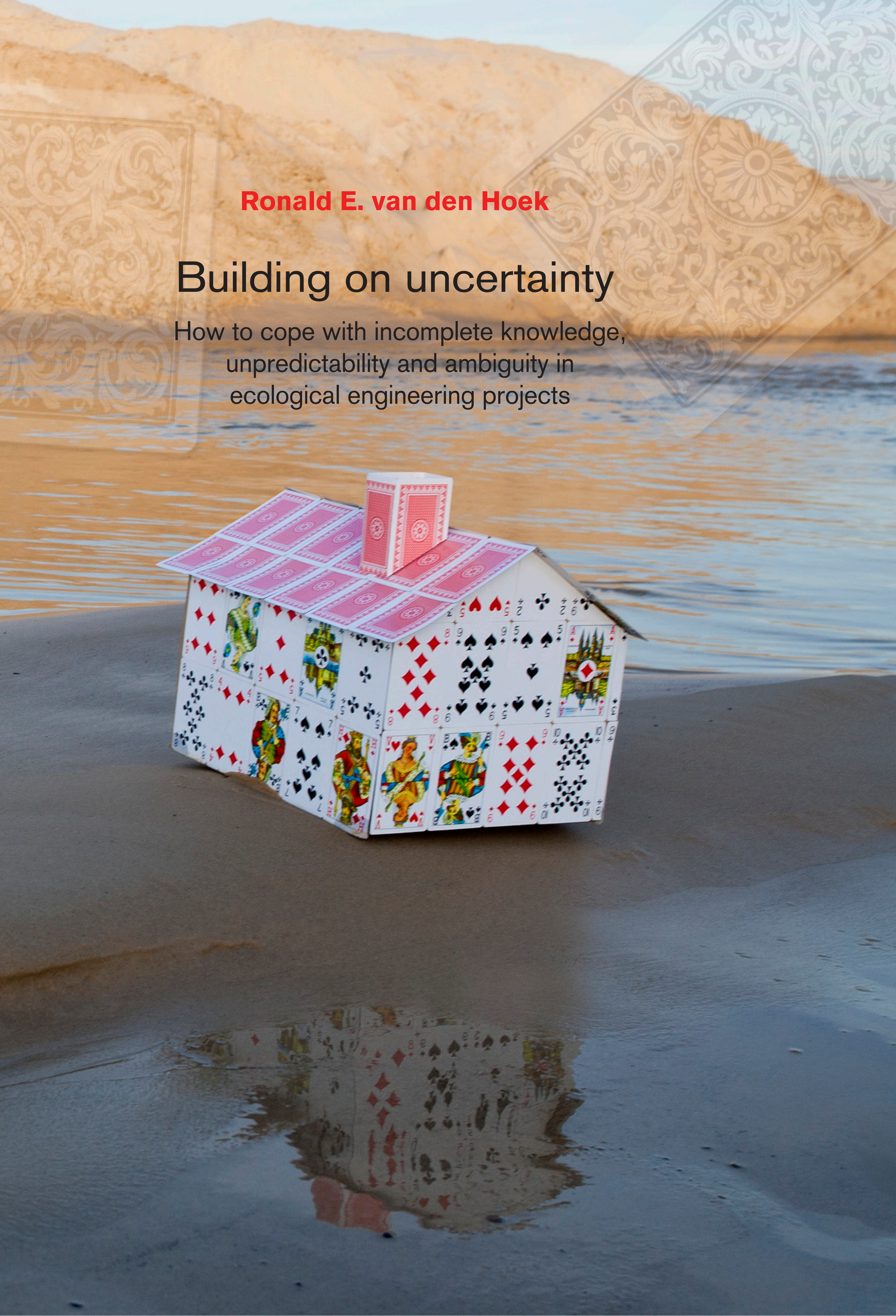
Ronald E. van den Hoek

Building on uncertainty

How to cope with incomplete knowledge, unpredictability and ambiguity in ecological engineering projects



BUILDING ON UNCERTAINTY

HOW TO COPE WITH INCOMPLETE KNOWLEDGE, UNPREDICTABILITY AND AMBIGUITY IN ECOLOGICAL ENGINEERING PROJECTS

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PROEFSCHRIFT

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“Vroeger was ik een twijfelaar, ik ben daar nu niet meer zo zeker van.”

(Herman Finkers)

CONTENTS

SUMMARY

Traditionally, coasts and riverbanks around the world are defended against flooding by using rigid flood infrastructure such as dikes and storm surge barriers. Rigid flood infrastructure is designed to withstand water levels up to a predetermined maximum. Human control over the environment is maximized and the effectiveness of the flood defences is secured as much as possible. However, the fixed dimensions of rigid flood infrastructure can be a major drawback, as these cannot be easily changed. This drawback becomes increasingly important nowadays: because the sea level is rising due to climatic change, the existing flood infrastructure is very likely to fall short in the future. Moreover, the closure of estuaries with storm surge barriers and dams in former years had devastating impacts on the local ecosystems. Thus, it is important to find new flexible and sustainable ways to safeguard human society from flooding.

Building with Nature (BwN) is an innovative flood defence approach, which seems capable of providing both the desired flexibility and sustainability. It is an ecological engineering approach which actively uses natural materials and dynamic processes (e.g., sediment, wind and currents) in the design of flood defence projects for achieving both human and natural goals (e.g., providing flood safety and creating new recreational space while providing opportunities for ecosystem development). The BwN approach uses flexible natural materials and fosters natural systems. Thus, flood defences using BwN principles can be rather easily adapted to changing conditions and the ecosystem is treated in a sustainable fashion. However, our understanding of natural systems is incomplete and natural dynamic processes are inherently unpredictable. As a result, the exact outcomes and consequences of a BwN project are highly uncertain on beforehand. This uncertainty may hamper decision-makers in their ability to decide and may even lead to hard discussions between project teams and stakeholders about the acceptability of a BwN initiative under consideration. Therefore, it is important to study the issue of uncertainty in the context of ecological engineering flood defence projects, which is done in this thesis. The introductory chapter provides the background and focus of the research, the objective and research questions, and the outline of the thesis.

Chapter 2 discusses which uncertainties are most important during the development process of a flood defence project based on BwN design principles. By performing interviews, by studying project documents and by attending meetings, the many uncertainties present during this flood defence project's development process are identified and thereafter classified using an existing uncertainty classification method. For each uncertainty, its importance is determined by analysing which specific uncertainties hampered or could potentially hamper the project development process. The results from

this analysis show that ambiguity about the social implications of a BwN project – for instance, about the impact on swimmer safety – is the most important kind of uncertainty. Ambiguity about social implications is potentially able to hamper BwN project development and is therefore far more important than the incomplete knowledge about the behaviour of the natural system and the inherent unpredictability of natural dynamics. The specific project studied was not hampered though, because it was a pilot project. Moreover, the governmental parties involved formed a powerful social coalition that was strongly committed to achieve a successful implementation of the project.

In Chapter 3, the origin of ambiguity in BwN projects is studied in more detail. Ambiguity refers to a situation in which there are too many possible interpretations of a problem and its solution, leading to confusion among the actors involved about what the problem is and which solution should be pursued. Thus, the inclusion of multiple actors in a development process, as proposed in BwN projects, can lead to a situation of ambiguity. Different interpretations emerge from the differences in interests, values, beliefs, backgrounds, previous experiences and the societal positions of the actors included (so-called actor attributes). Chapter 3 identifies which actor attributes are most important and can lead to ambiguity in BwN projects. For several important ambiguities that were identified in two BwN case study projects, the attributes underlying the individual frames of actors are identified. From this analysis, it is concluded that ambiguity seems to originate mostly from conflicting beliefs regarding the project and that the power of the actors involved mainly determines how an ambiguity is coped with in the project. Differences between actors' interests do not seem to cause ambiguity, as the interests are not conflicting.

Chapter 4 discusses the relations between different uncertainties by studying two BwN projects. An uncertainty analysis often starts with uncertainty classification (as is done in Chapter 2). This classification is usually performed by using an uncertainty matrix that categorizes the individual uncertainties into different kinds. Thus, all uncertainties are represented as if they are strictly separated and independent. However, in this research, it is recognized that fundamentally different uncertainties are often directly interrelated, which is visualized in so-called cascades of interrelated uncertainties. It is observed that the incomplete knowledge about the natural system and the unpredictability of natural processes are gradually re-interpreted from different societal perspectives, resulting in ambiguity in the social system. Using cascades for representing the interrelated uncertainties in a project elucidates new possibilities for coping with uncertainty, as each uncertainty in the cascade represents a potential node of intervention or facilitation.

In Chapter 5, it is assessed which new possibilities the cascades of interrelated uncertainties open for uncertainty management. While many people might perceive this interrelatedness as an increase in complexity, it is shown in Chapter 5 that the relations between different uncertainties can be actively used to effectively cope with uncertainty. As the uncertainties in the cascades are directly related, this implies that coping with one uncertainty in the cascade will influence those with which it is related. As each uncertainty in the cascade is a potential node of intervention or facilitation, the cascade informs project teams about the many possibilities they have to cope with uncertainty in their project. If a particular coping strategy falls short or system conditions change, the cascade points at the multiple alternative coping strategies that can replace the non-effective strategy. Moreover, the cascades can assist those responsible to identify ambiguities that could manifest themselves during project development. Consequently, a project team is informed about which actors should be involved in an early stage of the development process in order to prevent these potential ambiguities from occurring.

Chapter 6 presents the main conclusions of this thesis by summarizing the answers to the research questions. Overall, the research presented in this thesis constitutes an important contribution to the well-studied topics of uncertainty and uncertainty management, since it explicitly integrates ambiguity with the more common uncertainty kinds incomplete knowledge and unpredictability. To the BwN engineering community, the research shows that ambiguity is the kind of uncertainty that could hamper the development process of a BwN flood defence project, while their initial hypothesis was that incomplete knowledge and unpredictability were likely to be the hampering factor. Thus, the results point out that – in order to come to a successful implementation of a project based on BwN principles – it is more important to cope with the differences between different actors than to respond to uncertainty due to the lack of knowledge about the natural system. Furthermore, a structured analysis regarding the actor attributes underlying ambiguity has not been performed before. Moreover, this thesis explicitly addresses the interrelatedness between ambiguity and the more common uncertainty kinds incomplete knowledge and unpredictability, which is not done by other uncertainty conceptualizations in the literature. This interrelatedness between uncertainties can be of major value for the BwN engineering community, as it is demonstrated in this thesis that these relations can be actively used to cope with uncertainty.

SAMENVATTING

Van oudsher worden kusten en rivieroevers over de hele wereld verdedigd tegen overstromingen door gebruik te maken van harde waterkeringen, zoals dijken en stormvloedkeringen. Harde waterkeringen zijn ontworpen om waterhoogtes te weerstaan tot een vooraf bepaald maximum. De menselijke controle over de natuurlijke omgeving wordt op deze manier gemaximaliseerd en de effectiviteit van de waterkeringen wordt zoveel mogelijk gewaarborgd. De vaste afmetingen van harde waterkeringen kunnen echter ook een groot nadeel zijn, aangezien deze afmetingen niet makkelijk kunnen worden veranderd. Dit nadeel wordt vandaag de dag steeds belangrijker: omdat de zeespiegel stijgt door klimaatverandering is het zeer waarschijnlijk dat de bestaande waterkeringen tekort zullen schieten in de toekomst. Bovendien heeft de vroegere afsluiting van estuaria met stormvloedkeringen en dammen een verwoestende uitwerking gehad op de lokale ecosystemen. Het is dus belangrijk om nieuwe flexibele en duurzame manieren te vinden om de samenleving te beschermen tegen overstromingen.

Building with Nature (NL: Bouwen met de Natuur; afgekort als BwN) is een innovatieve aanpak voor hoogwaterbescherming, welke in staat lijkt te zijn om zowel de gewenste flexibiliteit als duurzaamheid te leveren. Het is een ecologische *engineering* benadering welke actief gebruik maakt van natuurlijke materialen en dynamische processen (bijvoorbeeld sediment, wind en golven) in het ontwerp van hoogwaterbeschermingsprojecten om zowel menselijke als natuurlijke doelen te verwezenlijken (bijvoorbeeld het verschaffen van hoogwaterveiligheid en het creëren van nieuwe recreatieve ruimte terwijl er simultaan ook mogelijkheden zijn voor natuurontwikkeling). De BwN aanpak gebruikt flexibele natuurlijke materialen en koestert het natuurlijke systeem. Waterkeringen die gebaseerd zijn op BwN principes kunnen dus relatief eenvoudig worden aangepast wanneer dat nodig is, terwijl het ecosysteem op een duurzame manier wordt behandeld. Echter, ons begrip van het natuurlijke systeem is onvolledig en natuurlijke processen zijn intrinsiek onvoorspelbaar. Als gevolg hiervan zijn de exacte resultaten en consequenties van een BwN project van tevoren zeer onzeker. Deze onzekerheid kan besluitvormers belemmeren om beslissingen te nemen en kan zelfs leiden tot moeizame discussies tussen projectteams en belanghebbenden over de aanvaardbaarheid van het BwN project. Daarom is het belangrijk om het vraagstuk van onzekerheid in ecologische hoogwaterbeschermingsprojecten uitvoerig te bestuderen, hetgeen wordt gedaan in deze dissertatie. Het inleidende hoofdstuk geeft de achtergrond en focus van het onderzoek, de doelstelling en onderzoeksvragen, en de opzet van de dissertatie.

Hoofdstuk 2 bespreekt welke onzekerheden het belangrijkst zijn gedurende het ontwikkelproces van een hoogwaterbeschermingsproject dat gebaseerd is op BwN ontwerpprincipes. Door interviews te houden, projectdocumenten te bestuderen en bijeenkomsten bij te wonen zijn de vele onzekerheden die aanwezig waren tijdens het ontwikkelproces van dit hoogwaterbeschermingsproject in kaart gebracht en daarna geclassificeerd met een bestaande methode voor onzekerheidsclassificatie. De belangrijkheid van iedere onzekerheid is bepaald door te analyseren welke specifieke onzekerheden het ontwikkelproces van het project hebben belemmerd of hadden kunnen belemmeren. De resultaten van deze analyse laten zien dat ambiguïteit over de maatschappelijke effecten van een BwN project – zoals de impact op zwemveiligheid – de belangrijkste soort onzekerheid is. Ambiguïteit over maatschappelijke effecten is potentieel in staat om de ontwikkeling van een BwN project te belemmeren en is daarom veel belangrijker dan de onvolledige kennis over het gedrag van het natuurlijke systeem en de intrinsieke onvoorspelbaarheid van de natuurlijke processen. Het specifieke project dat is bestudeerd werd echter niet belemmerd, omdat het een pilotproject was. Bovendien vormden de betrokken overheidspartijen een machtige sociale coalitie, welke sterk gecommitteerd was aan het realiseren van een succesvolle implementatie van het project.

In hoofdstuk 3 wordt de herkomst van ambiguïteit in BwN projecten in meer detail bestudeerd. De term ‘ambiguïteit’ verwijst naar een situatie waarin er teveel mogelijke interpretaties zijn van een probleem en zijn oplossing, hetgeen leidt tot verwarring onder de betrokken actoren over wat het probleem eigenlijk is en welke oplossingsrichting moet worden nagestreefd. Het betrekken van meerdere actoren in een ontwikkelproces, zoals wordt voorgesteld in BwN projecten, kan dus leiden tot een situatie van ambiguïteit. Verschillende interpretaties kunnen voortkomen uit de verschillende belangen, waarden, overtuigingen, achtergronden, vroegere ervaringen en de maatschappelijke posities van de betrokken actoren (zogenaamde actoreigenschappen). Hoofdstuk 3 identificeert welke actoreigenschappen het belangrijkst zijn en kunnen leiden tot ambiguïteit in BwN projecten. Voor een aantal belangrijke ambiguïteiten in twee BwN projecten zijn de onderliggende actoreigenschappen behorende bij de individuele *frames* van actoren geïdentificeerd. Uit deze analyse is geconcludeerd dat ambiguïteit lijkt voort te komen uit conflicterende overtuigingen. De macht van de betrokken actoren bepaalt voornamelijk hoe met een ambiguïteit wordt omgegaan in het project. Verschillende belangen lijken geen ambiguïteit te veroorzaken, omdat deze belangen ondanks het feit dat ze verschillen niet conflicterend zijn.

Hoofdstuk 4 bespreekt de relaties tussen verschillende onzekerheden door twee BwN projecten te bestuderen. Een onzekerheidsanalyse begint vaak met een onzekerheidsclassificatie (zoals wordt gedaan in hoofdstuk 2). Deze classificatie wordt doorgaans uitgevoerd met een onzekerheidsmatrix welke de individuele onzekerheden categoriseert in verschillende soorten. In een dergelijke matrix worden alle onzekerheden weergegeven alsof zij strikt gescheiden en onafhankelijk zijn. Echter, dit onderzoek laat zien dat onzekerheden die fundamenteel verschillen vaak direct aan elkaar gerelateerd zijn, hetgeen wordt gevisualiseerd in zogenaamde cascades van gerelateerde onzekerheden. Uit de observaties in het onderzoek blijkt dat onvolledige kennis van het natuurlijke systeem en de onvoorspelbaarheid van natuurlijke processen gaandeweg worden geherinterpreteerd vanuit verschillende maatschappelijke perspectieven, resulterend in ambiguïteit over de maatschappelijke implicaties van het BwN project. Het gebruik van cascades voor het weergeven van aan elkaar gerelateerde onzekerheden werpt licht op nieuwe mogelijkheden om met onzekerheid om te gaan, omdat iedere onzekerheid in de cascade een potentieel aanknopingspunt is voor interventies of verbeteringen.

In hoofdstuk 5 wordt besproken welke nieuwe mogelijkheden de cascades van gerelateerde onzekerheden bieden voor onzekerheidsmanagement. Hoewel veel mensen de relaties tussen verschillende onzekerheden kunnen opvatten als een toename in complexiteit, laat hoofdstuk 5 zien dat deze relaties actief kunnen worden gebruikt om effectief met onzekerheid om te gaan. Dat onzekerheden in de cascades direct aan elkaar gerelateerd zijn, suggereert dat het omgaan met de ene onzekerheid in de cascade de andere onzekerheden die hiermee gerelateerd zijn beïnvloedt. Omdat iedere onzekerheid in de cascade een potentieel aanknopingspunt is voor interventies of verbeteringen, verschaft de cascade informatie aan projectteams over de vele mogelijkheden die zij hebben om met onzekerheid om te gaan in hun project. Wanneer een bepaalde aanpak om met onzekerheid om te gaan tekortschiet of de omstandigheden veranderen, dan wijst de cascade naar de vele alternatieve strategieën die de niet-effectieve aanpak kunnen vervangen. Bovendien kunnen de cascades helpen om ambiguïteiten te identificeren die zich op den duur zouden kunnen manifesteren tijdens de projectontwikkeling. Aldus wordt een projectteam geïnformeerd over welke actoren in een vroegtijdig stadium betrokken zouden moeten worden tijdens het ontwikkelproces om de potentiele ambiguïteit te voorkomen.

Hoofdstuk 6 presenteert de belangrijkste conclusies van deze dissertatie door de antwoorden op de onderzoeksvragen samen te vatten. Deze dissertatie levert een belangrijke bijdrage aan de uitvoerig bestudeerde onderwerpen onzekerheid en onzekerheidsmanagement, aangezien ambiguïteit expliciet wordt gekoppeld aan de meer gebruikelijke onzekerheidssoorten onvolledige kennis en onvoorspelbaarheid. Het onderzoek laat zien aan de BwN ontwerpers en ingenieurs dat ambiguïteit het soort onzekerheid is dat het ontwikkelproces van een BwN hoogwaterbeschermingsproject zou kunnen belemmeren, terwijl hun oorspronkelijke hypothese was dat onvolledige kennis en onvoorspelbaarheid waarschijnlijk deze belemmerende factor zouden zijn. Aldus brengen de resultaten naar voren dat – om tot een succesvolle implementatie van een BwN project te komen – het omgaan met de verschillen tussen verschillende actoren belangrijker is dan het reageren op onzekerheid door gebrekkige kennis van het natuurlijke systeem. Verder is een gestructureerde analyse van de actoreigenschappen die ten grondslag liggen aan ambiguïteit nog niet eerder uitgevoerd. Bovendien bespreekt deze dissertatie expliciet het verband tussen ambiguïteit en de meer gebruikelijke onzekerheidssoorten onvolledige kennis en onvoorspelbaarheid, hetgeen niet wordt gedaan door andere onzekerheidsconceptualisaties in de literatuur. Deze relaties tussen onzekerheden kunnen van grote waarde zijn voor BwN ontwerpers en ingenieurs, omdat in deze dissertatie wordt getoond dat de relaties actief kunnen worden gebruikt om met onzekerheid om te gaan.

1 INTRODUCTION

1.1. BACKGROUND

Estuaries, coasts and rivers have always been among the most promising locations for humans to settle due to their high economic potential. These surface waters provide essential resources for agricultural irrigation systems and provide means for transportation of persons and economic goods. As a result, major cities all over the world – such as Amsterdam, Hong Kong, Jakarta, London, New York, Paris and Sydney – are located along rivers and seas. However, as these essential economic portals are located in flood-prone areas, they are continuously threatened by flooding and need to be protected against the water. Given the facts that weather conditions are likely to become more extreme due to climate change and that sea level will rise (IPCC, 2013), the enduring human struggle against the forces of the water is more important than ever before. Furthermore, as the global population grows, humanity puts increasing pressure on available space and resources, and the major cities keep on growing. Governments, societies and companies all over the world become increasingly aware of the need for sustainable solutions to this problem.

The Netherlands is one of the most densely populated deltaic areas in the world. Space for the multiple functions and activities in the Dutch society is continuously scarce. Due to its central position in Europe and its excellent accessibility, the Netherlands has acquired a key position in the European economy with for instance Rotterdam Harbour and Schiphol Airport. Over the centuries, the Dutch have gained a tremendous amount of experience regarding water management (Van de Ven, 1993). As early as the 11th century, local Dutch communities started to jointly organize their flood defences by building dikes. In the 13th century, the first democratic governmental institutions were founded: water boards – consisting of elected representatives from the local farming community – became competent water authorities recognized by the ruling nobility (Kuks, 2004). Nevertheless, despite the water management efforts of the Dutch, the flood defences of both riverbanks and coasts were still regularly insufficient to resist the water over the centuries (see Van de Ven, 1993; Tol and Langen, 2000; De Kraker, 2006; Van Koningsveld et al., 2008).

As a response to a major flooding in 1916, the *Zuiderzee* was closed off from the Wadden Sea with a 32 kilometre long dam in 1932, creating the current *Lake IJssel*. However, the overall state of the Dutch flood protection structures was problematic at that time. A prominent coastal engineer warned from 1937 on that flood defences in the South Western part of the Netherlands were in a poor condition, but the government did not attend to the matter due to a lack of funds and sense of urgency (Van Veen, 1962). In 1953, a dramatic flooding of the South Western provinces of the Netherlands shocked the Dutch society as it led to the death of 1,836 people (Gerritsen, 2005). The disaster caused a major attitudinal shift of both government and the general public, as everyone agreed that “this is never allowed to happen again”. Consequently, the Dutch government commissioned the so-called Delta Commission to come up with a plan to improve the flood defence system in order to prevent future disasters (Delta Commission, 1960). The commission created the Delta Plan consisting of major dike improvements and the closure of several large tidal inlets, which marked a shift to a probabilistic flood protection approach in which the statistical probabilities of flooding events became leading in the design of dikes and storm surge barriers (Vrijling, 2001). Over the years, the plans of the Delta Commission were implemented and the works – the Eastern Scheldt storm surge barrier and Maeslantkering in particular – became a world-wide premium example of flood protection. A paradigm of command-and-control – aimed to bring the unpredictable ecosystem into a predetermined and rather static state, emphasizing on reducing uncertainties and designing systems that can be predicted and controlled (Holling and Meffe, 1996) – was established more firmly than ever in water management. However, as traditional hard engineering works are usually designed to withstand events with a given probability of occurrence at the time of their construction, these works are probably not sustainable for a future in which the sea level is higher and more extreme weather events can be expected (Van Slobbe et al., 2013).

Whereas new 1953-type of disasters have been prevented successfully until now, the Delta Works and other rigid flood protection structures did have some (partly unexpected) negative side effects (see Eelkema et al., 2013 for an example). Already in the 1970s, major environmental concerns regarding the closure of the Eastern Scheldt estuary surfaced and made the responsible engineers change the initial design from a fully closed to a semi-open structure (Bijker, 2002; Disco, 2002). Furthermore, the Delta Works created a false feeling of absolute safety and thereby unintentionally resulted in a decreasing priority of flood defence efforts (Wesselink et al., 2007). A new wake-up call regarding flooding was received in 1993 and 1995 when the dikes along the rivers Rhine and Meuse almost collapsed, leading to the preventive evacuation of 200,000 people. These events were the onset for a renewed governmental sense of urgency regarding water management, leading to the Room for the River program (Van Stokkom et al., 2005), the National Water Plan (Ministry of Infrastructure and the Environment, 2009) and a Second Delta Commission (Delta Commission, 2008; Kabat et al., 2009).

1.2. BUILDING WITH NATURE: A NOVEL APPROACH IN WATER MANAGEMENT?

Motivated by the alleged lack of sustainability of the traditional hard engineering approaches and concerns about the environment (Airoldi et al., 2005), the paradigm in water resources management and flood protection is gradually shifting towards more environmental-friendly and so-called ecological engineering approaches (Pahl-Wostl et al., 2011). One of the principal examples of the current *'soft'* trends in Dutch water management is an approach known as *Building with Nature* (BwN). The Building with Nature approach originated in 1979 and was first introduced by the Czech engineer Hanzo Svaşek, whose coastal protection philosophy aimed at developing beaches and dunes instead of fighting the sea with hard structures (Waterman, 2008). In 2008, the approach took a flight when the BwN research program – executed by the EcoShape foundation – was launched by a consortium consisting of Dutch governmental agencies, research institutes, engineering companies and the two largest Dutch dredging companies (De Vriend and Van Koningsveld, 2012).

Building with Nature aims to actively utilize natural dynamics (e.g., wind, waves and currents) and natural materials (e.g., sediment, vegetation and organisms) in project designs for the realization of effective flood defences, while simultaneously providing opportunities for nature development (De Vriend and Van Koningsveld, 2012). Smit (2010) distinguishes between two main components of the BwN approach, namely:

- **The instrumental component** – aim to use natural processes in creating coastal infrastructure;
- **The goal-oriented component** – take a holistic perspective by actively looking for opportunities to improve the ecosystem.

The BwN approach has similarities with two already existing approaches in the field of water management. One similarity is with the approach of *ecological engineering*, which is defined as the design of sustainable systems that integrate human society within its natural environment for the benefit of both, aiming to restore ecosystems that are substantially disturbed by human activities and to develop new sustainable systems that have both human and ecological value (Mitsch and Jørgensen, 2003; Mitsch, 2012). Ecological engineering is the practice of creating symbiosis between the economy of society and the environment by fitting technological design to environmental self-design (Odum and Odum, 2003).

As the BwN approach advocates the use of flexible solutions that allow society to gradually adapt to the aforementioned changing circumstances such as sea level rise and climate change (De Vriend and Van Koningsveld, 2012), it also has some overlap with the concept of *adaptive (water) management*. Adaptive management originates from ecosystem management and views policies as experiments from which one can learn in order to improve the next policy decision (Holling, 1978; Walters, 1986). Each of these experiments is seen as a system perturbation of which the outcomes are uncertain (Walters and Holling, 1990), as our understanding of both the behaviour and drivers of the managed ecosystems are inherently limited (Pahl-Wostl, 2007). Hence, it must be possible to adapt management approaches and policies due to insights gained from past experiences (Pahl-Wostl et al., 2007b). While monitoring is suggested as an essential activity to acquire the knowledge necessary to learn (Holling, 1978; Walters, 1986), involving stakeholders in the adaptive management process is also of essential importance (e.g., Carpenter and Gunderson, 2001; Stringer et al., 2006).

1.2.1. Building with Nature: more than a technological challenge

According to Waterman et al. (1998), the BwN approach influences multiple coastal functions. Hence, projects using BwN design principles affect multiple stakeholders by definition. A BwN project seems to be, at least partly, what Dietz (2003) calls an 'environmental decision-making situation'. Dietz (2003) argues that, to come to good environmental decision-making, all stakeholders – those who are affected by or can affect a decision (after Freeman, 1984) – should have a say. However, the presence of a multiplicity of stakeholders can easily lead to a situation of ambiguity, in which it is no longer clear what the problem or its solution is. As a result, Building with Nature is more than just a technical, engineering-oriented approach.

The philosophy of the BwN approach advocates that active involvement of stakeholders is both required and beneficial (De Vriend and Van Koningsveld 2012). In the literature, many scholars address why stakeholders should participate in environmental decision-making, for instance by pointing at the potential benefits of stakeholder participation (see Reed, 2008, for a review), by discussing the social goals participation should aim to achieve (e.g., Beierle, 1999) or by giving substantive, normative and instrumental arguments why involving stakeholders is a requirement in projects or policy development (e.g., Fiorino, 1990). For instance, from a normative perspective, a proper stakeholder participation process is important as it includes the values of a wide range of affected stakeholders in decision-making (Beierle and Konisky, 2000), avoiding that minorities are excluded. This may increase public trust in decisions and governmental institutions (Beierle, 1999) and may empower stakeholders through the co-generation of knowledge (Brugnach and Ingram, 2012). Furthermore, stakeholders might perceive decisions as holistic and fair, which is very important if it concerns important issues in their daily life (Van den Bos, 2001). An essential pragmatic benefit is that lays and non-experts add local knowledge to the process and thereby address a problem from a different angle (Fiorino, 1990). On the other hand, participation is also an instrument to educate and inform the public (Beierle, 1999; Irvin and Stansbury, 2004). Hence, an initiative – such as a BwN project – should be well adapted to the specific, local social or environmental conditions (Reed, 2008). As such, effective participation should lead to better and more legitimate decisions (Fiorino, 1990; Randolph and Bauer, 1999; Beierle, 2002). Furthermore, a good participatory process can reduce conflict and improve adversarial relationships. In the end, this may even lead to more cost-effective decisions (Beierle, 1999) or reduced implementation costs (Reed, 2008).

1.2.2. Building with Nature: an internationally recognized philosophy

In the Netherlands, we can currently observe multiple examples of water management projects based on BwN design principles. Two exemplary cases are the Sand Engine Delfland and Safety Buffer Oyster Dam sand nourishments projects, which are used as case studies in this thesis (see Chapters 2-5). Other examples are the use of artificial oyster reefs ("ecosystem engineers") in the Eastern Scheldt estuary to trap sediment in order to protect intertidal flats from eroding and the use of willows to create floodplains in the Noordwaard polder to reduce wave overtopping of dikes (Borsje et al., 2011).

The basic philosophy of the BwN approach is not exclusive for the Netherlands, as the use of natural dynamics and materials in water management projects can be seen elsewhere as well. Initiatives such as the Working with Nature approach of PIANC and the Engineering with Nature approach of the US Army Corps of Engineers are based on philosophies similar to the Building with Nature approach (Van Slobbe et al., 2013). For instance, after Louisiana (USA) was struck by the disastrous hurricane Katrina in 2005, scientists opted that – next to the rebuilding of the damaged hard flood infrastructure – a sustainable redevelopment of the natural environment was essential to obtain a flood safe situation (Costanza et al., 2006; Lopez, 2009). Eventually, in May 2012, the Louisiana Master Plan for a Sustainable Coast was unanimously accepted by the state's legislature (Peyronnin et al., 2013). An essential part of the Master Plan is to invest in restoring barrier islands, headlands, and shorelines as first lines of defence against storms (CPRA, 2012). Another example concerns flood protection in tropical coastal zones. Some scholars found that mangroves provide a form of coastal protection as they dampen wave energy (e.g., Mazda et al., 1997; Das and Vincent, 2009; Zhang et al., 2012), although others still have their doubts whether these findings can be generalized (e.g., Baird et al., 2009). Nonetheless, a part of the BwN research program was dedicated to investigating the possibilities of restoration of mangroves for flood defence purposes. Regarding the use of BwN design principles in river management, Warner and Van Buuren (2011) discuss that Room for the River is not only a Dutch philosophy but that similar river management programs are executed in other European countries, such as Belgium, the UK, Germany and Hungary.

1.3. UNCERTAINTY: A MAJOR CHALLENGE FOR BUILDING WITH NATURE

Since the beginning of the Building with Nature research program, uncertainty has been recognized as an essential topic because of its potential (negative) impact on BwN projects. Uncertainty is a phenomenon that is preferably avoided in decision-making, as decision-makers, stakeholders and the general public all prefer certainty about the consequences of what we decide upon (Funtowicz and Ravetz, 1990). Whereas scientists are rather familiar with the concept of uncertainty, decision-makers, politicians and the public at large generally prefer certainty and deterministic solutions (Bradshaw and Borchers, 2000).

For a project based on BwN design principles, it is an inherent characteristic that a high level of certainty can never be provided. As mentioned above, BwN designs advocate the use of natural dynamics (such as weather conditions) and natural materials (such as sediment and vegetation). As our knowledge of the natural system is simply incomplete and natural dynamics such as the weather are inherently unpredictable, the outcomes of a BwN project are never fully under human control. Consequently, it is unavoidable that no 100% guarantees can be given to politicians and stakeholders about the outcomes of a project based on BwN design principles. Its exact impacts are extremely hard to predict on beforehand, which makes the decision-making process that precedes the project's implementation a major challenge. For decision-makers, stakeholders and even for those directly involved in the project, it might be hard to evaluate a project based on BwN design principles. Some may even question the acceptability of an initiative about which so little is certain. However, more knowledge does not necessarily solve the uncertainty problem. To the contrary, additional research might even generate more uncertainty, as this research might uncover different uncertainties or increase the awareness regarding particular knowledge gaps (Van Asselt, 2000). Furthermore, it is important to acknowledge that the different actors affected in the decision-making process can hold diverging views about what is at stake (Dewulf et al., 2005), which can lead to ambiguity and gives the uncertain situation a fundamentally different dimension.

Uncertainties are often seen as notorious troublemakers in decision-making in general and projects in particular. In projects, factors such as commercial and competitive pressures, collision of social, political and institutional norms and rules with financial and technical project goals, and shifting requirements of project stakeholders can all be a source of uncertainty (Jaafari, 2001). Uncertainty can create anxiety, cause (budget) retrenchment and paralyze action (Nowotny et al., 2001; Van Asselt, 2005). Uncertainty can lead to major time overrun if decision-makers become indecisive when the consequences of alternative solutions are perceived to be uncertain (Mysiak et al., 2008). A famous example in the Netherlands regarding the potential negative influence of uncertainty is the seemingly endless development process preceding the construction of the Second Maasvlakte, an extension of Rotterdam Harbour. Final decisions were enormously delayed, partly due to time-consuming consultations about uncertainties concerning the effects on silt, nutrients and biota in the Wadden Sea (see Hommes et al., 2009). Although additional studies eventually showed that the harbour extension would have no significant impacts on the Wadden Sea, the development process was delayed by more than one year.

In short, it can be hypothesized that projects that are based on BwN design principles – given their inherently uncertain nature – are susceptible to be hampered by uncertainty or might even be cancelled due to a perceived excess of uncertainty. As the BwN approach seems to be promising for taking up the important challenge to develop more sustainable flood defence solutions that can be flexibly adapted along with sea level rise, it would be a bitter disappointment if such initiatives are eventually cancelled for the wrong reasons. Therefore, I argue that it is essential to study the issue of uncertainty in the context of projects based on BwN design principles, in order to determine which uncertainties are most important and how these should be coped with.

1.4. RESEARCH QUESTIONS AND THESIS OUTLINE

In this thesis, I focus on identifying those (kinds of) uncertainties that can have a decisive or hampering impact on the development and implementation process of a BwN project. Such uncertainties are likely perceived as most relevant by project teams and stakeholders, as they could potentially affect the interests of these actors. Nevertheless, individual uncertainties are dependent on the specific context of the project under consideration. Hence, I study which kinds of uncertainties are most important during the development of BwN projects and how BwN project teams can analyse and cope with these uncertainties.

The thesis consists of six chapters. After this introductory chapter, the thesis continues with four chapters that were written as independent journal publications. Each chapter addresses one of the specific research questions that I aim to answer in this thesis. I will now discuss each of these research questions and thus the outline of the thesis.

Which uncertainties could have a decisive (negative) impact on the development process of a Building with Nature project?

In Chapter 2, I study the Sand Engine Delfland project (the most prominent example of BwN projects in the Netherlands), identify the most important uncertainties in the project and determine which uncertainties could have seriously hampered the project's development process. This study was performed using the existing uncertainty classification of Brugnach et al. (2008).

What is the origin of ambiguity in Building with Nature projects?

In Chapter 3, I discuss the underlying causes of ambiguity in BwN projects. Ambiguity is an uncertainty of key importance in many contexts and this is no less true for BwN projects. Although many scholars agree that ambiguity arises from a difference in frames between actors, it has – to my knowledge – not been studied which underlying attributes cause the interference between the frames of different actors. Based on the results of two BwN case studies – the Sand Engine Delfland project and the Safety Buffer Oyster Dam project – I investigated this matter.

How are different uncertainties related in the context of Building with Nature projects?

In Chapter 4, I investigate an uncertainty topic which is often touched upon but that has not been studied in detail before: the relation between different uncertainties, particularly the relation between uncertainties in knowledge and ambiguity. In this chapter, I show that fundamentally different kinds of uncertainty – incomplete knowledge and unpredictability ("not knowing enough") and ambiguity ("knowing differently") – are not independent but can be directly related in *cascades of interrelated uncertainties*. I argue that this consideration can be essential for coping with uncertainty in BwN projects.

Which benefits does the interrelatedness between different uncertainties have for coping with uncertainty in Building with Nature projects?

