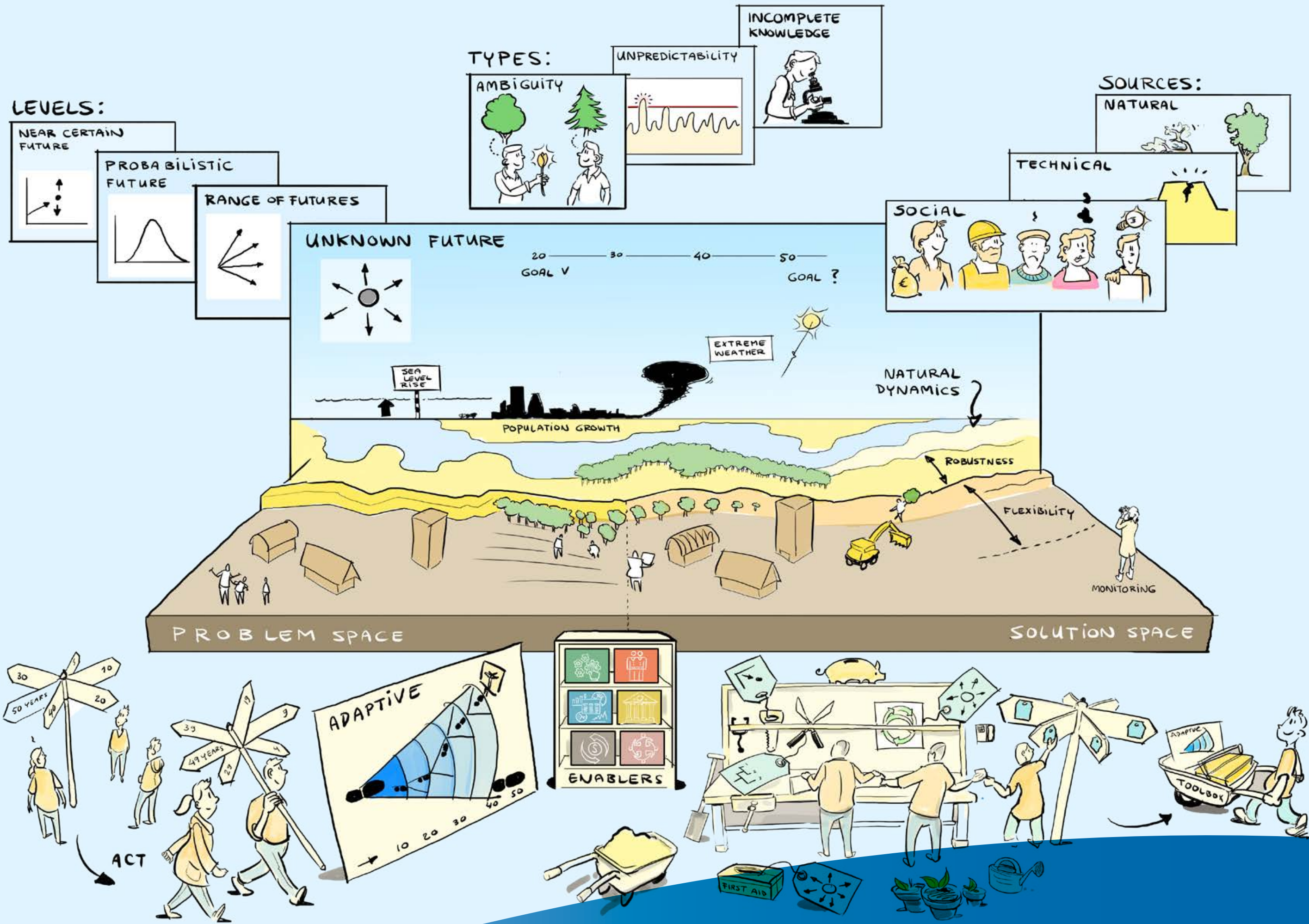

Building with Nature: a future proof strategy for coping with a changing and uncertain world

Working with uncertainties

EcoShape

Contents

Abstract

The influence of climate change on water related management challenges is felt worldwide. Backed by policies such as the European Green Deal, the UN Sustainable Development Goals and the Paris Agreement, there is a growing focus on Nature-based Solutions (NBS) and Building with Nature (BwN) to tackle current global challenges. However, the choice to implement Building with Nature rather than a traditional 'grey' infrastructure solution is often hampered by greater perceived uncertainty in the performance and implementation of Building with Nature. At the same time, the co-benefits of Building with Nature are well documented, and an increasing body of evidence showcases the value and functioning of Building with Nature under both daily and extreme conditions.

The objective of this whitepaper is to inform practitioners of Building with Nature about the concepts of uncertainty and how to use this as a strength in the dialogue to come to sustainable solutions for coping with future global change related uncertainties. Sources of uncertainty related to the BwN solution are often more manageable than the sources of uncertainties related to predictions of the future state of the problem. For instance, uncertainties related to the question 'how much sea-level rise can be expected' needs to be addressed independent of the uncertainties related to the solution itself (e.g., how can a mangrove greenbelt adapt to sea-level rise of 50 cm). Key considerations for working with uncertainties in Building with Nature solutions are:

1. Identification of all dimensions of uncertainty both related to the problem and solution at hand.
2. Adaptivity is key to work with deeply uncertain future challenges.
3. A toolkit of six enablers aids in implementing Building with Nature.
4. Adaptive design and targeted monitoring are essential in the management of Building with Nature solutions.

Based on a.o. the Ecoshape Building with Nature experience from over 12 years of 'learning by doing' at landscape scales for water management challenges, this white-paper argues that Building with Nature provides low-regret measures that can be both robust and flexible, and therefore suit adaptive planning strategies under uncertain futures. This in

The key planning characteristic to manage uncertainty of future water management challenges is adaptivity.

contrast to traditional grey solutions that generally seem cost-effective against their design time-horizons (e.g. 20 years), yet often remain in place long beyond these time frames, permanently altering the system in ways that reduce resilience and lead to considerable "regret" in terms of wasted investment and limited future adaptation possibilities.

The key planning characteristic to manage uncertainty of future water management challenges is adaptivity. Building with Nature is particularly well-suited to confront these new challenges due to the flexibility of the application. The aim should not be to eliminate or minimise dynamics and uncertainty, but rather to formulate plans that ensure system performance under different conditions. Adaptive planning and management approaches help to formulate such flexible and robust strategies and should consider long-term functioning and exogenous impacts on the system. Here, adaptation pathways can be used to identify path and scenario dependencies, and show risks of lock-ins and situations of high and low 'regret'.

Uncertainties in design and implementation of Building with Nature can be managed by using the six EcoShape Enablers as a toolkit. These enablers are based on the experience of pilot projects worldwide and provide guidance on how to frame uncertainties related to the physical system understanding, the stakeholder communities involved, the institutional settings, the business case and the management, maintenance and monitoring of Building with Nature solutions. Over-dimensioning, diversification and modularity are design principles that can be employed to ensure that a solution can cope with changing circumstances.

After implementation, the dynamic and adaptive character of Building with Nature allows for flexible management. For this an adaptive monitoring and maintenance framework should be set in place. This iterative monitoring and maintenance cycle includes targeted monitoring followed by the enaction of maintenance actions according to a predefined management framework, the formulation of which is an integral part of the planning process.

Given all uncertainties, there can be a desire to ignore uncertainties and to hold on to familiar predict-and-plan practices. However, identifying and managing uncertainties using Building with Nature is the most sustainable, resilient and future proof approach in the long run.

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EcoShape is public-private consortium of contractors, engineering firms, research institutes, NGOs, and governmental authorities that aim to develop and share knowledge about Building with Nature – an approach to create NBS - through pilot projects and research initiatives (valued at €80 million since its initiation in 2008) in flood safety, port development and ecosystem restoration in lower deltas. The drawings in this document were made by Joost Fluitsma.

