing criticism for its perceived rigidity, particularly in relation to regional development needs such as housing expansion and energy infrastructure (de Zeeuw & Rijcken, 2024). De Zeeuw & Rijcken (2024) argue

that greater flexibility - enabled by technological innovation within water management - would be necessary to reconcile climate adaptation strategies (Chapter 2). On the other hand, other scholars (Boelee et al., 2017; Janssen et al., 2017) argue that Nature-based solutions create more flexibility for climate adaptation.

Key finding 4: *Since 2014 (Chapter 2), ontic uncertainty has played a more prominent role in Dutch water management, making it increasingly difficult to sustain the level of consensus on the effectiveness of climate adaptation that had been achieved in 2014, when the national adaptation strategy for water management was adopted (Chapters 2 and 5). This more prominent role of ontic uncertainty is attributable to emerging scientific insights into accelerated sea-level rise since 2014 (Chapter 2). In addition, the occurrence of extreme weather events, such as the extreme drought in 2018 and the severe flooding in the Rhine basin in 2021 has further amplified ontic uncertainty about future climate conditions and the viability of the adopted climate adaptation strategies. Ambiguity also increased since 2023 regarding the flexibility and economic implications of the proposed strategies. The interplay between ontic uncertainty and ambiguity since 2014 has increasingly challenged the shared narratives and the coordination of climate adaptation strategies within Dutch water governance.*

9.3 THE ROLE OF BOUNDARY OBJECTS IN KNOWLEDGE EXCHANGE BETWEEN CLIMATE ADAPTATION RESEARCH AND WATER MANAGEMENT (RQ 2)

9.3.1 INTRODUCTION

Research question 2 addresses the role of boundary objects in knowledge exchange between climate adaptation research and water management across spatial scales.

Boundary objects are artefacts (things, concepts, discourses, processes, models, language, scenarios, etc.) that can simultaneously project disparate interpretations (section 1.4). They have interpretive flexibility, while constituting a solid nexus for communication and collaboration among disparate worldviews or knowledge systems (Franco-Torres et al., 2020). The use of boundary objects is a promising strategy to increase knowledge exchange between climate adaptation research and water management (section 1.3). In the analysis, a division in boundary objects is made between terms related to climate adaptation (section 9.3.2) and climate scenarios (section 9.3.3). It was investigated whether the interpretation

of these concepts is comparable in water management and climate adaptation research and whether the explanation of the terms change over time.

In this dissertation, boundary objects were not predefined as a fixed set of terms. Instead, they were identified inductively, based on terms that appeared in practice within climate adaptation research and water management. Climate scenarios and climate adaptation terms were considered boundary objects insofar as they functioned as shared reference points between water management and climate adaptation research. The role of boundary objects and boundary organisations, as theoretical concepts, is mentioned only in Chapter 2 and 4. The discussion of research question 2 is therefore primarily based on a retrospective reflection on the research results as described in Chapter 2 through 8.

Across the different time periods examined, shifts are evident in both the terms employed for *climate adaptation* and the interpretation of *climate scenarios*. These elements - climate adaptation terms and climate scenarios - can be conceptualized as boundary objects (figure 9-1), facilitating communication across disciplinary and institutional domains. Over time, these boundary objects have been increasingly mobilized in strategic ways to support knowledge exchange between climate adaptation research and water management practices at both national and regional levels in the Netherlands (Chapters 2 and 8).

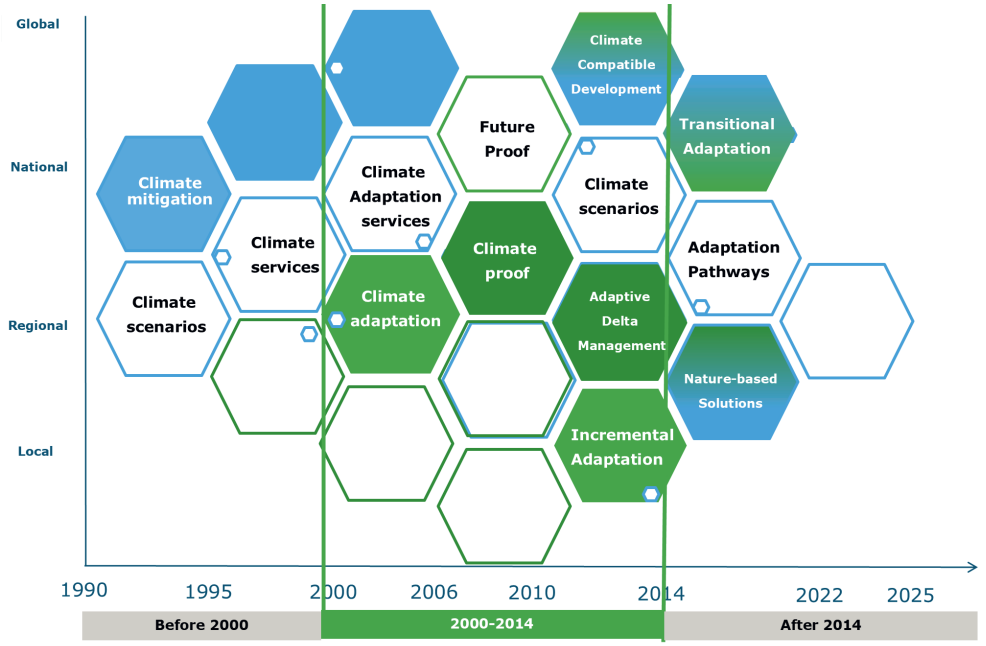


***Figure 9-1**, Use of terms for climate adaptation (green) and scenarios (white) at the interface between climate adaptation research and water management. The blue blocks are concepts that have connections with the studied boundary objects.*

First, the role, characteristics and concept development (2000-2025) of climate adaptation terms used at the interface are discussed (section 9.3.1, green blocks in figure 9-1). Subsequently, the role of scenarios and associated terms as boundary objects is analyzed (section 9.3.2, white blocks). The blue blocks represent contextual elements relevant to both boundary objects and are not discussed in a separate section. The y-axis indicates at which spatial scale the boundary objects were most frequently used at the studied units of analysis.

9.3.2 TERMS RELATED TO CLIMATE ADAPTATION AS BOUNDARY OBJECT

The term 'climate adaptation' was introduced in the Netherlands through the National Programme on Adaptation, Spatial Planning and Climate Adaptation (ARK, 2005–2009) (van Alphen & Bloemen, 2024), which replaced the previously used term 'Adaptation' (Chapter 2). Although ARK did not provide a formal definition, it emphasized a multi-sectoral approach aimed at managing the impacts of climate change. Central to this approach was the adaptation of spatial planning to ensure that climate-related effects remained within acceptable limits (Chapter 2). ARK also encompassed long-term strategies for flood protection, water management, biodiversity conservation, and public health.

Interestingly, the IPCC continued to use the term 'adaptation' until the latest assessment report (Intergovernmental Panel on Climate Change, 2023) (AR6). AR6 introduces the terms *'adaptation planning'*, *'adaptation response'*, *'incremental adaptation'*, and *'transformational adaptation'* into the climate adaptation research vocabulary.

In the Netherlands, the term climate proofing was introduced around 2005 by the initiators of the CcSP-programme (Kabat et al., 2005). They did not provide a dictionary-style definition but introduced the following line of reasoning (Chapter 2):

- Climate risks can no longer be assessed and managed with design rules based on stochastic hydrology. Scenario approaches are needed to explore climate risks of which the statistical variability is unknown (ontic uncertainty) (Chapter 4).
- The aim is to achieve regional development with an acceptable climate risk, while recognising that there are differences of opinion within society about which risks are acceptable (ambiguity) (Chapter 4).
- Implementing climate policies aimed at reducing greenhouse gas emissions is part of the concept (Chapter 3,8).

The line of reasoning was largely adopted by national water authorities, though not entirely. Thus, water managers partly fell back on design rules, and climate adaptation and mitigation remained distinct policies (Chapter 2). In addition, at regional and local level, this process took more time. Furthermore, it can be concluded that the term climate proofing was initially embraced within political circles, subsequently avoided, and eventually reintroduced (Chapter 2).

The first argument, using scenarios instead of design rules based on stationarity, was embraced by water management at strategic level in the Netherlands, while at operational level water managers tended to continue using stochastic hydrology. This is particularly observable in the development of climate-resilient flood risk strategies along the Dutch rivers and coasts (Mooyaart et al., 2023; Mooyaart & Jonkman, 2017) and to a lesser extent in the development of national and regional climate-resilient freshwater supply strategies (Chapter 5). It is also observed elsewhere like in the United Kingdom (Gersonius et al., 2013). Mooyaart et al. (2023) note that the shift from stochastic hydrology to scenario-based approaches leads to operational inertia, especially in storm surge barrier design. Nevertheless, research effort continues to resolve this inertia both for flood risks (Shabestanipour et al., 2024), freshwater supply (Diermanse et al., 2018) and drought risk management (Hurkmans et al., 2023).

The second argument, namely the pursuit of acceptable climate risks under conditions of divergent risk perceptions, was likewise recognized within the water management sector. This case study shows that it is difficult to acquire consensus on the acceptable risks for each involved sector (Chapter 3,5,6). The underlying positive message *"climate proofing offers opportunities for regional development"* was not fully adopted by water management. This can be explained by the fact that the opportunities (economic benefits or natural values) for regional development are often realized by landowners, whereas the costs are carried by water authorities. In the Netherlands, regional development is more commonly addressed through spatial planning, where the responsibility lies primarily with the provinces rather than with the water authorities.

The third argument - climate adaptation and mitigation belong together - was also, initially, not adopted in water management (Chapter 2). Instead, the term climate proofing was expanded in Dutch policies to *future proofing* (around 2010-2012). Mainstreaming environmental policies, such as climate mitigation, into climate adaptation strategies contribute additional sources of uncertainty for water management. In addition, concerns have been raised at the local level by water users and landowners regarding the financial implications of applying the precautionary principle, as precautionary measures in freshwater resources management may entail significant costs. These concerns illustrate why the positive framing of climate proofing as an opportunity for regional development has

not been fully embraced in practice. Instead of climate proofing, a strategy emerged to search for no-regret measures in water management at all spatial scales. By some scholars (Clarke & Murphy, 2023; Lindner & Stamm, 2025) and IPCC (AR6), this approach is qualified as an *incremental adaptation strategy.* Incremental adaptation refers to small, gradual changes made to existing systems, practices, or infrastructure in response to climate risks, while maintaining the fundamental characteristics of those systems (Intergovernmental Panel on Climate Change, 2023).

The term Adaptative Delta Management (ADM) and associated narrative, can be understood as a boundary object that prevailed in the period 2010-2014 (Chapter 2). ADM operated as a shared reference point that facilitated knowledge exchange across water management, spatial planning, and climate adaptation research. In this sense, also the associated narrative can be understood as a boundary object, given its interpretive flexibility and its role in connecting different domains. ADM promoted the implementation of no-regret measures in the short term, while allowing for scaling up of climate adaptation efforts in response to evolving scientific insights (Chapter 2 and 5; Dewulf and Termeer (2015)). Its interpretive flexibility enabled water managers, policymakers and researchers to engage with climate uncertainty without requiring consensus on specific climate change projections. In collaboration with the national Delta Programme, Dutch climate adaptation researchers began formulating long-term adaptation pathways to identify crucial decision moments. These pathways were intended to reassess whether a transformational adaptation strategy would prove more no-regret than an incremental strategy (Amorim-Maia & Olazabal, 2025). This process can be regarded as a next step to further enhance flexibility. In this approach, ontic uncertainty associated with climate risks was represented through temporal intervals rather than probabilistic estimates or scenario-based impact projections (Haasnoot et al., 2024; Muccione et al., 2024). In this way, adaptive delta management also exemplifies the characteristics of a boundary object: it accommodated multiple perspectives between water management and climate adaptation research.

Inspired by international research developments (Ficklin et al., 2018; Mitchell & Maxwell, 2010), climate scientists introduced the term *climate compatible development* (CCD) as a new term to compete with the term climate proofing within Dutch water management (Chapter 8). The new term re-emphasized the importance of combining climate mitigation and climate adaptation. It also became evident to climate adaptation researchers and water managers that the term climate proofing could inadvertently lead to a misunderstanding that climate-related risks could entirely be eliminated. However, the concept of CCD, as introduced in climate adaptation research, failed to gain traction within the Dutch water management discourse. As a result, the term did not effectively serve as a boundary object.

Since 2014, climate adaptation research developed a narrative embracing natural dynamics in water systems, not as a source of uncertainty, but as a strategic response to climate change. It is often described as the concept of Nature-based Solutions (NBS) (Chapter 7). The term Nature-based Solution can be seen as a boundary object that often is communicated as a narrative. NBS are defined as interventions that utilize ecological processes and ecosystem functions to address complex environmental and societal challenges (Bouw et al., 2020; Keesstra et al., 2023; Somarakis et al., 2019). This narrative reflects a shift within the climate adaptation research community towards more transformational climate adaptation. Another substantial group of researchers and water managers (de Zeeuw & Rijcken, 2024; Jonkman Sebastiaan & Merrell William, 2024; Mooyaart et al., 2023; Mooyaart & Jonkman, 2017) continues to follow the foundational water management paradigm of engineered solutions and risk control that predates the climate proofing discourse (Chapter 4).

Key finding 5: *The evolving terms related to climate adaptation, in particular climate proofing, functioned as a boundary object at the interface between climate research and Dutch water management. While the term climate proofing was politically embraced (2005-2010), it lacked clarity for operational water management and was avoided at a later stage (2010-2012) due to limited political consensus. Terms since 2014, including adaptive delta management and incremental adaptation, accommodate these shortcomings of climate proofing as a boundary object. Around 2018, a renewed use of the term climate proofing has emerged within Dutch water management. Unlike its initial introduction in the mid-2000s, the term is now frequently embedded within the broader narrative of adaptive delta management. This dissertation demonstrates the importance of examining shifts in dominant narratives at the science-policy interface, particularly when addressing uncertainties in climate adaptation decision-making that extend beyond the assessment of climate risks alone. Nevertheless, tensions persist between transformational adaptation approaches and traditional risk-control paradigms rooted in engineered water infrastructure.*

In line with this key finding, Amorim-Maia and Olazabal (2025) advocate for a reconceptualization of the term climate adaptation, drawing on similar lines of reasoning that underpin the concepts of climate proofing (Chapter 3) and climate-compatible development (Chapter 8). They further recommend the explicit incorporation of ambiguity-related uncertainty into climate adaptation frameworks. The findings presented in this dissertation support and extended this viewpoint, offering additional insights into how evolving narratives shape the understanding and management of prevailing uncertainties.

This dissertation, for example, identifies a shift in the dominant lines of reasoning concerning Lake Volkerak-Zoom. Initially, the lake was framed as a water-quality problem that required the re-introduction of controlled estuarine dynamics, combined with the creation of additional river-water retention capacity to reduce flood risks in the context of climate change (consensus in 2014, Chapter 5). Since 2014, however, the prevailing narrative has increasingly portrayed lake Volkerak-Zoom as a strategic freshwater resource considering climate change (Chapter 2). While modelled indicators for water supply and retention did shift in response to updated climate scenarios, the associated range of ontic and epistemic uncertainty remained of a similar magnitude in 2010-2014 (Bruggeman et al., 2013; Bruggeman et al., 2011) and since 2014 (Bruggeman et al., 2016; van der Brugge & de Winter, 2024; Wolters et al., 2018). What did change was that the effectiveness of the preferred climate-adaptation strategy became increasingly shaped by ontic uncertainty (sea-level rise, Chapter 2) and by divergent perspectives on socio-economic costs and benefits at both regional and farm scales (Chapter 5,6). In other words, this dissertation illustrates a shift in narratives that is better explained by ambiguity related uncertainty.

Research Question 2 was also intended to examine whether the role of the analysed boundary objects varies across different geographical scales. In the Dutch water management case, the terminology was employed across all spatial scales in the studied time period. The conceptualization and introduction of discussed boundary objects have deliberately been shaped by policymakers, water managers, and climate adaptation scientists operating at the science–policy interface at national and regional level, which can be concluded from Chapter 2 and 5.

Local water users are often confronted with this terminology without prior context and may initially perceive it as abstract or jargon laden. Over time, however, the terminology may develop into practical meaning for water users, particularly through experiential learning in pilot projects such as those described in Chapter 6. This pattern is consistent with broader findings reported in the literature. For example, Janssen et al. (2023), argue that boundary objects enable coordination across heterogeneous communities (e.g. scientists, entrepreneurs, policy makers) by allowing for both convergence and divergence in meaning. They identify mechanisms such as reflexive and collaborative learning as critical to stakeholder alignment in transformative adaptation efforts (Janssen et al., 2023; Werners et al., 2021). Learning mechanisms were not studied in this dissertation. However, it can be worthwhile to investigate learning mechanisms in a nested case study, as applied in this research.