In Chapter 5, I discuss which benefits the use of the 'cascade of interrelated uncertainties' approach can have for coping with uncertainty in BwN projects. Using the results of the Sand Engine Delfland project and the Safety Buffer Oyster Dam project as examples, I demonstrate how the early investigation of the cascade of interrelated uncertainties for essential project issues could have led to an adaptive instead of reactive management of uncertainty.

In Chapter 6, the main conclusions of this thesis are presented by summarizing the answers to the four research questions addressed above. Furthermore, I explicitly address the scientific and practical contributions of the research, and provide recommendations for further research.

2 IDENTIFYING THE MOST IMPORTANT UNCERTAINTIES IN THE DEVELOPMENT OF A BUILDING WITH NATURE PILOT PROJECT[1]

ABSTRACT

Building with Nature (BwN) is an innovative approach in flood policy, which aims to use natural system dynamics and materials for the design and realization of flood defence projects. However, as natural dynamics are inherently unpredictable, the use of BwN design principles requires a fundamentally different approach to uncertainty in flood management. In this chapter, we identify and classify the key uncertainties in the development process of a specific project using BwN design principles: the Sand Engine. Our results indicate that uncertainty about the social implications of applying BwN design principles is more relevant for project development than uncertainty in the knowledge base of the natural system. Although uncertainty did not hamper project development in this specific case, the changes in project design evoked by the use of BwN principles do not seem to be followed by proper changes in the development process preceding the project's implementation: in the Sand Engine project's development process, uncertainty is evaluated rather similar to the current flood defence practices. We claim that new approaches for dealing with uncertainty are needed, to successfully address the uncertainties typical to projects using BwN design principles.

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[1] Another version of this chapter has been published as: Van den Hoek, R.E., Brugnach, M., Hoekstra, A.Y., 2012. Shifting to ecological engineering in flood management: introducing new uncertainties in the development of a Building with Nature pilot project. Environmental Science and Policy 22, 85-99.

2.1. INTRODUCTION

The key role of uncertainty in policy development is increasingly acknowledged in numerous scientific disciplines, including environmental sciences (Van der Sluijs, 2007; Mysiak et al., 2008; Maxim and Van der Sluijs, 2011) and water policy science (Pahl-Wostl et al., 2007b; 2011). Contemporary flood management generally concerns the construction of rigid and often large-scale infrastructure, such as dikes, dams and storm surge barriers. In such an approach, often referred to in the literature as the command-and-control approach, emphasis is on reducing uncertainties and designing systems that can be predicted and controlled (Holling and Meffe, 1996). Although structures such as dikes and storm surge barriers have been relatively successful in the (recent) past, the highly optimized systems they create are vulnerable to unpredictable events greater than foreseen in the structure's design (Carlson and Doyle, 1999; Davidson-Hunt and Berkes, 2003), for instance an extreme storm well beyond expectations. Furthermore, despite the fact that human activities significantly alter the functioning of ecosystems (Vitousek et al., 1997) and threaten the sustainability of natural systems such as marine environments (Levin and Lubchenko, 2008), the effects of the command-and-control flood defence approach on natural processes are often not properly taken into account (Richter et al., 2003). Over recent years, changes in weather conditions and extreme events (Milly et al., 2008), accompanied by a changing perception of human responsibility towards incorporating ecological values in water policy (Gleick, 2000), have led to an increasing desire for ecologically sustainable water management (Richter et al., 2003), as well as sustainable development of coastal ecosystems (Adger et al., 2005) and flood management systems in general (Werritty, 2006). Command-and-control approaches do not seem fit to cope with these future challenges regarding the role of nature and ecology. Therefore, the paradigm of water management is slowly changing towards more nature-inclusive approaches (Pahl-Wostl et al., 2011).

Currently, in the Netherlands, an innovative nature-inclusive approach to flood management is emerging and being studied in a national research program, called Building with Nature (BwN). BwN is a form of ecological engineering (sensu Mitsch and Jørgensen, 2003) in flood management, as BwN design principles promote the use of natural materials and dynamics – such as sediment, vegetation, wind and currents – for the realization of effective flood defence projects, while exploring opportunities for nature development (Van Dalfsen and Aarninkhof, 2009; Aarninkhof et al., 2010). The use of BwN design principles for flood defence purposes can result in a variety of possible designs. For instance, researchers are studying the use of large-scale coastal sand nourishments or specific vegetation for flood protection and the application of oyster beds to prevent erosion of tidal flats (Borsje et al., 2011). However, the use of ecology and natural dynamics inherently adds high and often irreducible levels of uncertainty to a project's design process (Bergen et al., 2001). Hence, use of BwN design principles suggests that a fundamentally different attitude by stakeholders towards uncertainty in water policy and flood management is required. Instead of aiming at uncertainty reduction and control, the inclusion of nature and its unpredictable dynamics in the project design demands that policy development actors have the capacity to recognize and properly deal with the presence of higher levels of uncertainty.

Where scientists are familiar with the concept of uncertainty, policy-makers and the public at large generally prefer certainty and deterministic solutions (Bradshaw and Borchers, 2000). Uncertainty can influence policy and project development in numerous ways. For instance, a situation of indecisiveness can occur when policy-makers are uncertain about which measure out of a set of policy alternatives is most appropriate (Mysiak et al., 2008). Uncertainty can create anxiety, cause retrenchment and paralyze action (Nowotny et al., 2001; Van Asselt, 2005). Hence, projects can be severely delayed, may suffer from insufficient funds or can even be cancelled if the level of uncertainty is perceived as unacceptable. For example, Hommes et al. (2009) describe the case of the Second Maasvlakte extension of Rotterdam Harbour, a water engineering project at the Dutch coast in which final decisions were enormously delayed, partly due to time-consuming consultations about uncertainties concerning the effects on silt, nutrients and biota in the Wadden Sea.

In short, while the presence of uncertainty is inherent to the design principles of BwN, it is still undesirable in the current policy and project development practices. This contradiction leads us to the hypothesis that the development process of projects using BwN design principles is susceptible to be hampered by the inherent unpredictability of and incomplete knowledge about the natural system. To assess this hypothesis, it is of paramount importance to have a clear understanding of which uncertainties are most relevant to policy-makers, managers and the public in projects using BwN design principles. When the key uncertainties of the BwN approach are identified, strategies can be developed to manage these uncertainties effectively to prevent unnecessary cost and time overruns, or even cancellation, of promising initiatives. To this end, we performed an in-depth case study of the Sand Engine project, the first large-scale project in the Netherlands based on BwN principles. In this chapter, we identify and classify the relevant key uncertainties from the perspective of the development process of the Sand Engine project. Furthermore, we analyse whether the required change of attitude by stakeholders towards uncertainty when using BwN principles is accompanied by a change in the evaluation of uncertainty by project development actors.

This chapter is structured as follows. In Section 2.2, we discuss how we define and classify uncertainty. Section 2.3 describes the methodology of our study. Section 2.4 introduces the Sand Engine case study and the characteristics of its development process, while the results are presented in Section 2.5. In Section 2.6, we discuss the implications of our study's results. In the final section, we draw conclusions and point out the direction of our future research.

2.2. DEFINITION AND CLASSIFICATION OF UNCERTAINTY

In the literature, there is still no commonly accepted definition of the concept of uncertainty. For instance, Funtowicz and Ravetz (1990) describe uncertainty as *a situation of inadequate information*. This definition suggests that uncertainty will decrease if the amount or quality of information available increases. However, Van Asselt and Rotmans (2002) recognize that uncertainty can also prevail even in situations where sufficient information is available. An increase of information can result in an increase of our awareness of knowledge gaps, and thus in an increase of uncertainty (Van Asselt, 2000). Therefore, to help grasp all dimensions of uncertainty, Walker et al. (2003) define uncertainty as *any departure from the unachievable ideal of complete determinism*. This definition still regards uncertainty as a rather mathematical concept with the underlying assumption that uncertainty can always be *deterministically* characterized.

Van der Sluijs (2006) argues that uncertainty is much more than just numbers and probabilities: it is increasingly understood as a concept with both quantitative and qualitative dimensions, involving more than just statistical errors or inexact numbers. Findings from the study of Van der Keur et al. (2008) support this statement, as they conclude that more qualitative uncertainties than statistical uncertainties are present in policy development for integrated water resources management. In the context of major public projects, factors such as commercial and competitive pressures, conflicting social, political and institutional norms and rules with project financial and technical goals, and the shifting requirements of project stakeholders can all be sources of uncertainty (Jaafari, 2001). Maxim and Van der Sluijs (2011) define uncertainty as a lack of knowledge quality, arguing that *lack of knowledge* is only a part of the broader issue of *knowledge quality*. Koppenjan and Klijn (2004) grasp both the technical and social dimensions of uncertainty by adding *strategic uncertainty* (unexpected strategic actions of stakeholders) and *institutional uncertainty* (handling of policy development and the interaction between actors) to the knowledge-oriented *substantive uncertainty* (unavailability or different interpretations of knowledge).

Brugnach et al. (2008) address the topic of uncertainty from the perspective of multi-actor decision-making processes, in which the interaction between actors is just as essential for the interpretation of a problem as the available knowledge. Uncertainty is defined as *the situation in which there is not a unique and complete understanding of the system to be managed* (Brugnach et al., 2008). This definition regards uncertainty as much more than just a deficit of knowledge, including the many different interpretations regarding the problem and its solution that may coexist in a collective decision-making process. Policy development actors have different backgrounds, diverging preferences, and conflicting interests and values, which influence the framing of problems and the type of solutions chosen. Thus, actors may either interpret knowledge differently or use different knowledge during the framing process, the activity through which the meaning of a situation is negotiated among different actors (Putnam and Holmer, 1992; Gray, 2003; Dewulf et al., 2004). So, in decision-making processes where multiple actors are involved, the simultaneous presence of different but equally sensible knowledge frames is unavoidable. This may lead to ambiguity, a kind of uncertainty that indicates that there are multiple possible interpretations of a situation (Weick, 1995). The relevant dimension of ambiguity is something ranging from unanimous clarity to total confusion caused by too many people voicing different but still sensible interpretations (Dewulf et al., 2005).

Following the definition of Brugnach et al. (2008), we distinguish between three different kinds of uncertainty:

- **Unpredictability** – uncertainty due to unpredictable or chaotic behaviour of e.g. natural processes, human beings or social processes;
- **Incomplete knowledge** – uncertainty due to the imperfection of our knowledge, e.g. due to lack of specific knowledge, data imprecision or approximations;
- **Ambiguity** – uncertainty due to the presence of multiple knowledge frames or different but (equally) sensible interpretations of the same phenomenon, problem or situation.

Furthermore, we classify – following Brugnach et al. (2008) – in which part of the system to be managed the uncertainty is present. It is useful to make such a distinction between the different parts as it supports policy-makers to structure their knowledge about the system, though the three different parts of the system are all closely interrelated. Furthermore, strategies to manage uncertainties can be more specifically tailored to the part of the system in which the uncertainty is present. The following parts of the system to be managed are distinguished:

- **Natural system** – uncertainty concerning aspects such as climate impacts, water quantity, water quality and ecosystems knowledge;
- **Technical system** – uncertainty concerning technical elements and artefacts that are deployed to intervene in the natural system knowledge;
- **Social system** – uncertainty concerning economic, cultural, legal, political, administrative and organizational aspects knowledge.

Combining the three uncertainty kinds and the system in which the uncertainty is present yields a two-dimensional uncertainty classification matrix (Table 2.1). Similar to other scholars, such as Raadgever et al. (2011), this matrix was used to classify the uncertainties identified in our research.

Table 2.1 – Uncertainty classification matrix (adopted from Brugnach et al., 2008)

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge, inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems	unpredictability of the natural system	incomplete knowledge of the natural system	ambiguity regarding the natural system
Technical system infrastructure, technologies, innovations	unpredictability of the technical system	incomplete knowledge of the technical system	ambiguity regarding the technical system
Social system economic, cultural, legal, political, administrative and organizational aspects	unpredictability of the social system	incomplete knowledge of the social system	ambiguity regarding the social system

2.3. METHOD

For our research, we used three main data sources to identify the relevant uncertainties in our case study, the Sand Engine project. A detailed description of this innovative sand nourishment project will follow in Section 2.4. First, data was collected by document analysis. Publication of key documents is a method of communicating project progress, results and ideas to both project stakeholders and the public at large. The documents we reviewed primarily describe and discuss the technical content of the Sand Engine project. These key documents were carefully studied to identify uncertainty in the context of the written text. Table 2.2 shows a short overview of the key documents reviewed in this research (see Appendix A for a more detailed list). Second, three public information meetings were attended. During these meetings, the public at large was offered the opportunity to pose questions, express their appreciation or concerns about the Sand Engine project and to file complaints. Minutes were made for these meetings and these were studied. Table 2.3 shows a list of several keywords and topics that were specifically of interest for our study, both for the document analysis and the analysis of the meetings.

Table 2.2 – Key policy documents reviewed (names translated from Dutch)

List of key policy documents	
Ambition Agreement Sand Engine	Swimming Safety Report
Project Start Note EIA Sand Engine	Monitoring and Evaluation Plan
Guidelines EIA Sand Engine	Questions & Answers from Dutch parliament
Morphological Calculations Report	Historical report on ammunition in North Sea
Environmental Impact Assessment (EIA) Sand Engine	Sand Engine permits
Note of Answer to EIA Sand Engine	

Table 2.3 – Key issues signalling the presence of uncertainty

Key issues
Issues where **uncertainty** or **risk** is explicitly mentioned (e.g.: currently, it is highly uncertain what the exact sea level rise will be until 2100);
Issues where an **assumption** or an **estimation** is made (e.g.: it is assumed that sea level rise will be 1 m until 2100);
Issues where (a) **scenario(s) with a probability of occurrence** is given (e.g.: there is a 75% chance that sea level rise will be more than 1 m);
Issues where (a) **scenario(s) with an idea of likelihood** of occurrence is given (e.g.: sea level is more likely to be 2 m than 1.5 m in 2100);
Issues where a (range of) **possible scenarios without having an idea of likelihood** of occurrence (e.g.: sea level rise will be between 1m and 3m until 2100);
Issues where it is expressed that there is **ignorance** about the (future) situation (e.g.: nobody has an idea what sea level rise will be in 2100)
Issues where **lack of knowledge** is expressed and **cannot be decreased** (e.g.: weather conditions cannot be predicted over a 20-year time period)
Issues where **lack of knowledge** is expressed but **additional knowledge can be acquired** (e.g.: the effect of a measure is currently unknown but it can be studied by a small-scale practical experiment)
Framing or priority differences of stakeholders (e.g.: while expert A states that climate change is the cause of sea level rise, actor B claims that there is no evidence for climate change and thus disagrees that climate change is the cause of sea level rise);
Other interesting issues that are suspected to be an uncertainty but not stated.

Third, in April and May 2011, we interviewed six main project actors – three (former) members of the Sand Engine project team, one member of the project steering group and two experts involved in the Environmental Impact Assessment (EIA) and modelling – to identify the uncertainties that were essential in the Sand Engine's development process. The interviews provided an opportunity to identify uncertainties not reported in the key documents. We chose this specific group of interviewees, because they are or were directly involved – either as chairman, manager or expert – in several phases of the Sand Engine project's development process. Thus, for the interviewees, identifying and managing the Sand Engine project's uncertainties was a part of their (daily) activities. The interviews were conducted in the Dutch language, took between one and two hours, and were recorded and transcribed.

We performed semi-structured interviews, using a standardized interview protocol with seven open-ended main questions and several follow-up questions. At the start of the interview, the interviewees were invited to elaborate on their definition or understanding of the topic of uncertainty. Thereafter, the interview continued with an iterative process of identifying uncertainties and elaborating on the uncertainty's relevance for the Sand Engine's development process. For instance, the interviewees were invited to address whether the uncertainties (potentially) had an effect on the continuation of the project. Furthermore, we posed questions about how the identified uncertainties were managed or coped with.

After identifying the uncertainties explicitly and implicitly addressed in the key documents, during public information meetings and during the interviews, the results from these three analyses were combined into one comprehensive list. Thereafter, the identified uncertainties were classified using the adopted uncertainty matrix, as presented in Section 2.2. We constructed an uncertainty matrix for each phase of the Sand Engine's development process, in order to create an overview of the development of uncertainty over the course of the project.

2.4. CASE STUDY: THE SAND ENGINE DELFLAND PROJECT

2.4.1. Case description

Sand Engine Delfland (in Dutch: Zandmotor Delfland) is an innovative, 21.5 million m^3 sand nourishment project, carried out near Ter Heijde in the Dutch province of South Holland (Figure 2.1). After a development process of approximately three years, construction finally started in March 2011. The innovative aspects of the Sand Engine project are its size – currently, the annual sand nourishment volume for the entire Dutch coast has a target value of 12 million m^3 – and especially its post-construction operating principles. After construction, the large amount of sand nourished will spread along the coast by the natural dynamics (waves, currents and wind). This means that the coast, both beach area and dunes, will expand in a fairly natural way. Hence, the Sand Engine project is a clear-cut example of the nature-inclusive BwN approach.

Figure 2.1 – Sand Engine Delfland (https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt)

As the Sand Engine is a pilot project, it will be monitored extensively after construction to study whether this innovative sand nourishment method is capable of combining benefits for society (for instance, coastal maintenance and increased area for beach recreation) and development of the natural system (for instance, increased dune habitat for flora and fauna). Model calculations have given predictions for the development of the Sand Engine. Currently, it is expected that the distribution of the Sand Engine's sand along the coastline will take 20-50 years. Since weather conditions are unpredictable, especially over such a long time period, this prediction of sand distribution by natural dynamics involves high levels of uncertainty. Hence, the Sand Engine project is an interesting case study for our research concerning the role of uncertainty in the development process of projects using BwN design principles.

2.4.2. Development process of the Sand Engine project

The development process of the Sand Engine project consists of six phases (Figure 2.2). We reconstructed the timeline of this process using the project planning, the document analysis and the interviews. Each phase has its own characteristics, main activities and goals. Furthermore, the set of actors involved – who all have their own goals and interests – changes during the project and can differ from phase to phase. Van der Keur et al. (2008) address that different uncertainties are present in the various phases of project development. Therefore, we anticipate that different uncertainties will emerge and be relevant in the diverse phases of the Sand Engine development process.

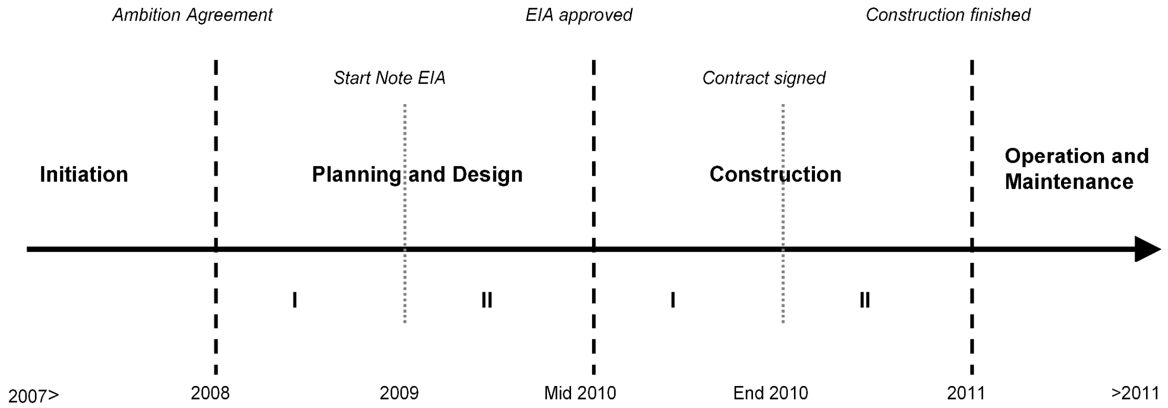

Figure 2.2 – Timeline of Sand Engine's project development process

In the Sand Engine **Initiation** phase, the potential of the several ideas was studied and the possibilities to create stakeholder commitment were explored. The phase ended with signing an "Ambition Agreement", in which for instance preliminary project goals were set, by several committed parties. The **Planning and Design I** phase was used to explore alternatives, identify knowledge gaps and establish guidelines for the EIA procedure. In the **Planning and Design II** phase, a preferred alternative was chosen from the set of four proposed designs and mitigating measures were defined to cope with potential undesired effects of the Sand Engine. In the **Construction I** phase, a tender was done to find a contractor for the project's construction and required permits were acquired. During the **Construction II** phase, the Sand Engine was constructed under the responsibility of Rijkswaterstaat. After construction, management of the Sand Engine peninsula was transferred to the Province of South-Holland. In the current phase of the project, **Operation and Maintenance**, the project's outcomes are monitored, and the recreational safety and effects on the surroundings are controlled.

Table 2.4 – Uncertainties in the Sand Engine (SE) project in the various phases of development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems	How will the SE develop morphologically? (e.g., in terms of its shape and speed of development) What will be the effect of the SE on the currents? (e.g., eddy formation, velocity increase) What will be the yield of the SE (e.g., total beach area increase, erosion)?	What will be the effect of the SE on the groundwater level? What will be the effect of the SE on the fresh water supply (e.g., salt intrusion)?	Is it clear which aspects are most important regarding the project's nature development goals?
Technical system infrastructure, technologies, innovations	What will be the effect of the SE on Scheveningen Harbour?	What is the relationship between sand mining and occasional findings of World War II ammunition on the beach?	Is World War II ammunition a potential recreational safety threat in the context of the SE? Are there clear standard requirements for the (measurement of) sand quality?
Social system economic, cultural, legal, political, administrative and organizational aspects	How much money will stakeholders contribute to the project budget? What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general? What will be the effect of the SE on beach commerce? How will legal officials behave during construction?	Which permits are needed for the SE construction? Which effect will the SE have on houses near the coast (e.g., flooding of cellars)?	Is the construction tender economically attractive for potential contractors? Will the SE have an effect on the quality of drinking water? Is it clear who should be the competent authority for the SE nature permits? Are all key stakeholders willing to (financially) commit to the SE project? Is the chosen location optimal for the project or not? Is it clear which project goal has the highest priority? Should management of the SE be transferred as planned (31 October 2011) or after construction is finished? Can recreational safety in the vicinity of the SE be guaranteed?

2.5. RESULTS

Table 2.4 summarizes the uncertainties from all phases of the development process of the Sand Engine project, classified according to their kind and the part of the system in which they are present. All uncertainties were either explicitly or implicitly mentioned in one or more key documents, during public information meetings or interviews. We constructed an uncertainty matrix for every project phase, summarizing the uncertainties relevant for project development in that specific phase (see Appendix B). These matrices contain the same uncertainties as Table 2.4, but provide insight in which particular phase(s) an uncertainty was present.

During our analysis, we recognized that three particular uncertainties were specifically addressed by at least four of the six interviewees. Moreover, the interviewees' description of the uncertainties expressed a high sense of urgency to actively cope with these issues as they potentially had severe consequences, namely cancellation of the Sand Engine project. Therefore, we argue that these uncertainties are typical examples of relevant key uncertainties for the Sand Engine project. We will now elaborate on these three uncertainties in more detail.

First, from an early stage in the project, there has been uncertainty about the influence of the Sand Engine on recreational conditions. These physical conditions in the coastal zone – for instance, the velocity of currents and the presence of quicksand on the beach – are largely determined by natural dynamics such as the weather, which are inherently unpredictable. However, during project development, discussions have not focussed on physical *recreational conditions* – all parties involved agree that these conditions are highly uncertain – but on the social implication of *recreational safety*. Opponents of the project formed an anti-Sand Engine action committee and claimed that it is unsafe to recreate in the Sand Engine's vicinity due the uncertainties around recreational conditions. However, according to the project team, uncertainties about the recreational conditions do not necessarily lead to an unsafe situation, if proper measures to control the recreational safety are taken. For instance, in the Sand Engine case, swimming is (temporarily) prohibited and active participation of the beach lifeguards was established, who received additional training. Although the interviewees were convinced that recreational safety is not at risk, there is still continuous attention for this issue. An interviewee stated:

> *"If it concerns uncertainties about safety… or uncertainties about health… [Those] are definitely uncertainties that can influence the entire societal debate. And then [can mean] 'end of project' as well."*

Second, the effects of the Sand Engine on groundwater levels and, consequently, on drinking water quality due to possible saltwater intrusion were an important issue in the Construction I phase. The project team claimed that changes in groundwater levels would not have significant effects on drinking water quality, as long as some minor mitigating measures were taken. However, a project stakeholder framed a situation of incomplete knowledge, arguing that there was not enough knowledge to support the claim that effects on groundwater levels would not be substantial. Hence, while the project team viewed the lack of knowledge as a minor concern, the project stakeholder framed the lack of knowledge as a major problem. Therefore, the stakeholder demanded additional research and even considered filing an official complaint, potentially causing significant and unacceptable delays. In the end, the project team adapted their own knowledge frame and commissioned an additional study regarding the groundwater problem. This study showed that the Sand Engine potentially had significant effects on drinking water quality. The problem was eventually solved by negotiating proper mitigating measures, such as installing a pumping station to transport salt sea water out of the vicinity of the drinking water area. For project development, the groundwater and drinking water uncertainties were a grave issue, as an interviewee clearly illustrated:

> *"That was the largest uncertainty of last year, groundwater problems… That could have really stopped the project… If we did not have a contract with a constructor by the end of 2010, necessary funding [would be retrenched]. Then we wouldn't have had funding for the project and that would have meant ['end of project']."*

Third, uncertainty about the financial commitment of stakeholders has been a continuing issue of attention. In the Initiation phase, the Province of South Holland was enthusiastic about the Sand Engine idea and took it as a promising initiative. However, several governmental agencies at the national level claimed that such an expensive experiment was undesirable, especially given the economic crisis at that time. In the end, an agreement was reached on a total available budget of limited size. However, in the Planning and Design II phase, the project team became anxious that potential constructors (i.e., dredging companies) would not adopt the team's knowledge frame that the Sand Engine would be an economically feasible project within the available budget. A potential constructor might also adopt a rather negative frame – constructing the Sand Engine is economically unattractive – and might decide not to commit to the project. One of the interviewees declared the following regarding this uncertainty:

> *"We had a budget ceiling of €50 million… We needed 18.5 million m^3 [of sand] to construct it… [The price of a cubic meter of sand] was half of what was paid for nourishment works at that moment. So in terms of pricing, [it was] not very attractive for a constructor. So [that] was an uncertainty. Yes. Are we going to get a constructor for this job?... We could not afford a failed tender. Then, we would [leave 2010 and cross into 2011]."*

2.6. DISCUSSION

2.6.1. What is the most important kind of uncertainty related to BwN?

There were many uncertainties identified in the Sand Engine case, but the uncertainties varied in the importance they had in project development. Our results suggest that ambiguity is most important for BwN project development. First, the number of ambiguities was larger than both the number of uncertainties due to unpredictability and incomplete knowledge (see Table 2.4). Second, as expressed in Section 2.5, we found out that the uncertainties about recreational safety, drinking water quality and financial commitment – which are all ambiguities – were more important for project development actors than other uncertainties. According to several interviewees, these ambiguities about sensitive social implications – for example, to what extent recreational safety in the vicinity of the Sand Engine can be controlled – could have severely hampered or even terminated the development process. However, according to the same interviewees, the ambiguities eventually did not hamper project development in the end as they were properly coped with.

We observe that ambiguity can emerge when the *significance* or *consequences* of either unpredictability or incomplete knowledge are framed differently by project actors. For instance, the ambiguity about how the Sand Engine affects drinking water quality was due to two conflicting interpretations of the *significance* of incomplete knowledge of the effects on groundwater levels. While one project stakeholder framed that the incomplete knowledge was a major problem and needed to be reduced by additional research, the project team initially framed that it was only a minor concern and there was no significant need for further study. In the end, the ambiguity was solved by negotiating appropriate mitigating measures, such as installing a pumping station. Similarly, the ambiguity about how the Sand Engine affects recreational safety was due to conflicting interpretations of the *consequences* of unpredictable coastal zone conditions. While the project team argued that the presence of the Sand Engine does not necessarily lead to an unsafe situation, project opponents claimed that lethal accidents will certainly happen and demanded to stop the project. In the end, the ambiguity was solved using specific safety control measures, namely prohibiting swimming in the vicinity of the Sand Engine and participating with and training beach lifeguards. These two examples show that the uncertainties – which are both ambiguities – were not solved by acquiring more information to reduce the underlying lack of knowledge, but by negotiation and participation of project actors. As ambiguity originates from the presence of conflicting knowledge frames, acquiring more information does not solve this specific kind of uncertainty (Brugnach et al., 2011). Facilitating dialogues, participation and negotiation are essential to cope with the presence of conflicting knowledge frames and create mutual understanding among the actors involved (Brugnach and Ingram, 2012).

Contrary to what we hypothesized, uncertainty about the natural dynamics was not directly hampering Sand Engine project development. Instead, our observations imply that it is more important to manage the implications of the project on the activities of society than to cope with the incomplete knowledge or unpredictability of nature and its dynamics. Uncertainty about social implications can be a powerful tool to hamper project development and influence the actors involved. For instance, the aforementioned anti-Sand Engine action committee recognized the power of the uncertainties about recreational safety and drinking water quality. They attempted to actively use these health and safety issues to negatively influence the perception of the public and project actors, during public meetings and via the media. Moreover, the action committee was able to mobilize politicians in the Dutch parliament for their cause. Parliament members posed official questions about recreational safety (reviewed document 1; see Appendix A) and drinking water quality (reviewed document 2; see Appendix A), and even explicitly demanded to stop the project. The anti-Sand Engine action committee did not focus their efforts on the unpredictable effects of the natural dynamics on recreational conditions or the incomplete knowledge about effects on groundwater levels (uncertainties in the natural system). They specifically focussed on recreational safety and drinking water quality (uncertainties about the social implications of the Sand Engine), as it is more easy to influence the public opinion and impose a negative knowledge frame to project development actors when safety issues seem to be at stake.

Furthermore, our results show that uncertainty regarding technical issues is even less relevant than the uncertainty regarding nature and its dynamics. First, in the Sand Engine project, the number of uncertainties in the technical system is much lower than in the natural and social systems (see Table 2.4). Second, several interviewees declared that the project does not present any technological challenges as it is not innovative regarding its nourishment technology. As one of our interviewees stated:

> *"Technically, [the Sand Engine] is not very exciting. Sand nourishment, the Dutch can do that, right? But other parties as well. There is a lot of [technical expertise]. That is not what all the fuss is about… The specificity of this project is in speed, in cooperation and in [managing] the environment. [Those] are the real dynamics and uncertainties."*

2.6.2. How does the use of BwN principles change the policy arena?

Policy and project development fundamentally changes when using a BwN approach instead of a command-and-control approach. Current flood defence approaches typically focus on the relatively short term of 5-10 years (Van der Brugge et al., 2005) and are often based on building rigid structures – such as dikes – with a well-defined spatial scale. An interviewed expert addressed why people generally prefer such solutions:

> *"The need to get a hold on the dynamic world is translated into a static image of the world. A picture. Well, the world looks like this [and] that is reassuring. Hence, that leads to [choosing] a dike [as flood protection measure]."*

BwN changes this landscape of static pictures in a dynamic world, as ecological engineering designs involve larger scales than contemporary engineering (Odum, 1989). First, as BwN projects are driven by unpredictable natural dynamics, it is hard to define the exact length of the temporal scale of the project. Projects based on BwN principles will typically be long-term projects, such as the Sand Engine with an expected life span of 20-50 years. Second, the exact spatial scale of a BwN project is hard to define. BwN solutions generally use flexible materials, such as sand, which will adapt and distribute under the influence of natural dynamics without respecting human-defined administrative divisions, such as municipalities, provinces and even countries. An interviewee illustrated the increased complexity due to temporal and spatial scales with a metaphorical example:

> *"For Rijkswaterstaat, it is quite easy. They say: I only have to [assure] that there is sufficient sand in [the] coastal system… But the province and the municipalities – then you are already zooming in – say: 'it is in my interest that [the sand] does not come on my doorstep but on [another] doorstep'. And why do they say that? [They have] interests on a smaller scale and the short term. And the visitor of the beach: he looks at an even smaller scale… 'At my entrance of the beach, I want to [actually] see the beach'. Additionally, you have to link the interests on the different scales with each other. Well, that is just very complicated. That is thus the largest difficulty of the project."*

Moreover, the use of a BwN approach makes it more difficult to determine to what extent stakeholders should be involved during project development. First, while command-and-control solutions generally address a single water policy issue such as flood protection, BwN approaches integrate multiple disciplines and therefore have multiple goals. Due to the increasing number of goals, the number of interested stakeholders – each with their own knowledge frames – is likely to increase as well. Second, as the spatial scales of a project using BwN design principles are variable, the number of (non-) governmental parties that perceive to be in the sphere of influence of the project can be larger than in a command-and-control project. Furthermore, as a BwN solution has a variable temporal scale, government officials have to make decisions about projects of which the effects are unpredictable and might not be visible before the next election period. It seems logical that this consideration will affect the preferences of such government officials when comparing a project that uses BwN design principles and a well-defined command-and-control project, although it is not exactly clear in what way.

In short, evaluating a BwN solution based on its short-term effects on a fixed spatial scale – as project development actors are used to with the command-and-control flood defence approach – is less suitable given the large-scale characteristics of BwN projects. However, we observe that project development actors still tend to evaluate the Sand Engine project, which is based on BwN design principles, as if it was a command-and-control project. Fundamental changes are not yet fully taken into account. For instance, in the public debate about recreational safety, focus is on the short term – the effect on the *current* swimmer safety at the Sand Engine site – and limited attention is given to the equally-relevant effects in later years. Another example is that it was unacceptable for some local politicians that the Sand Engine might have effects on Scheveningen Harbour. However, regarding such effects, no guarantees can be given as the Sand Engine's behaviour is not constrained by human-defined administrative divisions. Furthermore, the uncertainty about drinking water quality was partially caused by the difficulty to determine which stakeholders to involve or not. The complaining stakeholder was not a participant in the Sand Engine project team or a project group during the Planning and Design phases. As a result, the stakeholder's input and concerns emerged at a late and thus rather inconvenient moment, leading to a situation of ambiguity.

2.6.3. Why did uncertainty not hamper project development in this case?

Contrary to what we hypothesized, we observe that none of the identified uncertainties – despite that project actors were anxious about several subjects – hampered project development in the Sand Engine case. Some additional studies were required to clarify particular issues – for instance, effects on drinking water quality – but in the end, no serious delays were caused by uncertainty. We argue that there are two main reasons that project development in this specific case was not hampered by uncertainty.

First, the governmental parties committed to the Sand Engine project formed a social coalition, which can be a powerful means to assure that one frame prevails over other – less desirable – frames (Kaplan, 2008). According to four interviewees, both actors inside and outside the project team perceived the Sand Engine as "an innovation that must become reality". One interviewee illustrated the consequences of this positivistic attitude:

> *"The lights were always on green. They did not want to be bothered by the things that we do not know… [On the other hand], if you could have addressed [those things] more accurately, that [would not automatically mean] that you would have decided not to construct [the Sand Engine]."*

Interviewees characterized Sand Engine project development as a relatively fast process, but also stated that it was not allowed to take any risks regarding individual or societal safety. However, the abovementioned statement of the interviewee suggests that some uncertainties might have received less-than-regular attention in project development.

Second, the Sand Engine case is a pilot project and has an experimental character that deviates from regular projects. A pilot status can be used as an insurance to failure, as it enables risk minimization and facilitates dealing with uncertainty (Vreugdenhil et al., 2010). For instance, creating opportunities for new recreational activities is a goal of the Sand Engine project. However, it was not specified which types of recreation or how many recreants should be attracted, which means we cannot accurately measure success or failure of the project regarding recreational development. Similarly, other project goals were also formulated rather nonspecific and difficult to measure. This implies that a high level of certainty is not required – virtually any possible outcome can be interpreted as successful – and thus, the effect of uncertainty is minimized.

Although uncertainty did not hamper project development in the Sand Engine case, our results are valuable for anticipated future developments regarding sand nourishments and projects based on BwN principles in the Netherlands. According to the Delta Commission (2008), the annual sand nourishment volume in the Netherlands needs to increase to a level of 85 million m^3 per year in the period until 2050. Moreover, BwN solutions are explicitly mentioned as the preferred approach to strengthen the Dutch coasts (Ministry of Infrastructure and the Environment, 2009). Hence, more large-scale sand nourishments with similar volumes and design principles as the Sand Engine – and thus, with similar public attention, opposition, actor behaviour and project development processes – can be anticipated in the near future. If such initiatives based on BwN principles no longer have the pilot status, it is well possible that their project development process will be hampered by uncertainties similar to those identified in this chapter.

2.7. CONCLUSIONS

Uncertainty is much more than a deficit of knowledge. This classic scientific interpretation of uncertainty – still commonly used in, for instance, engineering communities – does not capture the fundamental consideration that uncertainty gets meaning and value in project development via its social implications. In the policy arena, multiple actors with different knowledge frames and interests interact and aim to influence the process and each other’s frames (Brock and Durlauf, 2001). While managing uncertainty, bridging the gaps between these actors from different communities – such as engineers, politicians, scientists and the public at large – and creating mutual understanding about the subject at hand is far more important than reducing incomplete knowledge or increasing our control over the unpredictable systems to be managed. These findings are in accordance with recent other studies. For instance, Lach et al. (2005) conclude that managing ambiguous relationships becomes far more important than managing the uncertainties of the structures and routines in water management. However, the results from our study suggest that actors still tend to evaluate the Sand Engine, a project based on BwN design principles, as if it was a command-and-control flood defence approach.

New approaches for dealing with uncertainty are needed that can deal with all kinds of unforeseen developments (Walker et al., 2010), which can always be anticipated regarding the unpredictable nature of projects using BwN design principles. However, more importantly, fundamentally different approaches are needed to cope with ambiguity (Brugnach et al., 2011), as the standard responses to cope with uncertainty – information gathering and top-down management – are no longer sufficient (Koppenjan and Klijn, 2004). Strategies are needed to cope with the diverging knowledge frames and interests of stakeholders, because they have different roles and backgrounds. Increasing participation, cooperation and dialogues between stakeholders can be powerful tools in this respect (Brugnach et al., 2011; Brugnach and Ingram, 2012). Nevertheless, it is important to realize that ambiguity can have different backgrounds and characteristics and often has a relationship with other, knowledge-related uncertainties.