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1. Introduction

Unprecedented challenges call for a shift in thinking

Changing climate conditions resulting in more extreme weather conditions, growing economy and rapid urbanization give rise to societal challenges of an unpreceded scale that are felt globally. These challenges come with great uncertainty. Prior experience in water management infrastructure planning has led to the development of methods to cope with some uncertainty in these plans. Implicit in these methods, however, is the assumption that the future will largely replicate the patterns of the past. These methods are inherently reactive, relying entirely on prior experience. With current uncertainties, such as the acceleration of climate change, extending beyond recorded experience, society is facing uncertain challenges on a scale much greater than it previously had to contend with (Marchau et al 2019). No longer can simply be relied on the historical record, but rather changes must be anticipated that extend beyond what is already known. This demands new, more flexible approaches and solutions that consider how to adapt water management strategies to changing conditions before they emerge (Haasnoot et al 2013). Building with Nature is particularly well-suited to confront these new challenges due to the flexibility of application (Van Eekelen & Bouw, 2020). Building with Nature solutions can typically be scaled-up as conditions change and often deliver a range of co-benefits and ecosystem services that contribute to broader system resilience (Cohen-Shacham et al 2019, Bridges et al 2018). Building with Nature solutions are often low- or no-regret actions which – at the very least – buy policy makers time for new information to emerge that signals directions and magnitude of longer-term changes. However, the application of Building with Nature can also introduce uncertainties that may be irreducible (Bergen et al., 2001). The natural dynamics inherent to these solutions means that their technical performance against key performance indicators may vary over short, medium and longer time scales, meaning that the formulation of reliable design standards becomes challenging. However, not accounting for all types, levels and sources of uncertainty implies an increased risk of failure, that would erode confidence in Building with Nature. Traditional grey solutions may seem cost-effective against their design time-horizons (e.g., 20 years). They often remain in place long beyond these time frames, permanently altering the system in ways that reduce resilience and constrain future adaptation options (Van Wesenbeeck et al 2014). In addition, usually only under a specific set of conditions there is a reasonable confidence in the technical performance of these traditional solutions. However, the current changes in these external conditions are so unpredictable that this reduces the confidence in the effectivity of these grey solutions on longer time scales. Moreover, 'grey' solutions can sometimes lead to additional negative social and environmental impact that reduce broader system resilience to other vulnerabilities (Cheong et al, 2013).

Definitions

Building with Nature and Nature-based Solutions

Building with Nature (BwN) and Nature-based Solutions (NBS) are similar in topic, and sometimes used interchangeably. In this paper we use the following definitions, adhering to those given by Cohen-Shacham et al (2019) for NBS and De Vriend et al (2015) for BwN. According to the International Union for Conservation of Nature the term Nature-based solutions (NBS) refers to "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (Cohen-Shacham et al, 2019). Building with Nature aims to embed natural processes in engineering solutions. It is an approach to delivering Nature-based Solutions. BwN meets 'society's infrastructural demands by starting from the functioning of the natural and societal systems in which [the] infrastructure is to be realized' (De Vriend et al 2015).

Green and grey Infrastructure

Green infrastructure intentionally and strategically preserves, enhances, or restores elements of a natural system, such as forests, agricultural land, floodplains, riparian areas, coastal forests (such as mangroves), and combines them with grey infrastructure to produce more resilient and lower-cost services. Grey infrastructures are built structures and mechanical equipment, such as reservoirs, embankments, pipes, pumps, water treatment plants, and canals. These engineered solutions are embedded within watersheds or coastal ecosystems whose hydrological and environmental attributes profoundly affect the performance of the grey infrastructure (Browder et al, 2019).

Robustness and Flexibility

Robustness refers to the ability of solutions to perform well across a range of plausible futures. Flexibility is defined as the ability of solutions to adapt to whichever conditions emerge.

1.1 Objective and reading guide

For planners, practitioners and all other stakeholders it is important to be aware of the different kinds of uncertainties that play a role in the ecosystem functioning and social context of implementing solutions for water management challenges. Building with Nature can be used to manage the physical, social and technical system in a sustainable and cost-effective manner. Because their strengths lie in their flexibility and robustness, Building with Nature is well suited to dealing with uncertainties. The objective of this whitepaper is therefore to inform practitioners of Building with Nature about the concept of uncertainty in relation to the decision and implementation process of Building with Nature, and how to use it as a strength. It aims to:

- Provide an overview of the different types, sources and levels of uncertainty.
- Describe the uncertainties that are specifically related to a problem (i.e., problem space)
- Describe the uncertainties that are specifically related to a solution (i.e., solution space)
- Provide an overview of how to deal with uncertainties and showcase examples of how uncertainty was dealt with in previous Building with Nature projects.

This paper starts by introducing the different types of uncertainty (Chapter 2). Next, the text is tailored to uncertainties that are encountered surrounding Building with Nature in the problem space. The uncertainties in the problem space are those associated with the core problem at hand. For example: how certain is the rate of sea-level rise or how extreme will an 'extreme weather event' really be. After this the uncertainties present in the solution space are presented, i.e., uncertainties specifically associated with the chosen solution itself and those originating from interaction between the solution and the outside world (Chapter 2). Finally, Chapter 3 gives an overview on how to deal with these uncertainties. It explains how to apply adaptive decision-making (Section 3.1), set the right environment (Section 3.2) and balance design and maintenance efforts (Section 3.3).

Example case Mangrove restoration

In this paper we use an example case to explain the concepts of uncertainties. Mangrove forests are a natural protective barrier along tropical coasts. Yet in many places this ecosystem is under pressure due to human interference and relative sea level rise. A large pilot study was setup as part of the EcoShape Building with Nature Indonesia Programme 'Securing Eroding Delta Coastlines' aiming at ensuring coastal safety and preventing coastal erosion through the restoration of mangrove forests. In Indonesia, mangrove loss is especially prevalent in poor rural communities, that must deal with an ever increasing severity and frequency of inundation events and loss of valuable land. The pilot took place in the Demak region in the North of Java and focused on enhancing the natural recruitment of fringe mangrove communities. The BwN design used permeable structures, made of bamboo and other local materials to attenuate incoming waves, and enhance the settlement of soft sediments behind these structures. Thereby these temporary permeable structures aided to create abiotic conditions that are favorable for mangrove seedling settlement and can be removed once the settled seedlings start to develop into a new forest. The Building with Nature approach was thus used to restore mangrove habitat that has been shrinking at an alarming rate over the last decades. For more info go to www.ecoshape.nl.

> *The uncertainties in the problem space are those associated with the core problem at hand.*

1.2 Key considerations for dealing with uncertainty in Building with Nature

Identify all dimensions of uncertainty

Decisions need to be taken despite the inevitable presence of uncertainties. Identifying uncertainties is important for both successful Building with Nature and traditional design and implementation. The aim should not be to eliminate or minimise dynamics and uncertainty, but rather to formulate plans that ensure system performance under different conditions. In order to achieve this, it is important that planning commences from a common understanding of what constitutes uncertainty in projects: its different types, sources and levels. Uncertainties related to the problem (e.g., how much sea-level rise can we expect) needing to be addressed are independent of the uncertainties related to the solution itself (e.g., can a mangrove greenbelt adapt to sea-level rise of 50 cm). A successful strategy focuses on the inherent dynamics and uncertainties in both the problem and proposed solutions and acknowledges that not all uncertainties need nor can be eliminated. This is elaborated and visualised in Chapter 2.

Adaptivity is Key

In (deeply) uncertain problem contexts, a traditional 'predict and design' approach is no longer suitable as the potential for accurately predicting future conditions is low. This can lead to considerable 'regret', in terms of wasted investment, the incidence of disasters, limited future adaptation choices, or missed opportunities.
The key planning characteristic to manage uncertainty while ensuring adequate system performance is adaptivity. Adaptive planning and management approaches help to formulate flexible and robust strategies and allow modifications of solutions and strategies as new information and conditions emerge. Adaptive approaches also help avoid situations in which future options become constrained by earlier decisions, or situations that result in assets being abandoned or becoming obsolete before reaching the end of their design lives. Time is therefore an important consideration in adaptive planning. We must ensure that our plans consider long-term exogenous impacts on the system that fall beyond the typical design life of grey infrastructure, as well as the potential costs of future adaptation. Strategies can prioritize uncertainties based on their potential impact on the system. Here, adaptation pathways can be used to identify path- and scenario-dependencies, lock-ins and situations of high and low 'regret'. Further reading is available in Section 3.1.