9.3.3 SCENARIOS AND ASSOCIATED TERMINOLOGY AS A BOUNDARY OBJECT

During the period 1995–2000, the Royal Netherlands Meteorological Institute (KNMI) defined climate scenarios as plausible representations of future climate conditions based on different assumptions about greenhouse gas emissions (IPCC, 1996), socio-economic developments, and climate system responses (Klein Tank et al., 1995). However, at that time, climate scenarios were mostly used to understand future emission profiles in the Netherlands and were separately developed from scenarios for future economic development (CPB Netherlands Bureau for Economic Policy Analysis, 1998), as described in Chapter 3 and 8. In addition, climate scenarios were developed by KNMI and offered towards both climate adaptation research and potential users, including water management. Initially those scenarios did not function as a boundary object (Chapter 2,3). The available climate scenarios represented the bandwidth in (ontic) uncertainty but were difficult to apply for water managers (i.e. the usability was low). For this reason, CcSP (2004-2012) developed scenarios and supporting tools to tailor national climate scenarios to different sectors and to make the climate information spatially explicit at different scales. These insights were used by KNMI in the development of the second (2006) and third generation (2013) KNMI climate scenarios. In the latest KNMI scenarios (2023), specific applications were developed tailored to water management, such as the inclusion of an additional drought indicator (Standardized Precipitation Index, SPI) (Chapter 6) alongside the existing precipitation deficit indicator, as well as scenarios for river discharge and groundwater levels (Chapter 2).

Terms such as *climate services* and *climate adaptation services* were introduced (Goosen et al., 2014) in climate adaptation research. However, these terms are not commonly used in water management. IPCC defines climate services as the production, translation, transfer, and use of climate knowledge and information in climate-informed decision-making and policy (IPCC, 2014b). The term *climate adaptation service* does not have an IPCC- definition. Goosen et al. (2014) describes *climate adaptation services* as a subset of climate services that specifically support adaptation to climate change. Although the boundary object *'climate adaptation services'* did not become common language at the interface, the underlying decision support tools have been applied in water management. Examples include the climate impact atlas, which is widely used to conduct climate stress tests by municipalities and provinces in the Netherlands (de Klerk et al., 2021). These stress tests assess vulnerabilities to climate-related risks such as heat, drought, flooding, and waterlogging, and are a key instrument within the Delta Programme's spatial adaptation strategy.

The term climate service is also used elsewhere in Europe to emphasise the usefulness of climate data (Boon et al., 2024; Lourenco et al., 2015). Internationally, the term *climate service* can be seen as an effective boundary object between meteorological services and

water management to assess climate adaptation options (Chapter 3,8), but its success is poorly evaluated (Boon et al., 2025). Whether this term also served as boundary object in the Netherlands was not explicitly investigated in this dissertation. However, it was investigated whether the disclosure of spatially explicit climate information can be an enabler for the broader application of, among other things, the drainage technologies as investigated in Chapter 6 en 7. The results of Chapter 7 showed that spatial mapping of practical experience with these techniques is of added value, in addition to spatially explicit information about climate change impacts for agriculture and water management under different climate scenarios.

A notable observation from this nested case study analysis is that climate adaptation researchers consistently develop scenario sets, either using climate change projections (Chapter 3) or using a defined number of adaptation pathways (Haasnoot et al., 2021), with the implicit aim of reducing the uncertainties perceived by potential end-users. However, this approach does not always work as desired, exemplified with the following observations from this dissertation:

- In 2000, the scenarios used in NRP-CC aimed to represent relationships between climate and economic variables across three alternative futures (Chapter 3). However, neither stakeholders nor scientific experts articulated distinct views on the implications for water management. Integrating independently developed scenarios from KNMI (climate), IPCC (emissions), and CPB (economy) into coherent impact analyses proved challenging. This issue was addressed post-2014 through the development of Delta Scenarios, which combine four plausible socio-economic and climate futures to support national-level water management (Bruggeman et al., 2016; Bruggeman et al., 2013; Bruggeman et al., 2011; van der Brugge & de Winter, 2024; Wolters et al., 2018). Despite their usefulness at the national scale, regional water managers still struggle to formulate differentiated adaptation strategies based on these scenarios (Chapter 2).
- In evaluating drought risk perceptions for crop yields at the farm level, climate scenarios were not used (Chapter 6). However, the methodology did distinguish between an *average year*, *a dry year*, and an *extremely dry year* when examining potential measures to mitigate these risks. This distinction was made based on the precipitation deficit associated with these classifications as employed by the Royal Netherlands Meteorological Institute (KNMI). Findings from Chapter 6 show that Dutch farmers (water users) distinguish differences between yield reductions that occur in an average meteorological year, where some degree of drought is typically expected, and yield reductions under extreme drought conditions. However, they do not make a further distinction between a *dry year* (i.e., drier than average) and an

extremely dry year. Similar observations have been reported in Norway (Dannevig & Aall, 2015), Finland (Mäkinen et al., 2017) and Australia (Clarke et al., 2013).

- Moreover, some regional policymakers questioned the spatially explicit information on agricultural water demand and supplementary water supply for Zeeland (Walcheren) derived from hydrological models, even though these models were intended to reduce epistemic uncertainty (Chapter 5,6,7). Their concerns focused particularly on the reliability of model estimates of the freshwater volumes stored in the unsaturated zone of agricultural soils at former tidal creek ridges in Zeeland. In contrast, entrepreneurs in sectors such as drinking water and food production largely accepted these model outputs at face value (Chapters 7). As a result, the introduction of scenarios did not uniformly reduce uncertainty across stakeholder groups; instead, it highlighted divergent levels of trust in model-based information.

Key finding 6: *Climate scenarios and climate services were intended to play a role at the interface between climate research and water management. However, the first (1998), second (2006) and third KNMI climate scenarios (2013) – designed in consultation with climate adaptation researchers and water management – did partly fulfil this role as a boundary object (chapter 2). Although the need for tailored scenarios was already articulated by KNMI during the Climate Changes Spatial Planning (CcSP) and Knowledge for Climate (KfC) programmes (2004–2014), the realization of this ambition took more time. The observed efforts to formulate a defined set of scenarios, both those presented in this dissertation (Chapter 3,8) and the pathways advocated by other scholars, reflect a broader trend toward tailoring climate information to the specific needs of stakeholders in the Netherlands. With the release of the KNMI-2023 scenarios, specific climate services for water management were offered - such as drought indicators for agriculture, river discharge and ground water table scenarios (Chapter 2) - thereby enhancing the role of climate scenarios as boundary objects.*

Key finding 6 underlines the conclusion of Boon et al. (2024), who identify the timely delivery of climate services for adaptation planning in general as a persistent bottleneck. Moreover, the evaluation of climate services, such as the use of climate scenarios, warrants greater scholarly attention (Ford et al., 2025). Ford et al. (2025) argue that the number of case studies available for evaluating the effectiveness of climate services in the context of the IPCC is currently insufficient, largely due to the limited publication of relevant (practical) knowledge and data in peer-reviewed literature. In this regard, this dissertation contributes new insights: Since 2014, governance mechanisms have been established within Dutch

water management to improve the timely delivery of climate services. Notable developments include the legal formalization of the periodic updating of KNMI climate scenarios and the institutionalization of regular reviews (aiming to include new scientific insights) of the climate adaptation strategy within the national Delta Programme (Chapter 2). Both represent institutional changes in the knowledge infrastructure linking water management and climate adaptation research.

9.4 STRATEGIES TO ADDRESS UNCERTAINTIES IN PARTLY CO-EXISTING INTERFACES (RQ3)

Research Question 3 explored what strategies exist for managing uncertainties within partly co-existing interfaces across spatial scales, with the aim of enhancing the practical usability of climate adaptation research.

Table 9-5 divides the observed strategies to address uncertainties into two categories: (1) at the interfaces and (2) solely in decision making. Across the units of analysis, a range of uncertainty-reducing strategies emerged (table 9-6). While certain approaches are shared by both climate adaptation researchers and water managers at the science-policy interface, others are exclusively applied by policymakers and decision-makers in operational settings (table 9-5).

Table 9-5, *categories of uncertainty reducing strategies.*

Strategy	Chapter
Strategies observed among researchers and water managers at the interface	
- Limiting the range of solutions to narrow policy options for decision-making	2,5
- Joint fact-finding to facilitate co-produced knowledge in ambiguous contexts	5
- Facilitating dialogue at the interface, even in ambiguous contexts	4,5
- Tailoring or limiting the number of scenarios and pathways	3,4,5,8
- Drawing on the experiential knowledge of water managers and policymakers	3,5
- Relying on scientific assumptions, expert judgment and scientific authority, when epistemic and ontic uncertainties are equally important	2,5
- Incorporating practical experience from water users and managers	3,5
- Using modelling & exploratory research to address epistemic & ontic uncertainty	2,6
Additional strategies observed used by water managers in decision making and planning	
- Deconstruction of consensus by denial claims or alternative narratives	2,5,7
- Negotiation guarantees for freshwater supply under uncertain conditions	5,7
- Acceptance of uncertainty, use of decision-making deadlines to prompt action	2,5
- Application of formal procedures such as Environmental Impact Assessments	5

Table 9-6, *Observed strategies and behaviours in addressing uncertainties in each unit of analysis at the interface between climate adaptation research and water management.*

Name of unit of analysis, summary	Observed generic strategies and behaviours in order of importance
Dutch National Research Programme Global Air Pollution and Climate Change (NRP-CC) - Integrated assessment of impacts of climate change and adaptation options for the Netherlands (NOP-IA). **Timeframe:** 1989 – 2001 **Research:** 2001 **Chp: 2,3,8** **Spatial Scale:** national science -policy interface (project)	• Reliance on assumptions, expert judgment (and authority) of researchers in case ontic and epistemic uncertainties are equally important • Reliance on experiences from policy makers & water managers • Investigation of epistemic & ontic uncertainties with modelling
International Dialogue on Water and Climate (DWC) - 18 stakeholder dialogues about climate research and water management all over the world. **Time frame:** 2002-2008 **Research:** 2002-2008 **Chp: 4** **Spatial scale:** international/national interface (programme)	• Reliance on experiences from policy makers and water managers • Reliance on assumptions, expert judgment & research authority • Provide room for dialogue between climate research and water management also in case of ambiguity • Investigation of epistemic and ontic uncertainties with modelling
Research programme Climate changes Spatial Planning (CcSP) **Time frame:** 2004-2012 **Research:** 2004-2012 **Chp: 2,3,4,8** **Spatial scale:** national interface with local & regional cases	• Investigation of epistemic and ontic uncertainties with modelling • Reliance on experiences from policy makers and water managers • Explorative research/ monitoring to address ontic uncertainties. • Reliance on assumptions, expert judgment & research authority • Limit and tailor the possible number of scenarios
Research programme Knowledge for Climate (KfC) **Time frame**: 2008-2014 **Research:** 2008-2014 **Chp: 2,5,6,8** **Spatial scales:** national, regional and local	• Investigation of epistemic and ontic uncertainties with modelling • Reliance on assumptions and expert judgment (and authority) • Reliance on experiences from policy makers and water managers • Reliance on practical experiences from water users • Limit and tailor the possible number of scenarios
National Delta Programme (DP) **Time frame:** since 2008 **Research:** 2008-2014 **Chp: 2,3,5,8** **Spatial scales:** national & regional	• Investigation of epistemic and ontic uncertainties with modelling • Reliance on assumptions, expert judgment & research authority • Limit the number of possible solutions and pathways. • Use of formal procedures (MER, EIA, etc.) • Joint-Fact-Finding in case of ambiguity • Deconstruction of the achieved degree of consensus by denial claims, alternative narratives or scientific hypotheses • Negotiation about freshwater supply guarantees • Accept uncertainties and create deadlines for decisions. • Reliance on experiences from policy makers and water managers
Programme Office Southwest Delta (DP-SWD) - **Time frame:** since 2004 **Research:** 2010-2014 **Chp: 5** **Spatial scales:** national, regional and local	• Investigation of epistemic and ontic uncertainties with modelling • Reliance on assumptions and expert judgment (and authority) of researchers in case ontic and epistemic uncertainties are equal. • Limit the number of possible solutions and pathways. • Use of formal procedures (MER, EIA, etc.) • Joint-Fact-Finding in case of ambiguity • Deconstruction of the achieved degree of consensus by denial claims, alternative narratives or scientific hypotheses • Negotiation about freshwater supply guarantees • Accept uncertainties and create deadlines for decisions. • Reliance on experiences from policy makers and water managers • Reliance on practical experiences from water users
Water Resources at farm level (GO-FRESH) as part of KfC **Time frame:** 2010-2019 **Research:** 2010-2014 **Chp 6** **Spatial scales:** local and regional interfaces	• Explorative research & monitoring, address ontic uncertainties. • Reliance on practical experiences from water users • Investigation of epistemic & ontic uncertainties with modelling • Reliance on experiences from policy makers and water managers • Reliance on assumptions, expert judgment & research authority • Deconstruction of degree of consensus by denial claims, alternative narratives or scientific hypotheses
Water reuse in food chains & drinking water production (WUR KB) A comparative case study analysis was conducted about the role of spatially climate information in adoption of water reuse techniques in the Southwest Delta and Ghana. **Time frame:** 2020-2022 **Research:** 2020-2022 **Chp 7** **Spatial scales:** regional (and international)	• Investigation of epistemic &ontic uncertainties with modelling • Reliance on assumptions, expert judgment & research authority • Reliance on experiences from policy makers and water managers • Reliance on practical experiences from water users (Chapter 6), • Deconstruction of the achieved degree of consensus by denial claims, alternative narratives or scientific hypotheses

Key finding 7: *Across the units of analysis, a range of strategies for reducing uncertainty was observed. Some of these strategies were employed by both climate adaptation researchers and water managers at the science-policy interface, whereas others were used exclusively by water managers in decision-making processes. The latter reduced uncertainty by imposing deadlines, narrowing the range of solution options, and relying on formal procedures, approaches that are far less common in climate adaptation research. These decision-making-specific strategies were also difficult to fully accommodate within the theoretical framework, revealing a gap between conceptual models and practical realities. Negotiation processes between water managers and water users (Chapter 5) likewise emerged as a mechanism for reducing uncertainty, despite the fact that scientific knowledge itself is, in principle, not subject to negotiation. Distinguishing between strategies that are jointly employed and those used exclusively by water managers is therefore essential for enhancing the practical relevance and usability of climate adaptation research in complex, multi-level governance settings.*

Shared strategies to address uncertainties

Findings from the Southwest Delta (Chapter 5) illustrate that strategies for addressing uncertainty vary among individuals, regardless of their role in water management, water use, or climate adaptation research. Consensus builders and deconstructors of consensus exist across all these domains. For instance, when a researcher proposes an alternative hypothesis regarding climate impacts, this constitutes a deconstruction of consensus comparable to denial claims or alternative narratives from stakeholders.

The nested case study research approach demonstrates that epistemic research strategies, such as tailoring climate information, are frequently employed to address both epistemic and ontic uncertainties at the national and regional interface with water management in the Netherlands. However, reducing uncertainty at the operational level, particularly among water users and landowners, requires significantly more time and effort compared to strategic water management (Key Finding 3).

The interface with water users is notably more complex to organize and involves a larger and more heterogenous group of individuals compared to national-level interfaces (Box 9-1). Each water user exhibits distinct strategies in response to uncertainty (Chapter 5). Also, researchers and policymakers have distinct strategies in response to uncertainties, however, those concern a much smaller number of individuals.

Box 9-1, *Climate adaptation research applied at farm level (Chapter 6) and results used to develop regional climate adaptation strategies (Chapter 5).*

In this study, three pilot projects focused on drainage technologies designed to buffer surplus winter precipitation in soil and groundwater systems, thereby enhancing drought resilience during summer in the Province of Zeeland (Chapter 6). These pilots were conducted in collaboration with three entrepreneurs who had been actively engaged in climate adaptation research over a four-year period. Researchers and water managers involved in the three pilot studies at the farm level also played a role in formulating regional climate adaptation strategies at both regional and national levels (Chapter 5). The three farmers themselves were somewhat more distant from this strategic process, focusing primarily on their own operations. Findings from these pilots were disseminated during annual group meetings with farmers (20–30 participants), and a broader group of farmers (142 participants) provided feedback via a survey. Additionally, a limited number of water users (farmers, drinking water factories, nature reserve managers) were interviewed (Chapter 5) or consulted at the regional level (Food processing Industry, Chapter 7). As highlighted in Chapter 6, the three participating farmers demonstrated considerably greater consensus regarding the uncertainties associated with the techniques under consideration compared to the 142 farmers who expressed their views in the survey. However, this too is only a sample of the approximately 2,400 arable farms and 300 fruit-growing enterprises located in Zeeland around 2014 (CBS & LEI, 2014). Each of these entrepreneurs has their own approach to assessing the uncertainties related to hydrological efficiency and investment costs. This illustrates the heterogeneity of decision-making processes within the agricultural sector regarding freshwater supply and attitudes towards uncertainties. Moreover, it underscores the importance of jointly investigating uncertainties in agricultural freshwater supply through collaboration among researchers, water managers, and farmers. Such cooperation fosters a more comprehensive understanding and supports the development of robust adaptation strategies.