Simultaneously, we need to address the increased complexity of the systems to be managed when using a BwN approach. Existing knowledge frames need to adapt to the increasing uncertainty due to both changing temporal and spatial scales. Currently, this increasing complexity is still easily associated with an increase of potential health and safety risks. People tend to overestimate the probability of occurrence of events of which the potential consequences are easily imagined and severe (Thacher, 2009). Early communication with stakeholders is needed to create awareness about and acceptance of the fundamental differences between projects based on BwN design principles and the command-and-control flood defence approach. We anticipate that effectively coping with these differences and other uncertainties associated with the BwN approach will be a critical success factor for this promising new initiative in the field of water management.

3 UNCOVERING THE ORIGIN OF AMBIGUITY IN NATURE-INCLUSIVE FLOOD DEFENCE PROJECTS[2]

ABSTRACT

In this chapter, we aim to uncover the origin of ambiguity in flood defence projects using Building with Nature (BwN) design principles. BwN is a new approach in flood management which simultaneously integrates societal goals – such as flood safety and recreation development – with nature development goals by actively using natural dynamics and materials in the project's design. As BwN projects affect multiple stakeholders and several societal functions, participatory project development is of key importance to successfully implement these projects. In such a multi-actor decision-making process, a diversity of actors is involved, each of whom has its own view on the project based on their own interests, values, beliefs, backgrounds and past experiences. As a consequence, BwN projects are susceptible to be hampered by the presence of ambiguity, a kind of uncertainty that results from the simultaneous presence of multiple frames. For two BwN case study projects, we identified where the ambiguities potentially affecting project development resided, derived the different actor frames and addressed the attributes underlying these frames. Our main finding is that ambiguity in BwN projects seems to originate from a contradiction between the *beliefs* different actors held. Furthermore, our results suggest that – in the current practice of BwN projects – the scientific knowledge of experts is perceived as more legitimate than the local knowledge and experiences of lay actors, which implies that experts have a more powerful position in multi-actor decision-making. Thus, our research underlines the difficulty of bringing local knowledge and past experiences of lay actors into collective decision-making.

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[2] Another version of this chapter has been accepted for publication as: Van den Hoek, R.E., Brugnach, M., Mulder, J.P.M., Hoekstra, A.Y. Uncovering the origin of ambiguity in nature-inclusive flood infrastructure projects. Ecology and Society.

3.1. INTRODUCTION

Water systems have always challenged human communities, as the threat of flooding has never been far from society's doorstep. In the 20th century, flood defence was dominated by rigid structures – such as dikes, dams and storm surge barriers – which are intended to strictly regulate and control water systems. Although the application of rigid structures to prevent flooding has been a success in the recent past, the negative impact of such strategies on ecosystems and natural processes is often not properly taken into account in flood management (Richter et al., 2003). Over the years, there has been a growing emphasis on incorporating ecological values in water policy (Gleick, 2000). This is reflected in water management, where the paradigm is slowly changing towards more nature-inclusive approaches (Pahl-Wostl et al., 2011). Building with Nature (BwN) is such a new approach of nature-inclusive flood management in the Netherlands. Instead of using the described rigid structures which intend to strictly regulate and control water systems, BwN design principles aim to utilize natural dynamics (e.g., wind and currents) and natural materials (e.g., sediment and vegetation) for the realization of effective flood defence, while providing opportunities for nature development (De Vriend and Van Koningsveld, 2012). Because projects using BwN design principles simultaneously integrate societal goals – such as flood safety and recreation – with nature development goals, multiple actors with a diversity of backgrounds are either directly involved or affected. Thus, in order to establish successful initiatives and come up with solutions that are acceptable for all those actors, participatory project development is of key importance.

In participatory project developments, such as those proposed by BwN, decisions are made collectively, favouring the involvement of a diversity of actors from different sectors and levels (state, regional, municipal). The underlying rationale is that including a diverse range of actors can lead to a more integral and better accepted project development process (Bouwen and Taillieu, 2004; Pahl-Wostl et al., 2007a). However, despite its benefits, multi-actor decision-making processes can be complicated to reach and implement. One difficulty originates from the multiplicity of frames that may be simultaneously present in decision-making. In a multi-actor setting, each actor can frame the project differently, causing a situation of ambiguity in which it is no longer clear what the issues of concern and action paths are (Brugnach et al., 2011), hindering participation and collaboration among actors. This consideration suggests that paying attention to ambiguity and framing differences is of essential importance in nature-inclusive flood defence projects. This idea is also supported by the results presented in Chapter 2, which showed that the project development process of the Sand Engine – an innovative sand nourishment project based on BwN design principles – was susceptible to be hampered by ambiguity.

However, dealing with differences in framing is far from straightforward, as the resulting ambiguity can polarize the actors. While some ambiguity is a necessity for generating change and innovation, it has to be kept manageable (Dewulf et al., 2005) as framing differences can also result in intergroup conflict (Gray, 2004). This issue is illustrated by the Sand Engine project, where opponents of the initiative had a negative view on the project's effects on swimmer safety and demanded its cancellation. As the project team was not willing to fulfil this request, the conflict even ended up in the Dutch parliament: a large political party supported the opponents, posed critical questions and demanded the immediate cancellation of the initiative (see Chapter 2). Although the project was eventually implemented successfully, this incident clearly illustrates the importance ambiguity can have in the development of flood defence projects using BwN principles. Moreover, it points to the need to identify the origin of the underlying framing differences, to develop better strategies for dealing with ambiguity and thereby prevent unnecessary cost overruns, delays or cancellation of promising initiatives.

The goal of this research is to investigate the origin of ambiguity in flood defence projects using BwN design principles. To this end, we studied the framing differences that emerged between the project development team and the stakeholders in two different BwN projects, namely the Sand Engine Delfland and the Safety Buffer Oyster Dam. Our analysis focused on identifying the differences that existed between the frames held by individual actors during project development. We pay particular attention to conflicting stakeholder interests, diverging values and beliefs, different backgrounds and past experiences as triggers of framing differences that may lead to ambiguity. For both aforementioned case studies, we performed interviews with key project actors, attended (public) project meetings and studied project documents as supporting material. After the data collection, we identified which ambiguities were most important for the case study project's development process, characterized the individual actors' frames regarding these ambiguities and identified the actor attributes underlying these frames.

The remaining part of the chapter is structured as follows. In Section 3.2, we define the concepts of ambiguity and frames, and identify various attributes that may influence the way actors frame reality. Thereafter, we discuss our methods (Section 3.3) and provide the results of our two case study projects (Sections 3.4 and 3.5). In Section 3.6, we discuss from which actor attributes the ambiguity in our case studies seems to originate and the implications our results have regarding strategies for dealing with ambiguity. Finally, we provide the main conclusions of our study.

3.2. FRAMES, FRAMING AND AMBIGUITY IN DECISION-MAKING

A frame refers to a sense-making device that mediates the interpretation of reality (Weick, 1995). As such it indicates what is relevant for an actor, or a group of actors, regarding a decision issue or events. By framing, a decision issue or an event acquires meaning, drawing the limits into what is the problem that needs to be decided upon, how it is defined and who is part of the decision (see Schön and Rein, 1994; Benford and Snow, 2000; Dewulf et al., 2009, for reviews on frames and framing processes). Actors' frames may diverge from one another, so in a decision-making process with multiple actors involved, the simultaneous presence of different but equally sensible frames is unavoidable. When these frames are incompatible, they can cause a specific kind of uncertainty called ambiguity which indicates that there are different possible, yet equally sensible, interpretations of a problem situation (Brugnach et al., 2008; 2011).

As illustrated in Section 3.1, a situation of ambiguity can be a major problem in decision-making as it can easily result in a state of indecisiveness or even conflict. The relevant dimension of ambiguity is something ranging from unanimous clarity to total confusion caused by too many people voicing different but still sensible interpretations (Dewulf et al., 2005). Different facts can mean different things for different actors, different issues can be held as relevant facts and different solutions can be favoured (Schön and Rein, 1994; Dewulf et al., 2004). Although similarities between actors and their preferences will probably contribute to avoid ambiguity, completely shared meaning and views are not required in multi-actor decision-making. Donnellon et al. (1986) argue that so-called equifinal meaning is sufficient: interpretations that are dissimilar but that have similar behavioural implications. If there is sufficiently shared understanding among actors, they have a common ground to come to a collective action or decision.

3.2.1. Actor attributes related to frames

Dewulf and Bouwen (2012) elaborate on the topic of framing differences and define issue framing as "arranging and rearranging the elements of an issue such that its meaning is altered. [This is] a process which involves selecting certain issue elements as part of the frame while leaving out others and putting particular issue elements into focus while leaving only a marginal role for other elements" (Dewulf and Bouwen, 2012). In short, this implies that individual frames can differ at a particular point in time when a focal element of one actor's frame challenges or conflicts with a focal element of another actor's frame with whom he or she interacts. For this research, we performed an extensive literature review to identify specific elements or attributes which several authors mention as playing an important role in framing processes and the formation of individual actors' frames.

Interests – the ambitions or goals of an actor and/or his organization – affect the framing process. Schön and Rein (1994) address that there is a reciprocal, but nondeterministic, relationship between an actor's frames and interests. Hence, while interests influence the way we frame an issue, frames can also influence our interests. In their studies on social movements organizations (SMOs), Snow et al. (1986) and Benford and Snow (2000) also discuss the connection between framing and interests, as they argue that creating a shared interest is a proper strategy to align frames among the SMO's participants and potential new SMO members.

The values and beliefs of an actor influence how he or she frames an issue (Benford and Snow, 2000; Nisbet and Mooney, 2007; Brugnach and Ingram, 2012). Values reflect an actor's sense of right and wrong and what he holds as important, while beliefs are propositions or premises an actor holds to be true. Hoekstra (1998) concludes that the perspectives actors hold in controversies in the field of water resources management differ due to their underlying basic values, beliefs and assumptions. Dewulf et al. (2005) discuss that differing beliefs can inform very different ways to make sense of an issue and can thus lead to different frames. Renn et al. (2011) address the topic of ambiguity and state that it refers to the presence of multiple values.

Personal backgrounds and experiences shape the way we frame (Bouwen and Tailleu, 2004; Gray, 2004). Actors with a background in either the natural or the social sciences can frame an issue rather differently (Dewulf et al., 2005). Furthermore, highly personal experiences – which are part of a personal subjective history – can inform different ways of making sense of a situation (Weick, 1995). Moreover, even if actors supposedly share the same experiences, they may still use different repertoires to make sense of what is going on (Brummans et al., 2008). Gamson and Modigliani (1989) and Nisbet (2009) discuss the role of the media in framing and state that in order to make sense of policy discussions, the audience integrates the frame provided by the media with its own pre-existing interpretations based on, for instance, personal experiences.

Frames can also derive from the societal position of an actor (Dewulf et al., 2005; Pahl-Wostl et al., 2007a; 2007b). In a multi-actor decision-making process, an actor can yield power from his specific position, by holding specific knowledge or from having a good reputation. Kaplan (2008) states that one frame can prevail over another if actors can gain power by supporting the frame of more powerful actors. De Boer et al. (2010) argue that actors with more power have more control over frames that are being used. Carragee and Roefs (2004) address that the role of power in framing is often neglected, while it is in fact a key issue. Furthermore, framing can be influenced by the political position of an actor. Framing differences can originate out of different levels of government, because of differences in electorate scale and responsibility (Dewulf et al., 2005). As Brugnach et al. (2011) state, ambiguity can occur at different political levels, and preferences at the regional policy level may (partly) contradict local and/or national policies.

In short, the results of our literature review suggest that the way in which an actor frames an issue is influenced by that actor's interests, values, beliefs, background, previous experiences and (societal or political) position. These attributes influence how people interpret reality and the type of interactions in which they engage. In this chapter, we focus on an analysis of how ambiguity in decision-making originates from a difference between the frames of individual actors. Building on the previously discussed work of Dewulf and Bouwen (2012), we suggest that the individual actor attributes can be interpreted as issue elements, of which some may contribute to an actor's frame regarding a certain issue and others may not. If the actors involved in a multi-actor decision-making process incorporate conflicting elements in their frames, the resulting framing difference can cause a tension potentially leading to a situation of ambiguity.

3.3. METHODS

As mentioned in Section 3.1, we study two flood defence projects based on BwN design principles in this chapter, namely the Sand Engine project and the Safety Buffer Oyster Dam project. We selected these specific projects because these are two of the most well-known examples of BwN projects in the Netherlands. Future BwN projects are likely to resemble these two initiatives. Additionally, we already had existing contacts with people involved in the projects.

For both case studies, we used interviews and observations as our main data collection methods. For the Sand Engine project (see Section 3.4), we first attended three public information meetings. During these meetings, stakeholders (i.e., those affected by the project who are not part of the project team) and the general public had the opportunity to pose critical questions, express their appreciation or concerns about the project and to file complaints. Minutes of these meetings were made and studied to understand the viewpoints of the stakeholders. Second, in April and May 2011, we interviewed six actors associated with the project team – three (former) members of the Sand Engine project team, one member of the project steering group and two experts involved in the Environmental Impact Assessment (EIA) and modelling – about uncertainty during project development. The semi-structured interviews were conducted in the Dutch language, took between one and two hours, and were recorded and transcribed. A standardized interview protocol with seven open-ended main questions and several follow-up questions was used. During the interviews, the interviewees were invited to elaborate on their definition or understanding of uncertainty. Thereafter, the interviews continued with an iterative process of identifying uncertainties and elaborating on the uncertainty's relevance for the Sand

Engine's development process. For this chapter, we specifically examined the ambiguities we identified in the project and did not take other kinds of uncertainty into account.

For the Safety Buffer Oyster Dam project (see Section 3.5), first, we attended a meeting of the project's knowledge development team in March 2012. This meeting was recorded and transcribed. The various discourses between actors were analysed to identify the project's main discussion topics and framing differences. Second, in April 2012, we attended a meeting of the project's sounding board, consisting of multiple stakeholders. During this meeting, the project team informed the sounding board on the progress of the project's development and invited them to respond to three alternative project designs. The meeting was not recorded, but minutes were made and studied to identify the main discussion topics and framing differences. Third, we conducted four interviews with actors associated with the project team (performed by two interviewers) and nine interviews with stakeholders (performed by one interviewer) in July, August and September 2012. During three of these interviews, two respondents were interviewed instead of one. Hence, in total, we spoke to six project team actors (three at the executive and three at the project level) and ten stakeholders. The semi-structured interviews were conducted in the Dutch language, took about one hour, and were recorded and transcribed. Two standardized interview protocols (one for the project team actors and one for the stakeholders) with up to fourteen open-ended main questions were used. During the interviews, the interviewees were invited to elaborate on those project topics that were most important for them, but that also caused the hardest discussions within the project due to the existence of diverging viewpoints.

For both cases, our analysis started with identifying which ambiguities were most important by considering two aspects: the ambiguity's potential impact and its project-wide relevance for the actors. During the interviews, we invited the interviewees to elaborate on the impact each ambiguity identified could have on the project's development process (e.g., can this ambiguity lead to substantial cost overrun, a substantial delay or even project cancellation?). Thus, we were able to assess whether the ambiguity was important (e.g., potentially leading to a significant delay of six months) or not important (e.g., only leading to a budget increase of €100). Moreover, after finalizing the series of interviews and meetings, we assessed during which interviews and meetings a particular ambiguity was brought up. If an ambiguity was brought up during several interviews and meetings, this clearly implies that the ambiguity has a project-wide relevance according to multiple actors and is not just the 'favourite subject' of one actor.

After identifying the most important ambiguities, we determined – based on the interview data and our observations at the meetings – which actors were holding different frames regarding each of these ambiguities. The individual frames of these actors were identified by carefully studying the interviews we had with them, specifically by assessing how they interpreted the particular subject the ambiguity concerned. We used the interviews with other actors, observations of the meetings and written documentation – such as project documents – as supporting material for identifying the frames, because these data sources often provided detailed additional information about the ambiguities and the frames of the individual actors. Thereafter, we identified the underlying actor attributes of the frames from the interview material, observations from meetings, project documents, information about the organization the interviewee is representing and common sense. For each attribute, we performed this identification by explicitly examining the research questions we propose in Table 3.1. These research questions were formulated based on the theory that we discussed in our literature review of the attributes. By answering these specific research questions, we were able to accurately identify each attribute for each actor. Finally, we compared the frames the different actors hold regarding the ambiguities, compared the attributes of the actors involved, and determined which of these attributes are conflicting and which are not conflicting. Thereby, we elaborated a deeper understanding of why the individual frames differ and can lead to ambiguity in decision-making.

To further clarify the methods discussed above, we provide Appendix C with a detailed example of how we identified the individual actors' frames and attributes from our research data. We extensively elaborate in Appendix C how we came to the results discussed in Table 3.5 (concerning one of the important ambiguities identified in the Safety Buffer case).

Table 3.1 – Questions posed to identify actor attributes regarding a specific discussion topic

Attributes – Questions
Interests – What are the main ambitions or goals of the actor?
Values – Which moral principles does the actor hold as important regarding the topic? Which criteria or boundary conditions are used to evaluate the topic?
Beliefs – Which propositions or premises does the actor hold to be true regarding the topic (even if there is no or contradictory evidence)?
Background – Which expertise, education or specific knowledge does the actor have regarding the topic? Is the actor an expert or a layman regarding the topic?
Experiences – From which (personal) historical situations does the actor draw to interpret the topic?
Actor position – What is the societal or political position of the actor regarding the topic compared to other relevant actors, in terms of power or influence?

3.4. CASE STUDY I: SAND ENGINE DELFLAND

3.4.1. Case description

Over the last centuries, the sandy Holland coast of the Netherlands has been continuously retreating (see Van Koningsveld et al., 2008 for an overview of the historical development of the Dutch coast). The balance between the supply of sediment from fluvial and marine sources, and the demand for sediment created by sea level rise is negative (Mulder et al., 2011). To tackle the problem of coastal retreat, the Dutch government implemented the Dynamic Preservation policy: the sandy coastline has to be maintained at its 1990 position by performing periodic, relatively small-scale, sand nourishments (Hillen and Roelse, 1995). Currently, the annual sand nourishment volume for the Dutch coast has a target value of 12 million m^3/year, while an increase to at least 20 million m^3/year is needed to preserve the sediment balance of the Dutch coast (Mulder et al., 2011).

Sand Engine Delfland (in Dutch: Zandmotor) is an innovative, 21.5 million m^3 sand nourishment pilot project near Ter Heijde in the Dutch province of South Holland (Figure 3.1). After a project development process of approximately three years, the Sand Engine peninsula was constructed between March and July 2011. It is a large-scale experiment to test the feasibility of mega-sand nourishments, which are anticipated to be more cost-effective and less disturbing for the natural environment due to their long expected lifespan of 20-50 years. The Sand Engine is based on BwN design principles, as the large amount of sand nourished will spread along the coast by the natural dynamics (waves, currents and wind), causing the coast – both beach area and dunes – to expand in a rather natural way.

Figure 3.1 – Sand Engine Delfland (https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt)

Currently, the Sand Engine is in the post-construction monitoring phase. Due to its pilot status, the project will be monitored extensively to study whether mega-sand nourishments are capable of combining benefits for society (for instance, coastline maintenance and increased area for beach recreation) and development of the natural system (for instance, increased dune habitat for flora and fauna). Model calculations of various alternative Sand Engine designs have contributed to decision-making by estimating morphological effects and changes in important indicators, especially coastline maintenance and dune development (Mulder and Tonnon, 2010). However, since weather conditions are highly unpredictable, especially over a 20-50 year period, these estimations involve high levels of uncertainty. As a consequence, project development was susceptible to be hampered by several important framing differences regarding the impact of the Sand Engine.

3.4.2. Results

We identified three important ambiguous issues in the development process of the Sand Engine project between the project team and stakeholders. Although the project was successfully implemented in 2011, all ambiguities identified concerned issues which – according to multiple interviewees – could have hampered the Sand Engine project development process or might even have led to its cancellation (see Chapter 2).

The first ambiguity – between the Sand Engine project team and the action committee 'Stop the Sand Engine' – concerned the effect of the Sand Engine on swimmer safety (Table 3.2). This discussion contains two main themes: **(1)** the effects of the Sand Engine peninsula on the *physical swimming conditions* – such as flow velocities – and **(2)** the risk that this will result in an *unsafe situation and accidents*. While the project team draws on its background as an expert regarding sand nourishments to evaluate the issue of swimmer safety and presumes its morphological predictive models to be trustworthy, the action committee consists of local residents with local knowledge based on personal swimming experiences. Both actors share the value that they have a social responsibility for the safety of human beings in the vicinity of the Sand Engine. Furthermore, regarding the physical conditions in the coastal zone, both opposing parties had the same belief that these conditions are unpredictable to a large extent. However, regarding the swimmer safety situation, we identified a key framing difference. The project team had the positive frame that the Sand Engine is an innovative and socially acceptable pilot project. This frame is mainly based on the belief that the project will not lead to unsafe situations if proper precautionary measures are taken, such as additional training for beach life guards and prohibiting swimming in the vicinity of the Sand Engine. However, the action committee held a more sceptical frame: the Sand Engine's construction is socially unacceptable as their belief is that it will have an adverse impact on swimming conditions. In the end, the project team has a more powerful position as they were supported by the national government, while the action committee was only supported by one political party.

Table 3.2 – Sand Engine ambiguity 1: swimmer safety

AMBIGUITY ABOUT THE EFFECTS OF THE SAND ENGINE ON SWIMMER SAFETY

Sand Engine project team	• Frame: the Sand Engine is an innovative and socially acceptable pilot project. The project is vital in order to learn about possibilities for future coastal maintenance
From which attributes does this frame originate?	• Interest: to learn about how to improve coastal maintenance, while simultaneously creating opportunities for nature and recreation • Value: social responsibility for human safety • Belief: the physical conditions of the coastal zone are unpredictable • Belief: the Sand Engine will not cause unsafe swimming conditions if proper precautionary measures are taken • Belief: morphological models generate trustworthy knowledge and predictions • Background: expert regarding flood defence and sand nourishments • Actor position: powerful actor supported by the government
Action committee	• Frame: the Sand Engine is a socially unacceptable initiative with adverse effects
From which attributes does this frame originate?	• Interest: to protect recreational safety, by preventing Sand Engine implementation • Value: social responsibility for human safety • Belief: the physical conditions of the coastal zone are unpredictable • Belief: accidents are a certainty due to negatively influenced swimming conditions • Background: local residents of the project area • Experience: in the near-shore coastal zone, unexpected current conditions can occur • Actor position: less powerful coalition supported by one of the larger political party

The second ambiguity concerned the effect of the Sand Engine on beach recreation conditions (Table 3.3). Specifically, there was a discourse between the project team and the action committee on the risk that dumped World War II ammunition would end up in the nourishment sand, posing a potential threat to beach tourists. The project team had its previously discussed positive frame, based on the belief that the construction of the Sand Engine will not lead to unsafe beach conditions. For instance, the project team draws on their experiences that constructors work with high-quality dredging ships equipped with special anti-ammunition grids and that previous nourishment did not have noteworthy ammunition incidents. However, the frame of the action committee was also quite sceptical regarding the risks of ammunition, as they held the belief that it is a certainty that accidents will happen. This viewpoint was further supported by an informal report of an amateur military historian, which discusses the risks and some past experiences with ammunition on the beach.

Table 3.3 – Sand Engine ambiguity 2: ammunition on the beach

AMBIGUITY ABOUT THE EFFECTS OF THE SAND ENGINE ON BEACH RECREATION CONDITIONS

Sand Engine project team	• Frame: the Sand Engine is an innovative and socially acceptable pilot project. The project is vital in order to learn about possibilities for future coastal maintenance
From which attributes does this frame originate?	• Interest: to learn about how to improve coastal maintenance, while simultaneously creating opportunities for nature and recreation • Value: social responsibility for human safety • Belief: the Sand Engine will not lead to unsafe beach conditions • Background: expert regarding flood defence and sand nourishments • Experience: dredging companies use ships with anti-ammunition grids • Experience: during regular nourishments similar to the Sand Engine, there were no noteworthy incidents with ammunition • Actor position: powerful actor supported by the government

Action committee	• Frame: the Sand Engine is a socially unacceptable initiative with adverse effects
From which attributes does this frame originate?	• Interest: to protect recreational safety, by preventing Sand Engine implementation • Value: social responsibility for human safety • Belief: accidents are a certainty as nourishment sand contains ammunition • Background: local residents of the project area • Experience: ammunition – which is occasionally found on the beach – can be dangerous • Actor position: less powerful coalition supported by one of the larger political party

The third ambiguity – between the Sand Engine project team and a drinking water stakeholder – concerned the effect of the artificial peninsula on ground water levels and drinking water quality (Table 3.4). Both actors share the value that they have a social responsibility for the health and safety of humans. According to several interviewees and as stated in the project's Environmental Impact Assessment, the positive project team frame – the project is socially acceptable – was based on the belief that the presence of the Sand Engine would not have substantial effects on ground water levels and thus would have no impact on drinking water quality, if some minor precautionary measures are taken. Due to strict time constraints, the project team preferred a fast, rather limited assessment of the effects and had the belief this was sufficient. However, the drinking water stakeholder was not satisfied, held the belief that the initiative would have a substantial impact and demanded additional research. They had the frame that the Sand Engine is an promising initiative, which might be acceptable after an accurate assessment of its impacts. While the drinking water stakeholder has the expert background regarding this specific topic, the project team is not an expert regarding drinking water. Moreover, the project team has a less powerful actor position than the drinking water stakeholder regarding this specific issue. The drinking water stakeholder was an essential and necessary partner for the realization of the Sand Engine project, because they were assigned with specific post-implementation maintenance and monitoring tasks.

Table 3.4 – Sand Engine ambiguity 3: drinking water

AMBIGUITY ABOUT THE EFFECTS OF THE SAND ENGINE ON GROUND WATER LEVEL / DRINKING WATER QUALITY

Sand Engine project team	• Frame: the Sand Engine is an innovative and socially acceptable pilot project. The project is vital in order to learn about possibilities for future coastal maintenance
From which attributes does this frame originate?	• Interest: to learn about how to improve coastal maintenance, while simultaneously creating opportunities for nature and recreation • Value: social responsibility for human health and safety • Belief: the Sand Engine will not have substantial effects on the ground and drinking water, if some minor precautionary measures are taken • Background: not a specific expert regarding drinking water • Actor position: less powerful actor as it requires the cooperation of the drinking water stakeholder for the project's maintenance and monitoring

Drinking water stakeholder	• Frame: the Sand Engine is an promising initiative, which might be acceptable after an accurate assessment of its impacts
From which attributes does this frame originate?	• Interest: to supply safe drinking water of high quality to society • Value: social responsibility for human health and safety • Belief: the Sand Engine will have substantial effects on ground water levels and thus is a threat for the quality of the drinking water supply • Background: experts regarding drinking water • Actor position: powerful actor as it is a required project partner

3.5. CASE STUDY II: SAFETY BUFFER OYSTER DAM

3.5.1. Case description

After the dramatic 1953 flooding of the South Western provinces of the Netherlands (causing the death of over 1,800 people), the Dutch government commissioned the so-called Delta Committee to come up with a plan to improve the Dutch flood defence system to prevent future disasters (Kabat et al., 2009). The committee created a Delta Plan, which consisted of major dike improvements and the closure of several large tidal inlets. Over the years, the plans of the Delta Committee were implemented and became a world-wide premium example of flood protection. However, while new disasters have been prevented successfully, the Delta Works did have some (partly unexpected) negative side effects. Due to the closure of the Eastern Scheldt estuary by the Eastern Scheldt Storm Surge Barrier, the tidal movement in the estuary was reduced with approximately 25% (Vranken et al., 1990; Mulder and Louters, 1994). Furthermore, the inflow of fresh sediment from the North Sea into the water system of the Eastern Scheldt is negligible due to the storm surge barrier, while the redistribution of sediment towards the estuary's channels remains constant (the so-called Sand Hunger problem). This imbalance between the Eastern Scheldt morphology and hydrodynamics leads to an internal redistribution of sediments, causing the erosion of the existing salt marshes and mudflats, and thus the loss of valuable ecological habitat and natural foreshore protection.

The Oyster Dam is a so-called compartment work in the Eastern Scheldt (Figure 3.2). One of its main functions is to decrease the total area of the Eastern Scheldt in order to increase the tidal difference of ebb and flood tide, that had dropped after construction of the storm surge barrier. Thus, the Oyster Dam partly is a countermeasure for the negative influence of the storm surge barrier on the tidal movement. Additionally, it functions as a flood protection work for the hinterland. Due to the construction of the Oyster Dam and the Philips Dam – a second compartment work in the Eastern Scheldt – the decrease of the tidal difference was limited to approximately 10% compared to the tidal difference before the construction of the Eastern Scheldt Storm Surge Barrier (Mulder and Louters, 1994; Eelkema et al., 2012). However, the described Sand Hunger problem still remains unsolved.

Figure 3.2 – Oyster Dam (https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt)

Currently, the Oyster Dam requires maintenance, as the stone layer on its slope has to be replaced. This maintenance work opened a window of opportunity for the pilot project Safety Buffer Oyster Dam (in Dutch: Veiligheidsbuffer Oesterdam): a sand nourishment of 425.000 m^3 in front of the dam to reduce future maintenance efforts of the dam, while simultaneously restoring one of the eroded tidal flats to its historical state. Furthermore, an erosion-preventing artificial oyster reef will be constructed north of the planned nourishment area. Both measures are clear-cut examples of the application of

BwN design principles: the initiative copes with the effects of the Sand Hunger problem using natural materials and dynamics, while concurrently strengthening the foundation of the Oyster Dam. The nourishment works were finished in October 2013. Nevertheless, a successful outcome of the pilot project has been far from certain due to the active involvement of multiple stakeholders and a project team that consists of two Dutch governmental agencies and a (non-governmental) environmental interest organization, who all have different basic interests and preferences.

3.5.2. Results

We identified two important ambiguous issues in the development process of the Safety Buffer Oyster Dam project between the project team and two stakeholders. Although the stakeholders have dropped their opposition in the meanwhile and now accept the development of the project, the initial ambiguity could have significantly hampered the Safety Buffer's development process. An official appeal against the project could have delayed the initiative for at least six months.

The first ambiguity – between the Safety Buffer project team and the economically vital oyster sector – concerned the effects of the Safety Buffer nourishment on the oyster beds that are located in the vicinity of the project area (Table 3.5). Although shellfish are able to filter a certain amount of sediment entering their gills, an excess will surely suffocate these organisms. During a recent nourishment pilot project, a mussel bed located nearby experienced some minor damage. Therefore, both the mussel and oyster sector initially framed the Safety Buffer nourishment as an unacceptable initiative, as they held the belief that large quantities of sand could damage their cultivated shellfish beds. While several interviewees – including a representative from the mussel cultivation sector – indicated that they currently are confident that the nourishment will not have any adverse impacts, the oyster sector still holds the strong belief that the Safety Buffer nourishment is potentially harmful. However, the oyster sector – contrary to the project team – does not have an expert background regarding flood management. Moreover, the project team holds the value to protect stakeholder interests and formulated the following project boundary conditions: **(1)** the Safety Buffer is not allowed to have any negative effects on stakeholders and **(2)** all unforeseen damage has to be fully compensated. Thus, the project team has the positive frame that the Safety Buffer is a socially acceptable project, as they intend to fulfil the boundary conditions and hold the belief that the expert judgment of the project's effects is trustworthy. Furthermore, the project team also refers to recent successful experiences with nourishment pilots in the Eastern Scheldt. Regarding the difference with the oyster sector, the actor positions seem to be rather equal: both the project team and the oyster sector indicated that they do not have sufficient power to overrule the other actor.

Table 3.5 – Safety Buffer Oyster Dam ambiguity 1: oyster sector

AMBIGUITY ABOUT THE EFFECTS OF THE SAFETY BUFFER NOURISHMENT ON OYSTER BEDS

Safety Buffer project team	• Frame: the Safety Buffer is an innovative and socially acceptable pilot project. The project is vital to learn about possibilities for future dike maintenance and dealing with the effects of the Sand Hunger
From which attributes does this frame originate?	• Interest: to learn about how to improve dike maintenance, while simultaneously aiming to improve the Eastern Scheldt estuary's natural, recreation and user quality • Value: social responsibility for the well-being of the Eastern Scheldt estuary • Value: responsibility not to harm external stakeholders' interests • Belief: the Safety Buffer will not have adverse effects on the shellfish beds • Belief: expert judgment yields trustworthy predictions • Background: expert regarding flood defence and sand nourishments • Experience: positive results of nourishment pilots in recent years • Actor position: although a powerful actor supported by the government, they claim to be unable to overrule the economically vital oyster sector

Oyster sector	• Frame: the Safety Buffer is an unacceptable initiative due to its potential adverse impacts on the oyster sector, although the degrading quality of the estuary is acknowledged
From which attributes does this frame originate?	• Interest: to maximize the profit of the oyster sector • Value: social responsibility for the well-being of the Eastern Scheldt estuary • Belief: the Safety Buffer will almost certainly have negative effects on the oyster beds • Background: economic users of the area, non-experts regarding sand nourishments • Experience: during a previous pilot, a mussel bed suffered some minor damage • Actor position: economically vital actor, although without formal power to prevent project implementation

The second ambiguity – between the Safety Buffer project team and an environmental interest group – concerned the effects of the Safety Buffer nourishment on the benthic organisms currently living in the soil of the existing tidal flat (Table 3.6). Similar to the Sand Engine framing difference on swimmer safety, this discussion contains two main themes: **(1)** the effects of the nourishment on the *living conditions of the benthic organisms* and **(2)** the *acceptability of the implementation* of a project with a major impact on those living conditions. Both actors share the value that the well-being of the Eastern Scheldt system is important. Furthermore, regarding the living conditions, both opposing parties had the same belief: most benthic organisms living in the soil of a nourished area will die. However, regarding the acceptability of the project, there was a key framing difference. The project team has the frame that the project is acceptable, based on the beliefs that the quality of the nourished tidal habitat improves in the future and that valuable knowledge is generated for future initiatives to preserve the Eastern Scheldt system. Initially, the environmental interest group had a quite different view on the acceptability of the project. Although they acknowledge that measures are needed to cope with the effects of the Sand Hunger, the group argued that it is unacceptable to nourish large quantities of sand on top of the benthic organisms. This frame was mainly based on the incorrect presumption that the total area of the existing tidal flat would be nourished. However, the project team – an expert in sand nourishment designs – intended to only nourish half of the existing tidal flat and use natural dynamics to gradually spread the sand towards the other part of the tidal flat. Furthermore, experiences with recent nourishment pilots in the Eastern Scheldt show that the benthic organisms reclaim their habitat within due time. Regarding this specific issue, the actor positions are rather unclear. Although the project team is powerful and supported by the government, the environmental interest group is an independent actor that can appeal against initiatives that discomfort them.

Table 3.6 – Safety Buffer Oyster Dam ambiguity 2: acceptability (benthic organisms)

AMBIGUITY ABOUT THE ACCEPTABILITY OF THE SAFETY BUFFER NOURISHMENT (BENTHIC ORGANISMS)

Safety Buffer project team	• Frame: the Safety Buffer is an innovative and socially acceptable pilot project. The project is vital in order to learn about possibilities for future dike maintenance and dealing with the effects of the Sand Hunger
From which attributes does this frame originate?	• Interest: to learn about how to improve dike maintenance, while simultaneously aiming to improve the Eastern Scheldt estuary's natural, recreation and user quality • Value: social responsibility for the well-being of the Eastern Scheldt estuary • Belief: benthic organisms currently living in the nourished area will die, but the tidal flat habitat will improve in the future • Belief: implementing the preferred design – partially nourishing the tidal flat – will yield knowledge that can be used for future initiatives • Background: expert regarding flood defence and sand nourishments • Experience: positive results of nourishment pilots in recent years • Actor position: powerful actor supported by the government
Environmental interest group	• Frame: implementation of the Safety Buffer is unacceptable, because of its initial adverse impacts on the natural environment
From which attributes does this frame originate?	• Interest: to protect the existing natural environment • Value: social responsibility for the natural environment • Belief: the benthic organisms currently living in the nourished tidal flat area will die • Belief: the full tidal flat area – not just a part – will be nourished • Background: laypersons regarding sand nourishments • Actor position: independent actor that can appeal against the project, potentially causing a delay of six months

3.6. DISCUSSION

In this section, we first discuss which of the actor attributes seems to be the conflicting focal element from which the ambiguity in our case studies originates. Second, we discuss that an actor's background seems to influence the perceived legitimacy of his or her viewpoint regarding the ambiguity. Finally, we elaborate what these two findings imply for how ambiguity is and should be coped with in our case study projects.

3.6.1. From which actor attributes does the ambiguity originate?

In Section 3.4 and 3.5, we identified five ambiguous issues which could have potentially hampered the development of our two BwN case study projects. Despite that these five ambiguities all concern a different issue, our results suggest a distinct similarity regarding the underlying actor attributes leading to ambiguity: the *beliefs* of the actors involved are contradictory. In terms of the discussed work of Dewulf and Bouwen (2012), the actor attribute *beliefs* seems to be the conflicting focal element from which the ambiguity resides.

Regarding both the ambiguities about swimmer safety and beach recreation conditions, the Sand Engine project team's positive frame is primarily based on the beliefs that **(1)** the project will not cause unsafe recreational conditions if proper precautionary measures are taken and that **(2)** morphological models provide trustworthy predictions for these conditions. The action committee's sceptical frame is based on the belief that accidents are a certainty due to negatively influenced swimming conditions. The ambiguity between the Safety Buffer project team and the oyster sector was also a contradiction of beliefs. Whereas the project team's positive frame is based on the beliefs that the Safety Buffer will not have adverse effects on the shellfish beds and that expert judgment provides trustworthy predictions, the oyster sector holds the belief that the Safety Buffer almost certainly has adverse impacts on their cultivated shellfish beds. The second Safety Buffer ambiguity – about the acceptability of the project despite initial negative impacts on benthic organisms – was caused by the incorrect presumption (i.e., a belief) of the environmental interest group that the total area of the tidal flat would be nourished. However, the project team's positive frame is based on the belief that their well-considered preferred design has limited impacts on the existing benthic organisms and improves their habitat in the future.