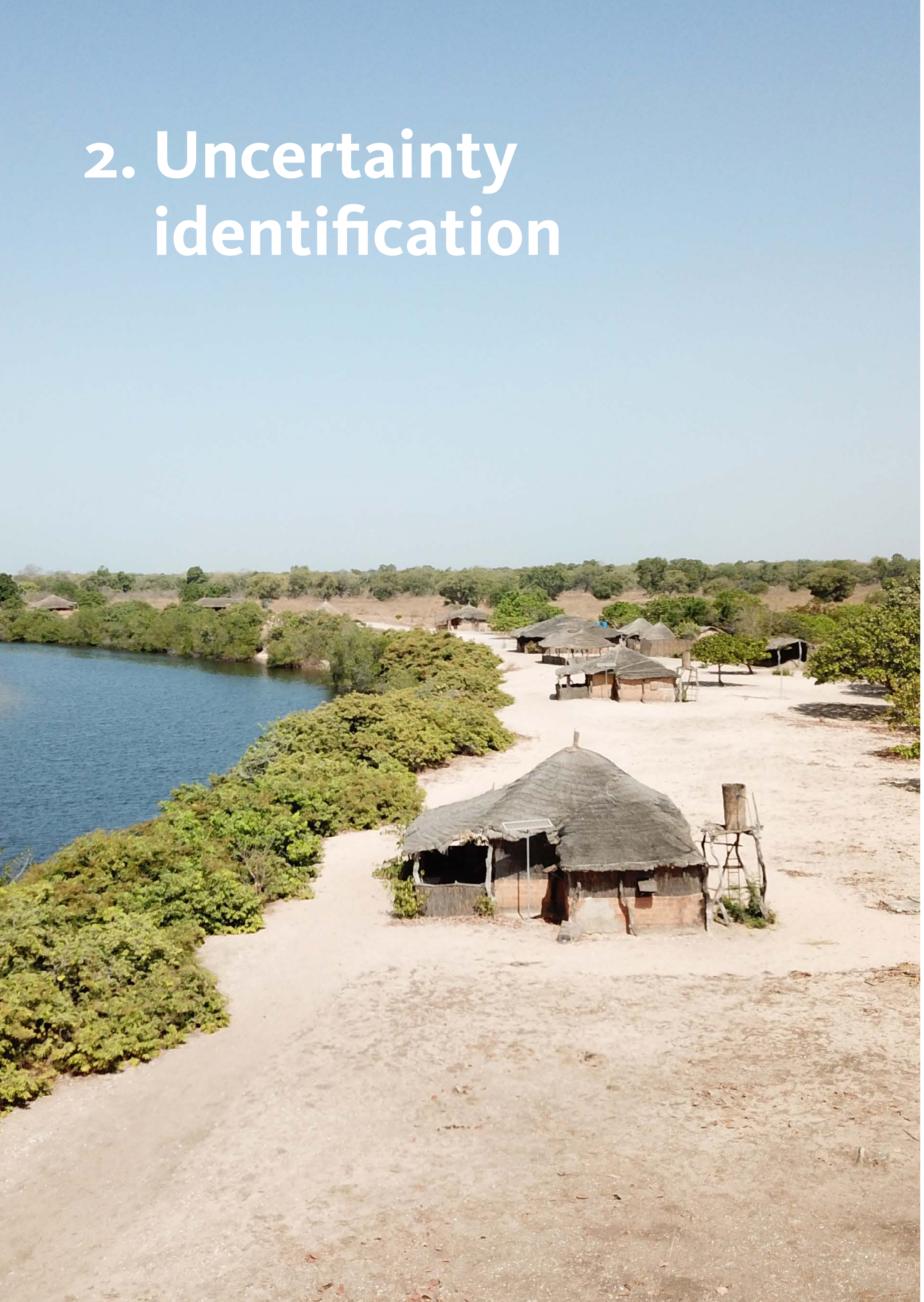
A toolkit of six enablers

Effective Building with Nature design and implementation requires setting the right environment. Applying the six EcoShape enablers, that are based on over 12 years of experience with BwN in pilot projects (van Eekelen & Bouw 2020), can help in effective implementation of Building with Nature whilst acknowledging that uncertainties are present. The focus of working with uncertainties falls under the enabler Adaptive management, monitoring and maintenance. Links to the other five enablers exist, as they provide guidance on how to overcome specific uncertainties related to their subjects: Technology and system knowledge, Multi-stakeholder approach, Institutional embedding, Business case and Capacity Building. More details in Section 3.2.

Adaptive design and targeted monitoring

Several design principles can be employed to ensure Building with Nature is able to cope with changing circumstances. For example, over-dimensioning, diversification and modularity can be used. Over-dimensioning introduces a redundancy with respect to the units of measurement of the design. Diversification is a risk management strategy that assumes that including many different types of assets is more resilient than a strategy that relies on only one or a few of the same asset. By introducing assets with different responses to changing conditions risk of failure of the overall solution is reduced. Modularity implies that the solution can be easily adapted to changing circumstances e.g. by adding an extra 'module' (e.g., sand) to increase the size of the solutions in line with alterations in the required performance level.

In general, the dynamic and adaptive character of Building with Nature introduces flexibility into strategies to maintain acceptable performance under a range plausible yet uncertain future conditions. This also implies that continuous management and monitoring are inherent to Building with Nature. This iterative process includes targeted monitoring followed by management actions according to a predefined framework, the formulation of which is an integral part of the planning process. Further reading in Section 3.3.



2. Uncertainty identification

What is uncertainty in water management infrastructure planning exactly? Is uncertainty related to unpredictable future climatic or socio-economic conditions? Or is uncertainty related to the technical performance of proposed solutions stemming from a lack of knowledge? Can uncertainty result from contested perspectives and values of stakeholders? Uncertainty has different types, sources and levels in planning problems, and it is important that practitioners can recognise these to ensure that uncertainties are addressed systematically during planning activities.

2.1 Types, sources and levels of uncertainty

Core messages:

- Uncertainty can be categorised according to its types, sources and levels
- Uncertainty can be reduced by further research, but will never be fully eliminated
- The type of problems Building with Nature addresses are typically highly complex and deeply uncertain, where all types and sources are present.

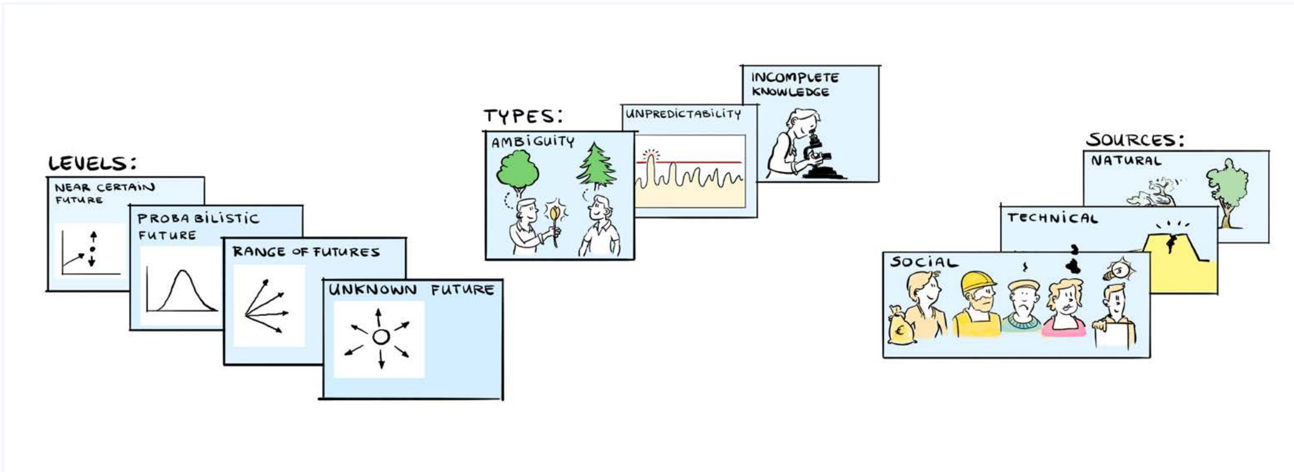
Three useful aspects to consider uncertainty include its types, sources and levels (Figure 2.1). While identifying uncertainties, it is important to recognise that uncertainties are often not independent of each other and cascading effects may be present.

2.1.1 Types

Three main types of uncertainty can be distinguished (Brugnach et al., 2008). Practitioners need to take into account that solutions must consider and address all three types (Figure 2.2). The three main types are:

- Unpredictability: i.e., 'cannot know': this relates to the uncertainty stemming from aspects such as naturally variable processes or the unpredictable interactions between stakeholders. Examples include: the occurrence of a future heat wave; the impacts of a heat wave on mangroves in a green-inclusive flood protection scheme; uncertainty about future election results that may change flood protection policy priorities. These uncertainties are always impossible to predict, which is a characteristic that we expect to remain so in the foreseeable future.
- Incomplete knowledge: i.e., 'do not know (yet)': this relates to the uncertainty stemming from, e.g., lack of knowledge, limited data availability or unreliable data. Examples include: the interactions between incoming waves with salt marsh stems; the maximum wave intensity that mangroves can resist; the economic impacts of extreme floods for populations located behind flood defences. This type of uncertainty can be reduced through additional monitoring and research to gain (more) knowledge or improve data availability/reliability.

Figure 2.1
Uncertainty can be categorised according to its type, source and level. Together they form the unknown future.



- Ambiguity: i.e., 'know differently': this relates to the presence of different interpretations of the same concept or situation stemming from, e.g., stakeholders having different and sometimes conflicting perspectives and values of a system (e.g., engineers vs. environmentalists, experts vs. generalists). Examples include: a strategic preference for cheap, single-function solutions over more extensive integrated approaches that provide co-benefits; and different levels of trust in existing design standards and norms. This type of uncertainty may be irreducible, with the different perspectives each sharing equal levels of plausibility and/or legitimacy. Ambiguity might be reduced by well-informed discussions with clear argumentations, but most importantly is must be recognised as being of influence in decision making regarding the type of solution for a give problem (Van den Hoek et al 2014, Warmink et al 2017, Giordano et al 2017).