Decision making specific strategies to address uncertainties

Joint Fact-Finding (JFF), as applied as a strategy to address uncertainties in the discussion about freshwater supply (Chapter 5), closely resembles the IPCC's formulation of summaries for policymakers. The analogy rests on the structured approach to consensus-building and uncertainty management (Ha-Duong et al., 2007; Petersen et al., 2015). Within the IPCC, scientific findings from multiple disciplines are systematically synthesized, and the resulting summary is negotiated line by line by member governments. Similarly, joint fact-finding in the freshwater supply context integrates perspectives from researchers, water managers, and farmers to collectively assess evidence, articulate uncertainties, and develop shared conclusions. A difference between Joint Fact-Finding and the IPCC process is that within the IPCC it is possible to reach agreement on the absence of consensus, an explicit "agree to disagree" position (Swart et al., 2009).

Formal procedures in water management and spatial planning—such as Environmental Impact Assessments—are well-suited for addressing epistemic uncertainties in short-term contexts (van Dijk, 2008). However, this dissertation illustrates that such procedures are less effective in addressing ontic uncertainties or ambiguity (Chapter 5), which are critical

when evaluating long-term climate adaptation strategies (Pot, 2023; Pot et al., 2024). The application of additional strategies in policymaking - beyond the uncertainty management frameworks used in climate research (e.g., IPCC) is in line with other studies. These behaviours have been previously documented in the literature (Dewulf & Biesbroek, 2018; Giordano, 2012; Petersen et al., 2015; Restemeyer et al., 2016; Zandvoort et al., 2019). Recently Moure et al. (2023) highlighted also the need to integrate social science perspectives into methods to address uncertainties in climate adaptation science (Moure et al., 2023). This may also offer a possible direction for integrating the two approaches to address uncertainties, as identified in this study, into a one theoretical model. Nonetheless, many climate adaptation researchers may not fully recognize these additional strategies at the outset of a research project. The usability of climate adaptation research can be enhanced by explicitly addressing these uncertainty-reducing behaviours in planning and decision-making, alongside strategies to address epistemic and ontic uncertainties.

9.5 CONCLUSIONS

Over the past 25 years (2000–2025), the climate adaptation research community in the Netherlands has made significant progress in developing strategic approaches to address ontic and epistemic uncertainties. These efforts have been supported using boundary objects - such as climate proofing, scenarios, and adaptation pathways - which have contributed to enhancing the usability of climate adaptation research. Although progress has been slower than initially anticipated by both climate adaptation research and water management, significant advancements have been achieved.

This nested longitudinal case study, as presented in this dissertation, illustrates how Dutch climate adaptation research has sought to reconcile different knowledge needs for addressing uncertainties:

- Between IPCC-style approaches focused on epistemic and ontic uncertainties and social science approaches that address ambiguity.
- Between regional authorities' need for context-specific climate information and national authorities' preference for standardized assessments using national models.
- Between formal planning tools (e.g., Environmental Impact Assessments) designed to manage epistemic uncertainty and exploratory research methods better suited to deal with ontic uncertainty.

These different knowledge needs - nested between different geographical scales - have been most clearly manifested during preparation (Commission Veerman, 2008), the initiation of the National Delta Programme (2009), the development of the first climate adaptation strategies for water management (2010-2014), and the five-year periodic evaluation of these strategies. It is not a coincidence that the Dutch National Delta Programme distinguishes three national climate adaptation strategies - called Delta Decisions - regarding flood risk management, freshwater supply, and spatial climate adaptation. By anchoring these three strategies at the national level, the Delta Programme ensures coherence and consistency across regions, while still leaving room for regional tailoring, amongst others the Southwestern Delta, the Rhine River Basin and the Wadden Sea area. This approach balances national priorities with regional flexibility to address their specific uncertainties, stakeholder interests, and ambiguities. So, it is not a coincidence, it was a strategic choice to guide regional climate adaptation strategies with national decisions.

While national-level strategies emphasized long-term planning and system-wide resilience, regional and local stakeholders often required context-specific, actionable insights tailored to immediate spatial and hydrological conditions. This tension highlighted the need for

adaptive governance mechanisms capable of bridging strategic ambitions with operational realities. The Delta Programme thus served as an interface where multi-scale knowledge demands were negotiated, though not always reconciled.

Since the launch of the National Delta Programme in 2009, climate adaptation research and water management have become increasingly intertwined. This integration has improved the relevance and applicability of research but has also introduced tensions related to the legitimacy and credibility of scientific institutions, particularly when findings challenge existing practices or extend beyond the water sector. This tension is captured in what has been termed the scientific authority paradox (Brown & Havstad, 2016; Kunseler & Tuinstra, 2017).

While the organizational structure of climate adaptation research has evolved since 2000, the transformation has not been as profound as originally envisioned by the initiators of programmes such as Climate Changes Spatial Planning. Sectoral shifts in knowledge production have occurred, but whether these changes are sufficient to support cross-sectoral climate adaptation remains a contentious question. Despite previous investment impulses aimed at structurally transforming the knowledge infrastructure between climate research, water management, and spatial planning, no coherent follow-up strategy was developed by policy makers to sustain this momentum. Although new funding mechanisms - such as the Dutch Growth Fund, successor to the FES[12] - have become available and are actively utilized by researchers and water management, a coordinated reorganization of sectoral research funding to support cross-sectoral climate adaptation research across ministries has not materialized. This institutional gap still limits the systemic embedding of transdisciplinary knowledge that is necessary to develop transformational adaptation strategies in water management.

[12] KFC and CcSP were funded from a national fund called 'Enforcement National Economic Structure (abbreviated as FES, established in 1995). FES was meant for investments in both infrastructure as well as for research and innovation (see chapter 2).

9.6 RECOMMENDATIONS

Finally, recommendations are formulated for both climate adaptation research and water management. Many of these recommendations are applicable for both climate adaptation research and water management.

Climate adaptation research

The following recommendations are proposed:

- It is recommended to critically assess whether epistemic approaches, such as probabilistic modelling of hydrological impacts, are appropriate in situations dominated by ontic uncertainty. In addition, contextual sensitivity is required when climate adaptation research is designed and formulated in cases with ambiguity.
- It is advisable to explicitly consider the different strategies individuals may use to address uncertainties in water management and climate adaptation research during the problem-analysis phase and the formulation of research questions. When the research starts, it is recommended to compose a research team that also reflects a balanced mix of strategic orientations toward uncertainty, specifically, the inclusion of fact-checkers, consensus builders, and deconstructivists. Such diversity increases the likelihood that research outcomes will be usable within water management practice.
- The usability of climate services for Dutch water management merits systematic evaluation across spatial and institutional scales, with particular attention to alignment with operational needs. It is further recommended that such evaluations not rely solely on quantifiable indicators, such as the frequency with which climate datasets are downloaded but also incorporate indicators that capture user experiences and learning processes associated with their application. Conducting such evaluations will help enhance operational relevance and support more effective navigation of the persistent uncertainties associated with climate projections, hydrological variability, and diverse stakeholder priorities.
- Continued research about how uncertainties are addressed across spatial scales is recommended. In this dissertation, the role of climate scenarios and climate adaptation as boundary objects has been examined through longitudinal observations in nested interfaces. For future research, it would also be worthwhile to investigate whether this role can be deliberately shaped, or whether its function in knowledge exchange across partially interconnected interfaces is determined solely by co-incidence and contextual factors.

- The approach to evaluate uncertainties in this study was primarily inspired by methodologies from climate adaptation research, the IPCC, and water management. Future research may benefit from integrating insights into dealing with uncertainty from other domains such as psychology, medical science, and marketing, where decision-making under uncertainty has been extensively examined.
- Further methodological development is needed to assess shifts in prevailing narratives and the deployment of boundary objects at the science–policy interface. Such approaches would complement traditional climate risk assessments and enhance the capacity to address ambiguity-related uncertainty.
- This dissertation employed a nested case study approach. This methodological choice enabled examination of how water managers and users engage with climate uncertainty at different scales. To further strengthen the empirical foundation of a nested case study approach, a structured approach is needed to assess how water managers perceive climate impacts and respond to uncertainty at different scales.

Recommendations for water management

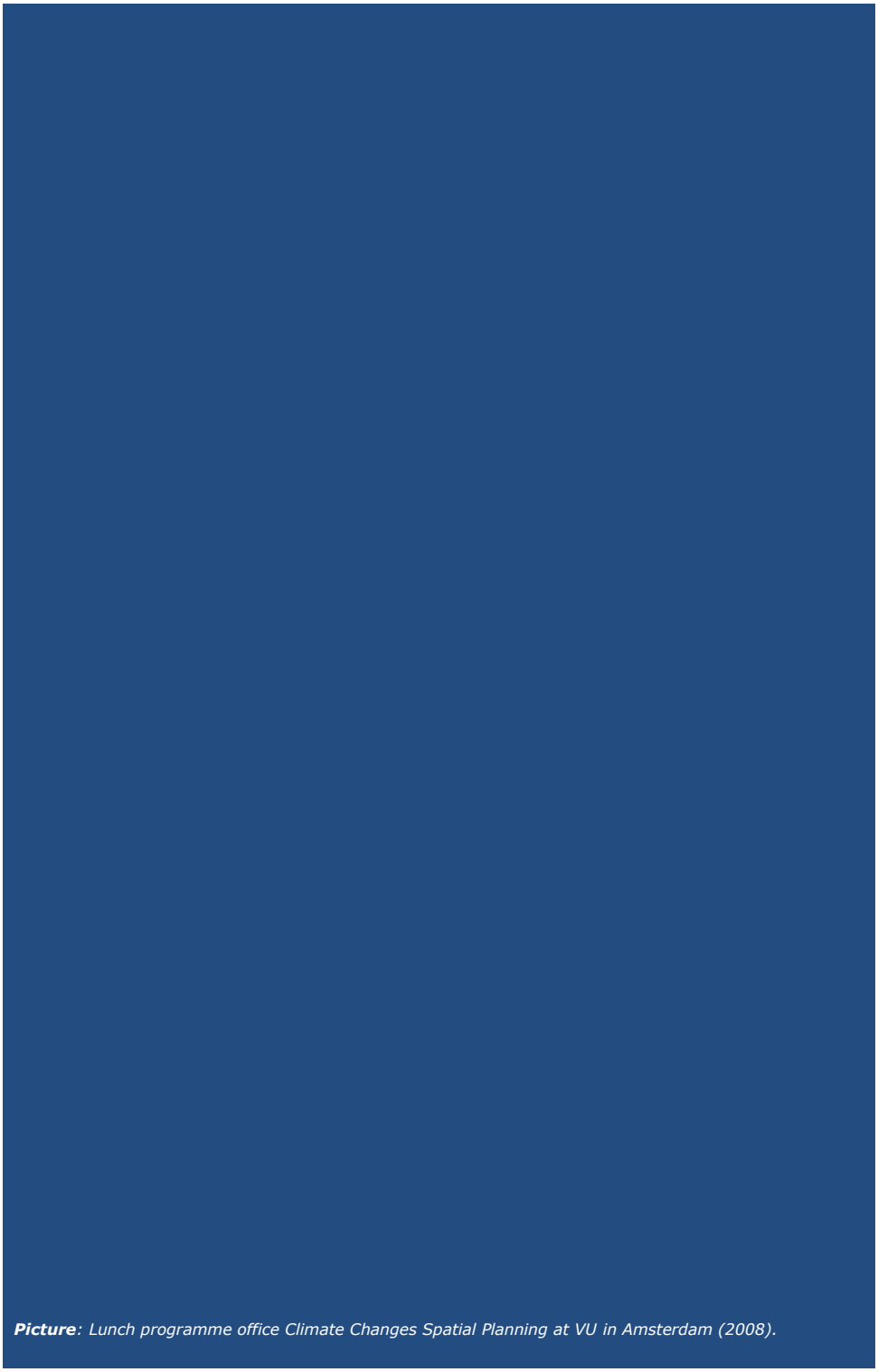
- The effectiveness of formal procedures, such as Environmental Impact Assessments (EIAs), can be enhanced by explicitly acknowledging ontic uncertainties. This requires alignment with exploratory field research and long-term environmental and climate monitoring. For example, in intertidal zones such as the Scheldt estuaries, supplementing EIAs with scenario-based ecological impact studies combined with an adaptive ecological monitoring approach supports decision-making when ontic uncertainties prevail.
- Joint Fact-Finding (JFF) initiatives between climate adaptation researchers, water users, and water managers should be actively promoted and strategically embedded in climate adaptation processes, especially in contexts shaped by ambiguity or political negotiation. To enhance their effectiveness at nested governance interfaces, JFF should be initiated early, ideally before research is commissioned, and supported through conditions that safeguard politically independent inquiry. In contexts where many interests are at stake, this means creating settings in which research can be conducted with minimal influence from political pressures or stakeholder interests.
- Structured reflection on learning processes, such as facilitated stakeholder workshops during policy making regarding water resources, can help to reveal conflicting risk perceptions, explore controversial hypotheses, and eventually foster shared understanding of trade-offs in regional drought risk management and beyond. Establishing the baseline situation in a water system and assessing the impact of a considered intervention is commonly undertaken in climate adaptation pilots, such

as for example described in chapter 6 (controlled drainage systems). The evaluation of such pilots can easily be expanded with an assessment of participants' initial understanding of the underlying problem and the intervention. This approach allows for the evaluation of learning processes, integrated with the technical assessment of the intervention itself.

- When epistemic and ontic uncertainties are equally significant, exploratory research both before and after implementation of climate adaptation strategies is recommended. This approach has proven effective in other domains relevant to water management, such as nature development projects (e.g., Marker Wadden; (Stouten et al., 2022; Willems et al., 2021). In the Marker Wadden project, extensive exploratory research was conducted on island building with fine sediment and initial ecosystem development before, during and after island construction.
- In current water management practice, stakeholder engagement often occurs after potential solutions to climate impacts have been assessed by policy makers, water managers and experts. The potential solutions are presented as distinct options towards the stakeholders (including water users). This sequential approach limits the opportunity to enrich these options with the creativity and knowledge of water users and stakeholders about their environment. A more inclusive and iterative engagement process is recommended, beginning at the stage in the pre-planning phase, providing insights into water users values and concerns before the start of a formal planning process. This may lead to mutual understanding between water users and water managers.

10





***Picture**: Lunch programme office Climate Changes Spatial Planning at VU in Amsterdam (2008).*

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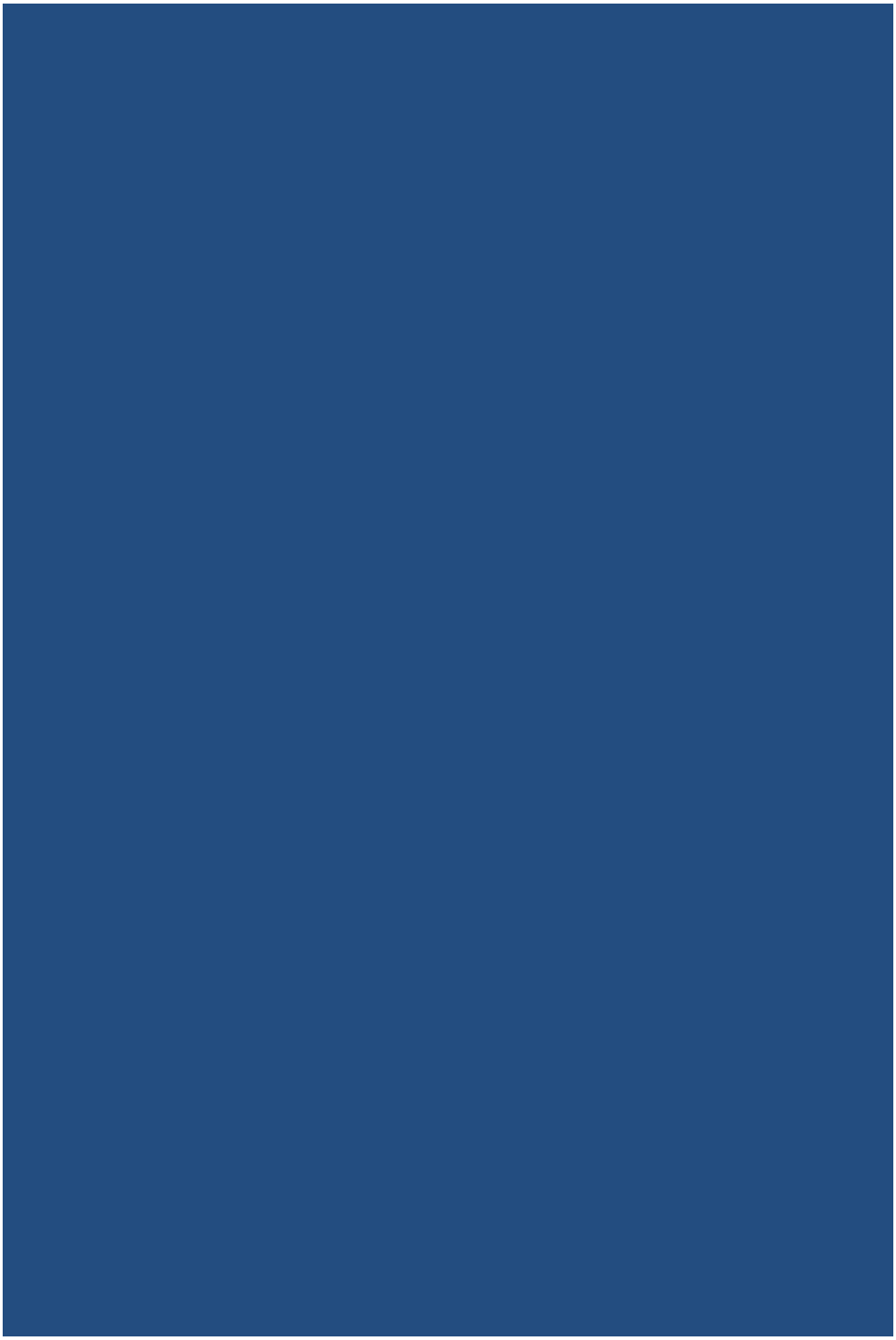
ANNEX A – SUPPLEMENT CHAPTER 6: DESCRIPTIVE STATISTICS AND DESCRIPTION OF THE DROUGHT RISK SURVEY