The ambiguity about the effect of the Sand Engine on drinking water safety is a special case, because – contrary to the other four ambiguous issues – the project team is not the actor that holds the most powerful position regarding this specific issue. Nevertheless, also in this special case, the beliefs of the actors involved are contradictory. The Sand Engine project team held a strong belief that the effects on the ground and drinking water were negligible, although there was only limited knowledge available. However, the drinking water stakeholder – an expert regarding this specific issue – demanded an additional extensive impact assessment, as their belief was that the project might have substantial effects on the quality of the drinking water supply.

The ambiguity in project development does not seem to originate from conflicting *values* or *interests* of the actors involved. Thacher (2001) suggests that, when particular actors aim to collaborate, problems often occur due to a conflict over differing values. However, while this may be generally true, in the two cases we studied, the project teams and the stakeholders share similar *values*, such as the social responsibility for human safety or the natural environment. As these moral principles are collectively shared, this implies that ambiguity in the project development of our cases does not originate from conflicting values. *Interests* is yet another attribute from which ambiguity could originate, because in the field of (intergroup) conflict research, diverging and incompatible interests, goals and ambitions have been a main focus of attention (see e.g., Campbell, 1965; Lewicki et al., 1992; Bornstein, 2003). However, in the specific cases we studied, we observe that the interests of the actors involved are dissimilar but not contradictory. This consideration suggests that, regarding the interests held by the different parties, there is a situation of equifinal meaning (sensu Donnellon et al., 1986), a common ground for the actors involved. In the Sand Engine case, the action committee's interest is to protect the safety of local swimmers and beach recreants, whereas the drinking water stakeholder is responsible for the quality of the drinking water supply. In the Safety Buffer case, the oyster sector defends its economic interests, whereas the environmental interest group's interest is to protect the existing natural environment. The main interest of the two project teams involved is to learn about how to improve the current flood defence practices, while simultaneously creating opportunities for users of the area, the natural environment and recreation. This project team interest is not precisely the same as the stakeholders' interests, but it is also clear they do not interfere. Hence, we argue that, although the interests of the actors involved are dissimilar, they do not seem to be the conflicting focal element from which the ambiguity in our case studies originates.

3.6.2. Whose beliefs seem to be perceived as more legitimate?

While we find that the ambiguity in our two case studies seems to originate from a difference between the beliefs of the actors, our results reveal that there is yet another actor attribute that seems to influence the perceived legitimacy of those beliefs, namely the actor's *background*. For each of the five ambiguous issues identified, we observe that one actor has an expert background regarding the issue and the other actor is a (group of) layperson(s). While the expert's previous *experiences* seem to be perceived as a legitimate source of knowledge, the experiences and stories of the lay actor are often not taken into account and seem to be considered as less legitimate.

Regarding the Sand Engine ambiguities about swimmer safety and beach recreation safety, the project team is the expert on sand nourishments and their effects. They further supported their positive frame by pointing at verifiable past experiences with sand nourishments, which were carried out without noteworthy incidents. The action committee is a group of laypersons regarding the topic of flood defence and sand nourishments. They supported their skeptical frame with stories of allegedly negative experiences with sand nourishments and with the aforementioned informal report by an amateur military historian. Even though the project team listened to these stories at the public meetings and acquainted themselves with the contents of the report, our observations suggest that these were not fully taken into account by the project team. During the interviews, the project team indicated that they “did not actively, over and over again, engage in conversation [with the action committee]” and instead focused on “good, honest information”, so on knowledge that they perceive as legitimate from their particular perspective. Furthermore, our document study revealed that the report was not taken into account because its storyline lacks verifiable evidence for a causal relationship between the Sand Engine’s construction and future incidents with ammunition. For the ambiguity about drinking water safety, the project team has significantly less expertise than the specialized drinking water stakeholder. In the end, the drinking water expert’s belief was perceived as the more legitimate one and the project team had to change their belief that the project would not have a substantial impact on the drinking water situation.

Similarly, in the Safety Buffer case, the project team is the expert regarding sand nourishments, their effects and development. While the oyster sector and environmental interest group can be regarded as an expert regarding the oyster trade and natural systems, they are laypersons regarding sand nourishments and the likelihood of damage due to a specific sand nourishment. As a justification of their positive beliefs, the project team enthusiastically referred to the successful experiences with recent nourishment pilots in the Eastern Scheldt. To the contrary, the oyster sector referred to a negative experience with a damaged mussel bed – presumably due to one of the recent pilots – and argued their oyster beds could suffer similar damage. However, during our interviews, the shellfish sector indicated that it is almost impossible for them to prove that there is a causal relationship between damaged shellfish beds and nourishment activities. Hence, the examples above illustrate that it is difficult for non-experts to have their experiences and stories been taken into account by the expert actors in collective decision-making.

In the field of risk assessment, the difference between experts and laypersons has been studied in detail. For instance, Slovic (1999) argues that while experts are often characterized as objective, analytic, wise, and rational-based on ‘the real risks’, in contrast, the layman public is seen to rely on ‘perceptions of risk’ that are subjective, often hypothetical, emotional, foolish, and irrational. Thus, while an expert is considered to evaluate risks using ‘objective’ beliefs, the layman can easily form ‘subjective’ emotional beliefs. However, there is no consensus about whether the expert’s or the layman’s viewpoint is the more legitimate one. While Slovic (1987) argues that the basic conceptualization of risk by laypeople is much richer than that of experts and reflects legitimate concerns, Kuran and Sunstein (1999) disagree and state that non-expert individuals often lack knowledge and expertise to make a reliable judgment. On the other hand, Klinke and Renn (2002) propose a dual approach to risk management, stating that the identification of risks and the formulation of risk evaluation criteria should be based on social concerns of the public, while the “objective” evaluation of the magnitude of those risks should be performed by experts. However, involving the emotions and feelings of lay people in the actual decision-making can be essential (Thacher, 2009). Lidskog (2008) argues that including citizens in the evaluation of risk in collective decision-making is necessary, as citizens' opinions and reflections can enrich expert advices and recommendations.

The results of our research suggest that, in the current practice of our two case study projects, an actor's *background* determines whether his or her beliefs are taken into account in the decision-making process or not. The beliefs and experiences of experts seem to be perceived as more legitimate than the beliefs and experiences of (local) lay actors, which suggests that experts have a more privileged and powerful position in multi-actor decision-making. In the next section, we will show that this consideration has major implications for the way in which we deal with ambiguity in collective processes.

3.6.3. What are the implications for coping with ambiguity in BwN projects?

In the ideal situation, coping with ambiguity implies addressing the underlying framing difference in a multi-actor participatory process, as this denotes that it is accepted that there are multiple ways of making sense of an issue (Brugnach et al., 2011; Brugnach and Ingram, 2012). However, judging which specific strategy to use for addressing a particular ambiguity depends on many different factors (Maurel, 2003; HarmoniCOP, 2005). We observe that – in the current practice of our two BwN case study projects – the *actor positions* (i.e., the actors' power) have major consequences for the way the ambiguity is dealt with.

Although the philosophy of the BwN approach advocates that active involvement of stakeholders is both required and beneficial (De Vriend and Van Koningsveld, 2012), we observe that – compared to the valuable insights in the literature on participatory processes – the actual participation of stakeholders often remains at a low level in the daily practice of our BwN case study projects. Such a low level of participation is characterized by top-down communication and an information flow which is mainly one-way (Rowe and Frewer, 2000). In the Sand Engine case, public meetings were the main method to involve stakeholders. Although those present were invited to express their views on the initiative, the described meetings mainly consisted of several extensive presentations to update the public on project development activities that had already occurred without stakeholders being involved. Thus, the level of stakeholder participation in the project generally seems to be limited to *informing* (sensu Arnstein, 1969). Furthermore, when confronted with the ambiguities about the effects of the Sand Engine on swimmer and beach recreation safety, the role of the action committee was basically reduced to that of a spectator (sensu Fung, 2006). Instead of solving the underlying framing difference, the project team prevented a hampered development process by using their power (see Table 3.2 and 3.3) to let their own frame prevail and neglect the action committee's frame (i.e., as there was governmental support, it was decided to implement the project despite persistent opposition). In terms of stakeholder participation, this mainly resembles the lowest form of involvement, namely *manipulation* (sensu Arnstein, 1969). To the contrary, regarding the ambiguity about drinking water safety, the project team had a less powerful position (see Table 3.4) which meant that a form of *partnership* (sensu Arnstein, 1969) was needed to solve the ambiguity. The drinking water issue was first addressed by doing the required additional impact assessment. As a result of this assessment, the project team changed their belief that the project would not have a substantial impact on the drinking water situation. In the end, the two actors started a negotiation which eventually resulted in the installation of a pumping station to prevent drinking water problems. Hence, our results suggest that, in the Sand Engine case, the level of stakeholder participation in a situation of ambiguity is related to the relative power the actors have.

Differently, in the Safety Buffer case, the project team indicated that they strive for a partnership in which project developers and stakeholders jointly make plans and develop strategies (sensu Fung, 2006). While stakeholders were invited for project meetings to jointly create an inventory of design requirements and preferences, the actual design process was outsourced to an external company. Although stakeholders were consulted about the design alternatives during a sounding board meeting, the project team explicitly expressed that they take the final decisions. Hence, we argue that the actual level of stakeholder participation is best characterized as *consulting* (sensu Arnstein, 1969). When confronted with ambiguity, power relations – which are rather unclear in the Safety Buffer case – seem to have influenced the way in which participation took place. Regarding the ambiguity about the project's effects on the oyster beds, both the project team and oyster sector manoeuvred themselves to an underdog position by stating that they are unable to overrule the other actor (see Table 3.5). Eventually, the project team chose to initiate a renewed interactive process – a sort of *partnership* (sensu Arnstein, 1969) – to jointly come up with a new set of design alternatives. Regarding the benthic organisms issue, the environmental interest group is an independent organization of concerned citizens who may appeal against projects that discomfort them (see Table 3.6). The project team engaged in extensive persuasive conversations with the environmental interest group, to convince them of the project's positive intentions and to change the previously discussed incorrect belief regarding the size of the nourishment area. In terms of stakeholder participation, the involvement of the environmental interest group was basically limited to *informing* (sensu Arnstein, 1969).

Moreover, we observe – for all five ambiguous issues identified in our two case studies – that the powerful actor is also the expert regarding the issue being framed. While these powerful experts support their beliefs with scientific knowledge that is perceived as legitimate, the laypersons involved are often unable to have their beliefs been taken into account in the decision-making process (as illustrated in Section 3.6.2). In short, our observations suggest that powerful actors with access to scientific knowledge and expertise are privileged over laypersons in the decision-making processes of our two BwN case study projects. However, both the knowledge of experts and non-experts need to be assimilated into the collective decision-making processes in BwN initiatives – as active participation of stakeholders leads to better and more legitimate decisions (e.g., Fiorino, 1990; Randolph and Bauer, 1999; Beierle, 2002; Huitema et al., 2009) – in order to create a shared knowledge base that is perceived as legitimate by all actors involved.

3.7. CONCLUSIONS

In this chapter, we studied the origin of ambiguity in the development process of projects based on Building with Nature (BwN) design principles. We investigated the attributes underlying the frames of the actors that hold diverging views on the issue being framed. Our findings suggest that ambiguity in multi-stakeholder decision settings – such as BwN projects – originates from a contradiction between the *beliefs* of the actors involved. Actors occasionally attempt to support their beliefs with reports and stories of past experiences. However, whereas knowledge and experiences of the powerful experts seem to be perceived as legitimate and verifiable, our observations suggest that knowledge and past experiences of non-experts – although these can be very valuable – are not taken into account in the decision-making process because they are hard to verify. For instance, we provided examples showing how difficult it is for non-experts to provide verifiable evidence that the project under consideration might have adverse consequences. Moreover, our observations suggest that the actor positions in terms of *power* are currently the most important determinant for how to cope with ambiguity. These findings suggest that – in the current practice of nature-inclusive flood defence projects – powerful actors with access to scientific knowledge are privileged over lay actors with local knowledge and experiences. However, human interactions can also shape frames and change an actor’s attributes. Hence, while in this chapter we have analysed differences between the frames of individual actors or a group of actors at a particular moment in time, future research will benefit from considering the interactional framing processes through which frames are shaped.

Carrying on a participatory process could be a promising means to align diverging beliefs in multi-actor project development in order to prevent or solve ambiguity (Brugnach and Ingram, 2012). However, our results indicate that, currently, project teams and experts have a much stronger position than non-expert actors. For instance, even though the Safety Buffer case can be characterized as a participatory process in which stakeholder requirements are taken into account as much as possible, the project team explicitly stated that they take the final decision regarding the implementation of the initiative. This example points out that even in cases where stakeholders are actively included in the participatory process, they are not necessarily granted with decisive influence regarding the action path chosen. This consideration implies that an important challenge would be to pay more attention to the underlying rules of participatory processes in order to come to more democratic knowledge co-production processes. The suggested way of doing so is to establish a decision-making setting in which the debate is free and open among all parties involved and affected, and all opinions are heard and respected (Richard-Ferroudji and Barreteau, 2012).

The results of our research demonstrate that it is difficult to bring the beliefs and past experiences of stakeholders to collective decision-making in nature-inclusive flood management. Currently, the lay public is regularly invited for all kinds of public consultation activities – for instance, the public meetings in the Sand Engine case – but they are rarely included in the knowledge production process (Lidskog, 2008). To come to a scientifically sound, socially robust and context-specific knowledge base, different knowledge sources (i.e., expert and local knowledge) should be integrated in participatory processes (Hommes et al., 2009). In order to share power and responsibility between the government and local stakeholders, it is a requirement to generate and use knowledge together (Berkes, 2009). In an open and transparent participatory process, actors can gradually develop a set of mutually shared beliefs regarding ambiguous issues and jointly develop knowledge that is perceived as legitimate by all those involved. If such knowledge from different sources and disciplines is used to define a problem and identify possible solutions, the final decision is the result of the interactive process of the group of participating actors instead of a single rational actor (Brugnach and Ingram, 2012). Such equitable participatory processes – in which an equifinal set of interests, moral principles, beliefs and the required legitimate knowledge base are developed and used by the actors involved – are likely to lead to better decisions and increased public support for promising Building with Nature initiatives.

4 ANALYSING THE CASCADES OF UNCERTAINTY IN FLOOD DEFENCE PROJECTS: HOW “NOT KNOWING ENOUGH” IS RELATED TO “KNOWING DIFFERENTLY”[3]

ABSTRACT

It is increasingly recognized that uncertainty concerns more than statistical errors and incomplete information. Uncertainty becomes particularly important in decision-making when it influences the ability of the decision-makers to understand or solve a problem. While the literature on uncertainty and the way in which uncertainty in decision-making is conceptualized continue to evolve, the many uncertainties encountered in policy development and projects are still mostly represented as individual and separated issues. In this chapter, we explore the relationship between fundamentally different uncertainties – which could be classified as unpredictability, incomplete knowledge or ambiguity – and show that uncertainties are not isolated. Based on two case studies of ecological engineering flood defence projects, we demonstrate that important ambiguities are directly related to unpredictability and incomplete knowledge in *cascades of interrelated uncertainties*. We argue that conceptualizing uncertainties as cascades provides new opportunities for coping with uncertainty. As the uncertainties throughout the cascade are interrelated, this suggests that coping with a particular uncertainty in the cascade will influence others related to it. Each uncertainty in a cascade is a potential node of intervention or facilitation. Thus, if a particular coping strategy fails or system conditions change, the cascades point at new directions for coping with the uncertainties encountered. Furthermore, the cascades can function as an instrument to bridge the gap between actors from science and policy, as it explicitly shows that uncertainties held relevant in different arenas are actually directly related.

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[3] Another version of this chapter has been published as: Van den Hoek, R.E., Brugnach, M., Mulder, J.P.M., Hoekstra, A.Y., *in press*. Analysing the cascades of uncertainty in flood defence projects: How “not knowing enough” is related to “knowing differently”. Global Environmental Change.

4.1. INTRODUCTION

Sea level rise due to climate change is a major concern for many countries around the world and calls for adaptive management of coastal zone areas (Nicholls and Cazenave, 2010) and coastal ecosystems (Thom, 2000), in order to create social-ecological resilience to coastal disasters (Adger et al., 2005). Regarding coastal protection, ecological engineering – the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Mitsch and Jørgensen, 2003) – seems to be a promising approach towards a sustainable future, as the feasibility of multiple alternative strategies is being researched (see Borsje et al., 2011, for a review). A prominent example of ecological engineering for coastal protection purposes is Building with Nature (BwN), a Dutch water management approach that aims to utilize natural dynamics (e.g., wind and currents) and natural materials (e.g., sediment and vegetation) for the realization of effective flood defences, while providing opportunities for nature development (De Vriend and Van Koningsveld, 2012). The basic philosophy of this approach is not exclusive for the Netherlands. The paradigm of water management is slowly changing from command-and-control approaches – hard engineering approaches emphasizing on reducing uncertainties and designing systems that can be predicted and controlled (Holling and Meffe, 1996) – towards more nature-inclusive approaches (Pahl-Wostl et al., 2011) and the use of natural dynamics in water management projects receives increasing international follow-up. Initiatives such as the Working with Nature approach of PIANC and the Engineering with Nature approach of the US Army Corps of Engineers are based on philosophies similar to the Building with Nature approach (Van Slobbe et al., 2013).

Although projects based on BwN design principles appear to foster the natural environment of the coastal zone in which they are implemented, a potential drawback of this ecological engineering approach is that the use of natural dynamics adds inherent uncertainty and ecological complexity to the designs created (Bergen et al., 2001). As weather conditions are unpredictable and our knowledge about natural system behaviour is incomplete, the outcomes of a BwN project are far from certain on beforehand. However, the uncertainties encountered during the development of a promising BwN project do not exclusively originate from shortcomings or inadequacies in the knowledge base. While the active involvement of local stakeholders is regarded as beneficial in order to come to better BwN solutions (De Vriend and Van Koningsveld, 2012), these stakeholders might have rather different or even conflicting views regarding the project. This can easily lead to ambiguity, a fundamentally different kind of uncertainty originating from the presence of too many possible interpretations of a situation (Weick, 1995). In Chapter 2, we found that ambiguity about the social implications of BwN projects is far more important for decision-making than uncertainty about the behaviour of the natural dynamics or the natural system, since these ambiguities could potentially hamper the project development process. Moreover, as time and spatial scales are not fixed in BwN projects, unanticipated developments can be expected at any moment. This suggests that, instead of a standard rigid uncertainty management plan, these dynamic projects require an uncertainty management approach that can be adapted to changing conditions.

While it is important to make a distinction between incomplete knowledge, unpredictability and ambiguity – because their nature is fundamentally different – they are not independent in the context of BwN projects (see Chapter 2). However, it is not fully clear what kind of relationship between different uncertainties exists. Even though the existence of such a relationship could be perceived as yet another complexity in an already complex field, it might also provide major benefits in the form of unexplored approaches to cope with interrelated uncertainties in water management projects. This is important because, in multi-actor decision-making processes, uncertainties that have a different nature normally require fundamentally different coping strategies (Walker et al., 2003; Van der Keur et al., 2008; Kwakkel et al., 2010; Brugnach et al., 2011). Common responses to cope with incomplete knowledge and unpredictability in decision-making are to acquire more information, e.g. by performing additional research and consulting experts, or to increase the top-down control over the process, e.g. by limiting the number of participants and centralizing the decision authority (Koppenjan and Klijn, 2004), but such strategies are unfit to solve a situation of ambiguity (Brugnach et al., 2011). However, if different uncertainties are interrelated, this situation might change since it suggests that coping with a particular uncertainty will influence those with which it is related. For instance, successfully coping with a particular situation of incomplete knowledge might influence an ambiguity with which it is related in a positive way.

In this chapter, our objective is to explore the relationship between different uncertainties. To this end, we combine the relational approach to uncertainty of Brugnach et al. (2008) with theory on cascades of uncertainty from climate change literature in order to elucidate new ways for coping with uncertainty. We aim to illustrate that those managing a project can benefit from the relationship between different uncertainties in order to adaptively manage uncertainty in initiatives such as BwN projects. Therefore, we study two BwN pilot projects (namely, the Safety Buffer Oyster Dam and the Sand Engine case), identify several *cascades of interrelated uncertainties* and address how these cascades were managed.

This chapter is structured as follows. First, we discuss the relational approach to uncertainty that we adopt and address our method for describing relations between different uncertainties (Sections 4.2 and 4.3). Second, we discuss our two case study projects, identify the most important uncertainties for each project and the uncertainties related to them, and describe how the project team managed these uncertainties during project development (Sections 4.4 and 4.5). Third, we discuss the characteristics of the cascades of interrelated uncertainties and the implications of our findings for uncertainty management (Section 4.6). In the last section, we present our main conclusions.

4.2. THEORETICAL CONCEPTS

4.2.1. Adopting a relational approach to uncertainty

We adopt the approach to uncertainty of Brugnach et al. (2008) that addresses the topic from a relational point of view, paying particular attention to how an actor (e.g., a decision-maker) relates to a problem situation he or she is to decide upon. Much can be uncertain regarding the characteristics of this problem, its possible solutions and the knowledge available about the system under consideration. However, this uncertainty has no particular significance or meaning for an actor involved in the decision-making process, until it leads to a situation in which it influences his or her ability to determine what the problem is or which action path to pursue. For example, in river basin management, uncertainty about the runoff of the river basin in itself may not be of importance for a decision-maker. However, when this decision-maker has to decide about raising the dikes along the river, he or she may become concerned about the characteristics of the river basin. As data about runoff is essential knowledge to come to an informed decision concerning the dikes, the uncertainty about this characteristic of the river basin now becomes significant and acquires meaning for the decision-maker. In short, an uncertainty has no meaning in itself, but acquires meaning when the decision-maker establishes a knowledge relationship with the system he or she aims to manage. Thus, uncertainty refers to *the situation in which there is not a unique and complete understanding of the system to be managed*.

According to the adopted conceptualization, uncertainty can originate from incomplete knowledge, unpredictability or ambiguity (Figure 4.1). Incomplete knowledge and unpredictability are recognized by many authors in the literature (see Van Asselt, 2000 or Walker et al., 2003, for a review). Incomplete knowledge originates from the imperfection of our knowledge, which may be reduced by additional research. It concerns what *we do not know* at this moment, but might know in the future if sufficient time and resources are available to perform additional research or collect more data. For instance, data might be imprecise but could be improved by more accurate measurements or model predictions could be improved by developing better models. Unpredictability is caused by the inherent chaotic or variable behaviour of, e.g., natural processes, human beings or social processes. Thus, it is different from incomplete knowledge: unpredictability concerns what *we cannot know* and therefore cannot be fully reduced by doing more research.

Ambiguity is an uncertainty of a different kind, as it is not about what we do not or cannot know: it is about actors *knowing differently*. Ambiguity refers to the situation in which there are different and sometimes conflicting views on how to understand the system to be managed (Dewulf et al., 2005; Brugnach et al., 2008; Renn et al., 2011). Actors can differ about how to understand the system, e.g. about where to put the boundaries of the system or what and whom to put as the focus of attention, or they can differ in the way in which the information about the system is interpreted, e.g., about what the most urgent problems are (Brugnach et al., 2008). Even though all three kinds of uncertainty refer to what a decision-maker knows about the system, their nature is very different. While the relevant dimension of incomplete knowledge and unpredictability ranges from complete deterministic knowledge to total ignorance (Walker et al., 2003; 2010), the relevant dimension of ambiguity is something ranging from unanimous clarity to total confusion caused by too many people voicing different sensible interpretations (Dewulf et al., 2005).

Figure 4.1 – Schematization of the adopted uncertainty conceptualization

Furthermore, the adopted relational approach to uncertainty distinguishes between three different parts of the system to be managed in which uncertainty can be present. Uncertainty in the natural system concerns aspects such as climate impacts, water quantity, water quality and ecosystems. Uncertainty in the technical system concerns technical elements and artefacts that are deployed to intervene in the natural system. Uncertainty in the social system concerns economic, cultural, legal, political, administrative and organizational aspects. Although it is useful to make this distinction as it supports decision-makers to structure their knowledge, it is important to acknowledge that the natural, technical and social system are all closely interrelated and interdependent. The integration of human and natural systems – which the BwN philosophy actively pursues by using natural dynamics as a 'technological instrument' – implies that the reciprocal relationship of human–nature interactions is explicitly acknowledged, recognizing that each human action will be followed by responses from the natural system and vice versa (Liu et al., 2007).

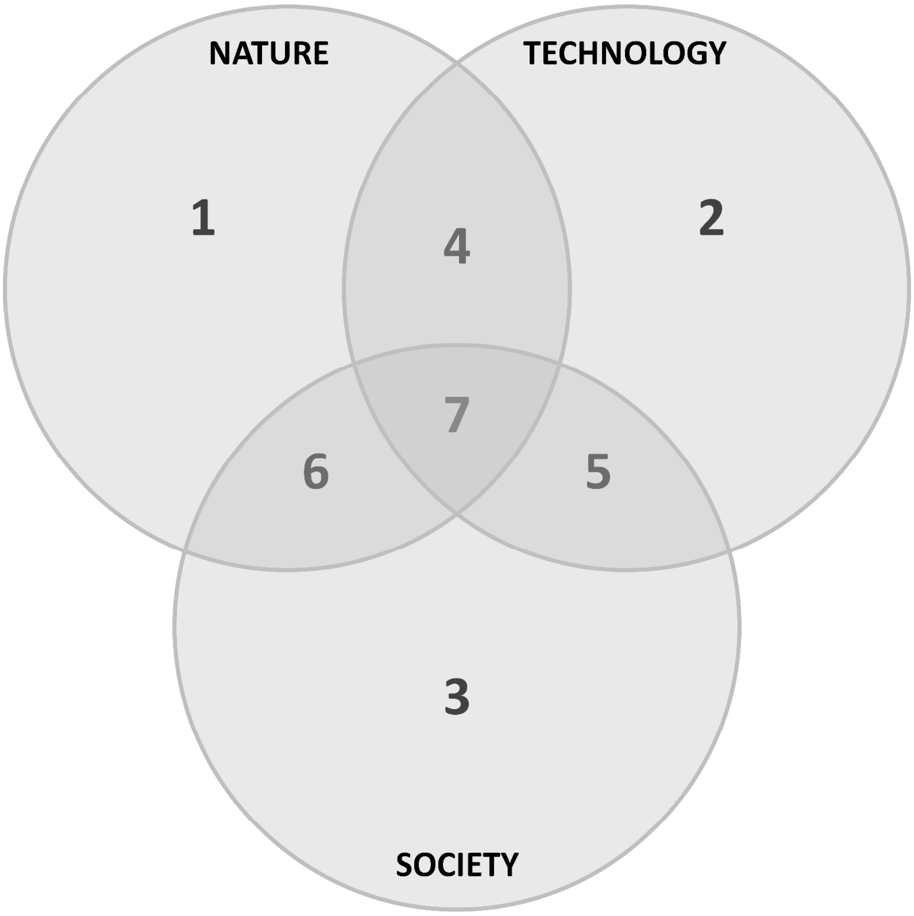

Figure 4.2 – Schematization of the system to be managed and its different parts. The numbers correspond to the numbers used in the text below

As the natural, technical and social parts of the system are related (Figure 4.2), we argue that an uncertainty can concern more than just one of these subsystems. Uncertainties in the areas 1, 2 and 3 mainly concern only a single subsystem, either the natural, technical or social one. However, an uncertainty can also concern both the natural and technical system (area 4), the technical and social system (area 5) or the natural and social system (area 6). For instance, knowledge about the effects of a particular technology on an ecosystem might be incomplete (hence: in area 4), the uncertain impact of a technology can be interpreted from a societal perspective (hence: in area 5) or an unpredictable natural phenomenon might influence a human activity (hence: in area 6). In all these examples, the uncertainty at hand cannot be clearly classified in one of the subsystems as there is no clear and transparent distinction possible. Finally, some uncertainties can concern all subsystems (area 7). For example, uncertainty about which technology to apply in a flood defence project (e.g., a command-and-control or a BwN approach) also has implications for both the natural system and social activities (hence: classify in area 7).

4.2.2. The cascade of uncertainty

Several scholars have acknowledged that there can be a causal relationship between different uncertainties. For example, in the context of international business, Miller (1992) states that it is a shortcoming that the risk and uncertainty literature mostly focus on individual uncertainties and calls for taking a multi-dimensional perspective of interrelated uncertainties. In health care literature, Hines (2001) argues that in cases when facing serious illness, efforts to find an effective intervention strategy should account for the interrelatedness of multiple uncertainties. Van Asselt (2000) explicitly mentions the relationship between incomplete knowledge and unpredictability, stating that the former can originate from the latter. Furthermore, in the context of modelling (e.g., Draper, 1995) and sensitivity analysis (e.g., Saltelli, 2000), uncertainty propagation is often described: the phenomenon that uncertainty in the input variables and parameters of a model propagates to an even larger uncertainty in the output of the model.

Although several authors mention that there can be a relationship between different uncertainties, there is only limited attention for how ambiguity is related to other uncertainties. Warmink et al. (2010) discuss uncertainty in environmental models and show that a particular uncertainty can often be broken down in several more specific uncertainties (either incomplete knowledge, unpredictability and/or ambiguity). Regarding model-based environmental decision-making, Van der Sluijs et al. (2005) remark that uncertainty in the knowledge base and differences in framing of the problem are interrelated aspects. More specifically, Van der Sluijs (2012) mentions that ambiguous knowledge assumptions and ignorance can lead to uncertainty in the knowledge base. However, it remains rather unclear what the implications of such a relationship would be.

In climate change studies, the process of uncertainty propagation – in translating global climate change predictions into regional scenarios and eventually impact assessments – has been described as the cascade of uncertainty or the uncertainty explosion (Schneider, 1983; Henderson-Sellers, 1993; Mitchell and Hulme, 1999; Jones, 2000; Schneider and Kuntz-Duriseti, 2002; Wilby and Dessai, 2010; Refsgaard et al., 2012). For example, climate predictions – which are highly uncertain due to our limited understanding of the climate system – describe an expected range of temperature increase and sea level rise over a specific period. Although these predictions can be used as input in, for instance, a coastal development model, the use of the model will accumulate the uncertainty as it is a simplified representation of reality. As a result, the uncertainty in the model outcomes is probably larger than the uncertainty in the input data. Decision-makers using the model outcomes to develop robust adaptation measures will probably propose solutions with major safety margins that are larger than the original climate input data would have required. Hence, this example illustrates that the incomplete knowledge or unpredictability in the input of the model is gradually amplified throughout the described cascade.

4.3. METHODS

In this chapter, we combine the relational approach to uncertainty of Brugnach et al. (2008) with the theory on the cascade of uncertainty from climate change literature, in order to describe *cascades of interrelated uncertainties*, expressing the relationship between different uncertainties in projects based on BwN design principles. We use the structure of Figure 4.2 to visualize these uncertainty cascades, in order to illustrate that uncertainties can concern several parts of the human-technology-nature system.

For this research, we used several data collection methods. For the Safety Buffer Oyster Dam project (Section 4.4), first, we attended meetings of the project's knowledge development team in March 2012 and the sounding board – consisting of stakeholders – in April 2012. Whereas the meeting of the knowledge team was recorded and transcribed, the sounding board meeting could not be recorded but minutes were made. For both meetings, we studied the data to identify important uncertainties, discussion themes and stakeholder issues in the Safety Buffer project. Second, we conducted four interviews with main project actors (performed by two interviewers) and nine interviews with stakeholders (performed by one interviewer) in July, August and September 2012. During three of these interviews, two respondents were interviewed instead of one. Thus, in total, we spoke to six main project actors (three at the executive and three at the project level) and ten stakeholders. The semi-structured interviews were conducted in the Dutch language, took about one hour, and were recorded and transcribed. Two interview protocols (one for the project actors and one for the stakeholders) with up to fourteen open-ended main questions were used as a guide and checklist during the interviews. During the interviews, the interviewees were invited to elaborate on those project topics that were most important for them, but that also caused the hardest discussions within the project. During the course of the interviews, several uncertainties regarding the discussed project topics were explicitly or implicitly mentioned.

For the Sand Engine project (Section 4.5), we used two main data collection methods. First, three public information meetings were attended, during which stakeholders and the general public had the opportunity to pose critical questions, express their appreciation or concerns about the project and to file complaints. We made minutes of these meetings, and used these to identify important uncertainties and to understand the diverging viewpoints regarding the project. Second, in April and May 2011, we interviewed three (former) members of the project team, one member of the project steering group and two experts – involved in the Environmental Impact Assessment (EIA) and modelling – about the most important uncertainties encountered during project development, how these could have hampered the project and how the uncertainties were coped with. In the period from May until November 2012, we performed three additional interviews to acquire specific information about the Sand Engine's recreational safety situation. The interviewees were invited to elaborate on the safety measures regarding recreation, the reasons why measures were changed and which specific uncertainties were coped with. The semi-structured interviews were conducted in the Dutch language, took between one and two hours, and were recorded and transcribed. Two interview protocols (one for the 2011 interviews and one for the 2012 interviews) with up to ten open-ended main questions and several follow-up questions were used as a guide and checklist during the interviews.

For both cases, we identified multiple uncertainties from the interview transcriptions and minutes, and used available project documentation and communication as additional material. Furthermore, we consulted interviewees or other project actors to acquire additional specific information if needed. The uncertainties identified were first classified according to the uncertainty typology discussed in Section 4.2.1. Thereafter, we assessed which uncertainties were perceived as most important by the interviewees by considering two aspects: the uncertainty's potential impact and its project-wide relevance for the actors. During the interviews, we invited the interviewees to elaborate on the impact an uncertainty could have on the project's development process (e.g., can it lead to substantial cost overrun, a substantial delay or even project cancellation?). Thus, we were able to assess whether an uncertainty was important (e.g., potentially leading to a significant budget increase of €500,000) or not (e.g., only leading to a delay of 1 day). Moreover, after finalizing the series of interviews and meetings, we assessed during which interviews and meetings a particular uncertainty was brought up. If an uncertainty was brought up during several interviews and meetings, this clearly implies that it has a project-wide relevance according to multiple actors and is not just the 'favourite subject' of one actor.

The uncertainties that were perceived as most important by the interviewees all appeared to be ambiguities, because these were most frequently mentioned and potentially could have had a major impact on the project's development process. Therefore, we used these ambiguities as the basis of our analysis. Inspired by causal loop diagrams, for each ambiguity, we traced other uncertainties (either incomplete knowledge, unpredictability or ambiguity) with which it is related, both directly and more indirectly. Thus, we identified several cascades of interrelated uncertainties that were of major importance in our case study projects. In the figures we use to present the cascades (see Figure 4.3 for an example), black arrows express that an uncertainty is related to another uncertainty. Furthermore, for each uncertainty, colours indicate if the uncertainty dominantly concerns unpredictability (green), incomplete knowledge (blue) or ambiguity (red). Finally, we compared the cascades to address their similarities and differences and to elaborate what our findings suggest regarding uncertainty management.

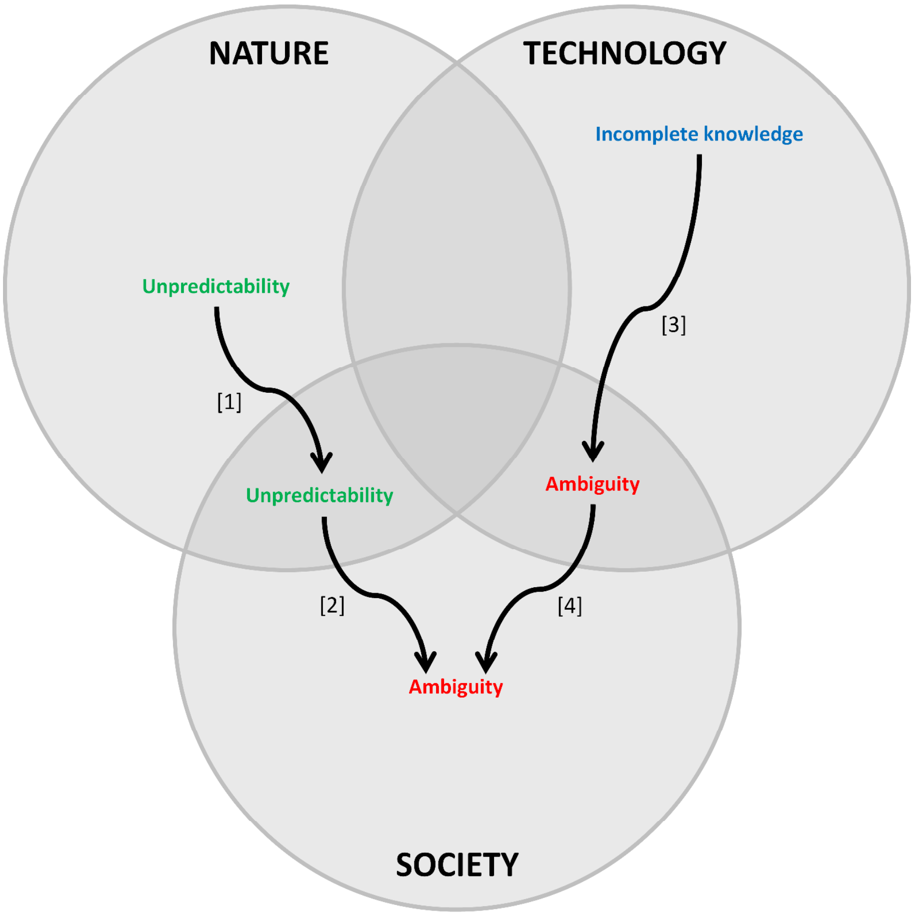

Figure 4.3 – Example of a cascade of interrelated uncertainties. Text colours represent the kind of uncertainty: incomplete knowledge (blue), unpredictability (green) and ambiguity (red)

4.4. CASE STUDY I: SAFETY BUFFER OYSTER DAM

4.4.1. Case study description

The Oyster Dam is a compartment work located in the Eastern Scheldt estuary. With a total length of approximately 10.5 kilometres, it is the longest dam of the so-called Delta Works which were implemented as a response to the dramatic flooding of the South-Western delta of the Netherlands in 1953. Along with flood protection for the hinterland, one of the Oyster Dam's main functions is to decrease the total area of the estuary in order to increase the tidal difference of ebb and flood tide, that had dropped after construction of the Eastern Scheldt Storm Surge Barrier. While this storm surge barrier is a key flood protection work as it closed off the Eastern Scheldt estuary, it also reduced the tidal movement in the estuary by approximately 25% (Mulder and Louters, 1994; Vranken et al., 1990). Due to the construction of the Oyster Dam and the Philips Dam – another compartment work in the estuary – the tidal difference decrease was limited to approximately 10% compared to the tidal difference before the construction of the Eastern Scheldt Storm Surge Barrier (Eelkema et al., 2012; Mulder and Louters, 1994). Furthermore, the inflow of additional sediment from the North Sea into the water system of the Eastern Scheldt is negligible due to the storm surge barrier, while the distribution of sediment towards the estuary's channels remains constant. This imbalance between the Eastern Scheldt morphology and hydrodynamics leads to an internal redistribution of sediments, causing the erosion of the existing salt marshes and mudflats, and thus the loss of valuable ecological habitat and natural foreshore protection. Hitherto, this so-called Sand Hunger problem remains unsolved.