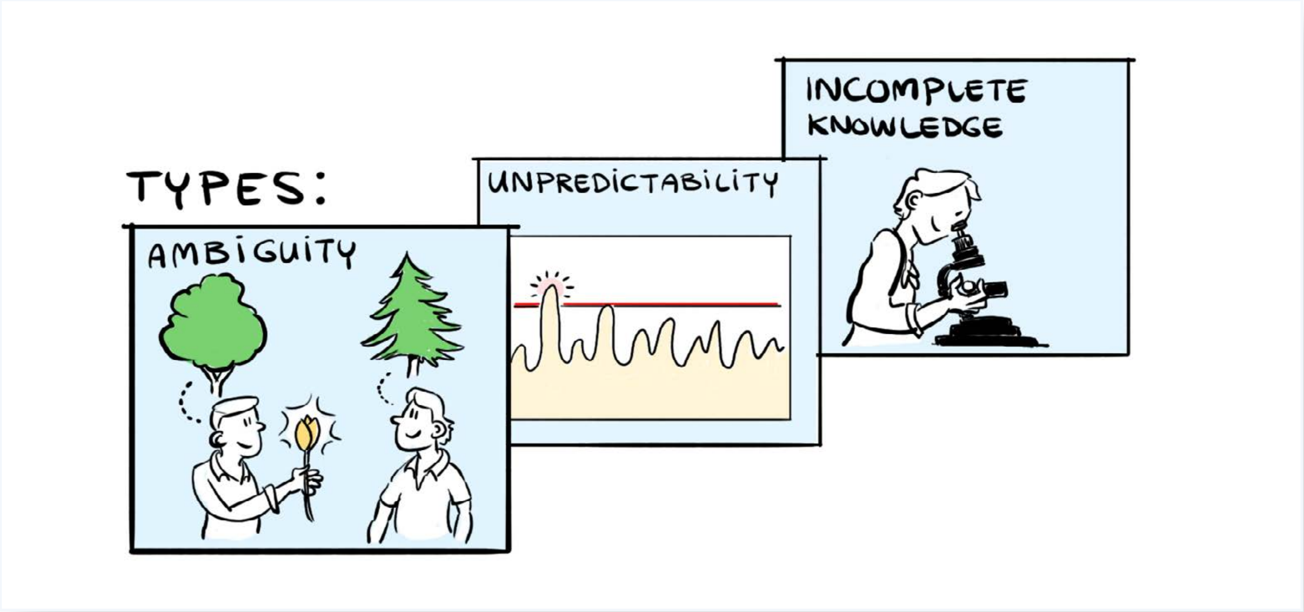
This typology reveals that we are unable to eliminate all forms of uncertainty from the problem context, independent of the choice for either 'grey' or 'green' solutions. Although we can seek to improve incomplete knowledge through additional research and monitoring, it is unlikely we will ever be able to completely reduce uncertainties characterised by unpredictability or ambiguity (Ounanian et al 2018). Furthermore, additional research may prove to be costly and bring limited new insights or delays action. This is not to discourage pursuing further research, but when considering how best to confront uncertainty for a given problem, we must first weigh the likelihood of the new knowledge shifting the outcome of the planning process. Practitioners need to recognize that infrastructure plans must take into account and plan all three types of uncertainty.

2.1.2 Sources

Uncertainty can also be classified according to its source (Figure 2.3). While it is not indispensable to classify uncertainties, it is nevertheless useful to ensure that all sources of uncertainty are given due consideration during problem analysis. Uncertainties can be grouped in three sources:

- Natural system: uncertainty relating to the dynamics of natural processes, including both exogenous environmental drivers of change (e.g., climate, water quality), as well as the response of ecosystems and ecological processes to those drivers that can be considered natural dynamics (e.g., breeding patterns).
- Technical system: uncertainty relating to the performance of interventions in the natural system, including both infrastructural (e.g., breakwaters) and technological (e.g., early warning systems). Here, the critical question is the probability that a proposed solution will achieve the desired functioning for a given application.
- Social system: uncertainty relating to all the economic, cultural, legal, political, administrative and organizational aspects surrounding the problem and any proposed solution. Examples include: the economic impact of extreme weather events; societal values and attitudes towards nature; the absence or emergent nature of design, operation or maintenance standards and norms for Building with Nature.

Figure 2.2
Types of uncertainty: ambiguity, unpredictability and incomplete knowledge.



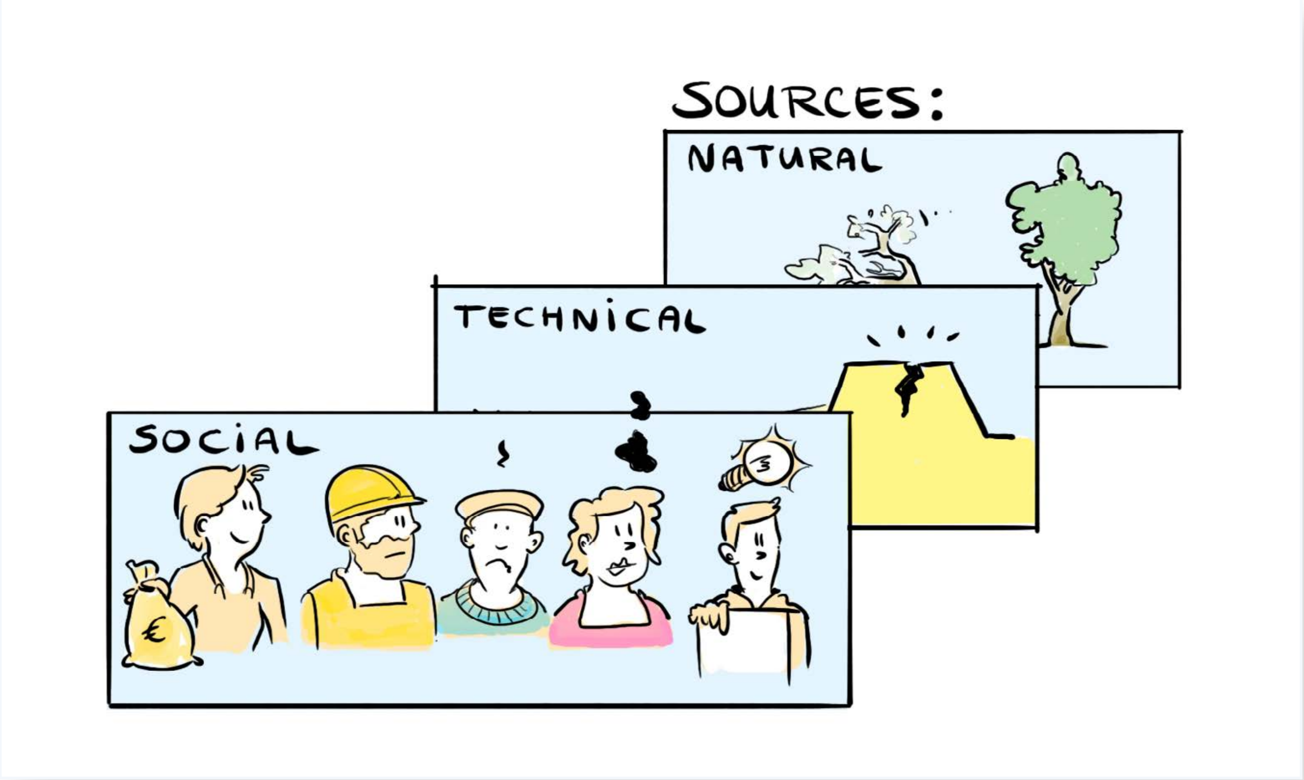
The uncertainty classification matrix by van den Hoek (2014) is a useful tool to identify the various uncertainties present in each of the different parts of the broader system according to their type and source (Table 1). It can be particularly useful in preventing some uncertainties from being ignored or forgotten during the analysis pfase.

2.1.3 Levels

In addition to its various types and sources, a distinction is made on the level of uncertainty, basically the 'intensity of the uncertainty'. This has implications for the types of assessment frameworks applied and the way decisions are made. Four broad levels of uncertainty related to future developments are distinguished (Table 2): a near certain future, a probabilistic future, a range of futures, and an unknown future, also called 'deep uncertain future'.