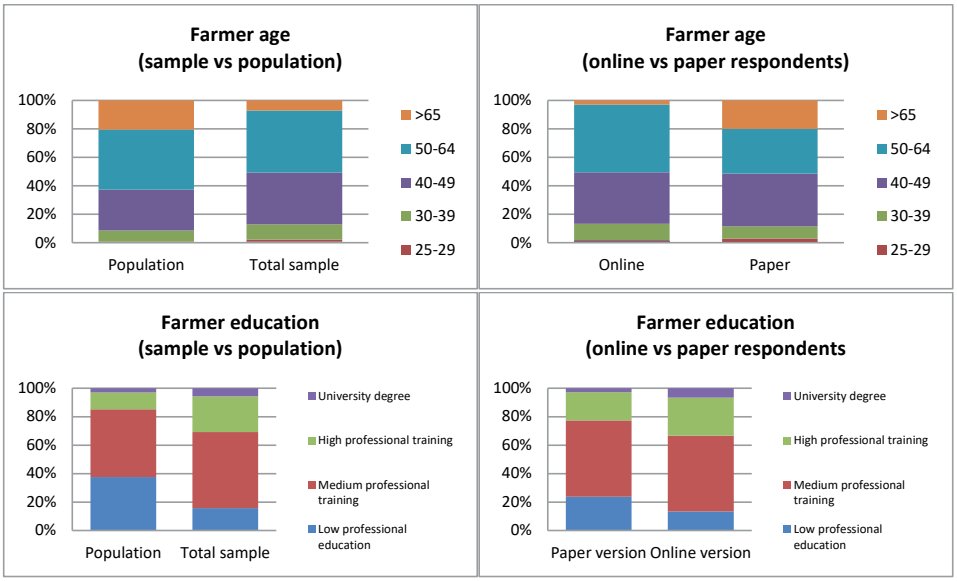
Supplement paper: Evaluation of socio-economic factors that determine adoption of climate compatible freshwater supply measures at farm level: a case study in the southwest Netherlands.

Jeroen A. Veraart 1, *, Rianne van Duinen 2,3, Jan Vreke1



Representativeness of the sample

To check the representativeness of the sample (141 respondents), the age, education, farm size, farm type and access to an external water supply were compared to those of the population using data from CBS Statistics Netherlands (see figure below). On average, farmers in the sample were slightly younger and better educated than the overall population they represented. Further, farmers above 65 years of age and/or with a low level of professional education are more under-represented in the online survey than in the paper questionnaire. Nevertheless, the differences between the population and the overall sample are small.



In the survey arable farmers (81% compared to 70%) and those who cultivated fruit and flowers were over-represented compared to farmers who cultivate grass and corn (12% compared to 26% of the actual population). The reply rate was thus higher for farm types that are more susceptible for drought (target group GO-FRESH experiments).

In the southwest Netherlands there are about 5500-6000 farms of which 50% arable farming, 12% horticulture and 6% greenhouse horticulture (CBS and LEI 2014) with a total turnover of 1.3 billion euros in 2012 (Visser and Van Tuinen 2012).

Summary survey questions

1: Survey item on protection motivation

This part of the survey is about several measures against water shortage and salinization caused by droughts. We are interested which of the measure you have already adopted and which ones you consider to implement in the future.

For each of the adaptation measures, please indicate which statement is applicable to your situation:

1. I have already implemented this measure
2. I am planning to take this measure within five years
3. I have thought about implementing this measure
4. I am familiar with this measure
5. I am not familiar with this measure
6. This measure is not implementable on my farm

2: Descriptive statistics

Variable	Description	Min	Max	Mean	S.D.
Level of adaptation motivation	Number of implemented adaptation measures	0	6	1.42	1.17
Field-scale measures	Adoption of field-scale measures (1 = yes; 0 = otherwise)	0	1	0.61	0.49
Farm-level measures	Adoption of farm-level measures (1 = yes; 0 = otherwise	0	1	0.46	0.50
Joint measures	Adoption of joint measures (1 = yes; 0 = otherwise	0	1	0.12	0.33
Perceived probability	Average chance on a 'dry year' and an 'extreme dry year'	2.50	58.33	22.94	11.26
Perceived severity	Average estimate of financial damage due to a 'dry year' and an 'extreme dry' year (x €100,000)	0	8.5	0.54	1.01
Perceived control efficacy	Average effectiveness of all adaptation measures	1	7	4.28	1.41
Perceived control field-scale measures	Average effectiveness of field-scale measures	1	7	4.19	1.69
Perceived control farm-level measures	Average effectiveness of farm-level measures	1	7	4.44	1.53
Perceived control joint measures	Average effectiveness of joint measures	1	7	4.35	1.96
Perceived cost	Average costs of all adaptation measures	1	7	4.86	1.25
Perceived cost field-scale measures	Average costs of field-scale measures	1	7	4.75	1.43
Perceived cost farm-level measures	Average costs of farm-level measures	1	7	4.94	1.52
Perceived cost joint measures	Average costs joint measures	1	7	5.04	1.76
Perceived self-efficacy	Average of four 7-point items on self-efficacy	1	7	3.84	1.39

3: Survey items on perceived probability and perceived severity

In a normal year the precipitation deficit during the growing season is approximately 110 mm.

1. Imagine an extreme dry year occurs, in which the precipitation deficit is 360 mm at the moment in the growing season crucial for your main crop / 2. Imagine a dry year occurs, in which the precipitation deficit is 220 mm at the moment in the growing season crucial for your main crop.

- How often (once in how many years) do you expect your farm to be exposed to an extreme dry / a dry year?
- In an extreme dry year / a dry year, how much financial damage do you expect for your farm?

4: Survey items on perceived control efficacy and perceived costs

This part of the survey is about several measures against water shortage and salinization caused by droughts. We are interested which of the measure you have already adopted and which ones you consider to implement in the future.

Thinking about protecting your farm against drought,

- How effective do you consider each of the following adaptation measures?
- How costly do you consider each of the following adaptation measures in terms of time/effort/money?

5: Survey items on perceived self-efficacy and Principle Component Analysis results

To what extent do you trust yourself to be capable to:

- Protect the farm against the consequences of drought
- Act correctly the moment a drought occurs
- Take suitable measures
- For farmers like me, it easy to protect my farm against the consequences of water shortage and salinization

6: Details on the adoption of drought adaptation measures

Descriptive statistics of the number of adopted measures show that the majority (75.9%) of farmers has adopted at least one adaptation measure. 0.7% of farmers have adopted more than 4 measures, see table below. The most common adaptation practice among farmers is optimizing the height and distance of drainage, which is adopted by 51.1% of farmers, followed by irrigation with 39% adopters. Freshwater injection into deep aquifers and desalination of brackish water has not been adopted by any of the farmers in the sample. These two technologies are in the first place intended for glasshouse horticulture farming and there are very few glasshouse horticulture farmers in the south-west Netherlands. Only two farmers (1.4%) in our sample indicated growing crops in glasshouses, compared to 2.5% of the total population. Furthermore, these farmers both indicated that glasshouse horticulture is not their main activity and that they dedicate only a small percentage of their total area to glasshouse horticulture. Therefore, the probability that one of the respondents would choose this strategy was small and it is not surprising that not one farmer in our sample has adopted this technique.

Adoption of drought risk mitigating strategies

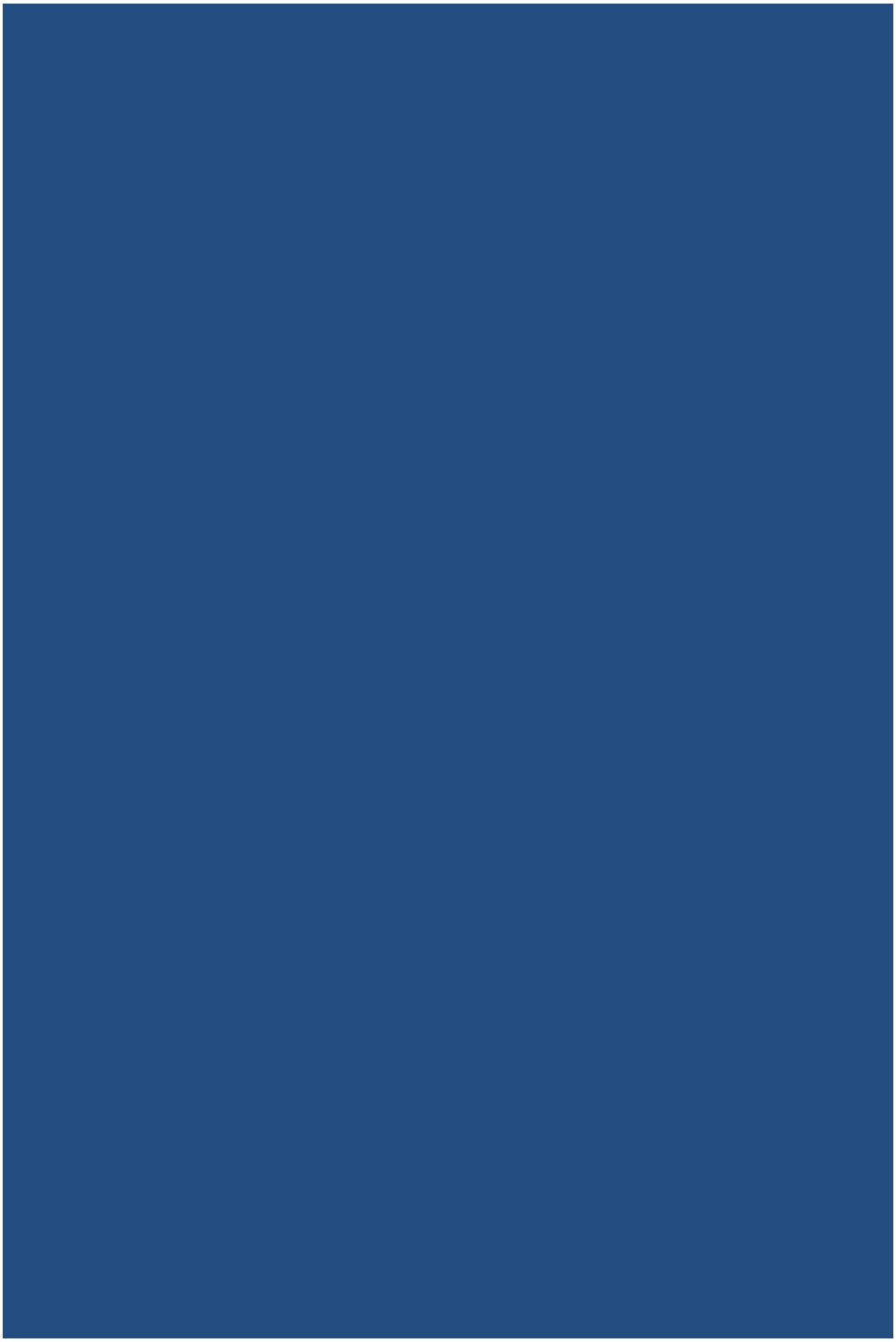
Dependent variable	Categories	Adopted (%)
Adaptation motivation	Adopted 0 measures	24.1
	Adopted 1 measure	33.3
	Adopted 2 measures	24.8
	Adopted 3 measures	13.5
	Adopted 4 measures	3.5
	Adopted > 4 measures	0.7
Adoption of field-scale measures	Optimizing height and distance drainage	51.1
	Automatic water level operated drainage	2.1
	Regulate water level in ditches	12.8
	Drain off brackish percolation water with a deep drain	2.8
	Freshwater storage in basin on parcel	5.7
	Adopted at least one field-scale measure	61.0
Adoption of farm-level measures	Irrigation	39.0
	Switch to more salt/drought resistant crops	4.3
	Weather insurance	10.6
	Desalinate brackish water	0.0
	Adopted at least one farm-level measures	46.1
Adoption of joint measures	Freshwater extraction from creek or sand-ridges	5.0
	Freshwater extraction from phreatic aquifers	8.5
	Freshwater injection into deep aquifers	0.0
	Adopted at least one joint measure	12.1

Additional information:

Duinen Rv, Filatova T, Geurts P, Veen Avd (2015) Empirical Analysis of Farmers' Drought Risk Perception: Objective Factors, Personal Circumstances, and Social Influence. Risk Analysis 35 (4):741-755. doi:10.1111/risa.12299

The Dutch version of the survey is available on request. Contact Rianne van Duinen.
Email: riannevanduinen@hotmail.com

Annex B – Supplement Chapter 5: Descriptive information interviews, Atlas-ti analysis, visualisation experiment and survey feasibility Rhine-Meuse-Scheldt Estuary



B1 – INTERVIEW SURVEY 2011

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 S1). The respondents were selected from participant lists of public consultation evenings and stakeholder meetings in which the programme office SWD was involved. Table S2 gives an overview of the addressed questions in the interviews. The original questions were in Dutch.

Table S1. *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, agriculture, hydrology, and soil physics

Table S2, Structure of the Interviews as done in August 2011. The original questions were in Dutch.

No.	Main structure and sub-questions
1	**The role of the respondent in regional freshwater resources management and salinisation issues around lake Volkerak-Zoom**
	- What organisation do you work? - What is your function? Do you work in a specific region? - Is salinisation in the Southwest Delta for you an important issue?
2	**Problems and solutions**
	- Which functions or sectors currently face already damage through salinisation? - Does salinisation also have positive impacts? - What is your vision about the future of freshwater resources management within the Southwest Delta?
3	**Visions about the policy arena**
	- Who are the actors within the policy process regarding salinisation issues around Lake Volkerak-Zoom? - Who decides about the level of salinisation?
4	**Dealing with knowledge within the policy process**
	- How do you try to influence the policy process about water management in and around lake Volkerak-Zoom? - What information do you take with to the policy process? - Which uncertainties do you bring forward? How do you advise others on how to deal with these uncertainties? - Do you face knowledge gaps that make it complicated for you to influence the policy process? - How honest/clear are other actors about uncertainties? - How is decided which knowledge gaps are important enough to initiate a research project? - Do you agree on how decisions are made about research?
5	**Qualitative knowledge about Fresh and Salt water in the Southwest Delta**
	- What is Fresh, Brackish and Salt water in your opinion? How do you to distinguish them apart? - Which ranges within the salt concentration (minimum, maximum) are acceptable for different water users (e.g. nature, horticulture, drinking water etc.)? What is the optimal salt concentration for each water user? - Could you show us on the map of the Southwest Delta where the issues of salinisation are most important? - At which location within the water system, you consider the salt concentration to be important: the main inlet point at Lake Volkerak, ditches within the regional water system, soil moisture, groundwater, or irrigation water? - When is the risk of saltwater damage high? In summer, winter, wet or dry season?
6	**Quantitative knowledge about Fresh and Salt water in the Southwest Delta**
	- How do you assess actual information about the process of salinisation at a certain moment of time? How do you evaluate this information? - Which type of data is important for you to know in order to evaluate potential salt damage risks? - What kind of actual salt damage did you experience/observe in the past? How did you know it was damage due to salinisation? - Do you use in your daily work criteria for chloride concentrations? For example, derived from literature? - How do you deal with uncertainties in your daily work? For example, in models and calculation. Do you use expert judgment? Do you avoid or ignore uncertainties?
7	**Final remarks**
	- Final remarks - Who else should we interview?

Atlas-ti software (Boeije, 2008; Friese, 2011) was used for labelling and coding quotations within the 19 interviews and managing the data. The initial coding was based upon the interview questions. During the analysis of textual data of the interviews the coding was means encoding incrementally adjusted and supplemented with sub-codes, e.g. axial coding (Boeije, 2008). Table S3 provides an overview of the used codes and the number of quotes in each interview.