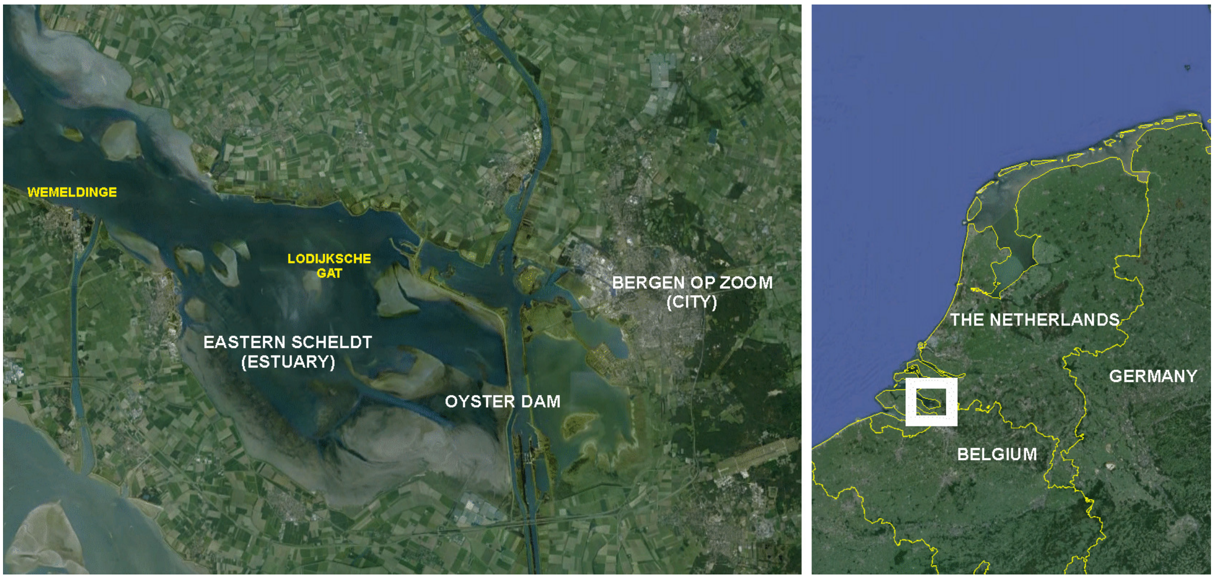

Figure 4.4 – Location of the Oyster Dam and Eastern Scheldt estuary in the Netherlands (source: Google Earth)

The Safety Buffer Oyster Dam pilot project (in Dutch: Veiligheidsbuffer Oesterdam) is a sand nourishment of 425.000 m^3 in front of the Oyster Dam – spread over a length of approximately 2 kilometres – to reduce future maintenance efforts, while simultaneously restoring one of the eroded tidal flats to its historical state (see Figure 4.4 for a map). Additionally, an erosion-preventing artificial oyster reef is planned to be constructed north of the nourishment area. The sand required for the nourishment operations was mined by dredging ships at the locations Wemeldinge (14 km from the nourishment location) and Lodijksche Gat (8 km from the nourishment location). The Safety Buffer project is a distinct example of the application of BwN design principles: both the nourishment and the reef aim to cope with the effects of the Sand Hunger problem by using natural materials and dynamics, while concurrently strengthening the foundation of the existing compartment work.

The nourishment works were finished in October 2013. Nevertheless, a successful outcome of the pilot project has been far from certain. The initiative was developed by an unusual coalition, formed by two Dutch governmental agencies and a non-governmental professional environmental interest organization. Each organization draws from its own basic interests, cultures and working procedures during the course of this specific project development process. Furthermore, the project development team invited stakeholders potentially affected by the initiative to participate in the development process. However, not every stakeholder in the project area was spontaneously willing to commit or contribute to the proposed plans.

4.4.2. Results

Sand mining

We identified important cascades of interrelated uncertainties regarding the impact of the Safety Buffer project's sand mining activities and the preferred location for these activities. First, cascade [5]-[6]-[7] in Figure 4.5 concerns the small-scale professional fishermen, for whom the sand mining area loses a major part of its economic attractiveness as the fish habitat is disturbed.

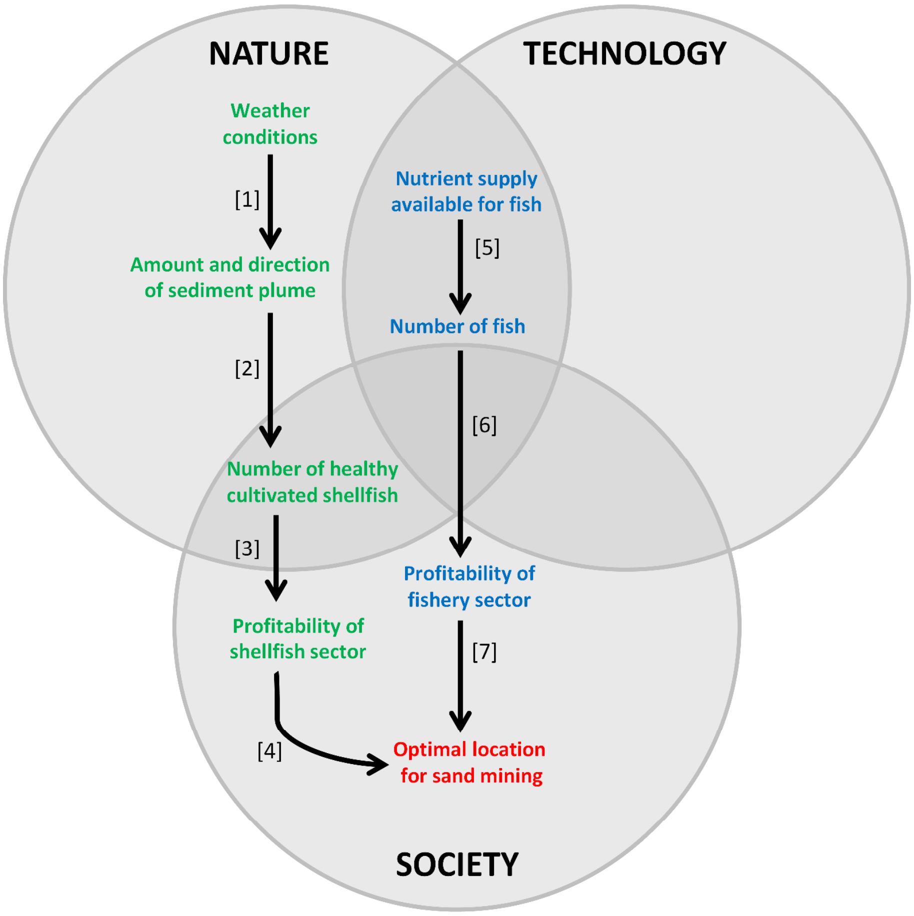

Figure 4.5 – Cascade of uncertainty regarding the impact of Safety Buffer sand mining on the (shell)fish sector. Text colour coding is equal to Figure 4.3

Although the uncertainty is rather low – it is clear enough that a large part of the nutrients in the upper layer of the estuary bed will disappear due to the mining activities – it remains unclear to what extent the fish population will be influenced. Second, for the shellfish industry (cascade [1]-[2]-[3]-[4] in

Figure 4.5), the sand mining activities could have an indirect, unpredictable financial impact. Dredging usually causes the formation of a plume of suspended sediment, which can have negative impacts on fish and shellfish (Wilber and Clark, 2001). Under specific weather and tidal conditions, this plume could drift off towards cultivated shellfish beds and cover these beds under a suffocating layer of sediment. Furthermore, the plume could cover the nutrient-rich upper layer of a highly populated fish habitat near the mining area.

The shellfish and fishing sector had a specific view regarding the sand mining activities and preferred a sand mining location with only a minor probability of undesired suspended sediment transport towards their (shell)fish areas. Furthermore, they demanded that mining activities only take place during low tide. The project team acknowledged the stakeholder concerns and invited both sectors to participate in the search for an appropriate sand mining location. During this process, several alternative locations were proposed and rejected. In the end, all participants agreed on the locations Wemeldinge and Lodijksche Gat. Furthermore, it was agreed that the sand mining activities will only take place during favourable tidal and weather conditions and impacts will be monitored extensively.

Sand nourishment

Regarding the sand nourishment activities, we identified three important cascades of interrelated uncertainties. First, similar to the sand mining activities, the nourishment could have negative – but yet unpredictable – financial consequences for the shellfish industry (Figure 4.6). After the nourishment is completed, it is expected that the nourished tidal flat will slowly erode over time. However, on the short term, it is unpredictable how the eroded sediment will behave as this depends on the weather conditions. Potentially, the suspended sediment could flow towards cultivated shellfish beds in the vicinity of the nourishment area, on which it can have an adverse impact. While the oyster sector interpreted the project as a potentially harmful development, the mussel sector was rather certain that no adverse impacts will be experienced. The project team aims to assure the interests of the shellfish sector by formulating the boundary conditions that **(1)** the Safety Buffer is not allowed to have any negative effects on stakeholders and **(2)** all unforeseen damage has to be fully compensated.

To establish a successful development process, the project team invited all relevant stakeholders during the first steps of the project to participate. However, for indistinct reasons, the oyster sector did not participate – although they were invited for all relevant meetings and received all project documentation – and started opposing the project through the regional media and the regional political arena. In the end, representatives of the project team and the oyster sector had a meeting, negotiated that the initial Safety Buffer design would be discarded and jointly developed a new design. Furthermore, the actors agreed that the impacts of the initiative will be monitored extensively.

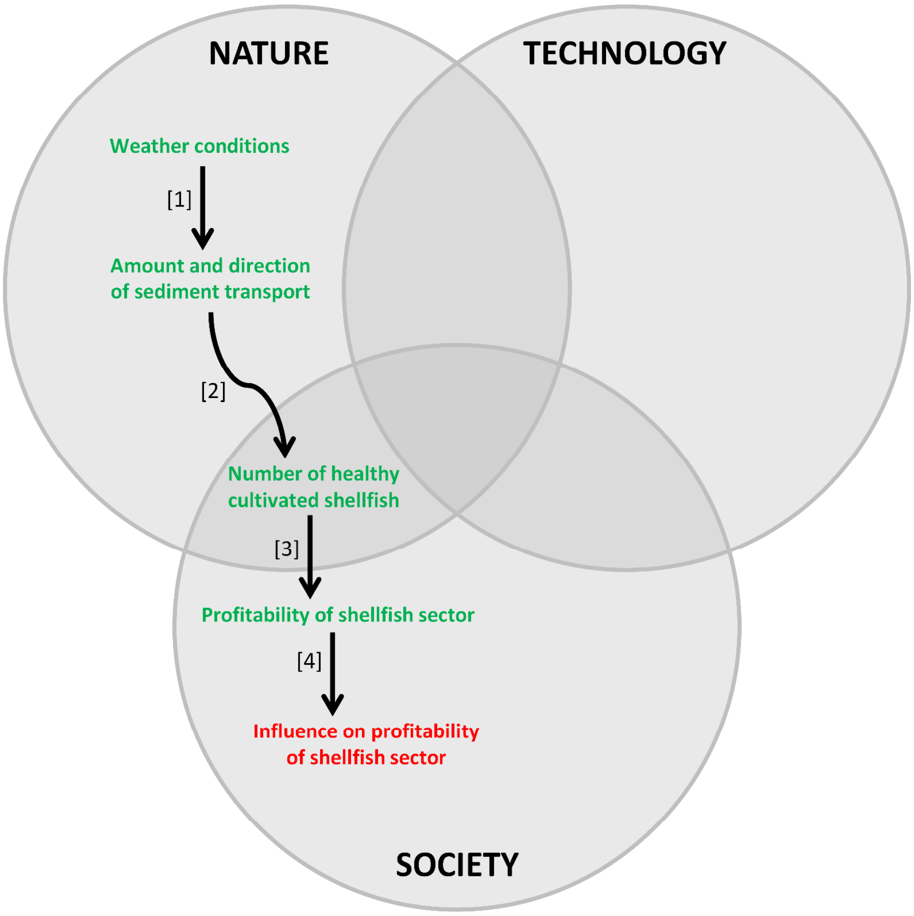

Figure 4.6 – Cascade of uncertainty regarding the impact of the Safety Buffer nourishment on the shellfish sector. Text colour coding is equal to Figure 4.3

The second uncertainty cascade (Figure 4.7) concerns the supposed financial consequences of the sand nourishment activities for some local fishermen, who have fishing grounds located north of the nourishment area. As the nourishment partially takes place on these fishing grounds, there is no doubt that a part of this area will – at least temporarily – disappear and become unfit for commercial activities. However, as these specific fishing grounds have not been used for over 10 years, it can be argued that the fishermen will not be financially damaged due the project. Therefore, it might not be needed to compensate for this area loss. However, due to unpredictable societal events – such as economic surprise or changes in the spatial use of the estuary – it might become necessary for the fishermen to recommence the use of these specific fishing grounds. To prevent problems in the project development process, the project team involved the fishermen in the creation of the plans and offered them a compensating area.

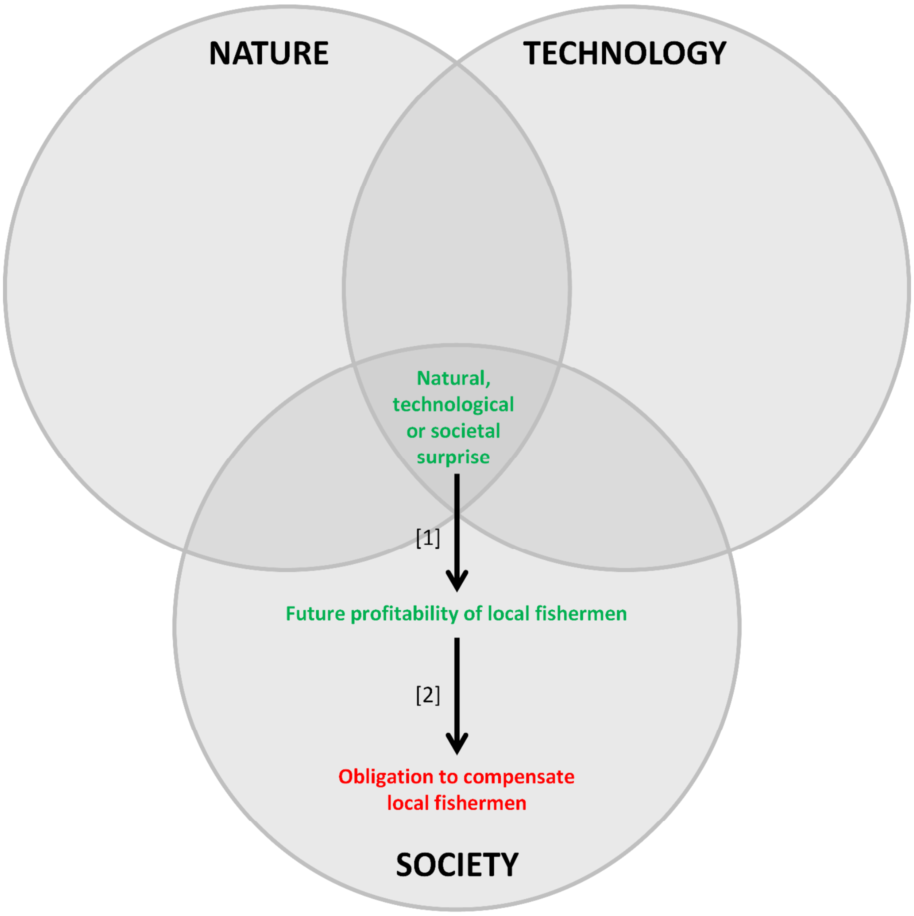

Figure 4.7 – Cascade of uncertainty regarding the impact of the Safety Buffer nourishment on local fishermen. Text colour coding is equal to Figure 4.3

The third cascade concerns the effects of the sand nourishment activities on the benthic organisms or benthos (i.e., organisms – such as worms – living on and in the estuarine bed). This issue is interpreted differently by two stakeholders, namely a local environmental interest group and an organisation for amateur fishermen. Although nourishments are generally considered an environmental-friendly method for coastal protection and restoration, there are significant negative impacts on the ecosystem in the short- and medium-term (Speybroeck et al., 2006). While the expectation is that most of the benthic organisms currently living in the tidal flat will not survive the Safety Buffer nourishment, it is uncertain how quickly the community will recover.

For a local environmental interest group, the project was not acceptable given its uncertain impact on the benthos community (cascade [1]-[2] in Figure 4.8). Whereas the project team chose an innovative design that only required nourishing half of the existing tidal flat, the environmental interest group believed that the project encompassed a nourishment of the entire flat. As a result, the project team needed to initiate extensive discussions with the environmental interest group to persuade them of the positive intentions of the project. Moreover, the recovery of the benthos community will be monitored.

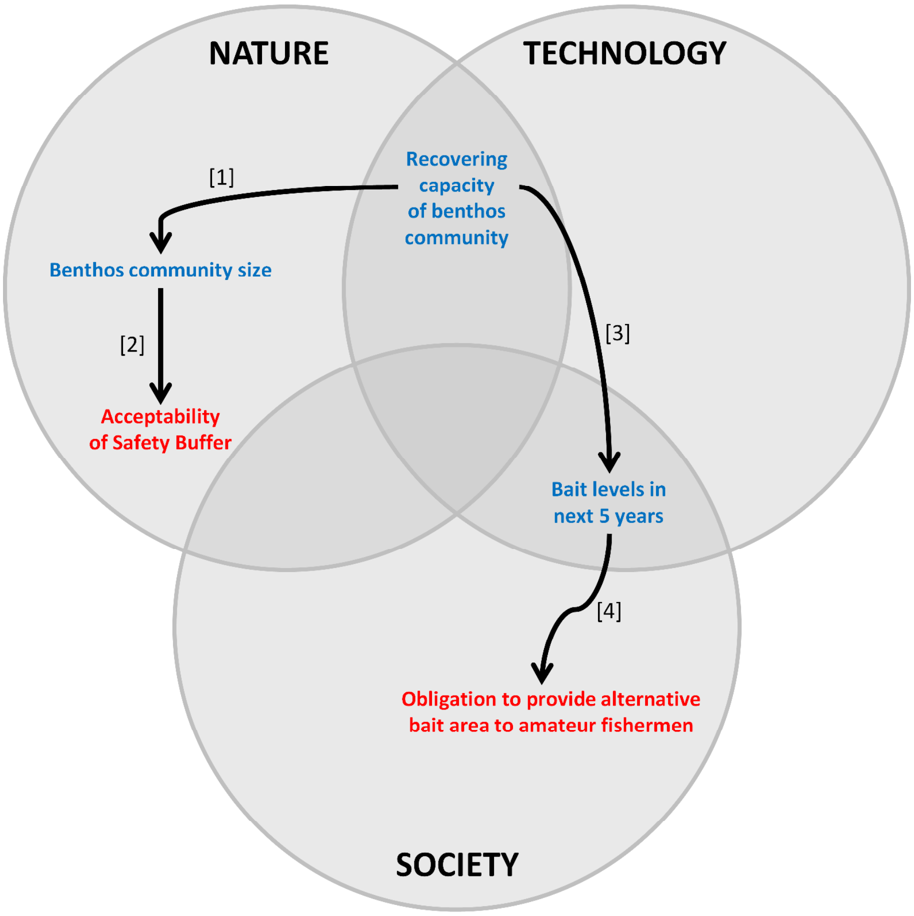

Figure 4.8 – Cascade of uncertainty regarding the impact of the Safety Buffer nourishment on benthos. Text colour coding is equal to Figure 4.3

Differently, an organization that protects the interests of amateur fishermen interpreted the aforementioned issue from a hobby fishing perspective (cascade [3]-[4] in Figure 4.8). Specific benthic organisms are used as offshore fishing bait, which is expensive to buy in shops but for free at designated bait extraction areas. Whereas a large-scale nourishment will probably lead to significantly lower bait levels during the first five years after the nourishment, exact estimations are unavailable because bait levels depend on how quickly the benthos community recovers. As the Oyster Dam area is one of the most visited areas for bait extraction, the amateur fishermen organization demanded an alternative area based on their official permit for using the Oyster Dam tidal flat. Although the project team and the amateur fishermen organization jointly examined alternative extraction areas, they disagreed about whether it was legally required to offer an alternative area: the Dutch government is allowed to withdraw the permit for 'water management and safety reasons'.

4.5. CASE STUDY II: SAND ENGINE DELFLAND

4.5.1. Case study description

The sandy Holland coastline continues to erode due to a decreasing amount of sediment from river sources, on-going land subsidence and sea level rise due to climate change. Hence, if the condition of the Holland coast is not attended to, serious flooding problems can be anticipated. In order to cope with the coastal erosion problem, the Dutch government implemented the Dynamic Preservation policy: the sandy coastline has to be maintained at its 1990 position by performing periodic, relatively small-scale, sand nourishments (Hillen and Roelse, 1995). Currently, the annual sand nourishment volume for the Dutch coast has a target value of 12 million m^3/year, while an increase to at least 20 million m^3/year is needed to preserve the sediment balance of the Dutch coast (Mulder et al., 2011).

Sand Engine Delfland (in Dutch: Zandmotor) is an innovative, 21.5 million m^3 sand nourishment pilot project near Ter Heijde in the Dutch province of South Holland (see Figure 4.9 for a map). After a project development process of approximately three years, the Sand Engine peninsula was constructed between March and July 2011. It is a large-scale experiment to test the feasibility of mega-sand nourishments, which are anticipated to be more cost-effective and less disturbing for the natural environment due to their long expected lifespan of 20-50 years. The project is based on BwN design principles, as the large amount of sand nourished will spread along the coast by the natural dynamics (waves, currents and wind), thus gradually creating a larger beach area with higher dunes. It is expected that the Sand Engine contributes to coastline maintenance and flood safety, provides additional room for nature by increasing the dune habitat for flora and fauna, and creates opportunities for new forms of recreation such as kite-surfing.

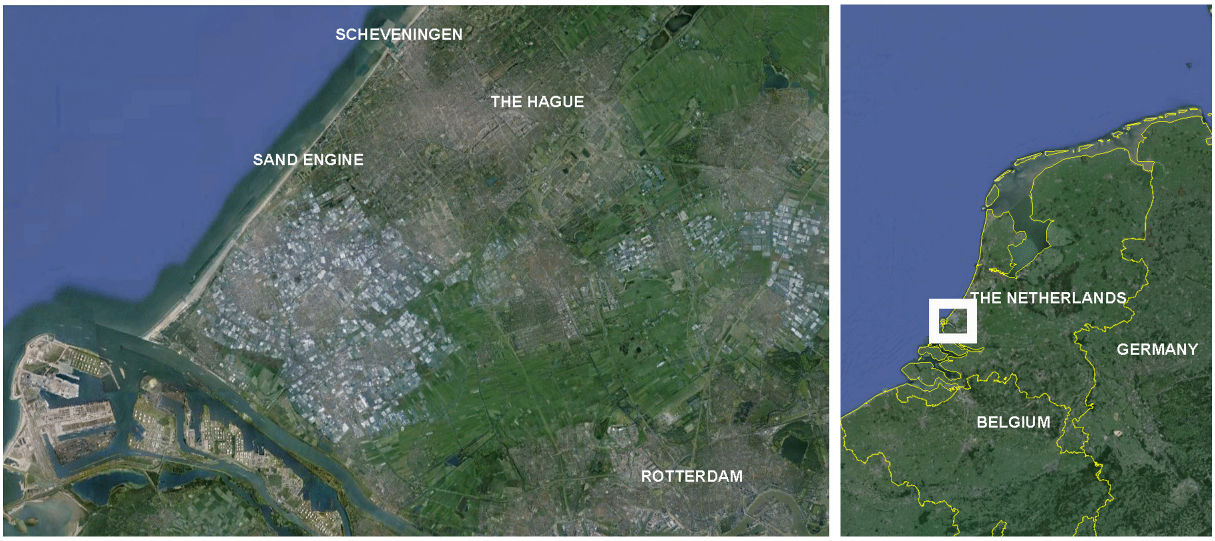

Figure 4.9 – Location of the Sand Engine in the Netherlands (source: Google Earth)

As the Sand Engine was constructed in 2011, it is currently subject to a monitoring and evaluation program which will last until, at least, 2016. It is extensively studied whether a mega-sand nourishment is capable of combining the aforementioned benefits for the human-technology-nature system in which it is implemented. However, since the weather conditions that drive the sediment transport are highly unpredictable – especially over a 20-50 year period – the project involves high levels of uncertainty which threatened the successful development of the Sand Engine.

4.5.2. Results

Sand mining

Contrary to the Safety Buffer case, we did not identify any Sand Engine-specific issues regarding the sand mining activities. While sand mining in the Safety Buffer case took place in the Eastern Scheldt estuary with many stakeholders affected, the sand for the Sand Engine was mined 10 kilometres offshore in the North Sea where stakeholders are only marginally affected. More importantly, for the Safety Buffer project, a project-specific sand mining permit was required. For stakeholders affected, it is relatively easy to appeal against such a permit. For the Sand Engine project, no project-specific permit was required as it was part of the national permit for regular coastal nourishments under the Dynamic Preservation policy.

Sand nourishment

With regard to the Sand Engine nourishment, we identified several important cascades of interrelated uncertainties. The first issue concerned the effects of the project on the local drinking water supply (Figure 4.10). There is incomplete knowledge regarding the precise effects of creating a major peninsula – such as the Sand Engine – in front of the existing beach area on the groundwater level and consequently, on the groundwater transport patterns. An extension of the coast due to the Sand Engine will lead to a widening of the freshwater table in the dune area. As a result, internal transport patterns of fresh water will change. This may lead to a decrease of efficiency of the existing drinking water pumping infrastructure. More importantly, it induces the danger of mixing contaminated groundwater from a polluted dune section with the drinking water table. While the local drinking water stakeholder was concerned about these potential effects of the Sand Engine and requested additional research, the project team at first was convinced that the limited knowledge available was sufficient to expect no adverse consequences for the drinking water supply. Because the drinking water stakeholder was planning an escalation regarding this issue as it was clearly unacceptable for them, the project team had to change their viewpoint. After a study of the hydrological processes, it was concluded that the Sand Engine might have significant effects on the ground and drinking water situation if no proper mitigating measures were taken. Therefore, negotiations between the two actors resulted in the installation of a pumping station, aimed to preserve the original groundwater table. Moreover, adaptations to the design of the beach area in the vicinity of the Sand Engine were made and the groundwater situation will be monitored extensively.

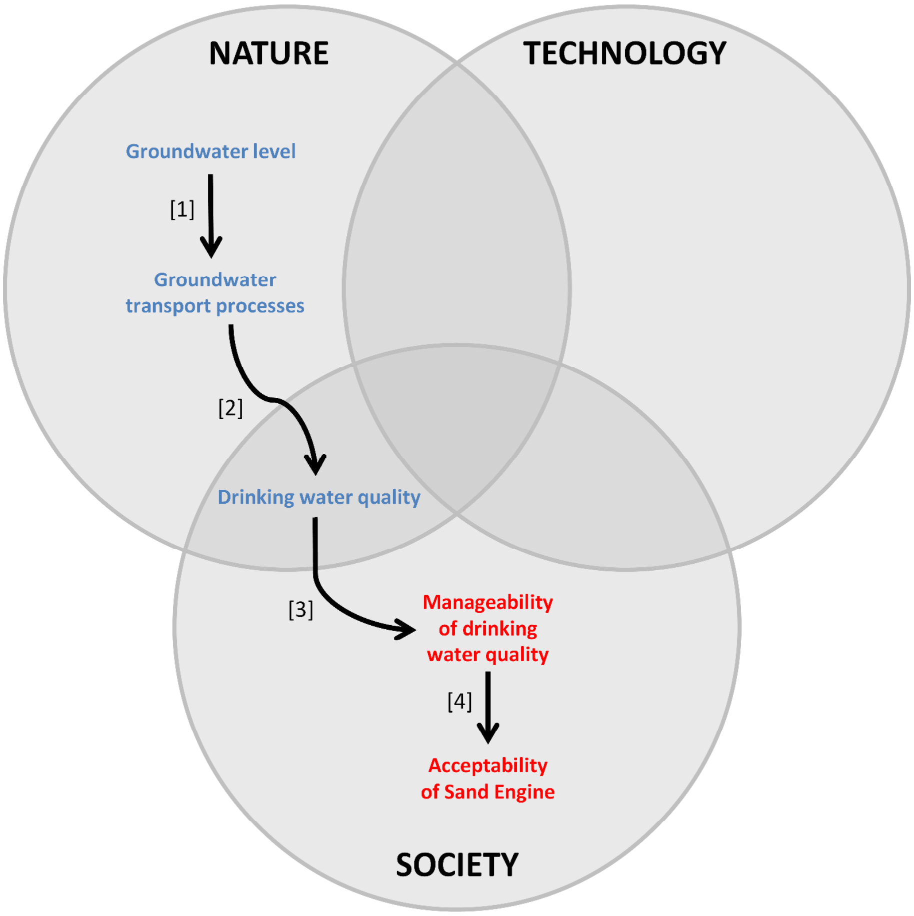

Figure 4.10 – Cascade of uncertainty regarding the impact of the Sand Engine on drinking water quality. Text colour coding is equal to Figure 4.3

The second cascade identified concerns financial aspects regarding the Sand Engine (Figure 4.11). As the Sand Engine is an innovative experiment, it is yet unpredictable if the concept will be successful. As the sediment transport along the coast on the short term is driven by unpredictable natural dynamics, this major uncertainty is the foremost determinant of the efficacy of the mega-nourishment concept. Additionally, while the Sand Engine's construction budget was restricted to 50 million euros, its sand volume had to be at least 18.5 million m^3. As these restrictions meant that constructors would only get half of the price regularly paid for a Dutch nourishment, the project team was concerned that the major dredging companies might refuse to construct the Sand Engine under the given preconditions. On the other hand, the Sand Engine could also be interpreted as a long-term investment, an innovative concept which draws extensive international attention and could result in an increase of dredging assignments world-wide. In order to prevent difficulties during the development process, the project team chose a participatory approach and started lobbying to assess its feasibility as early as possible. This approach resulted in a smooth and successful tender procedure for the Sand Engine's construction.

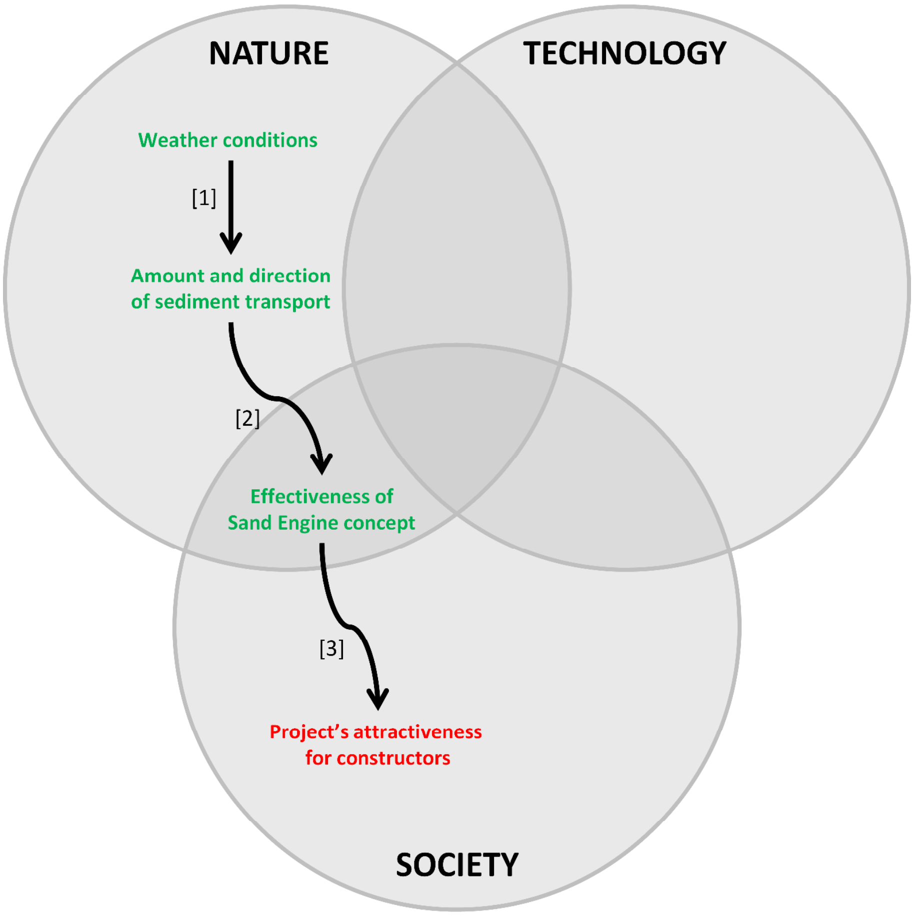

Figure 4.11 – Cascade of uncertainty regarding the attractiveness of the Sand Engine for constructors. Text colour coding is equal to Figure 4.3

Regarding the third uncertainty cascade, in the local political arena, it was observed that the Sand Engine might have adverse impacts on stakeholder activities in the surrounding municipalities (Figure 4.12). Specifically, there were concerns about the impact of the project on Scheveningen Harbour. Local politicians figured that the nourished sediment could potentially lead to an increasingly shallow harbour entrance, hindering its activities and eventually having an unpredictable negative financial impact. As a result, there were different views regarding the preferred location and shape of the Sand Engine in the early stages of the project. The project team chose an approach of persuasive communication to convince the opposing politicians that no harm would be done to the harbour activities.

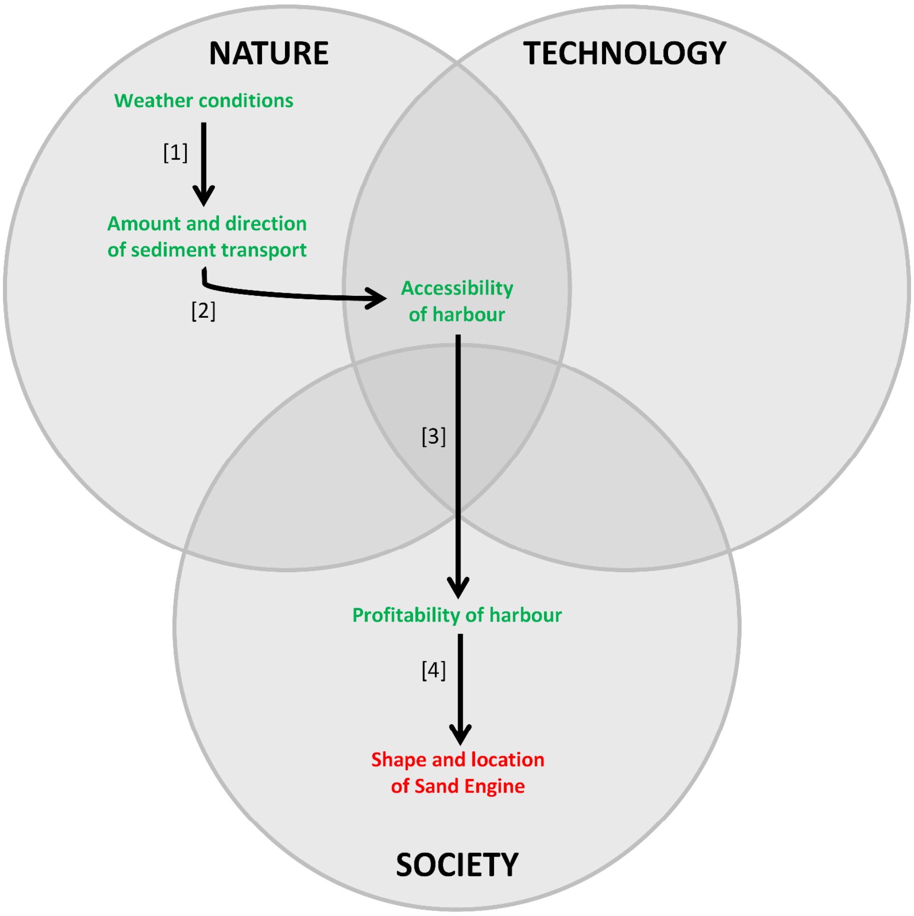

Figure 4.12 – Cascade of uncertainty regarding the impact of the Sand Engine on Scheveningen Harbour. Text colour coding is equal to Figure 4.3

Recreational safety: an uncertain issue of paramount importance

Finally and most importantly, the Sand Engine has major implications regarding recreational safety. The specific aspect of swimmer safety continues to be an issue of paramount importance, even after the project's implementation. During the development process, a group of local residents formed the 'Stop the Sand Engine' committee to express their concerns about the impacts on the recreational safety situation. During project development, they were fiercely supported in the Dutch parliament by one of the large political parties. The cascade of interrelated uncertainties concerning this particular issue has two branches, namely concerning swimmer safety (cascade [1]-[2]-[3]-[6] in Figure 4.13) and beach recreation safety (cascade [4]-[5]-[6] in Figure 4.13).