- Near certain future refers to a setting in which the future is largely predictable. These are generally situations involving short-term decisions, in which the system of interest is well-defined and can be analysed using, e.g. deterministic system models. The decision-making process is one of 'predict-and-act', dominated by the formulation of 'optimal' policies.
- Probabilistic future: refers to a setting in which the future can be described 'most likely'. The impact of potential interventions can be estimated using, e.g. stochastic models. Preferred interventions are then selected according to levels of acceptable risk. The decision-making process assumes that the future will largely resemble the past and existing trends.
- Range of futures: refers to a setting in which there are a limited set of (equally) plausible futures, none of which can be assigned definitive weights or probabilities. In these cases, traditional scenario analysis-type assessments are required which assume that the future can be predicted well enough with 'best-estimate' models. Decision-making tends to favour "robust" solutions that perform well across the range of plausible futures.
- Unknown future: refers to a setting involving longer-term decisions in which there are many plausible futures or where the future is completely unpredictable and unknown. Understanding of system interactions may also be contested or unknown. Assessing the impact of possible interventions in such contexts is difficult and demands new approaches often framed as 'decision making under deep uncertainty' (Marchau et al, 2019). These tend to favour solutions that exhibit both "flexibility" (ability to adapt to whichever conditions emerge) and 'robustness' (producing favourable outcomes in a most future scenarios).

Figure 2.3
Sources of uncertainty: social, technical and natural system.



2.2 Uncertainties arising from the problem and the solutions

Core messages:

- Uncertainties relate both to the problem at hand and to the proposed solution
- Uncertainty related to the problem is independent of the proposed solution
- Uncertainty related to the proposed solution relates to performance of the solution due to interaction with the outside world

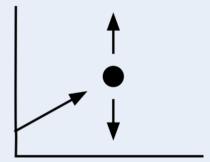
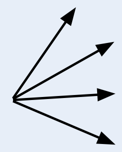
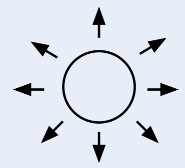
There is a distinction between uncertainties related to a specific problem/issue, and uncertainties related to a proposed solution. Uncertainty in the 'problem space' is fundamental to the core problem or question. In other words, what is in the main system vulnerability being addressed and what is uncertain about this? For example, how will sea-level rise (SLR) and extreme river discharge develop in time possibly resulting in flooding and how many assets will be at risk in the future? How will natural hazards such as drought, coastal, alluvial or pluvial inundation evolve over the coming years? Uncertainties in the 'solution space' are more related to a particular intervention, be it for example a conventional levee or a Building with Nature vegetated foreshore levee system. For example, how a particular solution performs under different conditions and how it interacts with its surroundings. That is, given the problem context, how certain is it that a proposed solution will perform as intended? For example, can the current design of sea walls withstand future storm events given the continues rise of sea level. Or can a mangrove flood defence system continue to attenuate waves given sea-level rise? The rate and magnitude of SLR is related to the problem space, however the performance of a solution given specified conditions (e.g., a certain rate of SLR) is part of the solutions space.

It is of equal importance to address uncertainties both in the problem and solution space. However, in many instances the concept of uncertainty is ignored in the evaluation of 'grey' versus 'green' infrastructure.

Table 1: Uncertainty classification matrix, including examples (adapted from van den Hoek, 2014).

		Types of uncertainty		
		Unpredictability Unpredictable behaviour of nature, humans or the system *We cannot know*	**Incomplete knowledge** Imperfection of knowledge, inexactness, approximations, etc. *We do not know (yet)*	**Ambiguity** Equally sensible interpretations of a phenomenon *Knowing differently*
Sources of Uncertainty	**Natural system**	Frequency and magnitude of future weather extremes	Detailed ecosystem responses to specific drivers (e.g. breeding patterns)	Contested natural phenomena, e.g. the perceived trust in the resilience of the ecosystem in relation to extreme events
	Technical system	Variable performance of NBS due to seasonal effects (e.g. growth patterns, sediment accretion)	Unknown effectiveness of NBS due to insufficient data or research (e.g. flood protection level provided)	Competing biases towards interventions that are simple and single focussed versus more complex and integrated; an absence of respected design norms
	Social system	Election outcomes; migration and settlement patterns	Indirect (integrated) economic impact of disasters	Contested values regarding, e.g. collective versus individual responsibility for disaster prevention and response

Table 2: Levels of uncertainty, related system models and decision-making approaches. Modified from (Marchau et al 2019).

What does it mean for...?	Near certain future	Probabilistic future	Range of futures	Unknown future
				
The future	Clear enough, knowable future	Alternate futures with associated probabilities	A few or many plausible futures without probabilities	Unknown or unagreed future
The system model	A single deterministic system model	A single stochastic system model	A few or many alternative system models	Unknown or unagreed system model
The system outcomes	A point estimate for each outcome	A confidence interval for each outcome	A range of outcomes	Unknown or unagreed outcomes
The policies or decision making	'Predict-and-act' or 'optimal' policy	Future will look like the past: 'trend-based' policy	Perform under range of scenarios: 'robust' policy	Recognize deep uncertainty: 'robust and adaptive' policy

Uncertainties in the problem space are the same and are independent of the type of solution that is eventually selected, while in the solution space, Nature-based Solutions are more often hampered by additional uncertainty relating to their implementation and technical performance compared to grey solutions. It is important to note that historically, grey infrastructure have dealt with a great deal of uncertainties. As a result, there are international standards for conventional flood defence infrastructure, such as levees. NBS are currently undergoing a similar process, where international institutes like the World Bank and IUCN, are now formulating standards for green infrastructure. By untangling uncertainties in the problem and solution space, it becomes possible to address those uncertainties specifically pertaining to Building with Nature. In the following chapter we address how to deal with these uncertainties.

2.2.1 Problem space

The types of problems for which Building with Nature solutions are being proposed are typically highly complex and mired in (deep) uncertainty. These are problem contexts in which all three types of uncertainty (unpredictability, incomplete knowledge, ambiguity) are present. The natural, technical and social processes contained therein are often interdependent and, in many instances, still largely unknown. The various actors involved cannot agree upon how the system functions or the likely future system state, let alone what interventions should be made to mitigate against possible impacts. Considering the different types, sources and levels of uncertainty is a relatively easy way to identify the different uncertainties acting on these systems. Also this approach helps to indicate the appropriate assessment and decision-making methodologies to apply in their analysis. In highly ambiguous settings, sufficient attention must also be given to stakeholder-inclusive processes of collaborative assessment to ensure that any ambiguities can be reduced and/or respected (Janssen et al 2020, Nesshover et al 2017).

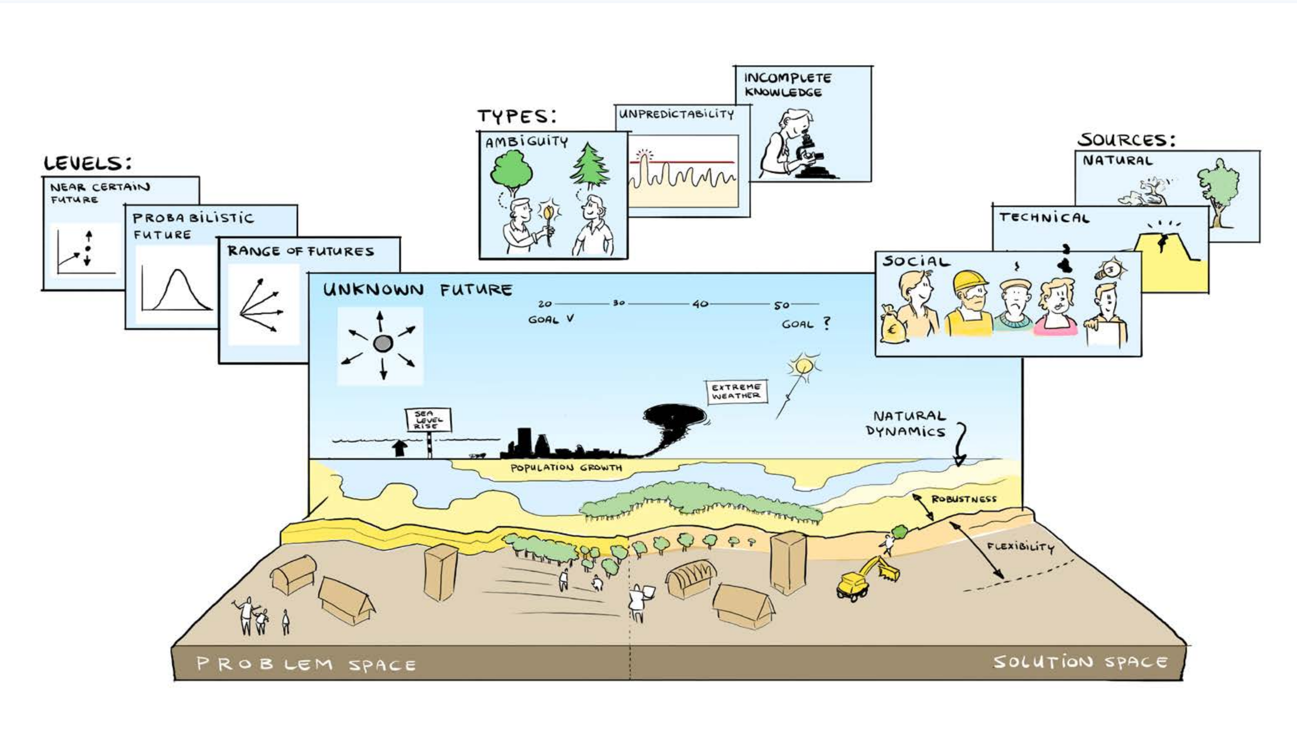
2.2.2 Solution space

The natural system with all its dynamics in time and space is a starting point for Building with Nature. The use of natural processes and materials in Building with Nature implies that solutions themselves are also inherently dynamic as processes evolve both in time and space. For instance, vegetation develops, and sediments are redistributed. This is considered a great strength of Building with Nature: incorporating dynamic natural processes as part of the design offers opportunities for flexibility and adaptability to deal with unforeseen developments and emerging complications. Uncertainty in the solution space originates from interaction between external factors (e.g. sea level rise, temperature, economic situation, political setting) and the performance of the solution itself.