Table S2, Used codes in *Atlas-Ti and overview of the frequency of the used codes.*

PRIMARY DOCS (Interview reports)																					
CODES	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Tot**
1a Organisation of respondents	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
1b Function(s) respondents	1	2	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	2	2	24
1c Geographical scale of the working area	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	1	1	1	22
2a Importance Salinisation in work	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
2b Damage (risks) due to salinisation	1	1	5	2	2	2	2	1	1	1	1	1	2	1	2	1	1	4	1	32
2c Positive effects of salinisation	1	1	3	3	1	1	0	1	3	1	2	1	1	1	1	3	1	1	2	28
2d Other terms used for salininsation	1	0	2	0	1	3	0	0	0	0	0	0	1	1	0	1	1	1	0	12
2e Desired future RMS Estuary	4	2	3	1	2	1	2	1	2	3	2	1	1	1	1	3	0	2	3	35
3a Process decision making	2	2	2	4	3	0	0	0	0	5	2	1	0	1	3	4	1	0	7	37
3b Key players in policy and decision making	1	1	2	3	2	2	2	1	1	1	1	1	1	1	1	1	3	1	5	31
3c Strategy of respondent to influence decision making	1	1	2	1	1	2	1	1	0	3	0	1	1	2	1	1	1	1	2	23
3d Statement responsibility research commissioning	1	1	1	1	1	1	1	1	1	1	0	1	1	1	2	1	1	1	2	20
4a Information brought in into decision making	1	1	1	2	1	7	1	1	2	0	3	1	0	1	2	1	1	3	4	33
4b Uncertainties within the debate (general)	3	1	1	4	3	3	2	1	0	2	3	1	1	4	0	4	4	1	5	43
4b Unc. salt leakages towards other water systems	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	2	0	1	7
4b Unc. (future) severity algal blooms in lake VZM	1	0	0	3	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	7
4b Unc. Development future brackish nature (lake VZM)	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	4
4b Unc. Financial consequences for agriculture	0	0	1	0	1	0	0	0	0	0	2	1	0	1	1	1	2	1	1	12
4b Unc. Combination with water retention (Grev)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
4b Unc. Crop damage in root zone (salt)	0	0	1	1	0	0	0	0	2	0	3	1	0	2	0	0	0	1	0	11
4b Unc. Hydrological water balance (supply, demand)	1	0	0	0	3	0	0	1	1	0	2	2	1	0	0	0	1	3	0	15
4c Respondents identifies a knowledge gap	1	1	4	1	3	7	1	1	6	2	4	1	2	3	1	1	1	1	1	42
4d Openness about personal knowledge gaps	1	1	3	1	1	2	1	1	1	1	3	1	1	1	1	1	1	1	2	25
4e Decisions about research	2	1	3	2	1	2	1	2	1	0	5	3	1	1	1	2	1	1	1	31
5a Definitions of fresh, salt, and brackish	1	2	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	23
5b Chloride concentrations irt water use	1	1	3	2	2	2	1	1	2	1	1	1	1	3	1	1	1	3	1	29
5c Chloride concentrations: where in the system	1	1	4	3	5	1	3	2	1	3	2	1	3	2	5	2	2	7	2	50
5d Seasonality in Chloride concentrations	2	2	2	2	2	0	2	1	1	0	1	1	1	1	2	1	1	2	0	24
5e How to measure Chloride concentrations	1	1	1	1	3	1	2	0	0	0	2	0	2	0	2	0	2	0	1	19
6 Who else should we interview?	2	0	0	1	1	0	1	1	0	1	1	1	1	1	0	2	2	1	0	16
Totals	35	27	49	45	45	44	29	23	30	32	45	27	30	36	35	38	37	42		**696**

In total 30 codes were used in atlas-ti. The final coding was largely based on subjects that respondents used to describe spatial and temporal (un)certainties about "salinisation" and fresh water supply in decision making and commissioning of research in the context of Lake Volkerak-Zoom. The encryption of the interviews was done by the interviewer, while the analysis and interpretation of the coding was done jointly with the participant observant.

Finally, the codes were rearranged and clustered in order to synthesize answers in relation to the research questions. In the final project report (Klostermann et al., 2013) (Dutch language), the synthesis is supported by a wealth of different quotes from the respondents. Within this article we decided to limit the use of quotes, because the translation of the language of speech is difficult. In the project report (Klostermann et al., 2013), the quotes are a representation of the wide variety of ways how respondents deal with uncertainties with regard to freshwater supply in delta regions. Given the limited

space we had to make selective use of quotes. The presented quotes in this article should therefore be seen as illustrative examples from individuals. They do not represent the wide variety of ideas as reported in the project report, nor should be seen as the opinion of a whole sector.

Because interviewer and participant observant jointly did the analysis it could be verified whether the subjects mentioned in the interviews also were observed by the participant observant within the internal and external meetings organized by the Programme Office Southwest Delta. The observations of the participant observant cover a period of time (2007-2014) and could be seen as a movie, while the interviews could be seen as a snapshot with more detail.

B2 - PARTICIPANT OBSERVATION

The principal investigator participated in 19 stakeholder meetings (2007-2011) organized by programme office South-West Delta (programme office SWD), and his role could be described as peripheral member of this network. In 2011-2014 the principal investigator participated in the monthly meetings of the policy team of the programme office SWD that was responsible for drafting the long-term policy for freshwater resources management and coastal safety. In this later period his role could be described as participant observant (Atkinson & Hammersley 1994) with an active membership role (Adler & Adler 1987). The principal investigator had a formalized task to assist the team with the formulation of an annual research agenda. Table S4 provides an overview of meetings in which the principal investigator participated.

Table S4, *Overview of meetings in which the principal investigator participated.*

Meetings in which the principal investigator participated in the period in which his role could be described as a *peripheral member* of the programme office Southwest Delta. Many of these meeting were organized by the Province of Zeeland jointly with the research programme Knowledge for Climate (KfC). In these meetings also many members of the programme office SWD participated.
• Brainstorm meeting about climate adaptation in Southwest Delta (*06/10/2006, location: Province Zeeland)* • *Stakeholder meeting Southwest Delta about water & climate (06-04-200, location Province Zeeland)* • *Science-policy meeting Wate r& Climate Southwest Delta (22/06/2007) (location Province Zeeland)* • *Workshop Knowledge Agenda Water & Climate SWD (18/12/2007) (location Province Zeeland)* • *Stakeholder meeting KfC Hotspot Water and Climate (23/05/2008) (Location Province Zeeland)* *After 2008 the collaboration between programme office SWD and KfC research programme increases, but the role of the principal investigator can still be described as a peripheral member, as he is not yet a formal member.* • *Participant in research project about long term water supply and demand in Southwest Delta commissioned by programme office SWD and KfC. This project included 3 stakeholder meetings with participants from programme office SWD (May 2009-December 2009). These meetings were organised at the programme office SWD (Goes, 2x) and once in Den Haag.* • *KfC Hotspot meeting Southwest Delta (14-12-2009) (location: Province Zeeland)* • *Attending the public consultation meeting "Preferred strategy to improve Water Quality Lake Volkerak-Zoom (January 2010) (Location: Bergen op Zoom, commissioned by Rijkswaterstaat).* • *Brainstorm meeting Knowledge agenda Water and Climate SWD (31//03/2010) (Location: Rijkswaterstaat, commissioned by Programme office SWD and Deltares)* • *Brainstorm meeting Programme proposal Delta programme – Southwest Delta (12/04/2010) (Commissioned by programme office SWD, RWS and National Delta programme)* • *Conference Southwest Delta (28/10/2010) (Location: Rotterdam, commissioned by programme office SWD)*
In December 2010/January 2011 the principal investigator is invited to become knowledge coordinator of the policy team Climate Adaptation. This invitation is done by the ministry of Economic Affairs and supported by the director of the programme office SWD. From this moment onwards the role of the principal investigator can be described as participant observant. On behalf of the programme office SWD the PA participated also in the knowledge network of the nation delta programme (4x a year between 2010 and 2014). This team meets each other with a frequency of once in 1 month. From every meeting minutes are available. In addition, the following meetings were organized in which the principal investigator participated:
• *Workshop problem analysis water and climate Southwest Delta (18-01-2011) (commissioned by programme office SWD and National Delta programme)* • *Work Conference problem analyses fresh water supply in West-Netherlands (11/03/2011: Location: Province South Holland))* • *Design atelier Problem analysis Water & Climate SWD (25/03/2011) (Location: Goes, Commissioned by Programme office SWD)* • *Meeting programme office SWD about strategies to cope with water & climate issues (31/05/2011) (Location: Goes, commissioned by Programme office SWD/National Delta Programme)* • *Meeting Climate change and flood risks (1/06/2011) (Location: RWS/Rotterdam; jointly commissioned by National Delta programme & Programme office SWD)* • *Thematic meeting about long-term ecological issues in the SWD as part of the problem analysis (24/06/2011) (Location: Goes, commissioned by programme office SWD)* • *Team building (2 days) programme office SWD (28/29 – 06-2011) (Location: Haamstede)* • *Team building (2 days) programme office SWD (Summer 2012) (Location: Renesse)* • *Team building (2 days) programme office SWD (Summer 2013) (Location: West-Kapelle)*

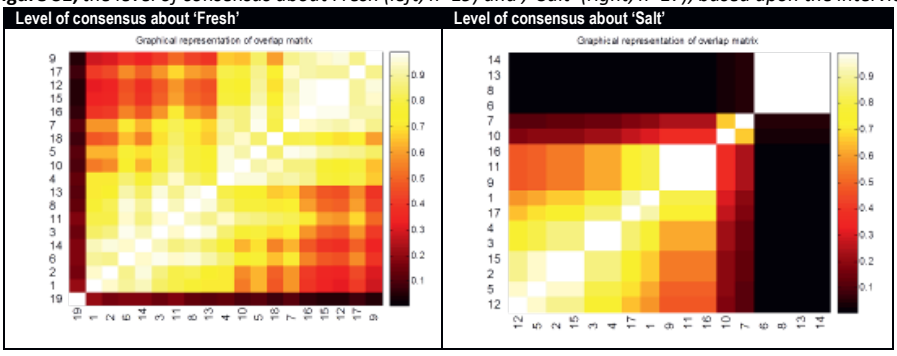
B3 SEMI-QUANTITATIVE EXPERIMENT

Because of the very frequent use of the terms 'freshwater', 'salt water' and 'salinisation' in both policy processes we first assessed how the respondents defined those terms in both qualitative arguments and quantitative terms in their daily live.

We asked which chloride concentrations (upper and lower limit) they associate with these definitions. The objective of this question was not to assess average estimations but to visualize and to explore the variation in the definition of freshwater and salt water from respondents by making correlation diagrams. Those correlation diagrams were made based upon Bayesian data analysis (Malakoff, 1999), probability distribution functions (Hendrix et al., 2006; Shannon, 1948) and statistical entropy theory (Jaynes, 2003; Kapur & Kesavan, 1992; Sornette, 2004).

The interview respondents frame their definition for 'fresh' or 'salt' water with expert knowledge from different systems: lake Volkerak-Zoom, the root zone of the crops or the regional water system. The respondents from the national Delta programme and NGO's (nature) define freshwater and salt based upon estuarine dynamics, e.g. at the scale of the Estuary. The water boards frame problems (and solutions) at the scale of the regional water system, while the root zone of the crops has the attention of both farmers and scientists that were part of the survey. Secondly, the assessed threshold value (chloride concentration) within the semi-quantitative experiment (figure 2) amongst respondents for freshwater depends on the purpose for which the water is used, as also observed in previous research (Brouwer & Velstra, 2010; Brouwer & Huitema, 2007; de Bruine & van Tuinen, 2011; Stuyt et al., 2011).

Figure S1, *the level of consensus about Fresh (left, n=19) and , 'Salt '(right, n=17), based upon the interview survey.*



With this semi-quantitative experiment, it was tried to explore and visualise the diversity in expert judgement regarding the definition of 'freshwater 'and 'salt water' amongst the

interview respondents. The respondents (n=19) were asked to define fresh and salt water in terms of chloride concentration expressed in mg/l. The interview question took into account that people often use intuition ad qualitative arguments when they are asked to estimate/quantify certain variables when they cannot use calculation tools (Polack, 2005). This was also observed within this experiment.

16 respondents based their estimation regarding freshwater on the most salt sensitive water use. Two respondents refused to define salt water because, in their opinion only the definition of freshwater is important in this case study, therefore the assessment of 'salt water 'is based upon estimations of 17 respondents. Each number in figure 2 corresponds to 1 respondent. The colours visualize the level of similarity (e.g. consensus) of the different estimates. The colour varies between white (full consensus) up to dark red (no consensus). Every respondent is, of course, fully in consensus with himself, their fore the diagonal of figure 2 is white. Left and right from the diagonal include the same information about the consensus (mirrored).

Respondents with comparable estimations are also clustered. For example, respondent 14,13,8 and 6 all define 'salt water 'as sea water with a chloride concentration of 18000 mg/l, while the other respondents use lower chloride concentrations to define 'salt water', the lowest estimate being 350 mg/l. The estimates regarding fresh water ranged between 50 en 600 mg/l. The observed differences in the estimates for salt water are, in absolute terms bigger for salt water compared to freshwater. One respondent identifies an inversed chloride concentration threshold for mussels, e.g. chloride concentration should not decline below 10.000 mg/l to guarantee mussel growth. The NGOs elaborate on the definition of brackish water in addition to fresh and salt water. They point out the importance of temporal fluctuations in chloride concentrations and spatial gradients for the development of nature.

B4 Additional interviews 2014 – feasibility study RMS Academy

In a later stage (2014) the principal investigator also conducted 17 additional semi-structured interviews between June 2013 and June 2014 for a different project (Veraart & Leemans, 2014) with the objective to explore opinions how Dutch & Flemish stakeholders in the Rhine-Meuse-Scheldt think about the idea to initiate a new science-policy interface in the Rhine-Meuse Scheldt Delta. Interviews were recorded in transcribed. Atlas-ti software (Boeije, 2008; Friese, 2011) was used for labelling and coding quotations and managing the data. All of the respondents have had the opportunity to check their personal interview report. The interview questions (table S5) were formulated in close co-operation with the commissioners of the research (Foundation Knowledge for Climate represented by Pier Vellinga) and the Province of Zeeland (Represented by Miss Thecla Westerhof). During the survey some questions were added. Respondents were asked to give (1) a geographical demarcation of the Southwest Delta, (2) indicate which question they missed and (3) finally asked what the Respondent's Heart claw was towards the Commissioners of this research.

***Table S5**, Interview Questions as used within the Feasibility study Rhine-Meuse-Scheldt Delta Academy. The original questions were in Dutch.*

No.	Main structure and sub-questions
1	**The role of the respondent in the science-policy interface within the Rhine-Meuse-Scheldt Estuary**
	- What organisation do you work? - What is your function? - How is your work related with knowledge use and knowledge production in the Rhine-Meuse-Scheldt Delta?
2	**Respondent's visions about the current functioning of the science-policy interface in the Rhine-Meuse-Scheldt Delta**
	- Which parties/institutions are important actors within the science-policy interface? How would you describe their role? - How is currently decided about knowledge needs? - How /When is decided that research is needed to address knowledge gaps? - Is the formulation of knowledge needs influenced by sectoral or institutional stakes? Is this a problem in your vision in view of decision making? - What is your opinion about the current division of tasks between applied research, fundamental research, consultancy, and trans/interdisciplinary research in the Rhine-Meuse-Scheldt estuary?
3	**The role of the respondent in the science-policy interface further explored**
	- Do you feel sufficiently engaged in the process of commissioning research? - How do you personally try to influence the process of knowledge production within the Rhine-Meuse-Scheldt Estuaries?
4	**The respondent's vison regarding the research agenda and knowledge gaps**
	- Which knowledge gaps, research themes and disciplines should be addressed?
5	**Utility and necessity of a new boundary organisation between science and policy in the Rhine-Meuse-Scheldt Delta**
	- What should be improved in the current science-policy interface? - Is there a necessity for a new boundary organisation within this region? - Which other initiatives should be taken into account? - How do you see the co-operation between the Netherlands and Flemish/Belgium actors within such a boundary organisation? - Should the private sector be involved? - What should be the societal impact of such a boundary organisation?
6	**Respondent's vision about the governance structure of such a boundary organisation**
	- Who should be responsible for financing such a boundary organisation? - Could you sketch your preferred profile of this boundary organisation? (tasks, entities, organogram) - Which persons/institutes should be involved? - What is a reasonable budget to run such an organisation? - Would you/your institute invest in such an organisation? -
7	**Final remarks**
	- Final remarks - Who else should we interview?

Table S6, *Overview of characteristics of the 17 interviewees*

Organisation	Function	Expertise
Province of Zeeland (interview with 2 persons)	(1) Decision maker (2) Policy maker	Spatial Planning, Water Management, Recreation, Nature Conservation
Erasmus University Rotterdam	Professor	Administrative Science
Retired/ZZP	Director Programme Office SWD (retired) Emiritus Professor Design & Architecture	National Delta Programme / Programme Office SWD
Research Institute for Nature and Forest (INBO) (Belgium)	Researcher, team leader	Biodiversity, Water Framework directive, Natura 2000
Deltares	Chair scientific Council Deltares	Water Safety, Water Supply, geology
Retired	Chair scientific Council Wageningen UR (retired) Chair Reflection Commission 'Future Southwest Delta'	Research Quality Assurance, Account management ministry of Economic Affairs
Alterra (Wageningen UR)	Director	Research Management
University of Antwerp (interview with 2 persons)	(1) Professor Estuarine Ecology, chair holder ECOBE (2) Science Support Officer/Account manager life Sciences	(1) Ecology (2) Governance/Finance mechanisms of research in Belgium
NIOZ	Director NIOZ-Yerseke Professor Estuarine Ecology	Estuarine Ecology
Ministry of Infrastructure and Environment	Director Knowledge management and Innovation	Knowledge management between the ministry of I&M, Rijkswaterstaat and official affiliated research institutes (KNMI, PBL, Deltares)
Scientific Advisory Council Province Zeeland	Chair Ex-director Library Zeeland	Innovation, Education
HZ University of Applied Science	Chair board of directors	Decision maker
Ministry of Economic Affairs	Ambassador Region Southwest Delta, member steering group Southwest Delta	Regional Economic Development
Havenbedrijf Rotterdam (Port Rotterdam)	Head Environmental Monitoring Maasvlakte 2, professor Ports&Navigation Technical University Delft	Harbour management, navigation, environment
Havenbedrijf Antwerpen	Support officer Environmental monitoring & spatial planning	Environmental Impact Monitoring, Ecology Scheldt Estuary
Rijkswaterstaat	Adminstrative director Programme Office SWD	Manager, account management
University College Roosevelt	Dean, professor Social Science	Law
It should be noted that 2 invited interview respondents refused to do this interview because they did not see the necessity of a new boundary organisation. Those were (1) the Flemish Ministry of Economic Development, Science, and Innovation and (2) WL Borghout (and Flemish water research institute, comparable with Deltares).		