As the weather conditions that drive the Sand Engine development are inherently unpredictable, the near-shore water conditions and thus swimming conditions are unpredictable as well. While the project team views swimmer safety as an important but manageable issue, the opponents of the project believe that accidents are a certainty. Similarly, the opponents fear that the project activities will transport dumped ammunition to the beach area. After World War II, residual German ammunition was dumped in the North Sea at specific sites 18 km offshore. However, some fishermen, who were paid to carry out this task, already started dumping some bombs shortly after leaving the harbour. Whereas the locations of the dedicated dumping sites are well-charted, the whereabouts of preliminary dumped ammunition are unknown and could theoretically be located at the Sand Engine's mining area. If the ammunition would not be detected by the preventive sea-bed scans and manage to get past the anti-ammunition grid of the dredging ships, it could end up on the beach and be a potential hazard. While the action committee viewed this as the most likely scenario, the project team was convinced of the reliability of the ammunition precautions because there were hardly any negative experiences with ammunition during past sand nourishments. To address the recreational safety situation, the project team intended to have a meeting with the opposing committee. However, according to the project team, the opponents declined invitations to discuss the project. Furthermore, multiple parliamentary questions regarding this subject had to be answered. Nevertheless, the opponents were not successfully convinced. In the end, the responsible Ministry decided to implement the project, overruling the opponents.

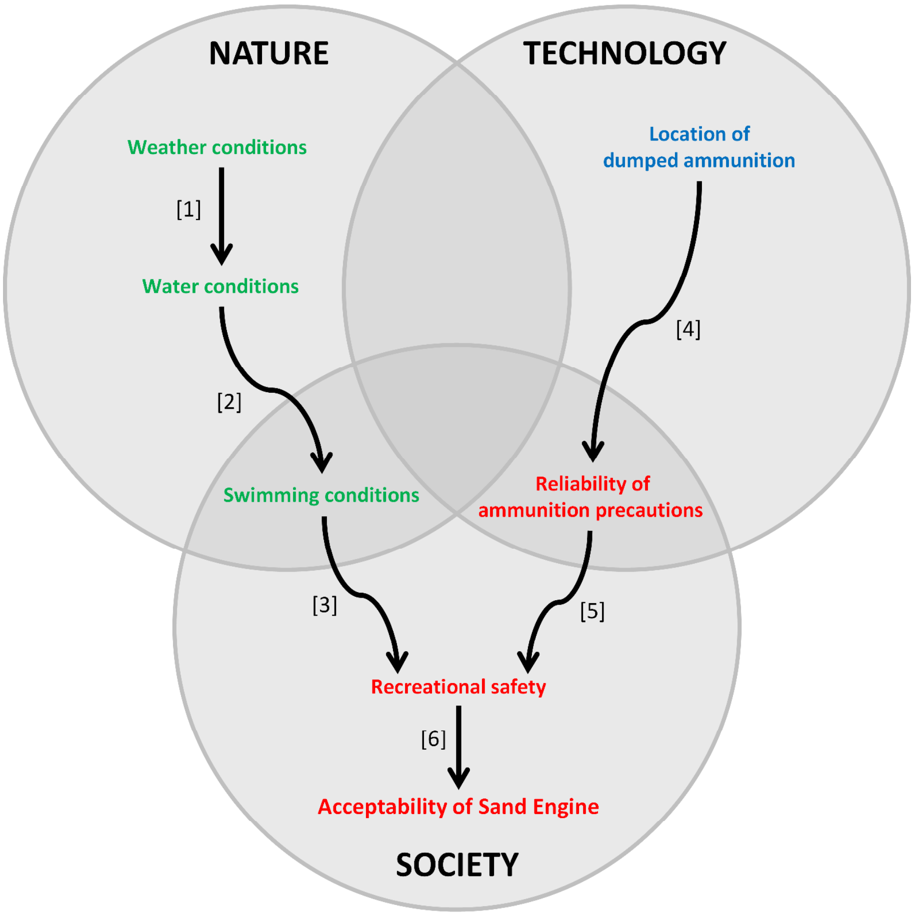

Figure 4.13 – Cascade of uncertainty regarding the impact of the Sand Engine on recreational safety. Text colour coding is equal to Figure 4.3

During the development process of the Sand Engine, the management plans regarding the swimmer safety situation mainly concentrated on communicative measures – such as 'do not swim' signs – and developing well-trained life guard brigades. However, after project implementation, the life guard brigades reported in April 2012 that they observed fast and potentially dangerous currents in the tideway at the Sand Engine. These circumstances were perceived as problematic as the official start of the bathing season was approaching (i.e., on the 15th of May) and the life guard brigades were unable to be fully operational by that time. Therefore, they requested the regional government to take additional safety measures to prevent accidents. An interviewee stated that the following advice was given regarding these additional measures:

> *"We advise them: either do nothing but warn people with [additional] 'do not swim' signs, or if really needed close [the tideway] with sand, or fence it off. Well, in any case: [do] not [use] stones… But preferably: do nothing. Because, well, you actually only disturb [the Sand Engine] if you manually move sand or nourish additional sand there. And in fact that is something we do not want."*

As (swimmer) safety has the highest priority for the government in any case, it was decided – despite the aforementioned advice – to close off the tideway with a small stone dam. Other governmental agencies and research institutes were disappointed about the new command-and-control type of safety measure, as it is not in line with the use of BwN design principles. Nevertheless, in July 2012, the swimming conditions seemed to be rather favourable and it was decided that a swimming prohibition was no longer needed. During one of the weekends in August 2012, one person died at the Sand Engine (due to a heart attack) and life guards had to perform about 80 rescues. This caused rumours, leading to a renewed swimming prohibition immediately after that troublesome weekend.

At the end of the bathing season in September 2012, the stone dam was removed in order to restore the initial situation of the Sand Engine. Currently, it is not clear if similar safety measures will be required in future bathing seasons. For the 2013 bathing season, a pilot is planned with a newly developed swimming water prediction model. This model is intended to predict swimming conditions two days in advance and could be used by the life guards to judge potential risks in the Sand Engine area.

4.6. DISCUSSION

In Sections 4.4 and 4.5, we discussed two flood defence projects based on BwN design principles and identified several cascades of interrelated uncertainties that were important during the development of these two initiatives. In this section, we reflect on the relationship between different uncertainties and discuss what the use of the uncertainty cascade concept implies for coping with uncertainty.

4.6.1. How are different uncertainties related in the two BwN projects?

By constructing a cascade of interrelated uncertainties for several apparent stakeholder issues (Figures 4.5-4.8 and 4.10-4.13), we demonstrate that fundamentally different uncertainties are not independent but interrelated. Although the topics of the uncertainty cascades deviate widely – from recreational safety to the financial consequences of an initiative – our results demonstrate that in each cascade the relationship ultimately results in *ambiguity in the social system*. This comes as no surprise, as the core activities of both project actors and stakeholders are located in the social system, where they use diverging organizational or personal interests, values and beliefs as a set of criteria to assess the quality or acceptability of a project regarding the particular stakeholder issue evaluated. The only partial exception is the issue about the wellbeing of the benthos (cascade [1]-[2] in Figure 4.8), where the amateur environmental interest group primarily evaluated the Safety Buffer project from a natural system perspective. The cascades of interrelated uncertainties mainly originate from either the unpredictable natural dynamics driving the project or incomplete knowledge about the impacts of the applied technology on the natural system. This seems rather straightforward, as natural dynamics are a central aspect of BwN designs. As these designs have an innovative character, it is difficult to predict the effects such a technological intervention will have on the natural environment.

The uncertainty cascade approach we propose differs from existing concepts that address the relation between different uncertainties – such as the uncertainty propagation approach – because it not only acknowledges incomplete knowledge and unpredictability, but also explicitly takes ambiguity into account. In our case study projects, we observe that incomplete knowledge about and unpredictability of natural processes or impacts on the natural system are gradually re-interpreted from different societal perspectives, resulting in ambiguity. Hence, the uncertainty transfers from the natural system to the social system and its *societal importance* seems to amplify throughout the cascade. Moreover, the same physical phenomenon can yield two uncertainties that are fundamentally different, due to the fact that they are interpreted from a different perspective. An example is the uncertainty about the impact of the Safety Buffer on the benthos community. While the amateur environmental interest group views the organisms as ‘animals’ (in the natural system) affected by the applied technology (cascade [1]-[2] in Figure 4.8), the amateur fishermen organization frames these organisms as ‘fishing bait’ and interprets the uncertainty as a negative impact of the technology on a societal function (cascade [3]-[4] in Figure 4.8).

The recreational safety issues in the Sand Engine case provide an excellent illustration of how multiple uncertainties form a cascade and are transferred between the different parts of the system to be managed. Cascade [1]-[2]-[3]-[6] in Figure 4.13 originates from the unpredictable weather conditions, the main dynamic design mechanism of the project. While the weather conditions redistribute the nourished sediment along the coast, these dynamics also create unpredictable water conditions in the near-shore coastal zone (represented by [1]). Local stakeholders re-interpreted these water conditions from a societal perspective, namely as unpredictable swimming conditions near the Sand Engine (represented by [2]). Hence, the uncertainty – although physically the same process – is transferred from a natural perspective to a societal one and becomes more important in terms of project development. While the project team viewed that the recreational safety situation is under control due to preventive measures, the stakeholders were very concerned and even questioned the acceptability of the Sand Engine (represented by [3] and [6]). Cascade [4]-[5]-[6] in Figure 4.13 originates from incomplete knowledge about the whereabouts of dumped ammunition. To prevent explosives from entering the dredging ships into the nourishment sand, the sea bed is sonar-scanned prior to the mining activities and the ships are equipped with anti-ammunition grids. During project development, the uncertainty about the whereabouts of the ammunition was transferred to a societal perspective (represented by [4]), as implicitly the stakeholders that oppose the Sand Engine hold a different view regarding the precautionary measures than the project team. Consequently, while the project team views recreational safety as under control due to the precautionary measures, the opposing stakeholders still view ammunition on the beach as a certainty (represented by [5]). The example above illustrates how the incomplete knowledge and unpredictability in the natural and technical system is gradually translated into different uncertainties, is transferred to a social perspective in the cascade and becomes increasingly important in terms of project development.

4.6.2. How do we cope with the cascade of interrelated uncertainties?

We argue that using cascades for representing the interrelated uncertainties in a project opens new possibilities for coping with uncertainty, as each uncertainty in the cascade represents a potential node of intervention or facilitation. Consequently, it might not be necessary to cope with each uncertainty identified in a project. As the uncertainties in the cascade are interrelated, this suggests that successfully coping with uncertainties that are caused by incomplete knowledge or unpredictability contributes to successfully coping with an ambiguity that is related to these uncertainties. Similarly, incomplete knowledge or unpredictability could be influenced by successfully coping with another situation of incomplete knowledge or unpredictability with which it is related.

Because incomplete knowledge, unpredictability and ambiguity can all be present in different parts of the human-technology-nature system, the strategies that can be used to manage the cascade of interrelated uncertainties are very diverse, as illustrated by the following example. In the Sand Engine case, there are multiple interpretations regarding the recreational safety situation. A direct method to cope with this ambiguity is to unite the efforts of the project team and opponents by jointly developing measures to safeguard the recreational situation, e.g. setting up a rescue brigade to watch over swimmers. Furthermore, communicative measures, such as ‘do-not-swim’ signs, can warn recreants about potential risks in the vicinity of the Sand Engine. However, the ambiguity can also be managed by coping with incomplete knowledge and unpredictability in the cascade. As discussed in Section 4.5.2, this occurred in practice after the Sand Engine’s implementation.

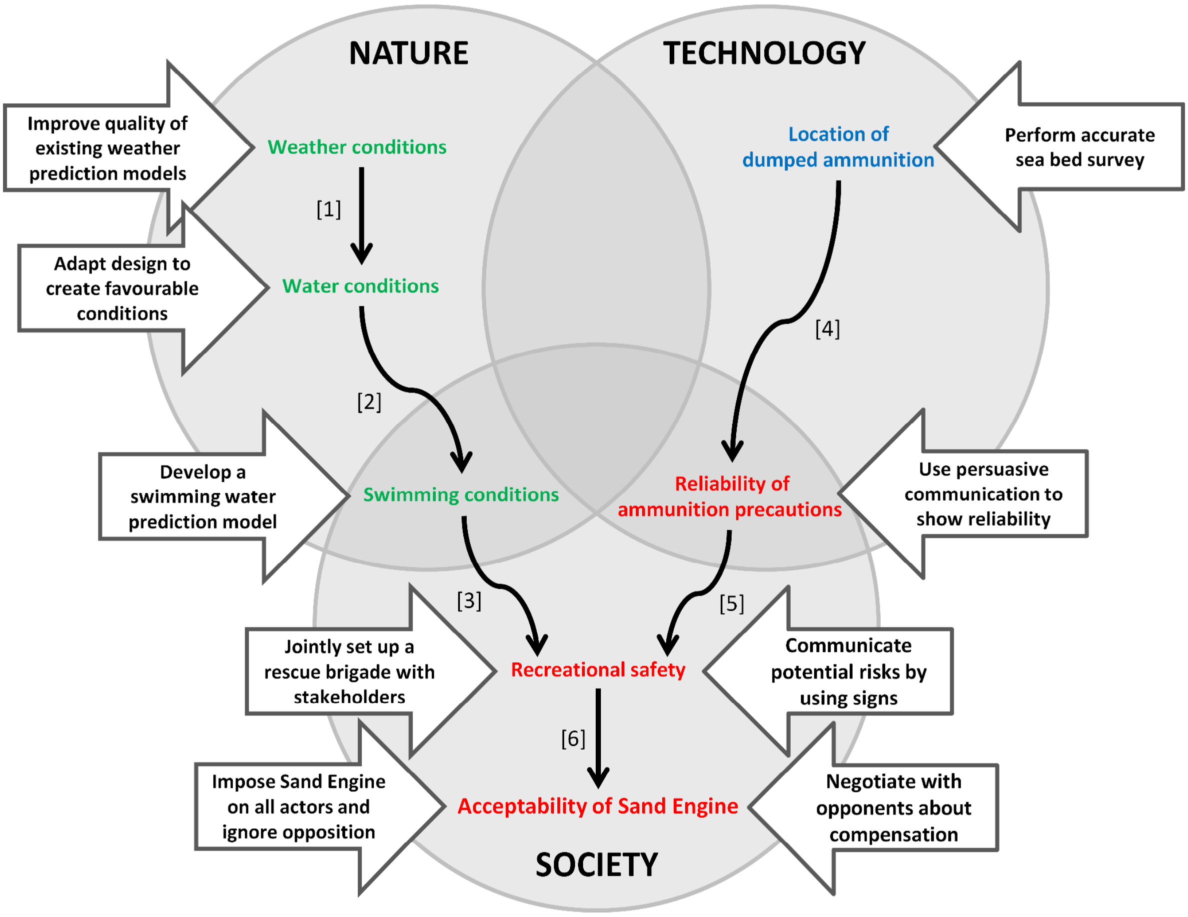

Figure 4.14 – Coping strategies for handling the Sand Engine’s recreational safety situation. Text colour coding is equal to Figure 4.3

For instance, in cascade [1]-[2]-[3]-[6] in Figure 4.14, the discussed swimming water prediction model could be an useful supportive tool to signal stakeholders when swimming conditions might be dangerous. However, in practice, the Sand Engine’s managers decided to manage an uncertainty even higher up the cascade. By creating the stone dam, the Sand Engine was physically adapted to create more favourable water conditions with respect to recreational safety. However, as a stone dam is not in line with the BwN approach, a sandy adaptation would have been a better alternative. Such an adaptation could already have been anticipated during the design phase of the project. Furthermore, current weather prediction models could be improved in order to give more accurate predictions of the Sand Engine’s development. Similarly, in cascade [4]-[5]-[6] in Figure 4.14, the project team could extensively communicate with the opponents to discuss the reliability of the techniques that prevent ammunition from entering the nourishment ships. One step up in the cascade, the project team might decide to commission a high-detail sonar assessment of the sea bed at the sand mining location in order to locate each single ammunition item present, to cope with the incomplete knowledge regarding the whereabouts of ammunition.

4.6.3. Towards adaptive uncertainty management

Flexible and adaptive approaches have been proposed to successfully implement policies and new infrastructures in the face of uncertain future system conditions and climate change (e.g., Hallegate, 2009; Wilby and Dessai, 2010; Haasnoot et al., 2013; Walker et al., 2013). We argue that the concept of the cascade of interrelated uncertainties is important for adaptive uncertainty management, as it provides insight to project teams and stakeholders about the uncertainties present and the diverse range of coping strategies available (as illustrated by the example in Section 4.6.2). As the uncertainties in the cascade are related, this suggests that coping with a particular uncertainty will influence those with which it is related. Thus, if a particular coping strategy falls short or system conditions change, the other points of facilitation and intervention in the cascade provide alternative coping strategies for the actors involved, offering the opportunity to adapt the uncertainty management approach that was previously pursued.

Although the cascades of interrelated uncertainties can be a powerful supportive tool to distinguish between the different nodes of intervention or facilitation available and to determine appropriate coping strategies, it is important to realize that those cascades are not necessarily static during and after the execution of a project. *Time* is a distinct aspect in projects based on BwN principles and the uncertainties associated with it (see Chapter 2). Ambiguity is particularly apparent *during project development* and stakeholders regularly want an issue to be resolved before giving their blessings to an initiative under development, as is illustrated by the following statements by two interviewees in the Safety Buffer case:

> *"If there is no [compensating] alternative, then we will not just give our permission to nourish on that area" {1} "Before they commence, [compensation] has to be arranged... And if it is not arranged? Well, nowadays, it is like this: it is unpleasant, but we almost permanently have lawyers." {2}*

Even after project implementation, new ambiguities may arise due to changes in legislations, political changes and changing actor preferences. Facilitating dialogues, participation and negotiation are essential to cope with ambiguity, in order to create a basis of mutual understanding among the actors involved (see, e.g., Dewulf et al., 2005; Van der Keur et al., 2008; Brugnach and Ingram, 2012). While incomplete knowledge and unpredictability are important during project development, it is even more important to acknowledge that it will remain uncertain until *after project implementation* whether an uncertain phenomenon will actually occur in reality. For instance, although the unpredictability of weather conditions can be an issue of discussion during project development, the phenomenon under consideration is a natural dynamic process which will not manifest itself until after project implementation. As this unpredictability remains a Sword of Damocles during project development, this consideration affects the way in which we should cope with this specific kind of uncertainty. In the current practice of our two BwN projects, we observe that monitoring of natural phenomena and project effects is the most commonly used strategy to address the incomplete knowledge and unpredictability. This provides valuable knowledge to those managing the project in order to adaptively fine-tune previously made design choices, project characteristics and uncertainty coping strategies if needed.

4.7. CONCLUSIONS

In common uncertainty classification approaches, uncertainties are represented as more or less disconnected specific issues about which decision-makers, modellers, stakeholders or other actors do not have a complete or unique understanding. However, the results from our two BwN flood defence projects show that we can extend this view on uncertainty. Different uncertainties, which can be of a fundamentally different nature, are directly related in *cascades of interrelated uncertainties*.

Uncertainty and scientific knowledge are often perceived differently by scientists, decision-makers and the public at large, creating a science-policy gap (Bradshaw and Borchers, 2000). Actors from different disciplines and with diverging backgrounds can interpret uncertainty differently or can hold different forms of knowledge as important (Dewulf et al., 2005). Uncertainty is often characterized from the scientific perspective, such as a modeller’s perspective (e.g., Walker et al., 2003). However, the understanding of knowledge and the interpretation of uncertainty are relational processes, as these processes depend on how the actors involved relate to each other and the context under consideration (Brugnach et al., 2008). The cascades of interrelated uncertainties can function as an instrument to explicitly connect the different uncertainties held relevant by different actors. Our cascade approach shows that the uncertainties experienced by a modeller can be important for a decision-maker and vice versa, as uncertainties that are interrelated in the cascade are relevant for each actor involved and not just for those from a specific perspective. Thereby, the cascades can be applied to establish links between all relevant actors – from science, policy and other disciplines – in order to come to better understood and jointly developed decisions under uncertain conditions.

While our results do not add new coping strategies to the already diverse range of methods to assess and handle incomplete knowledge, unpredictability or ambiguity (see e.g., Van der Sluijs et al., 2005; Refsgaard et al., 2007; Van der Keur et al., 2008; Brugnach et al., 2008, 2011; Raadgever et al., 2011;

Brugnach and Ingram, 2012), the extended view on the nature of uncertainty we propose opens windows of opportunity for uncertainty management. As the uncertainties are interrelated, this implies that successfully coping with a particular uncertainty in the cascade could influence other uncertainties related to it. As a result, it may not be needed to manage each uncertainty present in a promising project. Furthermore, the cascades can support the adaptive management of uncertainties. If a particular coping strategy fails or system conditions change, the cascades can point at new directions for coping with the uncertainties encountered. This is of particular interest for specific initiatives – such as those based on BwN design principles – that are not static but may change over time.

Developing more detailed guidelines for coping with the cascades of interrelated uncertainties in operational project management will be a challenging task, but also an interesting opportunity for future research. Nature-inclusive flood defence projects receive increasing international attention (Van Slobbe et al., 2013) and are seen as a promising adaptation measure against sea level rise, one of the most apparent global environmental change issues our society faces. The use of cascades of interrelated uncertainties during the development of these projects – to support the adaptive management of uncertainty – may provide a key contribution to the successful implementation of these promising initiatives.

5 COPING WITH UNCERTAINTY: THE BENEFITS OF THE INTERRELATEDNESS BETWEEN DIFFERENT UNCERTAINTIES[4]

ABSTRACT

For effective project management, successfully coping with uncertainty is a necessary condition to safeguard a promising initiative against severe delays, budgetary problems or even cancellation. Many classifications and typologies are available for uncertainty analysis and assessment, which represent each uncertainty encountered as strictly separated from other uncertainties. However, in Chapter 4, we claimed that what is uncertain about a problem cannot be captured as a separate and disconnected unit. Different uncertainties are interrelated in what we have called *cascades of interrelated uncertainties*, which can be advantageous for uncertainty management. In this chapter, we evaluate these advantages by studying two innovative flood defence projects. We determined which coping strategies were used to manage the projects' most important uncertainties – which were considered to be disconnected in these projects – and reflect on what could have been done when the interrelatedness between different uncertainties would have been considered. We found that an early assessment of the cascades of interrelated uncertainties can deepen the understanding of the problem at hand, informing a project team about which uncertainties are important, which ambiguities can be anticipated and which actors will be affected. Furthermore, each uncertainty in a cascade of interrelated uncertainties is a potential node of intervention or facilitation. Thus, assessing these cascades elucidates the many alternative coping strategies that can be pursued and, in this way, expands the possibilities for adaptive uncertainty management.

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[4] Another version of this chapter is under review as: Van den Hoek, R.E., Brugnach, M., Hoekstra, A.Y. Coping with uncertainty: the benefits of the interrelatedness between different uncertainties. Technological Forecasting and Social Change.

5.1. INTRODUCTION

Traditionally, uncertainty – a topic of high interest in both science and policy development – is mainly approached as a deterministic concept (see Walker et al., 2003, for a review), referring to the gap between the knowledge available and the knowledge needed by the actors in the decision-making process to make the best decision (Thiry, 2002; Walker et al., 2010). This approach suggests that uncertainty in decision-making can be relatively simply coped with by acquiring more knowledge. However, this is not that straightforward, as uncertainty can even prevail in situations where sufficient knowledge is available (Van Asselt and Rotmans, 2002). Gaining more knowledge or improving the knowledge quality might decrease uncertainty, but could also result in an increase of our awareness of knowledge gaps and thus in an increase of uncertainty (Van Asselt, 2000). It has also been argued that uncertainty has no meaning in itself for an actor involved in a decision-making process, until it leads to a situation in which it influences his or her ability to determine what the problem is or which action path to pursue. Thus, uncertainty refers to *the situation in which there is not a unique and complete understanding of the system to be managed* (Brugnach et al., 2008).

The many uncertainty classifications and typologies available in the literature (see, for example, Van der Sluijs, 1997; Van Asselt, 2000; Walker et al., 2003; Brown, 2004; Brugnach et al., 2008; Kwakkel et al., 2010) have provided different ways to distinguish between various types, levels, locations, natures and sources of uncertainty, such as *incomplete knowledge*, *unpredictability* and *ambiguity*. Although a classification provides valuable insights for decision-making regarding where, when and why uncertainty might be expected (Van Asselt, 2000), a drawback of using classification matrices is that the different uncertainties encountered are depicted as strictly separated and disconnected units, overlooking the possibility of interactions between uncertainties (Norton et al., 2006). Consequently, uncertainty management usually focuses on coping with the separated and disconnected uncertainties that were identified by using a particular classification matrix. For instance, Refsgaard et al. (2007) provide a detailed overview of coping strategies for each separate cell of a classification matrix based on Walker et al. (2003).

While incomplete knowledge, unpredictability and ambiguity are considered separately, these fundamentally different uncertainties are actually interrelated concepts. In Chapter 4, we showed that incomplete knowledge about or unpredictability of the system managed are often gradually re-interpreted from different societal perspectives, eventually resulting in ambiguity about the impacts of the project. For example, local water conditions in a project area are related to weather conditions, which are inherently unpredictable. However, this implies that swimming conditions in that area are unpredictable as well, which could cause ambiguity between different actors about the local recreational safety situation. As this example illustrates, the uncertainties encountered are not isolated, but are directly connected in what we have called *cascades of interrelated uncertainties*. This consideration has consequences for the way in which uncertainty should and can be coped with. As different uncertainties are interrelated, this implies that successfully coping with one uncertainty in a cascade influences the uncertainties with which it is related. Furthermore, each uncertainty in a cascade could be a potential node of intervention or facilitation for uncertainty management. As a result, it might be possible to pursue unconventional action paths and coping strategies to successfully manage both recognized and unanticipated uncertain conditions.

In this chapter, our objective is to assess the new possibilities that conceptualizing uncertainty in cascades of interrelated uncertainties opens for coping with uncertainty. To this end, we study how uncertainty was coped with during the development process of two flood defence projects based on Building with Nature design principles, the Sand Engine Delfland and the Safety Buffer Oyster Dam. We determined which coping strategies were used to manage the projects' most important uncertainties – which were considered to be disconnected in these projects – and reflect on what could have been done when the interrelatedness between different uncertainties would have been considered. Based on the results of our case study projects, we argue that an early analysis of the cascades of interrelated uncertainties is needed to elucidate alternative action paths and, in this way, expands the possibilities for adaptive uncertainty management.

This chapter is structured as follows. In Section 5.2, we discuss our analytical framework, describe how we performed our analysis and how we collected our data. Section 5.3 provides the results of our two case studies. In Section 5.4, we discuss the benefits of the cascades of interrelated uncertainties for adaptive uncertainty management, but also address that it is not a panacea. The final section provides our conclusions.

5.2. METHODS

5.2.1. Analytical framework

Following Brugnach et al. (2008), we view uncertainty relative to its role, meaning and relationship in decision-making, paying particular attention to how an actor (e.g., a decision-maker) relates to a problem situation he or she is to decide upon. We distinguish between three so-called uncertain knowledge relationships, namely incomplete knowledge, unpredictability and ambiguity. Incomplete knowledge originates from the imperfection of our knowledge, which may be reduced by additional research. It concerns what *we do not know* at this moment, but might know in the future if sufficient time and resources are available to perform additional research or collect more data. Unpredictability is caused by the inherent chaotic or variable behaviour of e.g. natural processes, human beings or social processes. Thus, it is different from incomplete knowledge: unpredictability concerns what *we* *cannot know* and therefore can never be fully reduced by doing more research. Ambiguity is an uncertainty of a different kind, as it is not about what we do not or cannot know: it is about actors *knowing differently*. Ambiguity refers to the situation in which there are different and sometimes conflicting views on how to understand the system to be managed (Dewulf et al., 2005; Brugnach et al., 2008; Renn et al., 2011). This system to be managed consists of three subsystems, namely the natural, technical and social system.

As uncertainty is traditionally conceptualized as a lack of knowledge, uncertainty management literature primarily focuses on coping with incomplete knowledge and unpredictability. As a result, acquiring more knowledge and imposing top-down control on the decision-making process are the most commonly used strategies to cope with uncertainty (Koppenjan and Klijn, 2004). However, these strategies are not necessarily effective for coping with any uncertainty encountered. For instance, ambiguity requires fundamentally different coping strategies that aim at resolving the differences between the actors involved (Brugnach et al., 2011). While coping with incomplete knowledge and unpredictability mainly calls for generating more or better knowledge and forecasts, coping with ambiguity requires that all relevant actors are jointly involved in realizing a commonly shared knowledge base (Brugnach and Ingram, 2012).

5.2.2. Case study research

The research discussed in this chapter is based on our analysis of two case study projects, namely the Sand Engine and Safety Buffer Oyster Dam projects. For the Sand Engine project, we used two main data collection methods. First, three public information meetings were attended, during which stakeholders and the general public had the opportunity to pose critical questions, express their appreciation or concerns about the project and to file complaints. Minutes of these meetings were made and studied to identify important uncertainties and to understand the diverging viewpoints regarding the project. Second, we performed nine interviews with individuals that were or are involved in the Sand Engine's development process or its maintenance after implementation. In April and May 2011, we interviewed three (former) members of the project team, one member of the project steering group and two experts – involved in the Environmental Impact Assessment (EIA) and modelling – about the most important uncertainties encountered during project development, how these could have hampered the project and how the uncertainties were coped with. In the period from May until November 2012, we performed three additional interviews to acquire specific information about the Sand Engine's recreational safety situation. The interviewees were invited to elaborate on the safety measures regarding recreation, the reasons why measures were changed and which specific uncertainties were coped with. The semi-structured interviews were conducted in the Dutch language, took between one and two hours, and were recorded and transcribed. Standardized interview protocols with several open-ended main questions and follow-up questions were used during both interview series.

For the Safety Buffer Oyster Dam project, first, we attended meetings of the project's knowledge development team in March 2012 and the stakeholder sounding board in April 2012. Whereas the meeting of the knowledge team was recorded and transcribed, the sounding board meeting could not be recorded but minutes were made. We studied the data of both meetings to identify important uncertainties, discussion themes and stakeholder issues in the Safety Buffer project. Second, we conducted four interviews with actors related to the project team (performed by two interviewers) and nine interviews with stakeholders (performed by one interviewer) in July, August and September 2012. During three of these interviews, two respondents were interviewed instead of one. Thus, in total, we spoke to six project team associates (three at the executive and three at the project level) and ten stakeholders. The interviewees were invited to elaborate on those project topics that were most important for them, but that also caused the hardest discussions due to the existence of uncertainty and diverging viewpoints. For each of these uncertainties, it was discussed how the project team aimed to cope with it. The semi-structured interviews were conducted in the Dutch language, took about one hour, and were recorded and transcribed. Two standardized interview protocols (one for the project actors and one for the stakeholders) with up to fourteen open-ended main questions were used.

For both cases, we studied project documentation and communication as additional research material. These documents indicate whether a particular uncertainty was coped with by acquiring more information (e.g., a research report on the topic is present) or by addressing the different viewpoints of particular stakeholders issues (e.g., there are emails in which stakeholders are invited to participate during a meeting). Furthermore, we consulted interviewees or other project actors to acquire additional information on specific uncertainties if needed.

The multiple uncertainties that were identified in the two cases were classified according to the framework discussed in Section 5.2.1. Thereafter, the importance of the uncertainties was assessed by considering two aspects: the uncertainty's potential impact ("can it lead to substantial cost overrun, a substantial delay or even project cancellation?") and its project-wide relevance for the actors ("is this uncertainty considered important by multiple interviewees and project actors?"). The uncertainties that were perceived as most important by the interviewees all appeared to be ambiguities. For each of these ambiguities, we determined which coping strategies the project team applied to handle it. Thereafter, we determined how successful these coping strategies were in preventing the potential negative impact of the ambiguity (e.g., substantial cost overrun, delay or project cancellation). Furthermore, we evaluated whether the applied set of coping strategies provides a *sustainable* solution: the strategies should not only offer a solution on the short term, but should also prevent the ambiguity from re-intensifying at a later stage in the project's development process.

Hereafter, we reflected on what could have been done when the interrelatedness between different uncertainties would have been considered. For each of the important ambiguities, we traced to which other uncertainties it relates, both directly and more indirectly (see Chapter 4). Thus, several cascades of interrelated uncertainties of major importance were identified in our case study projects. In the figures used to present the cascades (see Figure 4.3 for an example), black arrows express that an uncertainty is related to another uncertainty. Furthermore, for each uncertainty, colours indicate which of the three uncertain knowledge relationships it dominantly concerns (green for unpredictability, blue for incomplete knowledge and red for ambiguity).

For the cascades identified in our study, we determined an appropriate coping strategy for each individual uncertainty – thus, for each potential node of facilitation or invention – in the cascades. In our search for coping strategies, we were inspired by the various methods and techniques available in the uncertainty management literature (see e.g., Brugnach et al., 2008, 2011; Refsgaard et al., 2007) and by the many alternative strategies that were opted or applied in our case study projects. We carefully took into account that incomplete knowledge, unpredictability and ambiguity require fundamentally different coping strategies (following Brugnach et al., 2011). Furthermore, each strategy proposed was evaluated on two aspects. First, we evaluated whether the coping strategy could successfully cope with the particular individual uncertainty for which it is intended. Second, we hypothesized whether the strategy could have a positive influence on other uncertainties in the cascade with which it is related.

5.3. RESULTS

In this section, we present the results of our two case study projects. Both are innovative flood defence projects based on so-called *Building with Nature* (BwN) design principles, an innovative approach that utilizes natural dynamics (e.g., wind and currents) and natural materials (e.g., sediment and vegetation) for the integral realization of effective flood defence and nature development opportunities (Waterman, 2008; De Vriend and Van Koningsveld, 2012). We first give a concise description of each project and provide an overview of the most important uncertainties per case, the impacts these could have had on project progress and how (successfully) these were coped with. Thereafter, we explore our findings on the possibilities that the interrelatedness between different uncertainties offers for coping with uncertainty.

5.3.1. How was uncertainty coped with in our case studies?

Sand Engine Delfland

Due to continuing coastal erosion, on-going land subsidence and sea level rise, the sandy Holland coast becomes increasingly vulnerable to flooding. Therefore, the Dutch government implemented the so-called Dynamic Preservation policy: the Holland coastline has to be maintained at its 1990 position by performing periodic, relatively small-scale, sand nourishments (Hillen and Roelse, 1995). Sand Engine Delfland – a mega-sand nourishment of 21.5 million m^3 constructed in 2011 – is the first large-scale pilot project based on BwN design principles and has been a collaborative effort between public authorities, private companies and research institutes (De Vriend and Van Koningsveld, 2012). The main objective of the project is to stimulate natural dune development, while creating new opportunities for nature and recreational development. Furthermore, knowledge development regarding the applicability and efficiency of the mega-nourishment concept is a key objective of the project.

The Sand Engine is expected to redistribute along the Holland coast over a 20 to 50 year time period by natural dynamics such as waves and wind, causing both beach area and dunes to expand in a fairly natural way (see Stive et al., 2013 for an overview of preliminary project results). However, as weather conditions are unpredictable over longer time scales, predictions regarding the nourishment's coastal distribution involve high levels of uncertainty. Other major uncertainties concern the project's impact on swimmer safety and drinking water quality (see Chapter 2). To cope with these uncertainties, those responsible for the project mainly relied on strategies that are aimed at acquiring more knowledge. For instance, the project team commissioned high-quality model studies in order to acquire detailed scenarios of the 20-year morphological development of four Sand Engine design alternatives. Furthermore, an extensive monitoring and evaluation program was set up to assess the development of the nourishment and its impacts. Thus far, the model studies prove to be partially accurate. While the shape of the Sand Engine develops as predicted, the *speed* of the morphological development initially was higher than expected, probably due to the many storms during the first winter of the Sand Engine's existence.

Table 5.1 provides a concise overview of the most important uncertainties identified in the Sand Engine project, the impact these uncertainties could have had on the development process, the coping strategies used to manage these issues and the results of the strategies applied.