Uncertainty around the performance of the solutions can originate from the:

- Technical system: How certain can we be that the solution will achieve the desired performance level (e.g. flood protection levels, storm surge attenuation)? How much confidence can we place in existing NBS design guidelines?
- Natural system: How will the solution respond to the natural dynamics present in the system now and in the future, including large environmental drivers of change (e.g. mangrove resilience to increased storm frequency, patterns of vegetation density to seasonal or broader climatic changes like warming sea temperatures)?
- Social system: How will the performance or acceptability of the solution be affected by long-term shifts in social or cultural values? How do we adequately account for and value the ecosystem services provided by the solution? How do we reconcile the management and maintenance of the solution across multiple government agencies?

Figure 2.4
Uncertainties are related to either the problem space (e.g. related to climate change aspects such as sea level rise and extreme weather events and demographic change in the future) and solution space (e.g. related to the functioning of the solution over time)



Box 1

Natural uncertainties in the problem space

When taking into account uncertainty in Building with Nature projects, unpredictability of the exact frequency and magnitude of the problem is an ever-present type of uncertainty. Natural dynamics have different temporal and spatial variations. There is relative certainty regarding the frequency and magnitude of storms for certain locations. The same can be said about seasonal variation of rainfall, with a limited degree of uncertainty it is possible to predict where and when rainfall occurs and when flood risk is high. However, the exact timing and magnitude of these natural dynamics is still unknown and there remains yearly variation when a season starts and ends, or whether it is a relatively dry or a wet year. On longer timescales, large environmental and anthropogenic drivers like climate change will yield even greater unpredictability, and also it is unknown how much the climate will change at specific locations nor the impacts of these changes in terms of ecosystem response.

Similarly, what will be the effect of climate change on hydrological flows? Rainfall intensities may increase, but how much wetter will it become exactly? In coastal environments, changes in tidal movements and in wave conditions and amplitudes may lead to changes in salinity and hydrodynamic loads on structures in sea environments (Rubinato et al., 2020; Thoms et al., 2020). Sediment regimes are also expected to be impacted; e.g. more sediment erosion is expected due to higher rainfall intensities (Rubinato et al., 2020). There is still incomplete knowledge about these future impacts in terms of their timing and location of occurrence, magnitude, duration and frequency.

Uncertainties are interrelated and adaptation measures can trigger cascading effects. For example, there is uncertainty regarding how climate change will affect flooding frequencies and therefore what the required performance of a flood protection measure should be. At the same time, changes in flooding regime will change sedimentation rates, loads and wetting-drying regimes. Cascading effects to consider are those on the development of vegetation (which species will develop in these circumstances, in various stages of succession), with related potential geomorphological impacts downstream (Thoms et al., 2020). This interrelatedness of uncertainties asks for measures that deal with multiple uncertainties at the same time, instead of coping with each uncertainty individually.

3. A Building with Nature approach for working with uncertainties

The Building with Nature approach has many similarities with the framework of adaptive planning. They both address issues at the landscape level, look at long timeframes and require stakeholder engagement. However, there are still some principles of adaptive planning that can further inform Building with Nature and vice versa. For example, each of the six enablers can reduce or provide ways on how to deal with uncertainties. And principles such as modularity, diversification and over-dimensioning can be used to guide the design and implementation of a Building with Nature project. Implementing the Building with Nature approach can thus help avoid maladaptation such as lock-ins and stranded assets.

3.1 Adaptive decision-making

Core messages:

- In (deeply) uncertain problem contexts, a traditional 'predict-and-design' approach is no longer suitable
- Building with Nature approach is a strong example of adaptive planning
- The most important barrier hindering upscaling Building with Nature as adaptive management approach is the larger perceived uncertainty

Traditionally, infrastructure decision-making has followed a 'predict then act' approach whereby the performance of various measures is assessed and evaluated against a clearly identified set of static future conditions. In other words, the future is assumed to look a certain way and then design infrastructure to perform to these levels, which is a very reactive approach to flood risk management. For example, for years dikes have been designed in such a reactive manner and resulted in the continues alteration of the dike dimensions (e.g., crest level, lateral slopes and distance to river) as environmental conditions change. Now with deeply uncertain issues like climate change in the problem space a reactive approach is even more prone to maladaptation since the potential for accurately predicting future conditions is low. Ignoring uncertainty related to future developments (e.g., the magnitude and speed of sea level rise) in water management challenges can lead to regrettable outcomes at best and at worst results in a disaster. Adaptive planning on the other hand, takes deep uncertainty in the problem space into account and has a more proactive approach in managing the solution space (Kato et al 2008). Adaptive planning sets out to identify options that are low-risk or low-regret, i.e., which contribute to planning objectives but do not hinder future action and can be used to 'buy time' for new information to emerge that signals directions and degrees of magnitude of longer-term change. Monitoring system changes through time is consequently another important feature of adaptive planning and management, as planners must be able to identify the conditions at which further action is required.

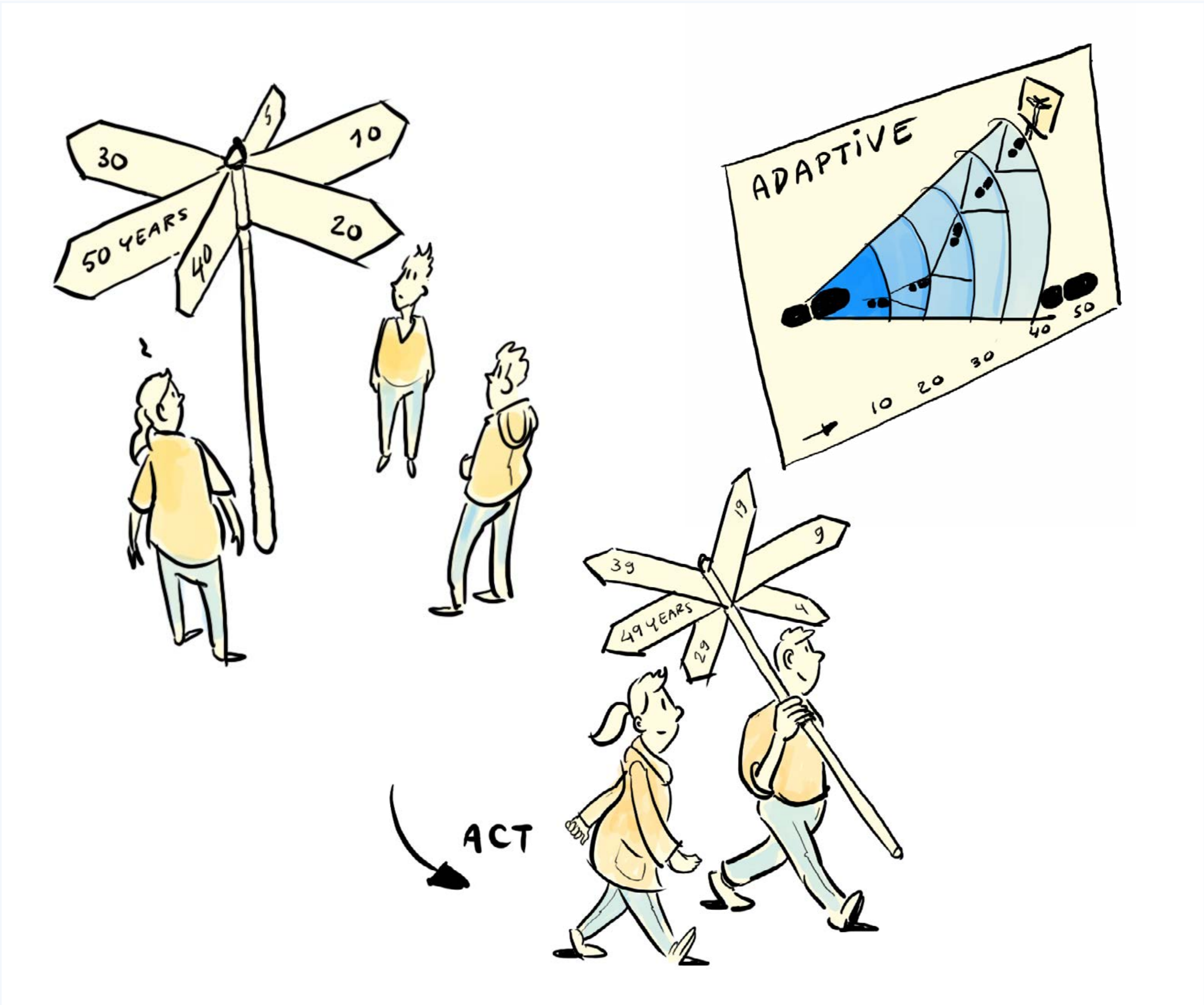
Time is an important consideration in adaptive planning. Most grey infrastructure typically remain in place for decades, such that the conditions under which it may need to perform in the future, will be entirely different to the present. Planners must be confident that the decisions made today will still serve the needs of tomorrow. A key aspect of this is ensuring that plans consider long-term exogenous impacts that fall beyond the typical life cycle of grey infrastructure, and which consider the potential costs of future adaptation.