The results of this additional interview survey were published by Knowledge for Climate (Veraart & Leemans, 2014). In summary: The analysis of these 17 additional interviews indicates that the approached institutes in the Netherlands and Flanders know each other through various networks. If you ask them directly, at first sight, everyone seems satisfied with the knowledge production and research articulation process in the Rhine-Meuse Scheldt

region. However, during the course of the interviews, some underlying bottlenecks were articulated in particular regarding at the interface between fundamental research, applied research, consultancy and transdisciplinary research. The majority of the respondents considered a new science-policy organisation not necessary. Collaboration with Flanders is considered by many respondents as useful in research programming and new initiative could create opportunities for doing bi-national research. Most respondents say it would be difficult to find public and private investors for such a boundary organisation. All interviewees state that the socio-economic and ecological issues in the delta require an integrated effort of many natural and social science disciplines. A majority also sees a niche for transdisciplinary research (in cooperation with stakeholders). Most respondents lay the North and South boundaries of the Rhine-Maas-Scheldt Delta at Antwerp and Rotterdam. There is no shared image about the East and West boundaries. The Flemish respondents are primarily focussed on collaboration with the Netherlands in view of the Scheldt Estuary and the interactions with the North Sea. For each societal issue (water safety, fresh water supply, logistics, ecology etc.) there are other networks and working agreements that determine the geographical boundaries of the problem.

Samenvatting



***Picture**: NOS Journalists broadcasting the Kick off of the Climate changes Spatial Planning Programme (Ralph Lasage, 2004)*

SAMENVATTING

Inleiding

Het meest recente IPCC-rapport (2023) concludeert dat klimaatverandering heeft geleid tot een mondiale gemiddelde atmosferische temperatuur die in de periode 2011-2020 ongeveer 1,1 °C hoger lag dan in het pre-industriële tijdperk (1850-1900). Tegelijkertijd neemt het aantal extreme weersomstandigheden wereldwijd toe. Ook in Nederland is het daarom noodzakelijk om het waterbeheer, de ruimtelijke ordening en de infrastructuur aan te passen aan een veranderend klimaat. Waterbeheerders en onderzoekers werken intensief aan de ontwikkeling en implementatie van klimaatadaptatiestrategieën. De besluitvorming hierover blijft echter complex vanwege verschillende vormen van onzekerheid.

Dit proefschrift onderzoekt hoe met deze onzekerheden wordt omgegaan binnen deels samenhangende interfaces tussen klimaatadaptatieonderzoek en waterbeheer op verschillende ruimtelijke schaalniveaus. Het doel is de kennisuitwisseling tussen klimaatadaptatieonderzoek en waterbeheer te verbeteren en daarmee de bruikbaarheid van klimaatadaptatieonderzoek voor de praktijk te vergroten. De volgende onderzoeksvragen staan centraal:

- Welke rol spelen verschillende typen onzekerheden bij kennisuitwisseling op het grensvlak tussen klimaatadaptatieonderzoek en het Nederlandse waterbeheer gedurende een langere tijdsperiode?
- Welke rol spelen grensobjecten (boundary objects) in de kennisuitwisseling tussen klimaatadaptatieonderzoek en waterbeheer, en verschilt deze rol tussen nationaal, regionaal en lokaal niveau?
- Welke strategieën kunnen worden ingezet om onzekerheden te adresseren binnen gedeeltelijk samenhangende interfaces, zodat de bruikbaarheid van klimaatadaptatieonderzoek voor het waterbeheer wordt vergroot?

Aanpak en theoretisch kader

Voor dit onderzoek is een geneste longitudinale casestudie uitgevoerd waarin het Nederlandse waterbeheer, met nadruk op de zoetwatervoorziening, centraal staat. De studie bestrijkt de periode 2000-2014 en bevat een doorkijk naar 2025. Acht interfaces zijn onderzocht op nationaal niveau, in de Zuidwestelijke Delta en op het niveau van individuele agrarische bedrijven. Bij het onderzoek waren talrijke professionals betrokken die zich strategisch bezighouden met de huidige en toekomstige zoetwatervoorziening van Nederland. In het proefschrift wordt een typologie gehanteerd waarin onderscheid wordt gemaakt tussen ambiguïteit, ontische onzekerheden en epistemische onzekerheden. Onderzocht is hoe waterbeheerders, onderzoekers en watergebruikers deze verschillende

typen onzekerheden hanteerbaar proberen te maken bij besluitvorming over klimaatadaptatie in het waterbeheer. Daarnaast is geanalyseerd hoe deze onzekerheden de kennisuitwisseling tussen de betrokken actoren beïnvloeden.

Het proefschrift bestaat uit een introductie (hoofdstuk 1), een beschrijving van de longitudinale casestudie (hoofdstuk 2), zes hoofdstukken gebaseerd op gepubliceerde resultaten (hoofdstukken 3-8) en een synthese met conclusies en aanbevelingen (hoofdstuk 9).

Hoofdstuk 2 beschrijft een historische analyse van de ontwikkeling van de interfaces tussen klimaatadaptatieonderzoek en waterbeheer op verschillende ruimtelijke schalen. Het hoofdstuk biedt eerst een beknopt overzicht van de ontwikkelingen vanaf het begin van de jaren zestig tot aan de publicatie van het derde IPCC-rapport rond 2000. Vervolgens wordt de ontwikkeling van deze interfaces voor de periode 2000-2014 uitgebreider geanalyseerd, waarna een doorkijk wordt gegeven naar de ontwikkelingen tot 2025. Voor elk van deze perioden wordt beschreven welke rol klimaatscenario's en klimaatadaptatie speelden bij het omgaan met onzekerheden op het grensvlak tussen onderzoek en waterbeheer. Gedurende meerdere decennia hebben zowel klimaatscenario's als het concept klimaatadaptatie gefungeerd als grensobjecten. Hun betekenis en functie veranderden echter onder invloed van institutionele ontwikkelingen binnen de interface tussen klimaatadaptatieonderzoek en het Nederlandse waterbeheer. Hoewel de kennisuitwisseling tussen beide domeinen aanzienlijk is verbeterd, blijven er belangrijke uitdagingen bestaan bij het ontwikkelen van integrale, sector overstijgende klimaatadaptatiestrategieën. Dit hoofdstuk laat zien dat in het waterbeheer de bestaande wetenschappelijke methoden voor het evalueren van onzekerheden nog te weinig rekening houden dat de rol van de verschillende typen onzekerheden kunnen verschillen in besluitvormingsprocessen over klimaatadaptatie op nationaal, regionaal en lokaal schaalniveau. Wanneer onzekerheidsanalyses op dit punt worden verbeterd, zal dit de toepasbaarheid van klimaatonderzoek vergroten.

Hoofdstuk 3 behandelt een enquête uit 2001 waarin de percepties van belanghebbenden en het oordeel van experts over de gevolgen van klimaatverandering voor het Nederlandse waterbeheer zijn onderzocht. Uit de resultaten blijkt dat experts en stakeholders overeenstemming bereikten over de risico's van overstromingen. Ten aanzien van de ernst van de gevolgen voor de zoetwaterbeschikbaarheid bestonden echter uiteenlopende opvattingen. Deze ambiguïteit bemoeilijkte rond 2001 de ontwikkeling en beoordeling van klimaatadaptatiestrategieën. Het hoofdstuk laat zien dat klimaatwetenschappers in deze periode steeds nadrukkelijker stakeholders betrokken bij onderzoek naar regionale en sectorale klimaatadaptatiestrategieën. Daarmee ontstonden nieuwe mogelijkheden om verschillende perspectieven op risico's en onzekerheden met elkaar te verbinden.

Hoofdstuk 4 beschrijft klimaatbestendigheid (climate proofing) als een strategisch afwegingskader waarin risico's, kansen, onzekerheden en veerkracht gezamenlijk worden meegenomen in besluitvorming over klimaatadaptatie in het waterbeheer. Binnen dit kader wordt afscheid genomen van de traditionele aanname van hydrologische stationariteit. In plaats daarvan ligt de nadruk op adaptief waterbeheer en toepassing van het voorzorgsbeginsel bij lange termijn beslissingen. Deze benadering stimuleert acceptatie van onzekerheden bij het ontwikkelen van langetermijnvisies en beleidsstrategieën. Bovendien worden leerprocessen tussen onderzoekers en waterbeheerders expliciet beschouwd als een belangrijke strategie om met onzekerheden om te gaan bij dit afwegingskader. Het hoofdstuk benadrukt dat organisaties en netwerken op het grensvlak van onderzoek en waterbeheer een cruciale rol spelen bij de toepassing van klimaatbestendigheid als afwegingskader. Daarnaast zijn zij essentieel voor het voeren van een bredere maatschappelijke dialoog over klimaatadaptatie.

Hoofdstuk 5 beschrijft hoe binnen besluitvormingsprocessen in de Rijn-Maas-Schelde-estuaria, en in het bijzonder rond het Volkerak-Zoommeer, is omgegaan met wetenschappelijke onzekerheden over klimaatverandering, waterkwaliteit, zoetwatervoorziening en waterberging in de periode 2000-2014. Op basis van literatuuronderzoek, interviews en meerjarige deelname aan het beleidsteam dat de voorkeursstrategie voor de Zuidwestelijke Delta ontwikkelde, is de status van wetenschappelijke kennis beoordeeld waarbij drie categorieën zijn gebruikt: *"overeenstemming"*, *"weerlegde kennis"* en *"onzekere kennis"*. Het hoofdstuk laat zien hoe consensus over wetenschappelijke inzichten kan ontstaan wanneer wetenschappers, beleidsmakers en stakeholders gedurende langere tijd intensief met elkaar samenwerken en kennis uitwisselen. Daarbij blijken ook onderhandelingsprocessen een belangrijke rol te spelen. Een voorbeeld hiervan is de consensus die ontstond over een strategie ter verbetering van de waterkwaliteit van het Volkerak-Zoommeer. Deze strategie omvatte de introductie van een beperkt getij en de gecontroleerde inlaat van zout water om toekomstige algenbloei te voorkomen. Na 2014 verminderde deze consensus echter door het ontstaan van nieuwe ontische onzekerheden. Voorbeelden hiervan zijn de niet verklaarbare afname van de algenproblematiek en de terugkerende discussie over kosteneffectieve oplossingen voor een toekomstbestendige zoetwatervoorziening van de landbouw rond het Volkerak-Zoommeer. Bij het omgaan met deze onzekerheden werden verschillende strategieën toegepast, waaronder joint fact-finding, het hanteren van duidelijke besluitvormingstermijnen en het toepassen van het no-regret-principe. Het hoofdstuk sluit af met aanbevelingen voor het vergroten van de bruikbaarheid en legitimiteit van klimaatadaptatieonderzoek binnen complexe governance-structuren.

Hoofdstuk 6 onderzoekt het belang van sociaaleconomische factoren voor de adoptie van innovatieve drainagesystemen in Zuidwest-Nederland. Deze systemen worden beschouwd als mogelijke adaptatiemaatregel voor afnemende zoetwaterbeschikbaarheid door klimaatverandering en verzilting. Drie drainagepilots werden gezamenlijk uitgevoerd door onderzoekers en agrariërs, met als doel het hydrologische rendement van de systemen door middel van veldexperimenten te bepalen. Daarnaast werd de sociaaleconomische haalbaarheid onderzocht via stakeholderworkshops en een enquête onder agrarische ondernemers over hun ervaringen met watertekorten. Bij de drie agrariërs die deelnamen aan de pilots nam het vertrouwen in de nieuwe drainageconcepten gedurende het project toe. Uit de enquête bleek echter dat onder niet-betrokken agrariërs nog aanzienlijke twijfel bestond over de praktische toepasbaarheid ervan. De resultaten laten zien dat betrouwbare toegang tot zoetwater, ondersteunende regelgeving, financiële prikkels zoals subsidies en sectorspecifieke maatwerkoplossingen voor akkerbouw en fruitteelt van groot belang zijn voor bredere toepassing van deze drainagesystemen. Daarnaast blijft verbetering van agro-hydrologische modellen noodzakelijk om het rendement beter te kunnen onderbouwen en wetenschappelijke onzekerheden verder te verkleinen.

Hoofdstuk 7 beschrijft een vergelijkende casestudie naar de toepassing van Nature-based Solutions op het grensvlak van voedselproductie en waterbeheer. Vanuit de Voedsel Systeem Benadering richt de analyse zich op regenwateropvang in de bodem, innovatieve drainagesystemen en hergebruik van afvalwater. Hoewel deze oplossingen technisch haalbaar en maatschappelijk acceptabel blijken, wordt grootschalige toepassing belemmerd door uiteenlopende biofysische, technische, institutionele en sociaal-culturele barrières. Het hoofdstuk laat zien dat ruimtelijke informatie, ontwikkeld in samenwerking met belanghebbenden, kan bijdragen aan het verminderen van deze barrières. De studie benadrukt daarnaast de rol van hardnekkige ontische onzekerheden bij het ruimtelijk expliciet maken van toekomstscenario's. Deze onzekerheden hangen grotendeels samen met beperkingen in de beschikbaarheid en kwaliteit van gegevens. Vooral onzekerheden rond toekomstig landgebruik en de berekening van gewasverdamping binnen het Nationaal Hydrologisch Model blijken hierbij een belangrijke uitdaging te vormen.

Hoofdstuk 8 reflecteert op een decennium van Nederlands klimaatadaptatieonderzoek aan de hand van twee omvangrijke onderzoeksprogramma's: Klimaat voor Ruimte (2004-2012) en Kennis voor Klimaat (2008-2014). Deze programma's vormden een belangrijke schakel tussen klimaatonderzoek, beleid, waterbeheer en praktijktoepassingen. Tijdens de uitvoering ervan vond een duidelijke ontwikkeling plaats: van nationaal georiënteerde klimaateffect analyses op basis van scenario's naar een meer geïntegreerde benadering waarin scenarioanalyses worden gecombineerd met interdisciplinair onderzoek naar concrete klimaatadaptatiemaatregelen op regionale en lokale schaal. Deze verschuiving

heeft bijgedragen aan de ontwikkeling van klimaatadaptatiestrategieën binnen verschillende sectoren, waaronder het waterbeheer.

Conclusies

Hoofdstuk 9 beschrijft de conclusies. Gedurende de periode 2000-2025 heeft het Nederlandse klimaatadaptatieonderzoek met succes methoden ontwikkeld om beter om te gaan met ambiguïteit, ontische en epistemische onzekerheden bij de ontwikkeling van klimaatadaptatiestrategieën voor het waterbeheer. De kennisuitwisseling hierover werd ondersteund door grensobjecten zoals klimaatscenario's, klimaatbestendigheid en later ook adaptatie- en ontwikkelpaden. Hierdoor is de bruikbaarheid van klimaatadaptatieonderzoek voor het Nederlandse waterbeheer aanzienlijk vergroot. Tegelijkertijd blijven verschillen van inzicht bestaan over de effectiviteit van klimaatadaptatie opties, met name wanneer technische maatregelen, landgebruiksverandering en Nature-based Solutions tegen elkaar afgewogen worden. Dit heeft geleid tot een cyclisch terugkerende ambiguïteit. Daarnaast hebben nieuwe ontische onzekerheden, onder meer rond zeespiegelstijging en de frequentie van extreme weersomstandigheden, de toepassing van klimaatadaptatieonderzoek opnieuw complexer gemaakt.

In eerste instantie lag de nadruk vooral op het verfijnen van klimaatscenario's en het uitvoeren van verkennend onderzoek naar klimaateffecten binnen de nationale onderzoeksprogramma's Klimaat voor Ruimte en Kennis voor Klimaat bij het adresseren van onzekerheden. Deze programma's hebben de kennisuitwisseling tussen onderzoekers en waterbeheerders gestimuleerd, ondanks hardnekkige onzekerheden over de gevolgen van klimaatverandering. Extreme droogteperioden, zoals in 2018, en de overstromingen in het Maasstroomgebied in 2021 hebben het gevoel van urgentie rond klimaatadaptatie daarna verder versterkt. Tegelijkertijd namen de onzekerheden rond toekomstige zeespiegelstijging toe. Om deze redenen zijn betere methoden voor onzekerheidsanalyse nodig. Daarbij is het van belang om in klimaatadaptatieonderzoek niet alleen rekening te houden met veranderingen in onzekerheden door de tijd heen, maar ook met onzekerheden die ontstaan doordat besluitvormingsprocessen in regionaal en landelijk waterbeheer slechts gedeeltelijk op elkaar aansluiten en op verschillende tijdschalen plaatsvinden.