Table 5.1 – Overview of important uncertainties and their coping strategies in the Sand Engine case

Issue about which project actors are uncertain	Potential impact of the uncertain issue	Coping strategies applied to manage the cascade	Result of the coping strategies applied
Impact on recreational safety, with specific attention for: • swimming conditions • presence of ammunition in the nourishment sand	Concerned locals formed an action committee and a large political party posed critical questions to the responsible minister as they were convinced that the Sand Engine would lead to serious accidents, Both parties requested for the cancellation of the project	Strategies that approach uncertainty as deterministic concept, such as: • swimming prohibition, signs and life guards • use of sonar and anti-ammunition grids on dredging ships • swimming conditions modelling study	Although there were some incidents with recreants, no major injuries were caused to the authors' knowledge. Nevertheless, the opponents' viewpoints were not attended to. Thus, the ambiguity about the recreational safety remained a potentially hampering factor for the development process
Impact on drinking water quality due to: • potential salt water intrusion • pollution from a local dune area	The local drinking water stakeholder stated that they would file an official complaint if no additional impact study would be done. This complaint could have led to a serious delay An essential budget deadline was approaching. This could have eventually led to the cancellation of the project	Initially, the response was rather passive. Thereafter, strategies that approach uncertainty as deterministic concept were pursued: • additional impact study on impacts on ground- and drinking water • drainage pipe and pumping station	To the authors' knowledge, no impact on the drinking water quality occurred. Although the ambiguity was eventually successfully coped with, it nearly led to the cancellation of the project
Impact on accessibility of Scheveningen Harbour due to: • nourishment sand blocking the harbour entrance	Cooperation of the municipality of the Hague was needed in order to come to a successful implementation of the project	Two strategies were mainly used: • communication aimed to persuade the municipality that project impacts are under control • an agreement about how to act in case of an accessibility problem	In an early stage, the ambiguity regarding the subject was addressed by making a proper management plan
Attractiveness for potential constructors, which could be viewed as: 1. long-term investment due to marking potential and innovative character 2. poor short-term profit and thus not interesting	An interested constructor needed to be found in order to successfully implement the project. This could have become difficult if all constructors would view the project as unprofitable	Communication strategy, namely: • lobbying activities	In an early stage, the potential ambiguity regarding the subject was prevented as it turned out that the project was doable within the available budget

Safety Buffer Oyster Dam

Due to the construction of a large storm surge barrier in the 1980s, the Eastern Scheldt estuary currently faces a major problem called the Sand Hunger: the on-going erosion of existing tidal flats – important bird habitats and natural flood defences – due to the disturbance of the sediment balance caused by the estuary's closure. The Safety Buffer Oyster Dam project is a practical and local response to the effects of this Sand Hunger problem. The pilot project – completed in October 2013 – consists of a sand nourishment of 425.000 m^3 to reconstruct an eroded tidal flat in the Eastern Scheldt estuary and the construction of an artificial oyster reef to slow down future erosion of that flat. While one of the project's goals is to gain knowledge about dealing with the effects of the Sand Hunger problem, the main objective is to develop a sustainable flood safety situation and a restored tidal flat landscape at the Oyster Dam for the next 50 years. The preferred design alternative proposes to nourish half of the existing tidal flat, while the sand will be redistributed to the other half by the natural dynamics. However, no predictive modelling studies regarding the nourishment's future development were commissioned by those responsible for the initiative.

Table 5.2 – Overview of important uncertainties and their coping strategies in the Safety Buffer case

Issue about which project actors are uncertain	Potential impact of the uncertain issue	Coping strategies used to manage the cascade	Result of the coping strategies applied
Impact of sand mining on shellfish sector and fishermen due to: • suspended sediment (covering shellfish) • nutrient removal (making the area less attractive for fish)	According to multiple interviewees, the project cannot be realized if it is not (at least informally) supported by the shellfish sector	Stakeholder participation, namely: • early involvement of stakeholders in a meeting to determine stakeholder demands and preferences • dialogues to find optimal sand mining location	All actors involved agree on the preferred sand mining location
Impact of nourishment on shellfish sector – in particular on the oyster sector – due to: • suspended sediment (covering shellfish)	According to multiple interviewees, the project cannot be realized if it is not (at least informally) supported by the shellfish sector	Stakeholder participation, namely: • early involvement of these stakeholders • jointly develop a new design with the oyster sector	Despite good intentions of the project team, the oyster sector acted strategically (skipping meetings and involving the media). Eventually, the opposition was decreased successfully by the new design process
Impact of nourishment on benthic organisms, interpreted from: • an environmentalist perspective • an amateur fishermen perspective (who use the organisms as bait)	The chairman of an environmental interest group suggested to take legal actions against the project, which could have caused a considerable delay. The amateur fishermen discussed similar actions during the interview we performed	Meetings to convince the environmentalists of the project's positive intentions Negotiation to find alternative area for amateur fishermen to harvest their bait	The environmentalists were successfully convinced. With the fishermen organization, an agreement about an alternative bait area was reached. Thus, both refrained from taking legal actions
Impact of nourishment on local fishing grounds because: • nourishment partially takes place on their area	The particular fishermen considered legal actions against the project, which could have caused a considerable delay	Negotiation to find alternative fishing grounds	An agreement about fishing grounds was reached. The fishermen refrained from taking legal actions

A coalition of governmental parties and local stakeholders worked out some initial ideas about the Oyster Dam's future in small-scale projects a few years ago. The current Safety Buffer project that eventually resulted from this preliminary work is executed by an unusual coalition, formed by two Dutch governmental agencies and a non-governmental environmental interest organization. Furthermore, the project team stimulates stakeholders to actively participate in the initiative and major uncertainties – such as ambiguity about the impacts on the shellfish sector – are primarily coped with by addressing the differences between the actors involved using a participatory approach. The project even started with a major stakeholder meeting, intended to come up with a list of stakeholder requirements that need to be taken into account as much as possible. Moreover, the project team formulated boundary conditions to protect stakeholders' interests: the Safety Buffer is not allowed to have any adverse impacts for stakeholders and all unforeseen damage has to be fully compensated.

Table 5.2 provides a concise overview of the most important uncertainties identified in the Safety Buffer project, the impact these uncertainties could have had on the development process, the coping strategies used to manage these issues and the results of the strategies applied.

5.3.2. Which possibilities could the cascades of interrelated uncertainties have offered in our case studies?

Coping with uncertainty via relations with other uncertainties

In our two case studies, uncertainties were coped with as if these can be represented as isolated units. While uncertainty management in the Sand Engine project mainly focused on handling the imperfection of the knowledge available (Table 5.1), the Safety Buffer project team primarily focused on coping with ambiguity by means of stakeholder participation (Table 5.2). However, we observed in our case studies that important uncertainties can be coped with by handling yet another uncertainty with which it is related. We will demonstrate this particular mechanism with an example from each case, where the project team (implicitly) coped with an uncertainty by using its interrelatedness with other uncertainties.

In the Sand Engine case, we observed a situation of ambiguity about the impact of the project on drinking water quality. This ambiguity was successfully coped with by addressing another uncertainty with which it is related. The construction of a major sand peninsula at a coastline will change underground water transportation patterns, but the knowledge regarding the exact impacts is incomplete. In the specific case of the Sand Engine, the drinking water supply nearby could come in contact with non-potable saltwater or might even become polluted with waste present in the local dunes. Nevertheless, following the results of the Environmental Impact Assessment, the project team was confident that the effects of the Sand Engine project on drinking water quality were manageable if some minor mitigating measures were taken. However, the local drinking water company anticipated problems with the drinking water supply and demanded an additional research. Otherwise, they would file an official complaint – as the project would be unacceptable for them – which would cause significant delays. Initially, the project team unsuccessfully attempted to address the ambiguity between them and the drinking water company as follows:

> *"We gave proper answers [to the drinking water company]. Then [we made] the draft permit and exactly the same questions popped up again from [the drinking water company]. And I really thought: 'how come?' [Our experts] tell me that everything is fine… [However, it turned out that] the engineering company's and our knowledge just wasn't sufficiently accurate."*

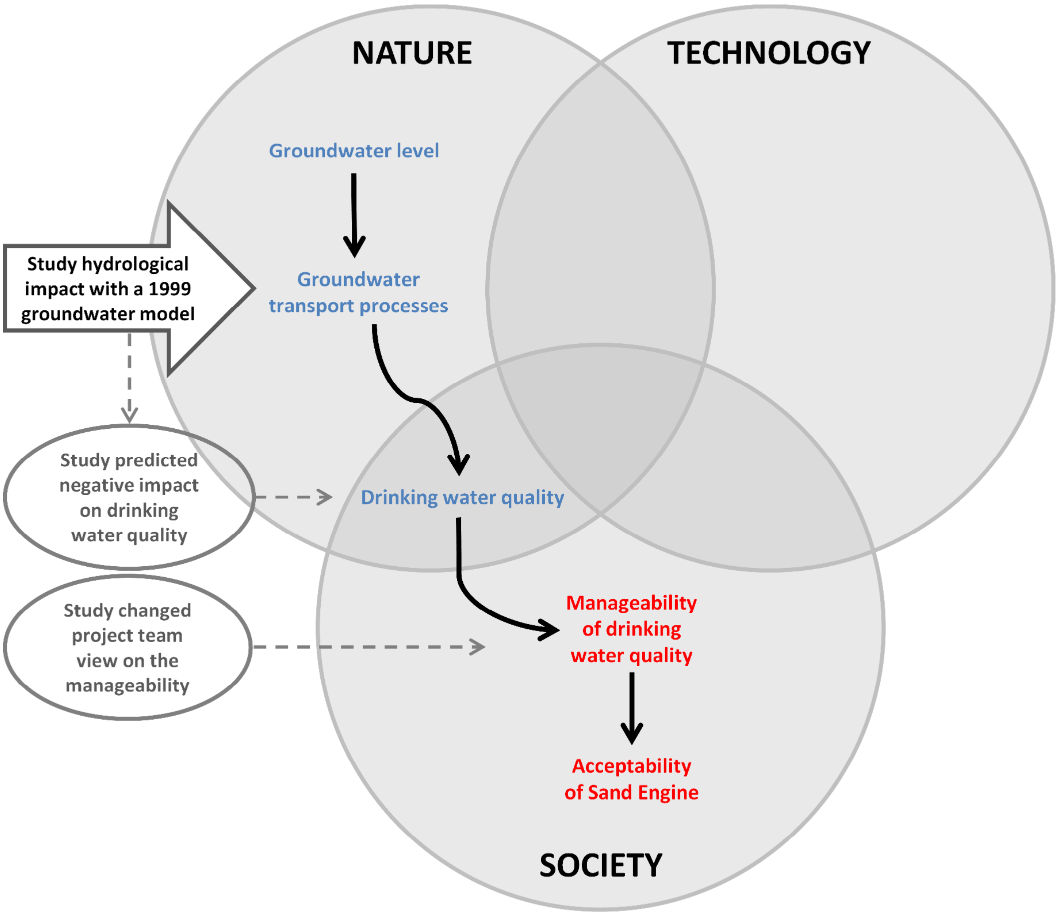

Figure 5.1 – Coping with ambiguity about the manageability of the drinking water quality. It was coped with by first handling the incomplete knowledge about groundwater transport processes related to it. Text colour coding is equal to Figure 4.3

Because the ambiguity between the two actors remained troublesome and an essential project deadline was approaching, the project team eventually had to commission the research requested by the drinking water stakeholder. Based on the information acquired from this research, it was found that the concerns were legitimate and that additional mitigating measures were needed (i.e., a drainage pipe with a pumping station). As a result, the project team acknowledged that the view of the drinking water company was the correct one. Thus, the ambiguity regarding the drinking water situation was successfully coped with by reducing the incomplete knowledge related to it (Figure 5.1).

In the Safety Buffer case, we observed a situation where successfully coping with an ambiguity reduced the urgency to acquire more knowledge during project development. The tidal flat reconstruction proposed in the Safety Buffer project requires nourishing a thick layer of sand on top of the existing flat, where so-called benthic organisms or benthos are living. The nourishment disturbs their habitat and will result in their death due to suffocation. In the following years, it is expected that the area will be gradually reclaimed by benthic organisms from other parts of the Eastern Scheldt, although our knowledge is still incomplete regarding the speed and extent of this recovery. While this was an acceptable outlook for the project team, the initial adverse impacts were unacceptable for a local amateur environmental interest group. In order to cope with this ambiguity, representatives from both parties had several meetings to have in-depth discussions about the project, its intentions and impacts. These meetings revealed that the interest group's assumptions about the project did not correspond with the actual design. As the meetings clarified the goals and intentions of the project, the interest group seized their opposition and the ambiguity was resolved. Additionally, acquiring more knowledge about the speed and extent of the benthos recovery was no longer a requirement of the interest group. Thus, by successfully coping with the ambiguity, the incomplete knowledge related to it became less important and lost its meaning in the decision-making situation. Instead, the interest group now embraces the learning opportunity the Safety Buffer project offers and fully accepts the initial adverse impact on the benthos:

> *"What strikes me is that I eventually had a quite positive feeling about it. That assessment [by the project team] is not so bad after all… One of the goals was 'to learn'. I find that quite amusing. Well, if we never do [a pilot project like this], then of course, we can never give an answer about how we should do [such a project] when it is really [necessary in the future]. So I think that's something positive. So, then you sacrifice a few hundred thousand beach worms. Well, fine."*

Coping with ambiguity in a proactive way

Ambiguity can become a hampering factor in the development process of BwN projects (see Chapter 2). This suggests that it might be very valuable to have knowledge – at an early stage during the process – about which ambiguities could emerge in order to proactively cope with those ambiguities before they can become a hampering factor. In our case study projects, we found examples of situations in which the responsible project team identified an ambiguity that could emerge from other uncertainties. As they (implicitly) recognized the interrelatedness between the uncertainties early on in the process, they were able to involve the relevant stakeholders in an early stage in order to adequately prevent the ambiguity from becoming a hampering factor in the development process.

Because the exact development of the Sand Engine is uncertain due to the unpredictable natural dynamics driving the project, its expected benefits are unpredictable as well. Nevertheless, in an early stage of the development process, both the budget available and the sand volume required for the project were already fixed. The project team realized that this might lead to ambiguity about the project's attractiveness for dredging companies. While the innovative Sand Engine project might be seen as a valuable marketing instrument for a dredging company in order to attract (inter)national customers (i.e., the view of the project team), the dredging company responsible for the project's construction would only earn half of the price normally received for a Holland Coast nourishment. Consequently, it was unclear if potential constructors would view the project as a major opportunity or a risky activity. To cope with this uncertainty, the Sand Engine project team started a lobby with the major Dutch dredging companies as early as possible in order to quickly assess the project's feasibility. In the end, this lobby gave a positive result, and the potential situation of ambiguity between the project team and the constructors was successfully prevented.

In the Safety Buffer case, we found a similar example. An organization representing amateur fishermen viewed the issue of the benthic organisms – discussed in Section 5.3.2 – from a different perspective. Specific benthic organisms (i.e., worms) are used as bait by amateur fishermen. The Oyster Dam tidal flat is one of the best locations for harvesting these worms, but the organisms will die due to the nourishment. The time frame within which the bait level will be restored to its initial value is highly uncertain. While the amateur fishermen organization claimed that an alternative bait area should be provided to them, the project team pointed out that this is not legally required for projects executed for flood safety purposes. Nevertheless, the project team identified this ambiguity with the amateur fishermen organization at an early stage, preferred to avoid a conflict situation and decided to propose an alternative bait area. Of course, the amateur fishermen organization appreciated the open-mindedness of the project team and agreed with the proposal that they would get an alternative area. Actually, the amateur fishermen organization had a very proactive attitude in order to resolve the matter. As soon as they realized that the Safety Buffer project might negatively affect the fishermen's activities, the organization initiated a search for an alternative which they could propose to the project team. As one of the interviewees stated:

> *"[The state water authority] just took that up very well at the Oyster Dam and figured prudently that we again had a major interest there. And [they] just called us for consultation in the initial stages… You can be against the project and just try to stop it. Insist [that you have] your permit and say:*

> *'[look], we just don't want it'… Or you could indeed think along from the beginning to come to a joint solution. And then we always prefer the latter."*

While we discussed two successful examples above, the Sand Engine drinking water situation (discussed in detail in Section 5.3.2) provides a good example of a missed opportunity to timely avoid a situation of ambiguity. Although the incomplete knowledge regarding the drinking water situation was already acknowledged as an important theme in an early stage, the potential ambiguity between the project team and the drinking water stakeholder to which this led was not properly recognized. A relatively easy coping strategy to avoid ambiguity at all would have been to actively involve the drinking water stakeholder in the process. However, the drinking water stakeholder was not actively involved in the process until after the Environmental Impact Assessment, which merely stated that 'agreements with the stakeholder need to be made'. The late involvement of the drinking water stakeholder was pointed out as one of the main reasons that the ambiguity eventually emerged:

> *"The drinking water [stakeholder] in fact also didn't want the [Sand Engine] because they weren't involved in the project team… [The groundwater issues] could have influenced the design if it had surfaced [earlier]. Very late in the process, it was acknowledged that [we] should take a closer look at it. In fact, for two reasons I think. [The drinking water stakeholder] was never fully involved in the project team. And the other reason is: at some point, we once had some workshop about the monitoring and [the drinking water issue] was not mentioned [at that occasion]."*

Elucidating many alternative coping strategies

Project teams can benefit from the information that a cascade of interrelated uncertainties provides. As discussed above, each uncertainty in a cascade of interrelated uncertainties represents a potential node of intervention or facilitation. If a BwN project team investigates the cascade in an early stage of the process, it can assist them to anticipate to any development that occurs over time. When a particular coping strategy fails, an overview of the many alternative possibilities is already available and no hasty decisions are required. In the Sand Engine case, the issue of swimmer safety provides an ideal example of how the cascades of interrelated uncertainties could have contributed to uncertainty management in the project.

Early on during the Sand Engine's development process, experts performed a predictive model study regarding the project's morphological development. One of the results of this study was that the *water conditions* in the vicinity of the Sand Engine were expected to be unpredictable. Consequently, it was acknowledged that the effects of the nourishment on *swimming conditions* – a physical aspect – were also highly uncertain. Therefore, the experts explicitly advised to perform an additional study regarding the swimming conditions. Moreover, an appropriate assessment of the relations between the different uncertainties at that time could have provided the insight that the issue has a social dimension as well: if stakeholders realize that the swimming conditions are unpredictable, this will likely affect their view on the *swimmer safety* situation. As safety is a essential issue, ambiguity can easily arise about the *acceptability* of a project that could negatively influence human safety. Thus, at this stage of the development process, several alternative coping strategies could have already been identified by the project team if they had considered the interrelatedness between different uncertainties. While the additional study regarding the swimming conditions could have improved the insight in the physical conditions, early stakeholder involvement could have been a strategy to cope with the potential ambiguity about the safety situation.

However, the project team initially approached the recreational safety issue as an isolated – and rather deterministic – uncertainty and focused on creating a robust management plan consisting of measures such as a swimming prohibition, do-not-swim signs and professionalizing the local life guard brigades (Figure 5.2).

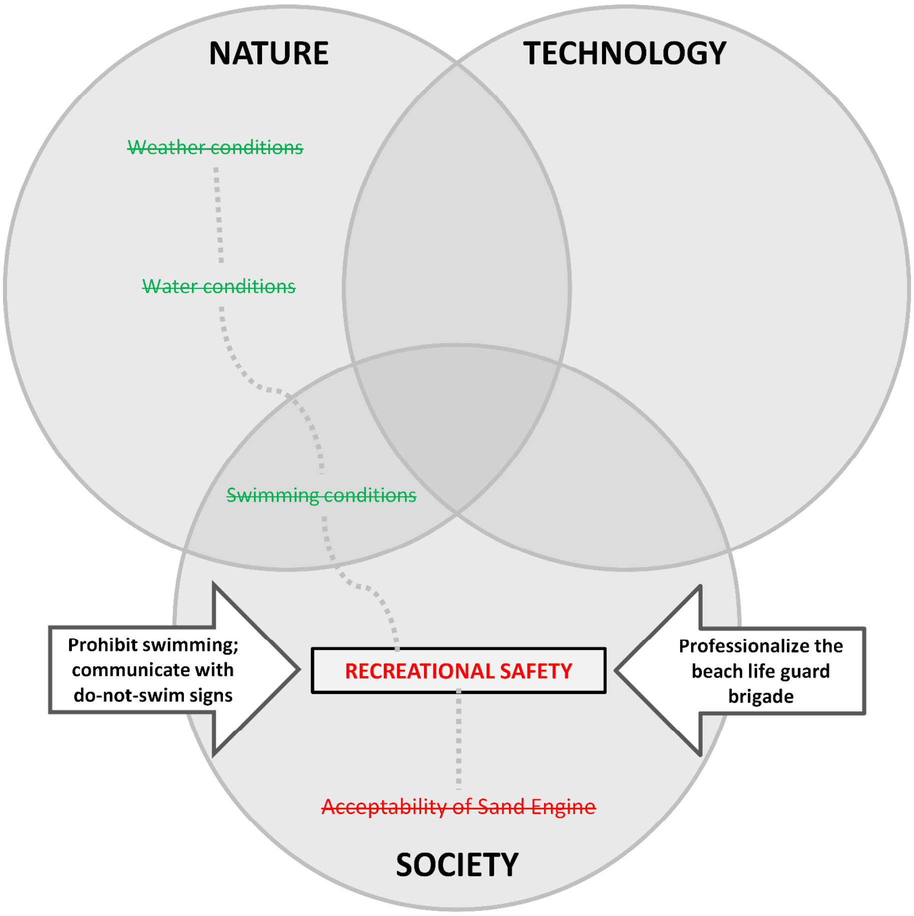

Figure 5.2. Actual coping strategies to manage recreational safety issue. All attention is given to the isolated uncertainty 'recreational safety'. Text colour coding is equal to Figure 4.3

The project team was convinced that their management plan was sufficient to assure a safe situation, but seemingly failed to adequately assess the social dimension of the problem. A group of local inhabitants – supported by a large political party – had a different view regarding *swimmer safety*, fearing that the Sand Engine would create a highly unsafe recreational situation and viewing the project as *unacceptable*. While the local inhabitants formed an action committee to oppose the initiative on the internet and during public meetings, the political party requested its cancellation in the Dutch parliament. Whereas an early assessment of the cascade of interrelated uncertainties could have been very valuable, in practice the project team did not fully understand the subject until the opposition had already emerged. The following interviewee statement exemplifies that ambiguity is not necessarily negative, as it can also increase the understanding regarding the problem at hand:

> *"I think that [the action committee] helped us to sharply define the subject of swimmer safety… Due to them, it was put high on our agenda… I am not sure if we would have done so well without that group. I actually do not know that. Safety is always on top. Always. But such a group helps you to give it additional [attention]."*

Eventually, the project team commissioned a model study to acquire a detailed forecast of the Sand Engine's impacts on the swimming conditions. A more logical response at that time would have been to meet the opponents and discuss their differences. Although the project team invited the action committee for such a meeting, they did not accept this offer and the ambiguity between them was not explicitly addressed. Nevertheless, the opposition gradually reduced and the project was eventually successfully implemented without significant time overrun or budgetary problems.

After project implementation, several alternative coping strategies were needed with regard to the swimming situation because the Sand Engine developed much faster than predicted. For example, a swimming conditions prediction model is currently being developed, which allows life guards to forecast conditions up to 2 days in advance (i.e., a strategy to predict swimming conditions). Furthermore, in April 2012, the life guard brigades reported that they observed fast and potentially dangerous currents in a tideway at the Sand Engine. Such an event was not taken into account in the aforementioned management plan. Governmental experts analysed the situation and strongly recommended to refrain from interfering with the BwN pilot project. As alternative option, it was suggested to close off the beach with fences (i.e., a strategy to manage swimmer safety). Nevertheless, the responsible managers decided to close off the tideway with a stone dam in May 2012 (i.e., a strategy that alters the water conditions). This decision displeased all experts and the non-transparent decision-making process was criticized. Moreover, the event provided a window of opportunity for the action committee to re-enter the playing field. In a coverage of a Dutch current affaires television program, the committee's chairman was interviewed and fiercely criticized the project. In the end, the situation had no severe consequences, but did result in a considerable amount of negative publicity.

In short, this example discusses how an early assessment of a cascade of interrelated uncertainties – in this particular case, the swimming situation at the Sand Engine – could have led to a better understanding of the problem at hand and a more effective set of alternative coping strategies at an earlier moment in the development process (Figure 5.3).

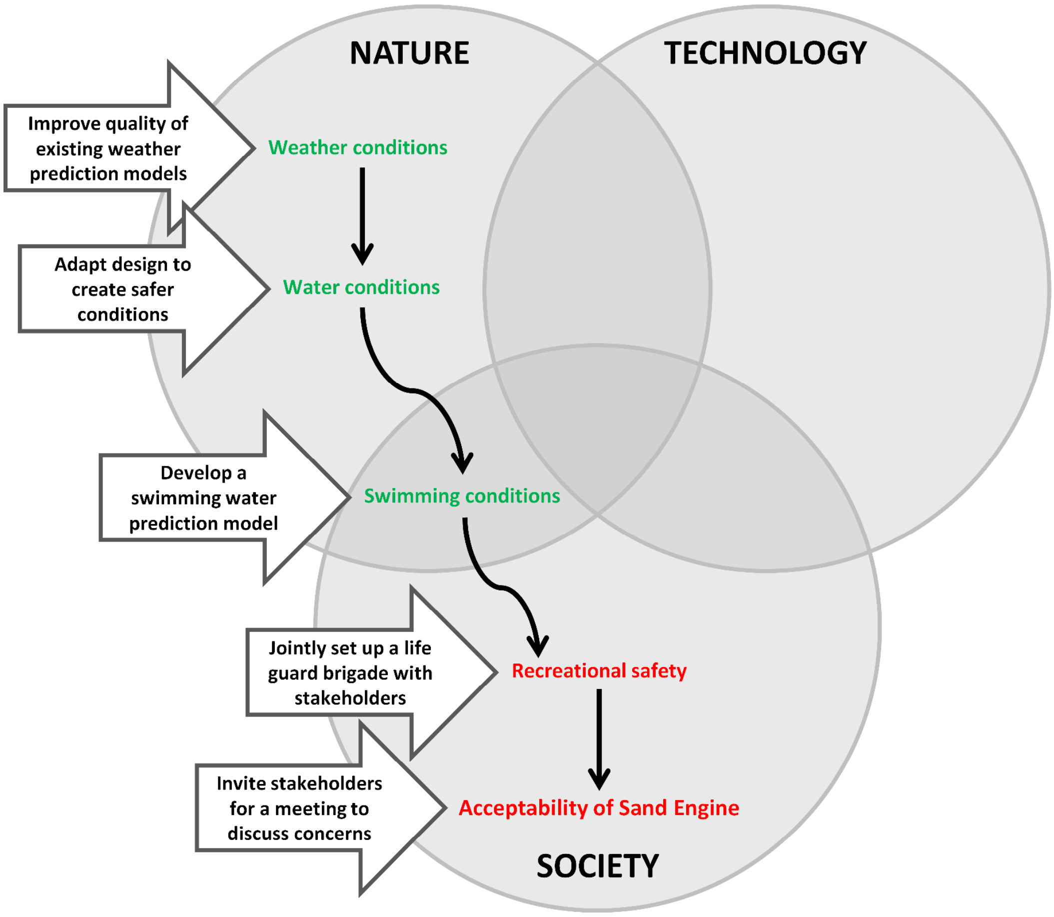

Figure 5.3. Optional coping strategies to manage recreational safety issue. Multiple points of intervention and facilitation are provided by using cascades of interrelated uncertainties. Text colour coding is equal to Figure 4.3

5.4. DISCUSSION

In the previous section, we described the results of our case study projects and showed how the interrelatedness between different uncertainties is (often implicitly) used for uncertainty management. With the cascades of interrelated uncertainties, we propose an analytical approach to *explicitly* map the interrelatedness between uncertainties, in order to inform a project team about which uncertainties are important, which ambiguities can be anticipated and which actors will be affected.

As BwN projects are driven by unpredictable natural dynamics, system conditions can change at any time – even after project implementation – and an uncertainty management approach that proved to be very effective might eventually fall short due to an unanticipated surprise. Thus, this suggests that it is important that those responsible for the development of a BwN project have the capacity to adapt their uncertainty management approach if needed. In the Sand Engine project, the best models and experts available were used to formulate trustworthy forecasts regarding the project's future developments and impacts. This resulted in adequate predictions of the development of the Sand Engine's shape, forecasts needed for applying swimmer safety measures and essential information about the impacts of the project on the drinking water supply. However, the future can never be flawlessly forecasted in BwN projects. An interviewed expert stated the following regarding this issue:

> *"Now, the Sand Engine was calculated using a coastal morphology model. But I think, off the cuff, that there are like 10 reasons why that model is not [accurate]. That is, among other things, because you model on the very long term. So than inevitably you have to simplify particular things… you take a sort of annual average as model input… run [the model] for 20 years and get an outcome. [But] particular things are modelled less accurate. Storms that occur once in a while… So the expectation is just simply that processes could go much faster than we predicted using those coastal morphology models… What does [the Sand Engine] do in case of a storm? Then you observe, of course, that it goes much faster."*

We argue that the *cascade of interrelated uncertainties* provides the analytical means to come to an adaptive uncertainty management approach in dynamic projects such as those based on BwN design principles. Compared to existing conceptualizations of uncertainty, it provides an improved conceptual model that creates a better understanding of the uncertainties that we face, acknowledging that our knowledge is inseparable from the people that are involved in the decision-making process. Instead of coping with uncertainties as isolated units, our approach acknowledges that an uncertain problem can consist of multiple fundamentally different, yet interrelated uncertainties. As these different uncertainties in the cascade are interrelated, this means that coping with a particular uncertainty will influence those with which it is related. If a particular coping strategy fails or predictions turn out to be incorrect, the other uncertainties in the cascade provide alternative coping strategies for the actors involved, offering the opportunity to adapt the uncertainty management approach that was previously pursued. As each uncertainty in the cascade represents a potential node of intervention or facilitation, the knowledge about the cascade can assist those responsible to adaptively anticipate to any development that occurs over time. At an early stage during the project's development process, an overview of the many alternative coping strategies will already be established if the cascades are properly assessed and no hasty decisions are required regarding to which coping strategy to pursue.

Moreover, compared to existing uncertainty conceptualizations, the cascades of interrelated uncertainties add the comprehensive analytical means to identify those uncertainties – and especially those ambiguities – that are unknown but could become a hampering factor in a project's development process. We demonstrated how assessing a cascade of interrelated uncertainties at an early stage provides the insight to proactively anticipate to a potential ambiguity. If it is clear which ambiguities can be expected, this provides essential information about which actors to involve during a project's development process. Many scholars advocate early and active participation of stakeholders as an important means to cope with uncertainty and ambiguity (e.g., Newig et al., 2005; Van der Keur et al., 2008; Renn et al., 2011), leading to better and more legitimate decisions in the end (Fiorino, 1990; Randolph and Bauer, 1999; Beierle, 2002).

However, stakeholder participation is not a straightforward activity, because stakeholders can behave strategically at any time if this is to their advantage. In the Safety Buffer project, for instance, the oyster sector and – to a lesser extent – the mussel sector were concerned about the planned nourishment and the activities to acquire the nourishment sand. Due to these activities, sand will likely become suspended in the water column. It is uncertain how this suspended sediment will behave and where it will be transported. If the cloud drifts off towards the commercially cultivated shellfish beds, an excess of sediment will certainly suffocate these mussels and oysters. While the mussel sector did not oppose the project and participated during project meetings, the oyster sector initially did not participate – although they were invited for all relevant meetings and received all project documentation – and did not join any meeting for indistinct reasons. Instead, in May 2011, representatives of the oyster sector started opposing the Safety Buffer project in the regional media, characterizing it as an unacceptable "deathblow" for the oyster industry. After a polemic between the project team and the oyster sector that lasted until September 2011, the actors finally agreed on having a meeting and negotiated that the initial Safety Buffer design would be discarded in favour of a jointly developed new design. Although the oyster sector indicated that their opposition was based on substantive arguments, several interviewees (implicitly) suggested that the opposition was strategically motivated and aimed at attaining financial benefits. As a result, the project team initially underestimated the urgency of the situation and made incorrect assumptions regarding the oyster sector:

> *"Then you can thus wonder: 'how come that you didn't bring [each actor from] the shellfish sector into play from the start?' [Well:] with the shellfish sector, we were already busy a few doors away. And we did not see through that this [topic] could be so sensitive."*

In short, we argue that the use of the cascades of interrelated uncertainties for uncertainty analysis in projects such as those based on BwN design principles can yield major benefits for uncertainty management. However, it is also important to be aware that it is not a panacea for successfully coping with uncertainty due to the inherent unpredictable behaviour of both nature and humans.

5.5. CONCLUSIONS

For effective project management, successfully managing the uncertainties that are encountered is a necessary condition (Atkinson et al., 2006). In each project executed, the past and present are not fully understood, the future is unknown and the action path required can be interpreted in many ways from multiple perspectives. If uncertainties are not effectively coped with and doubts are created about the desirability or even acceptability of an initiative, it can influence the project's development process in numerous adverse ways. Uncertainty can cause concerns among major stakeholders or politicians, might cause retrenchment of project funds and might lead to a paralysis of actions (Nowotny et al., 2001; Van Asselt, 2005). As a result, projects that were once seen as promising initiatives can be severely delayed, may suffer from budgetary problems or might even be cancelled.

In this chapter, we evaluated the benefits on the cascades of interrelated uncertainties – the uncertainty analysis approach proposed in Chapter 4 – by demonstrating the essential contributions this approach could have made to our two BwN case study projects. In this specific type of projects, an adaptive approach to uncertainty management is a necessity due to the inherent dynamic design principles of these initiatives. We showed that an early analysis of uncertainty using the cascade of interrelated uncertainties could deliver a vital contribution to the adaptive uncertainty management required in these BwN initiatives. Assessing a cascade of interrelated uncertainties informs a project team about which uncertainties are important, which ambiguities can be anticipated, and which actors will be affected. As different uncertainties are related in a cascade, coping with a particular uncertainty will influence those with which it is related. Thus, if a particular coping strategy fails, the other uncertainties in the cascade provide many alternative coping strategies for the actors involved. This allows for uncertainty management planning in advance, reducing the need for ad-hoc troubleshooting and hasty decisions. Furthermore, assessing a cascade of interrelated uncertainties at an early stage provides the insight to proactively anticipate to an emerging ambiguity or even preventing an ambiguity from occurring at all. Last but not least, early assessment of the cascades could provide essential information about who to involve during a project's development process or not. If the relevant people are involved at the appropriate time, particular uncertainties could be coped with in a better way.

Although we do not provide guidance with respect to the specific coping strategies that need to be used in order to manage uncertainty in general and in BwN projects in specific, some important lessons can be learned from the cases we discussed. In the Sand Engine case, uncertainty is mainly conceptualized as a lack of knowledge. As a result, the project team primarily aimed to cope with uncertainty by developing more or better knowledge. While this successfully provided clear expectations regarding the future development of the project, our examples illustrate that – in BwN projects – there is always a significant likelihood that particular processes or impacts will not be in accordance with the forecast. In the Safety Buffer case, uncertainty was approached as an issue that needs to be coped with by developing a common understanding between the actors involved. Although stakeholder participation is important and should start as early as possible, it is not a panacea (Ingram, 2013) as our cases studies clearly illustrate. Stakeholders can behave unpredictable and in a strategic way, even if they are involved at an early stage. Thus, it depends on the specific context and the particular uncertainty cascades encountered in that context which coping strategies should be preferred. An interesting option for simultaneous knowledge development and stakeholder participation might be *participatory monitoring* (see Conrad and Hilchey, 2011, for a review), an approach in which stakeholders are actively involved in acquiring information about the development of the particular initiative under consideration. If knowledge is generated in a participatory way in environmental decision-making, this generally enhances the legitimacy and quality of the decisions, especially under uncertain conditions (Hage et al., 2010).

6 CONCLUSIONS AND RECOMMENDATIONS

In this thesis, I studied which uncertainties are most important during the development and implementation process of flood defence projects that are based on Building with Nature (BwN) design principles and how these uncertainties can be coped with. This chapter presents the conclusions drawn from this research. In Section 6.1, I answer each of the four research questions provided in the Introduction (Section 1.4). Section 6.2 summarizes the contributions this research makes to both the scientific literature and the BwN engineering community. In Section 6.3, I propose directions for future research that can be conducted as a follow-up on the research performed for this thesis.

6.1. CONCLUSIONS

6.1.1. Uncertainties and their potential hampering impact on BwN projects

The first research question addressed in this thesis is: *Which uncertainties could have a decisive (negative) impact on the development process of a Building with Nature project?*. In Chapter 2, I studied the Sand Engine Delfland project (the most prominent example of BwN in the Netherlands), identified the project's most important uncertainties and determined which of those uncertainties could have had a hampering effect on the project development process. In order to come to a generalizable result, I focussed on determining which of the three kinds of uncertainty – i.e., incomplete knowledge, unpredictability and ambiguity (as defined by Brugnach et al., 2008) – was most important.

The research started with the hypothesis (see Section 2.1) that 'the development process of projects using BwN design principles is susceptible to be hampered by uncertainty due to the inherent unpredictability and incomplete knowledge of the natural system'. This hypothesis was, for a major part, fuelled by the initial interpretation of uncertainty as described in the BwN program proposal (EcoShape, 2008, p. 39-40):

> *[There are] uncertainties that are inherent to nature (for example, the weather on the long term) and [that] thus cannot be reduced by acquiring more information or performing more research, but also uncertainties that relate to a lack of information or knowledge, with simplified assumptions or schematizations in the models used. In an eco-dynamic design process, these uncertainties have to be, distinguished according to their types, made explicit in order to come to the proper assessments.*

This description shows that uncertainty in the context of BwN was initially conceptualized as just a lack of knowledge, which is still the common interpretation of uncertainty in engineering communities. In this thesis, I have extended this view on uncertainty by showing that knowledge and uncertainty are inseparable from the actors involved. As the results of Chapter 2 illustrate, ambiguity about the social implications of a BwN project is far more important than uncertainty about the behaviour or dynamics of the natural system. These findings are in accordance with the results of other recent studies, which increasingly acknowledge the importance of ambiguity and non-quantitative uncertainty in water management. Lach et al. (2005) conclude that, for water resources agencies, it becomes far more important to manage their relationships with other parties with conflicting demands and needs – which could potentially lead to ambiguity – than managing the uncertainties of the physical structures and working routines. Van der Keur et al. (2008) argue that qualitative uncertainties dominate statistical uncertainties in policy development for integrated water resources management. Hommes (2008) concludes that ambiguity is a key characteristic of complex water management problems.

6.1.2. The origin of ambiguity in BwN projects

The second research question addressed in this thesis is: *What is the origin of ambiguity in Building with Nature projects?*. In Chapter 3, I studied the Sand Engine Delfland and Safety Buffer Oyster Dam projects to deepen the understanding of the origin of ambiguity in projects based on BwN design principles. In a multi-actor decision-making setting (such as in a BwN project development process), each actor can frame the project differently, which may cause a situation of ambiguity in which it is no longer clear what the issues of concern and action paths are (Brugnach et al., 2011). Different authors in the literature studied the issue of frames and framing (see Dewulf et al., 2009, for a review), and suggest several actor attributes – such as interests, values, beliefs and experiences – that shape the way in which an individual actor frames reality. In this research, I aimed to uncover how differences in the attributes of different actors lead to ambiguity in BwN projects.