Building with Nature approach can offer a solution to dealing with the deeply uncertain issues arising in the problem space. Such solutions are particularly well-suited to confront challenges that extend over long periods and encompass vast areas (i.e. climate change) due to its flexibility of application. Building with Nature adheres to the aforementioned criteria of adaptive planning, i.e. they can be scaled-up as conditions change, they are low- or no-regret, they buy policy makers time and ensure that alternative options remain available. However, often Nature-based Solutions are not seen as a viable option because of the many perceived uncertainties.

Planners must be confident that the decisions made today will still serve the needs of tomorrow.

For example, what is called into doubt is their effectiveness at reducing flood risk. These uncertainties can act as a barrier for the implementation of a Nature-based Solution. Yet the level of uncertainty (e.g., they are unknown and unpredictable) is manageable and not deeply uncertain. It is a form of ambiguity that these manageable uncertainties in the solution space are considered a barrier for implementation: the unfamiliarity with the solution may create a feeling of uncertainty that is higher than the actual level of uncertainty. When uncertainties in the solution space are properly addressed during the design phase of a project, they become more manageable. For example, although it is known that mangrove forests can attenuate waves, the exact dimensions required are unknown. Such an uncertainty can be remediated in the short-term, by overdimensioning the mangrove forest. In the long-term, such a knowledge gap can be addressed by conducting experiments and in situ measurements. Such uncertainties should thus not hamper adding Nature-based Solutions to the portfolio of viable measures that address climate change issues. And although there are many uncertainties in the solution space when it comes to Nature-based Solutions, they excel at addressing uncertainties in the problem space in an adaptive manner.

Figure 3.1
Decisions need to be made despite uncertainty. In deep uncertain problem context taking a large step using a 'predict and design' approach is unfavourable. The key is to be able to take smaller steps by using an adaptive approach.



3.2 Creating the right environment

Core messages:
- EcoShape has defined six enablers to implement Building with Nature. Each of them addresses specific uncertainties in their own way.
- The enablers address the most essential societal, economical and natural factors that are important for dealing with uncertainty.

Based on the experiences of over a decade of learning-by-doing, intersectoral collaboration, multidisciplinary fundamental and applied research, EcoShape has identified six enablers that are instrumental to address the unique characteristics of Building with Nature projects (Van Eekelen & Bouw, 2020). These enablers can aid in the creation, implementation and upscaling of Nature-based Solutions through the Building with Nature approach. The six enablers are strongly interlinked, and each play a role when it comes to working with uncertainties. The enabler Technology and system knowledge underscores the importance of striving to acquire new knowledge so that we better understand the social, natural and technical systems. Hereby uncertainties pertaining to incomplete knowledge in each of these systems can be addressed. The Multi-stakeholder approach helps us better understand the social system; it is a way to acquire local knowledge and is part of the entire Building with Nature implementation process. For example, a workshop event where local stakeholders engage in friendly discussion can reduce ambiguities about how demographics in their city might change over the next 50 years. Furthermore, stakeholder engagement is crucial for ensuring that a Building with Nature solution is properly embedded at an institutional level. Quite often it is uncertain which governmental agencies are responsible for the maintenance and operation of a Building with Nature solution. In cases where the problem is deeply uncertain, the enabler Adaptive management, maintenance and monitoring requires more attention. A well-established business case also reduces uncertainty, with a focus on finance and economics. This enabler supports Building with Nature practitioners to better understand the costs and benefits of a solution, be it a green or grey one. And finally, it is essential that stakeholders are not ambiguous about what Building with Nature constitutes. The enabler Capacity building ensures that both civil engineers, policy makers and ecologists alike, are aware of the Building with Nature approach and its co-benefits or limitations.

Below, each of the enablers are described in more detail, by use of the example of coastal protection by mangrove belt restoration. A description and set of goals are given for the example case where Building with Nature is applied for mangrove habitat restoration as means to reduce coastal flood risk. The descriptions given are not exhaustive and are aimed at making the relationship between enabler and uncertainties more tangible.

3.2.1 Technologies and system understanding

This enabler aims to reduce incomplete knowledge and helps better understand unpredictable dynamics of the technical, ecological and socio-economic systems. Thereby reducing ambiguity and highlighting inherent variabilities.

Examples how this enabler can help with working with uncertainties:
- Understanding how long it takes to deliver benefits when restoring and conserving mangrove habitat.
- Understanding the design parameters for mangrove habitat in order for it to withstand large storm events.
- Understanding how the performance of mangroves will be affected by long-term trends such as population growth and shifts in land use.
- Understanding the co-benefits of mangroves and how to quantify them.

3.2.2 Management, monitoring and maintenance

This enabler offers ways on how to deal with incomplete knowledge, ambiguity and unpredictable dynamics in the social, natural, and institutional systems. By continuously monitoring risks and the performance of measures under changing conditions, we can update our existing knowledge base and adapt how risks are managed.

Examples how this enabler can help with working with uncertainties:
- Diversifying the measures that address flood risk, not only focusing on restoring mangroves, also other flood risk reduction measures such as levees and early warning systems.
- Over-dimensioning the minimal required mangrove area needed in order to reduce flood risk.
- Monitoring program that measures increase in risk (e.g., relative sea level rise) and status of the mangrove belt and stipulates when mangroves only are no longer a viable solution.
- When maintaining mangrove habitat, setting Key Performance Indicators (KPIs) that define parameters of what a healthy mangrove habitat looks like.

3.2.3 Multi-stakeholder approach

This enabler provides support how to reduce ambiguity of different stakeholders, identifying their values and incorporating different sources of knowledge. In highly ambiguous settings, sufficient attention must be given to stakeholder-inclusive processes and collaborative assessments to ensure that any ambiguities can be respected and/or reduced. This enabler facilitates the other enablers.

Examples how this enabler can help with working with uncertainties:

- Identifying key stakeholders when restoring mangrove habitat.
- Understanding who would benefit and how they value mangrove habitat.
- Understanding local social, environmental and institutional systems.
- Understanding the willingness of local communities to get involved and defining their responsibilities in the restoration and maintenance of mangrove habitat.

3.2.4 Institutional embedding

This enabler focusses on the implementation of a Building with Nature measure at an institutional level. It reduces ambigities and unpredictability by establishing clear governance responsibilities.

Examples how this enabler can help with working with uncertainties:

- Understanding the relevant policies when it comes to flood risk and mangrove restoration.
- Understanding and aligning the tasks/responsibilities/ mandates of governmental agencies that deal with flood risk and mangrove restoration.
- Establishing safety norms for mangroves at an institutional level.

3.2.5 Business Case

This enabler reduces ambiguity and improves imperfect knowledge on the financial and economic aspects of Building with Nature.

Examples how this enabler can help with working with uncertainties:

- Monetizing the co-benefits of restoring and conserving mangrove habitat.
- Understanding the expenditures, revenues, risks and opportunities of restoring and conserving mangrove habitat.
- Compare with grey solutions by making a long-term cost benefit analysis of both strategies.

3.2.6 Capacity building

This enabler is geared to sharing existing knowledge, to improve imperfect knowledge, to better understand unpredictable dynamics and reduce ambiguities.