Vanaf ongeveer 1990 hebben zowel klimaatscenario's als het concept klimaatadaptatie regelmatig gefungeerd als grensobjecten binnen het Nederlandse waterbeheer. De precieze rol van deze grensobjecten veranderde echter in de loop der tijd. Zij vervulden een belangrijke functie bij het faciliteren van de dialoog tussen wetenschappelijke disciplines en tussen verschillende bestuurlijke niveaus. Voor 2000 vervulden IPCC-scenario's deze rol al gedeeltelijk, maar hun ruimtelijke resolutie was te grof voor praktisch gebruik in het Nederlandse waterbeheer. De eerste generatie KNMI-scenario's bleek hiervoor beter

geschikt. Tussen 2000 en 2014 kreeg het gebruik van deze scenario's bovendien een formele plaats binnen het nationale waterbeleid. In dezelfde periode ontwikkelde ook klimaatadaptatie zich tot een belangrijk grensobject. Daaraan verwante begrippen, zoals klimaatbestendigheid, ondersteunden strategische discussies over de toekomst van het waterbeheer. Tegelijkertijd bleven dergelijke concepten voor operationele toepassingen vaak relatief abstract. Na 2014 nam de bruikbaarheid van klimaatscenario's verder toe door de ontwikkeling van klimaatdiensten (climate services), waaronder aanvullende scenario's voor rivierafvoeren en droogte-indicatoren. Desondanks blijft de interpretatie van dergelijke informatie voor waterbeheerders een uitdaging. De periodieke actualisering van KNMI-scenario's en de herijking van voorkeursstrategieën binnen het Deltaprogramma zijn inmiddels institutioneel verankerd. Deze ontwikkeling laat zien dat klimaatkennis steeds sterker wordt geïntegreerd in het Nederlandse waterbeheer. Tegelijkertijd concludeert dit proefschrift dat de interface tussen klimaatadaptatieonderzoek en waterbeheer na afloop van Kennis voor Klimaat deels weer een meer sectorale invulling heeft gekregen. Hoewel de kennisuitwisseling de afgelopen 25 jaar aanzienlijk is verbeterd, blijft het ontwikkelen van integrale strategieën voor waterbeheer, landgebruik en infrastructuur een belangrijke uitdaging.

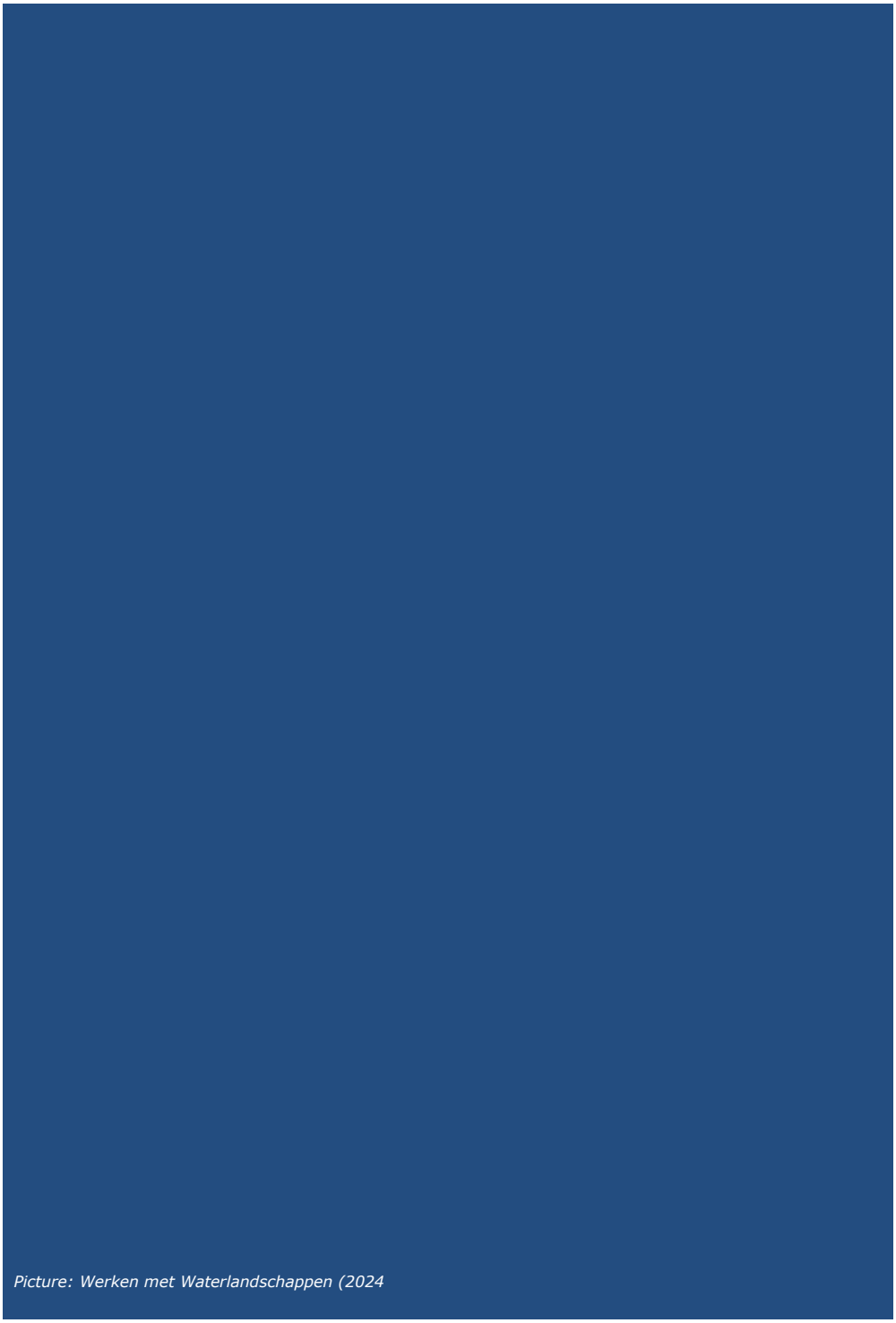
Sinds 2000 zijn uiteenlopende strategieën toegepast om onzekerheden op het grensvlak van klimaatadaptatieonderzoek en waterbeheer te adresseren. Voorbeelden van gezamenlijk toegepaste strategieën zijn joint fact-finding, het beperken van het aantal te onderzoeken klimaatadaptatieopties en het uitvoeren van experimenteel onderzoek wanneer ontische onzekerheden een grote rol spelen. Daarnaast beschikken waterbeheerders en beleidsmakers over procedurele instrumenten, zoals milieueffectrapportages en vastgestelde besluitvormingstermijnen. Vooral op nationaal en regionaal niveau werd veel gebruik gemaakt van epistemische benaderingen. Op regionale en lokale schaal blijkt dit vaak complexer vanwege de grotere diversiteit aan betrokken stakeholders. De bruikbaarheid van klimaatadaptatieonderzoek kan verder worden vergroot wanneer wordt erkend dat consensusvorming over kennis binnen besluitvormingsprocessen deels een sociaal en bestuurlijk proces is. Tegelijkertijd blijft het essentieel om onderscheid te maken tussen onderhandelbare belangen en niet-onderhandelbare wetenschappelijke bevindingen.

De geneste longitudinale aanpak van deze casestudie maakt zichtbaar hoe klimaatadaptatieonderzoek voortdurend moet inspelen op uiteenlopende kennisbehoeften op verschillende schaalniveaus en binnen verschillende sectoren. Binnen het Deltaprogramma is geprobeerd nationale doelstellingen op het gebied van waterveiligheid, zoetwatervoorziening en ruimtelijke adaptatie te vertalen naar regionale deelprogramma's, zoals de Zuidwestelijke Delta. Deze koppeling blijkt waardevol voor strategisch waterbeheer, maar biedt vaak onvoldoende context voor lokale stakeholders. Hoewel

klimaatadaptatieonderzoek en waterbeheer de afgelopen decennia dichter naar elkaar zijn toegegroeid, ontbreekt nog altijd een samenhangende strategie voor structurele transdisciplinaire samenwerking. De aanbevelingen uit dit proefschrift benadrukken daarom het belang van vroegtijdige betrokkenheid van lokale stakeholders en bredere toepassing van joint fact-finding. Daarnaast kan het waterbeheer zijn klimaatadaptieve capaciteit vergroten door nieuwe klimaatdiensten te ontwikkelen en experimenteel onderzoek, monitoring en formele procedures, zoals milieueffectrapportages, beter op elkaar af te stemmen. Tot slot laat deze studie zien dat een geneste longitudinale casestudie geschikt is om interacties tussen verschillende schaalniveaus inzichtelijk te maken. De bruikbaarheid van klimaatadaptatieonderzoek kan verder vergroot worden door hieraan extra aandacht te geven. Dit kan ook bijdragen aan het ontwerp en besluitvorming over transformatieve klimaatadaptatie strategieën in het waterbeheer.

Biography





Picture: Werken met Waterlandschappen (2024

BIOGRAPHY



Jeroen Veraart was born in 1975 in Wouw and grew up in Fijnaart. He obtained his VWO diploma at the Norbertus Lyseum in Roosendaal (1994). He holds an MSc degree in Environmental Sciences from Wageningen University (2000) with specialisations in Aquatic Ecology, Water Quality Management and Environmental Studies. He started his professional career at the environmental system analysis group in 2000 (Wageningen University) and moved in 2002 to Alterra (currently known as Wageningen Environmental Research) and started as scientific support officer of the Climate Change and Biosphere Research network (CCB). Thanks to the gained experiences within the research programme 'Climate changes Spatial Planning' (2004-2012) and its successor 'Knowledge for Climate' (2008-2014) he became specialized in the field of climate research and water management. Currently he holds a position as senior researcher at Wageningen Environmental Research.

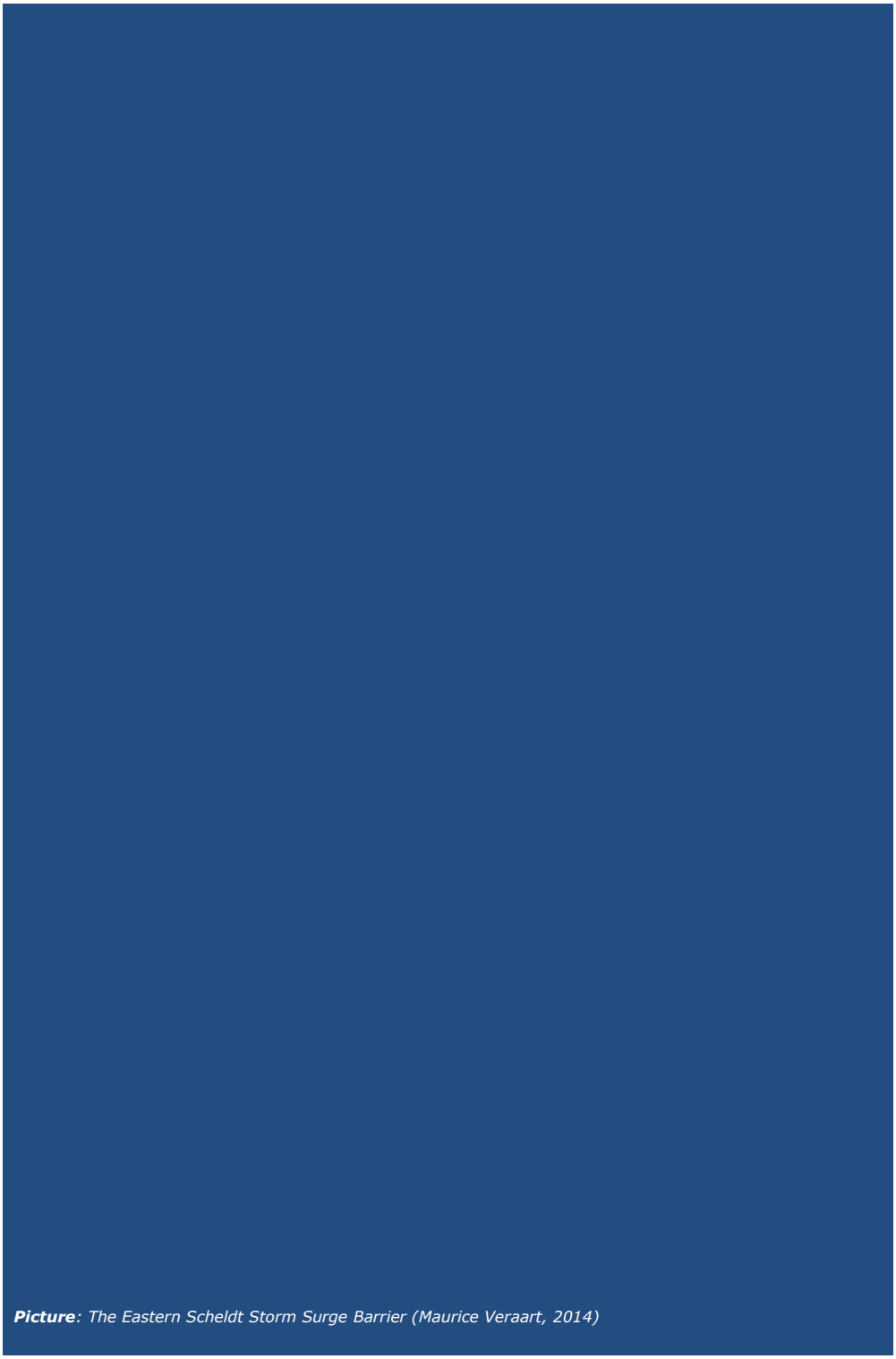
His projects are often multi- to transdisciplinary in character and deal with topics such as climate adaptation, wetland restoration, biodiversity challenges in rivers, lakes, and coastal areas (including the North Sea). He combines knowledge and methods from different research fields to achieve new results. He has done research in the Europe and the Netherlands, commissioned by the Dutch Government, European Commission and Dutch regional institutions such as Nature Conservation Authorities, Water authorities, Provinces, and private sector. In addition, Jeroen has been knowledge broker for various national research and policy programmes such the LNV applied research programme 'Ecology Dutch Delta and rivers (since 2016), the national Delta programme (2009-2014) and strategic WUR-research about marine resources and climate policies at the North Sea. Since 2019 he assists the ministry of LNV and the European Environmental Agency (2022) with regard LULUCF Climate Policies, about wetlands and coastal areas. He has a MSc in Environmental Sciences (2000, Wageningen University) and currently conducts doctoral research about the role of climate research in Dutch water management (historical analysis).