The findings from my research suggest that ambiguity in the multi-stakeholder decision setting of a BwN project originates from a contradiction between the *beliefs* of the actors involved. Moreover, our observations suggest that the *power* of the actors involved is currently the most important determinant for how to cope with ambiguity. If the project team is the most powerful actor regarding a particular ambiguity, they can easily use their power to force a decision that is favourable for them. Interestingly, we observed that the *interests* of the actors are often dissimilar but not conflicting. This observation suggests that, regarding the interests held by the different parties, there is common ground between the actors involved.

The results presented in Chapter 3 demonstrate that it is difficult to involve local stakeholders in such a way that their beliefs and experiences become an integral part of the decision-making processes of projects based on BwN design principles. If local stakeholders could be involved to a larger extent, this might create conditions for a participatory process in which decision-making comprises more than relying on the judgment of rational experts and scientific knowledge. Participatory processes could be developed in which project teams and stakeholders jointly develop a knowledge base that is perceived as legitimate by all actors involved, resulting in both better decisions and increased stakeholder support for BwN initiatives.

6.1.3. The interrelatedness between different uncertainties in BwN projects

The third research question addressed in this thesis is: *How are different uncertainties related in the context of Building with Nature projects?*. In Chapter 4, I explored how different uncertainties are related in the Sand Engine Delfland and Safety Buffer Oyster Dam project. Although I expanded the view on uncertainty in BwN projects in Chapter 2 – by demonstrating that ambiguity is the most important kind of uncertainty in the Sand Engine project – I observed that the ambiguities identified were not isolated but closely related to other uncertainties. By definition, uncertainty classification methods – thus, also the approach of Brugnach et al. (2008) used in Chapter 2 – structure uncertainties in matrices, representing uncertainties as quite disconnected specific issues. However, the results from the case studies showed that different uncertainties are often actually interrelated. I observed that incomplete knowledge about and unpredictability of natural processes or impacts on the natural system are gradually re-interpreted from different societal perspectives, resulting in ambiguity. In Chapter 4, it is proposed to use *cascades of interrelated uncertainties* to visualize this interrelatedness.

Actors from different disciplines and with diverging backgrounds can interpret uncertainty differently or can hold different forms of knowledge as important (Dewulf et al., 2005). The understanding of knowledge and the interpretation of uncertainty are relational processes. These processes depend on how the actors involved relate to each other and the context under consideration (Brugnach et al., 2008). The cascades of interrelated uncertainties can function as an instrument to explicitly connect the different uncertainties held relevant by different actors, in order to come to better and jointly developed decisions under uncertain conditions. The uncertainties perceived by a modeller can indirectly be important for a decision-maker, and vice versa, as uncertainties that are interrelated in the cascade are relevant for each actor involved and not just for particular actors focussed on specific uncertainties in the cascades.

6.1.4. Adaptive uncertainty management in BwN projects

The fourth research question addressed in this thesis is: *Which benefits does the interrelatedness between different uncertainties have for coping with uncertainty in Building with Nature projects?*. In Chapter 5, I built on the findings of Chapter 4 and explored the potential benefits that the cascades of interrelated uncertainties could have in the context of flood defence projects based on BwN principles. There is already a multitude of methods to assess and cope with uncertainty in the literature (see e.g., Refsgaard et al., 2007; Van der Keur et al., 2008; Brugnach et al., 2008, 2011), but these methods focus on how to respond to specific individual uncertainties. Here, I argue that the *cascade of interrelated uncertainties* provides a new means for uncertainty analysis, improving the understanding about the links between different uncertainties and supporting the search for appropriate ways to respond to those uncertainties.

As each uncertainty in the cascade represents a potential node of intervention or facilitation, the knowledge about the cascade can assist those responsible to adaptively anticipate to any development that occurs over time. Early assessment of the cascades of interrelated uncertainties provides the insight to proactively respond to an emerging ambiguity or even prevent an ambiguity from occurring at all, reducing the need for ad-hoc troubleshooting and hasty decisions. Moreover, such an early assessment might provide essential information about who to involve during a project's development process or not. If the relevant people are involved at the appropriate time, particular uncertainties could be coped with in a better way. Thus, assessing a cascade of interrelated uncertainties informs a project team about which uncertainties are important, which ambiguities can be anticipated, and which actors will be affected. In Chapter 5, I showed that as the uncertainties in the cascades are interrelated, successfully coping with a particular uncertainty in that cascade could influence other uncertainties related to it. If a particular coping strategy fails or reality proves predictions wrong, the cascade shows which alternative nodes of intervention remain and provides the means to come to an adaptive uncertainty management approach in dynamic projects such as those based on BwN design principles.

6.2. CONTRIBUTIONS OF THE RESEARCH

The research presented in this thesis makes several important contributions to both the scientific literature and the BwN engineering community. In Chapter 2, a contribution is made to the BwN engineering community by showing that ambiguity is the kind of uncertainty that could hamper the development process of BwN flood defence projects, while the BwN community's initial hypothesis was that unpredictability and incomplete knowledge were likely to be the hampering factor for BwN initiatives. The results from my research point out that in order to come to a successful project based on BwN principles, it is more important to cope with the differences between different actors than to respond to uncertainty due to the lack of knowledge about the natural system.

In Chapter 3, a contribution is made to the scientific literature because – as far as I know – a structured analysis of the actor attributes underlying ambiguity has not been performed before. Many scholars have studied frames and framing process (see Dewulf et al., 2009, for a review) and argue that framing differences can lead to ambiguity. Several scholars have identified actor attributes that influence the way in which people frame reality. However, it was not yet addressed which actor attributes interfere in a situation of ambiguity. Although the specific result of the research presented – i.e., actors hold conflicting *beliefs* in situations of ambiguity – might not be generalizable, the structured analysis performed points at new directions for investigating the underlying causes of ambiguity in multi-actor decision-making.

Chapter 4 contributes to the scientific literature by explicitly addressing the interrelatedness between *ambiguity* and the more common uncertainty kinds *incomplete knowledge* and *unpredictability*. While there are concepts in the literature that address linkages between different uncertainties – such as uncertainty propagation in climate change models – these existing approaches conceptualize uncertainty as a lack of knowledge and focus on the quantitative accumulation of uncertainty. Whereas none of the existing concepts explicitly considers the role of ambiguity, I have addressed how uncertainties in models and predictions eventually lead to ambiguities of significant importance in multi-actor decision-making. Moreover, in Chapter 5, I showed that this interrelatedness between uncertainties is not only interesting from a scientific-analytical point of view, but that it also has value for the BwN engineering community. The results from my research suggest that the interrelatedness between uncertainties can have benefits for coping with uncertainty during the actual development of BwN projects. For instance, I demonstrated how an important ambiguity in the Sand Engine case was coped with by handling another uncertainty – due to incomplete knowledge – with which it is related.

6.3. RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the results presented in this thesis, I propose the following directions for future research. First, as discussed above, the case studies used for the research are Dutch pilot projects based on BwN design principles. A logical follow-up on this thesis would be to study other cases in the Dutch context. The results between cases might differentiate, particularly because the cases studied in this research were pilot projects, which may not be representative for regular projects. For example, as was discussed in Section 2.6.3, uncertainty eventually did not hamper the Sand Engine project partly because it was a pilot project. If the project would not have had the pilot status, the design chosen or even the overall outcome of the development process might have been radically different from what was eventually decided.

Second, another follow-up could be to study projects in non-Dutch contexts in order to investigate uncertainty in BwN projects in a different cultural setting and geographical situation. For example, it can be anticipated that ambiguity will manifest itself in a different way in a different cultural context. Similarly, a fundamentally different geographical context – with a different climate and a natural system with its own peculiarities – might lead to a different role of incomplete knowledge and unpredictability during BwN project development. For instance, weather conditions and vegetation in the Netherlands are fundamentally different from those in – for example – Bangladesh or Singapore, which means that major differences between BwN project designs in these countries can be anticipated.

Third, in Chapter 3, I uncovered the origin of ambiguity in our two BwN case study projects by analysing the differences between the frames of individual or groups of actors at a particular moment in time. However, I did not consider how human interactions can shape frames and change an actor's attributes. Hence, further research would be required to study the interactional framing processes through which frames are shaped during BwN project development. Furthermore, it is required to study additional cases in or outside the BwN context to verify whether the specific result of this study – the *beliefs* of the actors involved differ in a situation of ambiguity – can be generalized.

Fourth, the proposed conceptualization of the cascades of interrelated uncertainties calls for further explicit empirical application and testing in BwN projects. For instance, as touched upon in Chapter 4, the development of a detailed guideline on how to cope with the cascades of interrelated uncertainties in operational project management could be an interesting but challenging task for future research. Furthermore, I think that another research opportunity would be to study whether the proposed conceptualization of the cascades of interrelated uncertainties is applicable outside the context of BwN or even in another field than water management. In such other fields, the cascades of interrelated uncertainties may also be a useful and effective analytical means to support the actors involved in the important challenge of coping with uncertainty.

APPENDIX A

This appendix provides an overview of the Sand Engine documents that were reviewed for Chapter 2.

[1] Aanhangsel van de Handelingen, Kamerstukken II, 2010/2011a. 196, pp. 1-2, [URL]: https://zoek.officielebekendmakingen.nl/ah-tk-20102011-196.html, [Appendix to Dutch parliamentary reports, Dutch House of Commons].

[2] Aanhangsel van de Handelingen, Kamerstukken II, 2010/2011b. 965, pp. 1-2, [URL]: https://zoek.officielebekendmakingen.nl/ah-tk-20102011-965.html, [Appendix to Dutch parliamentary reports, Dutch House of Commons].

[3] Ambitieovereenkomst pilotproject Zandmotor: Natuurlijk werken aan de Delflandse Kust!, 2008. [URL]: http://www.dezandmotor.nl/uploads/2011/03/090519ambitieovereenkomst-zandmotor.pdf, [Ambition Agreement Sand Engine].

[4] Nota van antwoord op inspraakreacties inzake MER Zandmotor aan de Delflandse Kust, 2010. Rijswijk/Rotterdam, juni 2010, Ministerie van Verkeer en Waterstaat Rijkswaterstaat Noordzee / Zuid-Holland, [URL]: http://www.dezandmotor.nl/uploads/2011/03/nota-van-antwoord.pdf, [Note of Answer to EIA Sand Engine].

[5] Pilot Zandmotor Delflandse Kust: Startnotitie milieueffectrapportage, 2008. Grontmij Nederland B.V., Houten, 18 december 2008, 13/99088668/RJJ, [URL]: http://www.centrumpp.nl/Images/Startnotitie%20Zandmotor%20binnenwerk%20gepubliceerd1_tcm318-292131.pdf, [Project Start Note EIA Sand Engine].

[6] Prognose zwemveiligheid Zandmotor: stromingen en bodemontwikkeling, 2010. Shore Monitoring & Research, herziene versie december 2010, [URL]: http://www.dezandmotor.nl/uploads/2011/03/prognose-zwemveiligheid-zandmotor-stromingen-en-bodemontwikkeling.pdf, [Swimming safety report].

[7] Projectnota/ MER: Aanleg en zandwinning Zandmotor Delflandse Kust, 2010. definitief, februari 2010, [URL]: http://www.dezandmotor.nl/uploads/2011/03/mer-hoofdrapport-zandmotor-mer.pdf, [EIA Sand Engine].

[8] Richtlijnen milieueffectrapport aanleg Zandmotor, 2009. Ministerie van Verkeer en Waterstaat – Rijkswaterstaat Noordzee / Zuid-Holland, [URL]:

http://www.centrumpp.nl/Images/6%20richtlijnen%20CPP_tcm318-295749.pdf, [Guidelines EIA Sand Engine].

[9] Document without a title written by military historian Dennis de Hoog, 2010. Dumped explosives and ammunition in the North Sea, commissioned by the committee Stop de Zandmotor. Stichting D.E. de Hoog, [URL]: www.stopzandmotor.nl/download.html, [Historical report on ammunition in North Sea].

[10] Watervergunning 907516 / 1050167, 2010. Hoogheemraadschap van Delfland, [URL]: http://www.centrumpp.nl/Images/Besluit%20Watervergunning%20zandmotor_tcm318-296704.pdf, [Water Permit].

[11] Morfologische berekeningen MER Zandmotor, 2009. Deltares, [URL]: http://www.innoverenmetwater.nl/upload/documents/Morfologische%20berekeningen%20MER%20Zandmotor%20(rapport).pdf [Report with morphological calculations Sand Engine].

[12] Monitoring- en evaluatieplan Zandmotor, 2010. DHV B.V., [URL]: http://www.dezandmotor.nl/uploads/2011/03/monitoring-en-evaluatie.pdf, [Monitoring and Evaluation Plan].

APPENDIX B

Table B.1-B.6 summarize the uncertainties that were identified as playing an explicit or implicit role in the individual phases of the Sand Engine's development process. In the **Initiation** phase (Table B.1), we identified unpredictability about how the Sand Engine and the natural system will behave after it is constructed. Furthermore, it was unpredictable how much money stakeholders were willing to contribute to the project. Several government parties were discussing about the necessity of the Sand Engine and had different knowledge frames about whether it was acceptable to perform such a large-cost project in a period of economic problems. Hence, the commitment of important governmental stakeholders was still ambiguous.

Table B.1 – Uncertainties in the Initiation phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems	How will the SE develop morphologically? (e.g., in terms of its shape and speed of development) What will be the effect of the SE on the currents? (e.g., eddy formation, velocity increase) What will be the yield of the SE (e.g., total beach area increase, erosion)?		
Technical system infrastructure, technologies, innovations			
Social system economic, cultural, legal, political, administrative and organizational aspects	How much money will stakeholders contribute to the project budget?		Are all key stakeholders willing to (financially) commit to the SE project?

In **Planning and Design I** (Table B.2), the unpredictable behaviour and effects of the Sand Engine had social implications: there was uncertainty about effects on swimming and recreational conditions. Furthermore, there was ambiguity concerning the project's goals and optimal location. Rijkswaterstaat wanted the Sand Engine to contribute to coastal safety, while the province of South Holland was mostly interested in enhancing the recreational quality of the coastal zone. The municipalities all had their own local goals and interests. As a result, all parties preferred a different project location. A specific theme in the location discussion was Scheveningen Harbour, as effects of the Sand Engine on this harbour were unacceptable for local politicians.

Table B.2 – Uncertainties in the Planning and Design I phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems	How will the SE develop morphologically? (e.g., in terms of its shape and speed of development) What will be the effect of the SE on the currents? (e.g., eddy formation, velocity increase) What will be the yield of the SE (e.g., total beach area increase, erosion)?		
Technical system infrastructure, technologies, innovations	What will be the effect of the SE on Scheveningen Harbour?		
Social system economic, cultural, legal, political, administrative and organizational aspects	How much money will stakeholders contribute to the project budget? What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general?		Are all key stakeholders willing to (financially) commit to the SE project? Is the chosen location optimal for the project or not? Is it clear which project goal has the highest priority?

In **Planning and Design II** (Table B.3), a more specific uncertainty concerning the project goals emerged. As no specific and measurable nature development goals were defined in either the EIA or another project document, the ecologists involved in the Sand Engine project were unable to construct a shared knowledge frame during ecology-oriented project workshops. Some ecologists preferred alternatives that promote existing nature, where others favoured alternatives that potentially attract new species. Regarding the recreational conditions, discussions focussed on the more socially-oriented issue of recreational safety. Furthermore, there was uncertainty about the (economic) attractiveness of the Sand Engine for constructors (i.e., dredging companies).

Table B.3 – Uncertainties in the Planning and Design II phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems	How will the SE develop morphologically? (e.g., in terms of its shape and speed of development) What will be the effect of the SE on the currents? (e.g., eddy formation, velocity increase) What will be the yield of the SE (e.g., total beach area increase, erosion)?	What will be the effect of the SE on the groundwater level?	Is it clear which aspects are most important regarding the project's nature development goals?
Technical system infrastructure, technologies, innovations	What will be the effect of the SE on Scheveningen Harbour?		
Social system economic, cultural, legal, political, administrative and organizational aspects	How much money will stakeholders contribute to the project budget? What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general? What will be the effect of the SE on beach commerce?		Is the construction tender economically attractive for potential contractors? Are all key stakeholders willing to (financially) commit to the SE project? Is the chosen location optimal for the project or not? Can recreational safety in the vicinity of the SE be guaranteed?

In **Construction I** (Table B.4), there was uncertainty related to acquiring the required permits and about the attractiveness of the construction tender. In this phase, opponents of the Sand Engine project actively attempted to stop the project by pointing out potential recreational safety problems. Furthermore, the lack of knowledge about the effects on the fresh water supply created a severe commitment problem.

Table B.4 – Uncertainties in the Construction I phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems		What will be the effect of the SE on the groundwater level? What will be the effect of the SE on the fresh water supply (e.g., salt intrusion)?	
Technical system infrastructure, technologies, innovations		What is the relationship between sand mining and occasional findings of World War II ammunition on the beach?	Is World War II ammunition a potential recreational safety threat in the context of the SE?
Social system economic, cultural, legal, political, administrative and organizational aspects	What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general?	Which permits are needed for the SE construction? Which effect will the SE have on houses near the coast (e.g., flooding of cellars)?	Is the construction tender economically attractive for potential contractors? Will the SE have an effect on the quality of drinking water? Is it clear who should be the competent authority for the SE nature permits? Are all key stakeholders willing to (financially) commit to the SE project? Can recreational safety in the vicinity of the SE be guaranteed?

In **Construction II** (Table B.5), the attention in project development shifted to issues that could potentially endanger the successful construction and management of the project. Legal officials can behave unpredictable, take strategic decisions and some have legal power to stop the project. For instance, there was uncertainty concerning measurements of sand quality. The project team claimed that measurements were proper and quality was sufficient, where legal officials framed that measurements were not done properly and results proved that the sand was contaminated. Furthermore, there was uncertainty about the date that the management of the Sand Engine peninsula should be transferred from Rijkswaterstaat to the Province of South Holland. The construction was highly successful and finished months earlier than planned. Where Rijkswaterstaat framed that management should be transferred as soon as construction was finished, the Province of South Holland was unwilling to assume responsibility earlier than the initially planned completion date.

Table B.5 – Uncertainties in the Construction II phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems			
Technical system infrastructure, technologies, innovations		What is the relationship between sand mining and occasional findings of World War II ammunition on the beach?	Is World War II ammunition a potential recreational safety threat in the context of the SE? Are there clear standard requirements for the (measurement of) sand quality?
Social system economic, cultural, legal, political, administrative and organizational aspects	What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general? How will legal officials behave during construction?		Are all key stakeholders willing to (financially) commit to the SE project? Should management of the SE be transferred as planned (31 October 2011) or after construction is finished? Can recreational safety in the vicinity of the SE be guaranteed?

In the **Operation and Maintenance** phase (Table B.6), only three uncertainties can currently be identified. Swimming and recreational conditions will be issues for monitoring by researchers. Moreover, opponents of the Sand Engine will probably continue to address recreational safety issues.

Table B.6 – Uncertainties in the Operation and Maintenance phase of Sand Engine (SE) project development

	Unpredictability unpredictable behaviour of nature, humans or the system	**Incomplete knowledge** imperfection of knowledge inexactness, approximations, etc.	**Ambiguity** equally sensible interpretations of a phenomenon
Natural system climate impacts, water quantity, water quality, ecosystems			
Technical system infrastructure, technologies, innovations			
Social system economic, cultural, legal, political, administrative and organizational aspects	What will be the effect of the SE on swimming conditions? What will be the effect of the SE on recreational conditions in general?		Can recreational safety in the vicinity of the SE be guaranteed?

In short, we observe that the importance of the social implications of the Sand Engine gradually increased during project development, probably due to the gradually increasing involvement of stakeholders and societal interests. When initiatives become more concrete, it becomes easier and increasingly important to imagine the consequences of such plans for society. For instance, in the Initiation phase, the uncertainty about the effect of the project on coastal conditions (uncertainty in the natural system) was identified. In the Planning and Design I phase, uncertainty about swimming conditions was identified as a specific theme (uncertainty in the social system). In the Planning and Design II phase, the important social discussion about the implications of the Sand Engine for recreational safety was fully exposed (uncertainty in the social system regarding societal implications). After the approval of the EIA at the end of the Planning and Design II phase, the focus in project development radically shifted from the physical aspects of the Sand Engine to the preparation of the construction and monitoring. During the Construction II phase (see Table B.5), uncertainty in the natural system was even completely absent in project development, as the main interest of this phase was the physical construction of the Sand Engine.

APPENDIX C

In this Appendix, we provide an example of the methods used in Chapter 3. We extensively discuss how we built Table 3.5, concerning the ambiguity about the effects of the Safety Buffer nourishment on oyster beds. Regarding this particular ambiguity, the project team and the representatives of the oyster sector have different frames. For both actors, we show how we identified their frame regarding the Safety Buffer's effects and the actor attributes associated to this frame, by assessing the research questions posed in Table 3.1 using our research material (such as transcripts of interviews and meetings we attended, project documents and even a media publication). Table 3.1 can be found in the Methods section of Chapter 3. Table 3.5 can be found in Section 3.5.2.

C.1. PROJECT TEAM FRAME AND ATTRIBUTES

The project team's **frame** regarding the Safety Buffer is that it is an innovative and socially acceptable pilot project, that is vital to learn about possibilities for future dike maintenance and dealing with the effects of the Sand Hunger. The project team consists of employees of the governmental and non-governmental institutions that proposed the Safety Buffer initiative. Such institutions initiate and support an initiative if they are convinced of its innovative potential and the opportunities it can provide. They would not initiate or support an initiative if it is socially unacceptable, e.g. because there is a considerable risk that stakeholders will be harmed. More specifically, the project team will not execute the project if they frame the Safety Buffer as an unacceptable initiative with regard to the oyster sector. As a representative of the municipality were the oyster beds are located remarked:

> *"We cannot imagine that [the project team] will dump a pile of sand there without looking at the consequences. That is not how Rijkswaterstaat works… Rijkswaterstaat [observed] that [problem] with the oyster sector. So they immediately indicated: well, we will perform the [sand] mining and nourishment very carefully. We will monitor very well. We will [monitor] if there is [damage] or no damage. So I got the feeling: they are really on top of it and will not [perform the project] just like that. No, it is really a process that has been [done] carefully from the beginning until the end."*

During the meeting of the Safety Buffer knowledge team we attended – several project team members are also part of this team – the following statements illustrate how those responsible for the Safety Buffer project frame the initiative and the positive intentions they have towards the stakeholders:

> *"[The Safety Buffer] is viewed as a unique project to yield knowledge about the Sand Hunger… We want to learn from this… How can I slow down [or] reduce the Sand Hunger with this [concept]." "The fact that you create a Safety Buffer at all, with the idea: it extends the maintenance period of such a dike… [By doing this project, we can] provide insight about that and make that reasoning transparent. And that is a very complicated [issue]… What does [the Safety Buffer concept] mean for*

> *[flood] safety?" "If we want to enter that [participatory] process with the stakeholders, then we need to be open and say: [stakeholders], how do we [feel] and what puts [you] into trouble? Or are their opportunities? How are we going to make something out of [this project] that makes everyone stronger?"*

Following Table 3.1, we identified the main **interest** of the project team by answering the research question 'what are the main ambitions or goals of the actor?'. For the project team, we identified that their main interest is to learn about how to improve dike maintenance, while simultaneously aiming to improve the Eastern Scheldt estuary's natural, recreation and user quality. We identified this actor attribute from our interviews with those associated with the project team. For instance, the following was stated:

> *"Which interests play a role? It just started, very basically, with [dike] strengthening… [Additionally], we would, by [nourishing] sand, do something about the Sand Hunger, restore the natural value to what it was 20 years ago… And then additionally the combination with some recreation and of course [some benefits for] the mussel and oyster sector." "An important reason why the project team eventually did not choose the first design we had, was because we wanted to learn from [the project]… And then we entered in discussion: yes, but how do we learn the most?"*

Following Table 3.1, we identified the main **values** of the project team by answering the research questions 'which moral principles does the actor hold as important regarding the topic? which criteria or boundary conditions are used to evaluate the topic?'. For the project team, we identified that an important value is their social responsibility for the well-being of the Eastern Scheldt estuary. Interviewees said the following about this:

> *"The higher goal. The higher goal: the Eastern Scheldt has to stay well. And we all want to get money out of it and enjoy it. But how do we do that?" "We very much want that [the Safety Buffer] is a step in working towards a sustainable Eastern Scheldt" "Whoever wants to join should pull up a chair, in order to jointly attempt to develop the Eastern Scheldt sustainably."*

An important value of the project team with regard to stakeholders in general – and hence with regard to the oyster sector in specific – is that they view it as their responsibility not to harm the interests of stakeholders. This value was an explicit boundary condition for the design process. During a sounding board meeting on 18 November 2011, this was explicitly communicated by a project team representative to all stakeholders present. In the minutes of that meeting, the following is reported:

> *During the development of the final design, the following 4 design criteria will be applied: (1) the users [i.e., stakeholders] and functions must not be damaged by either the dredging [i.e., sand mining] or sand nourishment… (3) if there is unexpected damage – in contradiction to the scientific insights – then this will be compensated according to the common claim settlements.*

Following Table 3.1, we identified the **beliefs** of the project team by answering the research question 'which propositions or premises does the actor hold to be true regarding the topic (even if there is no or contradictory evidence)?'. Regarding the ambiguity about the effects of the Safety Buffer on the oyster beds, the project team clearly believes that the project will not have adverse effects on shellfish beds. During the sounding board meeting of 20 April 2012, which we attended, this belief was explicitly communicated to those present. In the minutes of the meeting, it is reported that the risk of damage for the mussel and oyster sector is minor for the preferred design alternative. During the interviews, project team members avoided direct statements concerning the oyster sector, but the following quote – although an implicit statement – clearly supports the belief we identified:

> *"In [the oyster sector's] way of thinking, it was about damage and so forth. Because that was their major concern: 'there comes the sand'. Because [the Safety Buffer] was in the centre [of the estuary] and of course, there are all those oysters. But those are very far away [from the Safety Buffer]."*

Furthermore, the propositions that the project will not have adverse effects on shellfish beds was based on the belief that the judgments of experts involved in the project yield trustworthy predictions. We observed that no modelling studies were present among the project documentation, which points at the key role of experts in predicting the effects of the project. An interviewee remarked the following on this:

> *"[The design process was done] particularly with expert knowledge. And thus hardly based on data and that sort of things or models… I think that [any of the designs] will not really give any trouble for those [oyster] beds nearby, as long as some [precautions] are taken. And that has to do with the construction…[more than] with the spreading of the sand after [construction]."*

Following Table 3.1, we identified the **background** of the project team by answering the research questions 'which expertise, education or specific knowledge does the actor have regarding the topic? is the actor an expert or a layman regarding the topic?'. Several members of the project team – some of which we have interviewed – are an employee of Rijkswaterstaat, the state water authority of the Netherlands. Obviously, these are individuals with extensive expertise and knowledge regarding water management issues in general and sand nourishments in specific. Furthermore, an interviewed project team member – who is not an employee of Rijkswaterstaat – stated the following:

> *"[Regarding] the expertise there is [at Rijkswaterstaat] in Middelburg and their commitment…[Currently], it is more about contract management…the advanced engineering… Yes, Rijkswaterstaat is just immensely experienced with that… My admiration and respect for Rijkswaterstaat has grown [due to this project]."*

Following Table 3.1, we identified the **experiences** of the project team by answering the research question 'from which (personal) historical situations does the actor draw to interpret the topic?'. Regarding these experiences, the project team regularly points at the positive results of other nourishment pilots in recent years to strengthen their argument and to justify the development of the Safety Buffer. For instance, during the interviews, the following was stated:

> *"Then, we were busy with the Sand Hunger Survey in the Eastern Scheldt. And we were looking for the next pilots or experiments after the Galgeplaat [and the] Schelphoek [nourishment] pilot. Because those were all well on track. But now [we were looking for] something bigger… Galgeplaat went well." "[The Safety Buffer provides the opportunity] to extend the experience that we have gained with sand nourishments in the Eastern Scheldt."*

Additionally, the success of previous pilots is often referred to in project documents, such as the so-called Execution Plan Safety Buffer Oyster Dam. This plan includes statements about the Galgeplaat nourishment, such as:

> *The results of this small-scale experiment are promising… However, in order to work on the strengthening of the tidal flats on a larger scale, [both] more knowledge and pilot projects on a larger scale are required… This Safety Buffer Oyster Dam project can contribute regarding this knowledge requirement.*

Following Table 3.1, we identified the **actor position** of the project team by answering the research question 'what is the societal or political position of the actor regarding the topic compared to other relevant actors, in terms of power or influence?'. We uncovered that the actor position of the project team regarding the specific ambiguity we are addressing in this Appendix is ambivalent. Although the project team is a powerful actor supported by the government, they claim to be unable to overrule the economically vital oyster sector. Moreover, this claim was supported by several stakeholders we interviewed. A selection of quotes from our interview material illustrates this:

> *"Could you potentially be able to overrule the shellfish sector?... That will not work. You cannot just overrule the shellfish sector. Just to be clear, we don't even want that."* (interviewed project team actors) *"If you have that entire sector against you, they can just block such a plan. They have that power." "If the entire oyster sector becomes obstructive, [the project] will get into trouble."* (interviewed stakeholders)

C.2. OYSTER SECTOR FRAME AND ATTRIBUTES

The oyster sector **frame** regarding the Safety Buffer project is that it is an unacceptable initiative due to its potential adverse impacts on the oyster sector. Nevertheless, the sector does acknowledge that the quality of the estuary is degrading due to the Sand Hunger. We identified this frame based on the following statements of a representative of the oyster sector we interviewed:

> *"We, [the] Dutch Oyster Association, acknowledge that there is a problem in that Eastern Scheldt, thus that there is Sand Hunger… We were absolutely not amused [about the project]; that is obvious… We do not pay for it, we didn't ask for it, we will never ask for it at that spot. We are in fact against [the Safety Buffer] at that spot. Because we prefer not to see it [constructed]. Because we do not need it… Why do you have to do it exactly where our [oyster]beds are?... There always is a certain risk. So I am convinced that you can never give 100% watertight guarantees for the future."*

Following Table 3.1, we identified the main **interest** of the oyster sector by answering the research question 'what are the main ambitions or goals of the actor?'. The oyster sector is represented, both in the Safety Buffer project and in general, by the Dutch Oyster Association (in Dutch: Nederlandse Oestervereniging). This organization consists of nearly all commercial oyster producers. As the main goal of a common commercial business is to be as profitable as possible within reasonable and ethical boundaries, we argue that it is reasonable to assume that the main interest driving the oyster sector is maximizing their profit. Consequently, the specific concern of the oyster sector regarding the Safety Buffer project is that it could endanger their profitability. As the interviewee stated:

> *"My interest is that there is no damage of course… What if those oyster die?... Then it is a natural disaster, they'll say. Oyster producers: gone!... If it goes wrong here, then you have a significant [financial] loss."*

Following Table 3.1, we identified the main **values** of the oyster sector by answering the research questions 'which moral principles does the actor hold as important regarding the topic? which criteria or boundary conditions are used to evaluate the topic?'. We identified that, despite their focus on their own business, both the oyster and mussel sector feel a social responsibility for the well-being of the Eastern Scheldt estuary in which they cultivate their shellfish. Several interviewees commented on this. For instance, the following was said:

> *"We, [the] Dutch Oyster Association, acknowledge that there is a problem in that Eastern Scheldt, thus that there is Sand Hunger" "On the one hand, [the shellfish sector] constantly says: we commit ourselves, we want to contribute to it… But on the other hand, you have to realize that their interest is, of course, rather minor. It is a societal responsibility they feel which they bear there. So that is an interesting position of the [shellfish] sector. They have no obligation, it maybe isn't even in their own interest and nevertheless, they still do it… Yes, less tidal flats theoretically [means] more mussel cultivation beds or oyster cultivation beds. But they are not into it like that. Fortunately!" "We were able to experience the blessings of the Delta Works, in the sense that [those made it possible that] the shellfish culture in Zeeland [still] exists. But [now] we are confronted with the side effects. And that is, among others, the Sand Hunger… So we do not want to turn our back to the societal reality of what is going on and that that is experienced as a loss from [a] natural point of view."*

Following Table 3.1, we identified the **beliefs** of the oyster sector by answering the research question ‘which propositions or premises does the actor hold to be true regarding the topic (even if there is no or contradictory evidence)?’. Regarding the specific ambiguity discussed in this Appendix, we identified one essential belief: the Safety Buffer will almost certainly have negative effects on the oyster beds. The main representative of the oyster sector sharply communicated this belief in an interview with the regional newspaper in May 2011. It was actually due to this interview that the ambiguity between the project team and the oyster sector surfaced:

> *If this [nourishment] takes place, that means the deathblow for the [oyster] sector.*

Furthermore, the oyster sector representatives expressed similar concerns in a letter sent to the members of the Provincial authority in August 2011:

> *The oyster sector is very worried about the [proposed] nourishment at the Oyster Dam… In case of an excess of sand transport, [the oysters] will be covered…and will suffocate. With major anxiety we await the execution of the project plan.*

During the interviews, the bottom line of the concerns was expressed as follows:

> *“We are very concerned that, (a) during the sand mining… that sand will enter the oysters, causing the oysters to die… and (b) [similarly], at the moment that the sand nourishment has taken place at the Oyster Dam.”*

Following Table 3.1, we identified the **background** of the oyster sector by answering the research questions ‘which expertise, education or specific knowledge does the actor have regarding the topic? is the actor an expert or a layman regarding the topic?’. This attribute was partly derived by using common sense. Obviously, both the representatives of the oyster sector – i.e., the Dutch Oyster Association – and the commercial oyster companies are not experts regarding water management or sand nourishments, as this is not their profession. Regarding the background of the oyster sector, our interviewee touched upon this while describing the reason for their involvement in the project:

> *“There are two production sites [in Zeeland]: Lake Grevelingen and the Eastern Scheldt. In the Eastern Scheldt, the oyster beds are located in the immediate vicinity of the Oyster Dam… Therefore, we are a stakeholder [regarding the Safety Buffer].”*

Following Table 3.1, we identified the **experiences** of the oyster sector by answering the research question ‘from which (personal) historical situations does the actor draw to interpret the topic?’. The oyster sector aimed to strengthen their argument by pointing at the negative side effects on a mussel bed due to an earlier nourishment pilot. As our interviewee stated:

> *“Look, the first pilot, so that was on a tidal flat at the Schelphoek. [A pilot] regarding that Sand Hunger. Well, [at the Schelphoek], there is some damage at a mussel bed. But that is [just] an incidental damage. However, if it goes wrong here [at the Safety Buffer and the oysters are harmed], then you have a significant [financial] loss… Yes, so therefore we proposed to raise a damage fund.”*

Following Table 3.1, we identified the **actor position** of the oyster sector by answering the research question ‘what is the societal or political position of the actor regarding the topic compared to other relevant actors, in terms of power or influence?’. Similar to the project team, the actor position of the oyster sector is ambivalent. The oyster sector has no formal power to prevent project implementation, as they do not have the authority to take decisions. Nevertheless, because the oyster sector is an economically vital actor, this suggests they have a powerful position (as discussed above regarding the actor position of the project team). For instance, an interviewed project member stated:

> *“The oyster sector is really very important for Zeeland… There is big money in that [sector]. And there are major interests [attached] to that.”*

However, during the interview, the oyster sector representative claimed that his sector does not have a powerful actor position and cannot influence the development of the Safety Buffer:

> *“We, [the oyster sector], are of course a very important party in this whole business… Well, the people I represent, they are [against] that sand nourishment… [However], it is fighting windmills… Opposing Rijkswaterstaat and the Province, that is too much for me and my 36 [Dutch Oyster Association] members.”*

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LIST OF PUBLICATIONS

JOURNAL ARTICLES

Van den Hoek, R.E., Brugnach, M., Hoekstra, A.Y., *under review*. Coping with uncertainty: the benefits of the interrelatedness between different uncertainties. Technological Forecasting and Social Change.

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Ronald van den Hoek was born on 12 September 1984 in Vriezenveen, the Netherlands. He received his pre-university education (VWO) at the 'Openbare Scholengemeenschap Erasmus' in Almelo (1996-2002). Thereafter, he studied Industrial Engineering & Management at the University of Twente in Enschede (2002-2008). In October 2005, Ronald obtained his BSc degree with a case study research on derivative product development in Dutch production companies. During his master's study, he specialized in chemical process technology to further strengthen his technical background. Ronald obtained his MSc degree on his birthday in 2008. His graduation project, carried out at DSM Engineering Plastics BV in Emmen, was a feasibility study regarding the potential implementation of statistical process control in the Compound production plant.

After a period as sales engineer at Quality2Process BV in Delden, Ronald started his PhD project in October 2009 at the Department of Water Engineering and Management (WEM) at the University of Twente. His PhD project focused on studying uncertainty in flood defence projects based on Building with Nature (BwN) design principles and was embedded in the national BwN research program executed by the EcoShape foundation (subproject GOV 3.1). Ronald published the results of his research in international peer-reviewed journals, such as 'Global Environmental Change' and 'Environmental Science and Policy'. He also contributed to the so-called BwN Guidelines, which offer practical information and tools for developers and users of BwN projects. Furthermore, he presented his research at international conferences in the Netherlands (IGS conference 2010 and 2011; MOPAN 2012), the USA (Resilience 2011), Brazil (Group Decision & Negotiation 2012) and Austria (EGU General Assembly 2013).

Next to his research activities, Ronald supervised several BSc and MSc students during their final assignments, organized field trips for the BSc course Water, provided guest lectures about his research for the MSc course Integrated Water Management and was a working class lecturer for the BSc project Water. Furthermore, he organized presentations for the Water Management group (2010-2012) and organized the yearly WEM outing (2011).

Since November 2013, Ronald works as a Lecturer Business Engineering at Saxion University of Applied Sciences in Enschede.