Key projects

PPS - Werken met Waterlandschappen (2021-2024) (www.waterlandschappen.nl)
PPS - Klimaatbuffer PWN – Zuiverend Landschap (2023-2024)
PPS - Greenhouse Gas Emissions from Wetlands in Groningen
BO – Ecology Water and Climate Change in rivers-lakes and estuaries (LNV)
KIMA – Marker Wadden (2016-2021)
DCC - Delta Climate Centre (since 2025)

Authors' key publications





***Picture**: The Eastern Scheldt Storm Surge Barrier (Maurice Veraart, 2014)*

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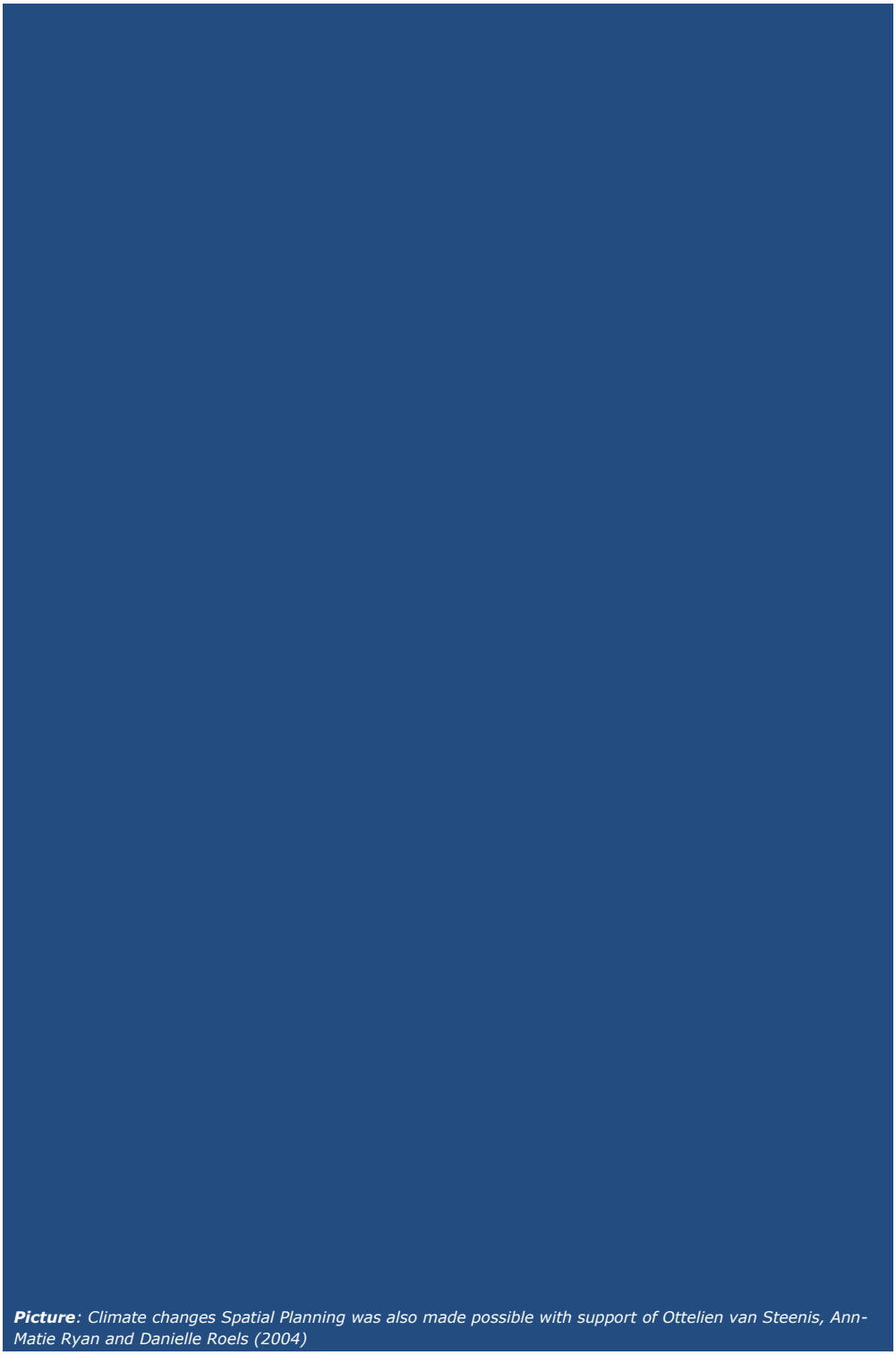
Acknowledgements





***Picture**: Climate changes Spatial Planning was also made possible with support of Ottelien van Steenis, Ann-Matie Ryan and Danielle Roels (2004)*

DANKWOORD

Het samenbrengen van kennis uit klimaatadaptatie-onderzoek en waterbeheer was (en is) een voortdurend en complex leerexperiment voor mijzelf, maar ook voor de onderzoekers, professionals en beleidsmakers om mij heen. Mijn professionele loopbaan, die in 2000 begon, op het snijvlak van klimaatonderzoek en waterbeheer, bood mij de gelegenheid om te reflecteren op de uiteenlopende manieren die zijn ingezet hier mee om te gaan, wat heeft geresulteerd in dit proefschrift.

Vele collega's en ikzelf hebben vaker gedacht dat dit proefschrift nooit af zou komen, maar het is na ongeveer twee decades dan toch gelukt. Over de exacte loopduur van mijn promotietraject bestaat bij menigeen nog wel onduidelijkheid. Dit dankwoord geeft verschillende hints voor de lezer om de exacte loopduur te kunnen bepalen.

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Als je de co-auteurs van Hoofdstuk 3 tot en met 8 naslaat zijn er, naast mijn officiële begeleiders, nog zeventien andere vakcollega's die een bijdrage hebben geleverd die ik wil bedanken. Uit deze lijst van co-auteurs wil ik als eerste in het bijzonder Judith Klostermann bedanken. Met Judith heb ik tussen 2010 en 2014 veel samengewerkt om inzichten te verzamelen over het adresseren van onzekerheden over de zoetwatervoorziening in de

Zuidwestelijke Delta en waar hoofdstuk 5 het resultaat van is. We waren voorts beiden wetenschappelijk projectbegeleiders voor het onderzoeksprogramma Klimaat voor Ruimte. Ik was dat vanaf het begin en Judith kwam erbij rond 2008. Veel heb ik van Judith geleerd over kwalitatieve onderzoeksmethoden. Tot slot heeft Judith in de eindfase een *'gentle'* review gedaan over een concept van deze dissertatie. Het woord 'gentle' staat niet voor niets tussen aanhalingstekens. Een extra woord van dank ben ik ook verschuldigd aan co-auteurs Ekko van Ierland en Dolf de Groot. Beiden zijn inmiddels met pensioen. Zij waren tussen 2000 en 2001 de projectleiders van het NOP-Impact onderzoek (hoofdstuk 3) waar ik aan bijdroeg. NOP-Impact was het eerste klimaatadaptatie-onderzoek in Nederland dat heeft geprobeerd inzichten over klimaateffecten uit verschillende sectoren te combineren. Dat onderzoek voerden we uit in een consortium bestaande uit Wageningen Universiteit, Alterra (heden: Wageningen Environmental Research) en het ICIS-Maastricht. Ik heb veel geleerd van de ICIS-aanpak van Pim Martens en Maud Huynen. Met de kennis van nu zouden we een cross-sectorale workshop over klimaatadaptatie in 2025 overigens heel anders aanpakken, maar dit ter zijde. Verder wil ik natuurlijk ook de overige co-auteurs van mijn papers in dit proefschrift bedanken in willekeurige volgorde waren dat: Saskia Werners (H3), Jan Verhagen (H3), Peter Kuikman (H3), Marloes Bakker (H4), Rianne van Duinen (H6), Jan Vreke (H6), Cora van Oosten (H7), Vincent Linderhof (H7), Confidence Duku (H7), Wilfred Appelman (H7), Annemarie Groot (H7), Marjolein Sterk (H7), Kim van Nieuwaal (H8) en Peter Driessen (H8).

De basis voor mijn PhD-onderzoek startte dus in de nadagen van het NOP-onderzoeksprogramma, zonder dat ik dit zelf toen al wist. Op een dag in 2001 kwam ik op het kantoor van Alterra terecht voor een soort van sollicitatiegesprek met Pavel Kabat en Reinder Feddes voor de functie van programmasecretaris van het Climate Change & Biosphere centre (CCB). Ik kreeg daarna een tijdelijk contract van negen maanden dat liep via de Wageningse leerstoelgroep Waterhuishouding, terwijl mijn werkplek bij Alterra was. Ik kreeg drie taken mee van Pavel en Reinder. Ik moest het CCB-netwerk ondersteunen bij het indienen van financieringsvoorstel voor een onderzoeksprogramma met de latere titel Klimaat voor Ruimte (KvR) samen met andere kennisinstellingen. Het CCB was een samenwerkingsverband van een combinatie van leerstoelgroepen bij Wageningen Universiteit en DLO-instituten die zich bezighielden met de biosferische en sociaaleconomische aspecten van klimaatverandering en landgebruik. Pavel was ook bezig om met het IHE-Delft een tweejarig internationaal traject op te zetten om de dialoog aan te gaan over waterbeheer en klimaatverandering (Dialogue on Water & Climate, DWC), een uitvloeisel van het Wereldwaterforum dat in 2000 werd gehouden in Den Haag. Daar lag een tweede taak voor mij binnen het tijdelijke contract. Tot slot werd ik gevraagd om, samen met het CCB-bestuur, een businessplan te schrijven om het CCB om te vormen tot een Wagenings Expertise Centrum Klimaat. De eerste twee taken lukten ons (KvR, DWC), maar

het businessplan voor een Wageningens Klimaat Centrum werd nooit afgerond. In 2002 maakte ik de overstap van Wageningen Universiteit naar Alterra. Zo raakte ik ook intensief betrokken bij de uitvoering van het onderzoeksprogramma Klimaat voor Ruimte. Tegelijkertijd beleefde ik met o.a. Henk van Schaik, Molly Hellmuth, Bill Cosgrove, Rick Connor, en Roland Schulze spannende avonturen in Bonn (Freshwater Conference), Kyoto (derde Wereld Water Forum) en Bangladesh in het kader van DWC, waar ik met plezier op terugkijk. In deze beginperiode (2002-2012) werkte ik vooral veel samen met de Vrije Universiteit Amsterdam (o.a. Kees Dorland, Florrie de Pater, Onno Piek, Jeroen Aerts, Ralf Lasage, Pier Vellinga en Berend van Zeggeren) en het KNMI (o.a. Bart van den Hurk, Koos Verbeek, Rob van Dorland, Fons Baede en Gerbrand Komen). Bij Alterra waren Cor Jacobs, Bart Kruijt, Wilma Jans, Kaj van de Sandt, Herbert Ter Maat, Ronald Hutjes en Ottelien van Steenis mijn vaste KvR-maatjes.

Eddy Moors was tussen 2002 en 2017 mijn leidinggevende. In deze periode van 15 jaar heb ik zes keer aan Eddy beloofd *volgend jaar* het proefschrift af te ronden in R&O gesprekken. Ik ben hem dankbaar voor zijn geduld. In de gangen van het Lumen-gebouw kwam ik ook vaak Fulco Ludwig tegen die standaard vroeg of mijn proefschrift al niet af was. En ik moet toegeven, Eddy was uiteindelijk toch 7 jaar sneller klaar met zijn promotie dan ik, als ik als ik uitga van de startdatum 2000. Bezien vanuit mijn formele WIMEK-inschrijving als PhD-onderzoeker (2013) ben ik echter weer sneller dan Eddy. Zelfs het vaststellen van een startdatum van een promotietraject vraagt dus om het adresseren van onzekerheden. Voorts was Eddy, samen met Hester Biemans, Saskia Werners en Herbert Ter Maat de bedenker van de zogeheten Schrijfweek. Delen van hoofdstuk 3,5 en 6 zijn geschreven tijdens deze schrijfweken in Frankrijk, België en Zeeland. De jaarlijkse belofte aan mijn leidinggevende dat ik volgend jaar klaar zou zijn met het proefschrift heb ik daarna nog een paar keer herhaald bij Derk Rademaker en pas mijn belofte vervuld toen Annemarie Groot mijn leidinggevende werd.

In de periode 2010-2014 was er toch echt sprake van versnelling en zeer productieve periode in mijn PhD-onderzoek. Dat werd vooral mogelijk gemaakt door het onderzoeksprogramma Kennis voor Klimaat (KvK) en door het nationale Deltaprogramma. Het waren jaren van een intensief kennis-cocreatie proces waarbij de zoetwatervoorziening en het maken van en een integrale klimaatadaptatie voorkeurstrategie voor het waterbeheer in de Zuidwestelijke Delta centraal stond. Binnen KvK heb ik veel geleerd over zoetwatervoorziening in Laag-Nederland van mijn collega's bij Deltares, KWR-Water, Provincie Zeeland, STOWA en ZLTO zoals Ad Jeuken, Gualbert Oude Essink, Eelco van Beek, Esther van Baaren, Pieter Pauw, Koen Zuurbier, Rob Ruijtenberg, Vincent Klap, Nico Landsman en Carla Michielsen. Tussen 2010 en 2014 maakte ik deel uit van het team met

de naam 'Lange Termijn', als onderdeel van het Programmabureau Zuidwestelijke Delta. Dit team werkte aan de voorkeurstrategie voor de Zuidwestelijke Delta en stond onder leiding van Joost Schrijnen (Directeur Gebiedsprogramma Zuidwestelijke Delta) en Martie van Essen (LNV). In een periode van vier jaar kwamen we om de 2-3 weken bij elkaar bij het kantoor van Rijkswaterstaat in Rotterdam. Op cruciale momenten in dit proces organiseerden Joost en Martie ontwerpateliers met allerlei stakeholders van de Zuidwestelijke Delta in het oude gemeentehuis van Goes. In deze periode heb ik veel geleerd over het combineren van ontwerpend onderzoek met hydrologische modellen en gebiedskennis. Hoofdstuk 5 en 6 omschrijven het eindresultaat.

Na 2014 ging ik veel meer werken buiten het Deltaprogramma en was ik vooral bezig met de natuuropgaven en ambities in de Rijkswateren via het beleidsondersteunend ondersteunend onderzoek voor het ministerie van LNV. Natuurlijk kwamen bij dit onderzoek ook effecten van klimaatverandering aan bod, maar het onderwerp klimaatadaptatie kwam minder centraal te staan in mijn dagelijks leven als onderzoeker. Dat vertraagde ook de voortgang in mijn PhD-onderzoek. Ik bleef echter wel lid van het kennisnetwerk van het Deltaprogramma, geleid door Jos van Alphen en Pieter Bloemen, en zo bleef ik op de hoogte van de laatste ontwikkelingen.

In 2015 organiseerde ik mijn eigen schrijfweek en ging ik, samen met mijn partner Rianke, een paar dagen op bezoek bij Pavel en Anneke in Oostenrijk. Hier schreef ik de eerste conclusies van deze dissertatie en werkte ik het idee van een longitudinale casestudie analyse verder uit. Terwijl ik en Pavel met de dissertatie aan de slag waren, gingen Rianke en Anneke naar Wenen om de beroemde werken van Gustav Klimmt te bekijken. Er kwam nog een extra gast naar het IIASA toe, Wim van Vierssen. Zo kon het gebeuren dat Pavel moest overwerken, terwijl er twee gasten waren. Anneke werd in allerhaast door Pavel gevraagd om mij, Rianke en Wim die avond op een etentje te trakteren.

Na 2018 kwam het onderwerp klimaatadaptatie weer meer terug in mijn dagelijkse werk. Zo raakte ik betrokken bij de evaluatie van gerealiseerde natuurlijke klimaatbuffers op verschillende plaatsen in Nederland. Dat leverde weer inspiratie op om dit proefschrift toch weer op te pikken. Het klimaatbufferproject dat Natuurmonumenten heeft uitgevoerd in de Onlanden, wil ik in het bijzonder noemen. Met succes is hier waterberging, natuurontwikkeling en reductie van broeikasgasemissies uit natte natuur gerealiseerd. Paul Vertegaal, noemde de Onlanden als voorbeeld van *'Klimaat in het Kwadraat'*. In dit gebied kreeg Wageningen Universiteit, onder leiding van Bart Kruijt, de kans een monitoringsprogramma op te starten naar het effect van vernatting op broeikasgasemissies uit moerasveen. Het combineren van praktijk en onderzoek kan dus wel. En datzelfde zag ik ook gebeuren in onze samenwerking met drinkwaterbedrijf PWN. Met PWN maakten we

een schets voor een Zuiverend Landschap die gecombineerd kan worden met extra buffercapaciteit voor drinkwater in het licht van klimaatverandering.

Er is ook een leven naast dit proefschrift geweest. Gelukkig maar. Zo kon ik mijn energie kwijt op het voetbalveld bij GVC in Wageningen. Ik deed bij GVC ook bestuurservaring op (2005-2020). Naast het spelen van wedstrijden hield ik me bezig met toernooitjes organiseren en scheidsrechters regelen. Hoogtepunten uit de voetbaltijd waren o.a. het tweemaal winnen van de Bertus van den Heuvel Cup bij WAVV onder leiding van Captain Kalis, een legendarische reis naar Schotland, een drietal artikelen over de historie van GVC in de Voetbal International en twee wedstrijden tegen profclub Sparta uit Rotterdam in 2003 en 2011. De wedstrijden tegen Sparta werden in 2003 georganiseerd in het kader van het honderdjarig jubileum door o.a. René Kuiper, Arjan Wals en Raoul Beunen en in 2011 door o.a. Kornelis Jorna en Dennis Snoek. In 2011 mocht ik ook zelf meespelen tegen Sparta en vocht ik een sportief duel uit met Wout Holverda: en echt, zonder ellenboogstoot. Ook de derde helft met GVC- iconen zoals Sven Da Silva, , Wiebe Aans, Geert Willems, Lauran de Schutter, Pim Beerling, Rene Kuiper, Ivo Drissen, Imre Overeem, Tim de Groot, Paul Bovenmars, Joost de Jong, Reurt Boelema en vele anderen was een hoogtepunt. Jongens bedankt voor de vele leuke momenten op de Bongerd.

Een andere hobby betrof vrijwilligerswerk op Mallorca dat ik tussen 2000 en 2012 deed in het natuurgebied s'Albufera. Bijna ieder jaar ging ik in het voorjaar daar naartoe, het vrijwilligerswerk werd gecoördineerd door Nick Riddiford en Macu Férriz. Mijn taak was om waterplanten te karteren en alle deelnemers hierover te vertellen. Tegelijkertijd hielp ik andere veldwerkers met bijvoorbeeld vogels of nachtvlinders (motten) tellen. In de gesprekken met hen heb ik toch ook veel ideeën opgedaan voor dit proefschrift. En het was ook gewoon gezellig en leuk. Dankjewel Nick en Macu!

Mijn grootste dank gaat echter uit naar Rianke, mijn allerliefste, steun en toeverlaat. Zij heeft veel geduld gehad, wanneer ik weer een weekeinde aan het manuscript moest werken. Zeker in het laatste jaar gebeurde dit nogal eens een keer. Jouw onvoorwaardelijke liefde is het mooiste wat er is. Ik ben ook supertrots dat jij de voorpagina hebt willen illustreren met Fraktel-Art. Een heel mooi geschenk. Ik wil voor altijd bij jou zijn.

Jeroen Veraart, Heelsum, 29 december 2025

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