Examples how this enabler can help with working with uncertainties:

- Ensure that stakeholders become aware of the social, environmental and institutional system that governs mangrove restoration.
- Ensures stakeholders become aware of benefits of mangrove ecosystems.
- Ensures that relevant governmental agencies have the knowledge and skills when it comes to designing, implementing, maintaining a Nature-based Flood Defence such as mangrove habitat.

3.3 Balancing design and maintenance efforts

Core messages:

- A balance exists between Building with Nature design efforts and maintenance efforts
- The implementation phase in Building with Nature is typically longer than the construction phase
- Over-dimensioning, diversification and modularity are design strategies to manage uncertainties
- Monitoring and maintenance allows to adapt inherently dynamic Nature-based Solutions to changing circumstances

Building with Nature designs are dynamic and therefore keep developing during the project life-time both under stable and changing (climatic) conditions as a result of natural processes. Solutions can be designed in such a way that these natural dynamics are unlikely to put the overall functioning of the solution at risk and limiting maintenance efforts. In other words, a balance exists between initial efforts and investments and those needed for adaptive monitoring and maintenance. It depends on the specific situation at hand which strategy to deal with uncertainties should be applied and to which extent. Selecting the appropriate strategy (or set of strategies) for a specific project depends on aspects from the technical, natural and socio-economic system that are present.

In case no legislation and financing constructions are in place to ensure monitoring and maintenance efforts

after construction, a strategy with more emphasis on the design and the initial intervention is favoured over a strategy with more effort in adaptive monitoring and maintenance. In this light, be aware that the timeline of the implementation phase (time required to reach an objective) can differ from the timeline of the construction phase (time required for initial intervention). Typically Building with Nature is applied on a system scale and the accompanied spatial and time scales require the solution to develop in time after construction. In the next sections design strategies and guidance on monitoring and maintenance frameworks for Building with Nature are presented.

3.3.1 Design tools: over-dimensioning, diversification, modularity

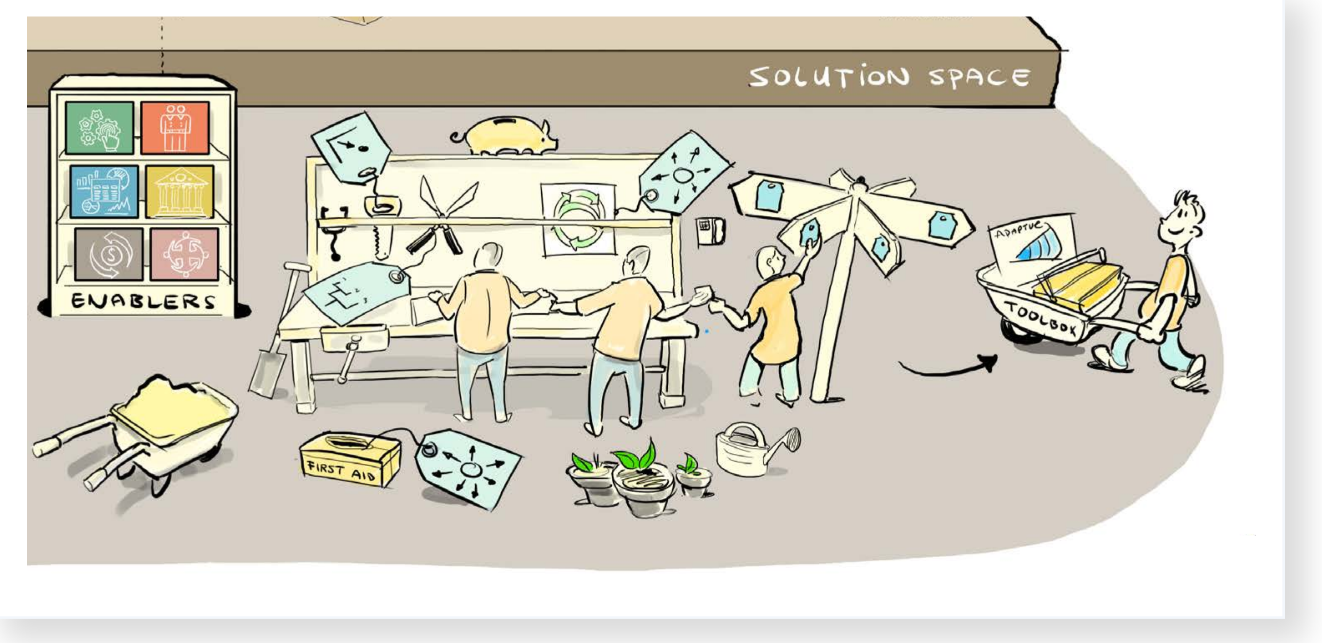
It is important to consider uncertainties when detailing the design. There are different planning and design principles that can be employed to ensure a solution is able to cope with change or adapt to changing circumstances (Albers and Deppisch, 2013). Some of these principles are inherent to Building with Nature, namely their flexible and adaptive nature (i.e. their modifiable nature and ability to change over time), and their stabilizing and buffering capacity (i.e. their ability to resist and absorb disturbances). Other principles can be used to further detail a Building with Nature design:

Over-dimensioning

This strategy implies a redundancy with respect to the units of measurement of the design. For example, as the magnitude of sea level rise is not known as yet, we anticipate and design for the worst-case scenario. This strategy could result in measures that are very costly and not cost-effective. Over-dimensioning can be selected for different reasons, including:

- If the design quantities to meet functional system requirements are uncertain, but not so much so that over-dimensioning involves many additional costs;
- If the ecosystem is as such that it cannot be disturbed by subsequent interventions during the life cycle of the solution;
- If a (larger) budget is only available at the start of a project and little budget is available for monitoring or maintenance.

Figure 3.2
Building with Nature is applied on system scale and therefore associated with relatively large spatial and time scales. This implies that the solution develops in time and monitoring and maintenance is needed after construction to assure successful implementation. Building on the experience from over 12 years of implementing Building with Nature at landscape scales for water management challenges, the EcoShape partners have a great toolset (workbench) to design and steer development after construction. From this toolset a fit-for-purpose selection can be chosen to set out to the desired direction.



Working with uncertainties by over-dimensioning – Example of Hondsbossche Dunes.

An example case in which over-dimensioning was one of the selected approaches is the Hondsbossche Dunes (Leenders et al 2018). The Hondsbossche and Pettemer sea dike no longer met the required safety standards and thus required reinforcement. The original dike was reinforced with a natural barrier of about 35 million cubic meters of sand supplied on the seaside of the dike. The reinforcement design consisted of a soft shallow foreshore and beach, and a varied dune landscape that has the potential to develop valuable ecological habitats, such as dune valleys.

The technical uncertainties in the project comprised mainly the function of the Hondsbossche Dunes as a coastal defence system up to 25 years after construction. A robust design of the Hondsbossche Dunes was made to ensure that safety levels would still be met with expected future rises in sea level. Robustness was realized by over-dimensioning: applying an additional volume of sand at construction that resulted in initially higher flood safety levels than mandated.

Monitoring of the morphological development of the Hondsbossche Dunes in the first three years after construction showed that the natural dune growth rate is now expected to keep pace with the rising sea level and subsidence up to 2050 (assuming the foreshore, intertidal area and beach are maintained according to current standards). This example illustrates that lessons are learned through monitoring, which can be used in optimization of future Building with Nature projects.

Diversification

This strategy assumes that incorporating many different assets and types of assets as part of the design carries lower risk than a strategy with only a few, similar types of assets. This line of thinking is originating from the financial sector, where diversification is a risk management strategy. For Building with Nature this strategy can applied by putting in place multiple assets that perform the same function (e.g. wave attenuation), but have a different response to changing conditions. For instance, combine seagrass habitat and mangrove restoration where possible in combination with hybrid solutions including levees in the hinterland and early warning systems to reduce the overall risk. Also, stimulating species diversity and diversified management helps diversify the status of the BwN solution.

Working with uncertainties by diversification – Example Noordwaard wave attenuating willows

Within the Dutch Room for the River program, the polder Noordwaard functions as an extra river branch of the Nieuwe Merwede river at times of high discharge. Plans to heighten the levee were poorly viewed by the local population. Therefore, the aim shifted from a traditional design towards a Building with Nature design that omitted the otherwise required levee heightening. Alternatives were explored for a design that utilized the wave-reducing effect of willows, as wave reduction would lead to a significant reduction of required total dike height. The final design consists of a willow tree forest in front of the dike, which has a 0.7m lower crest than a traditional design with a similar flood protection level. A diversification approach was applied in the choice of willow species. The willow forest consists of a mix of species (i.e. Salix alba and Salix viminalis). This diversification results in a decrease of the risk of a disease or pest affecting the entire forest thereby decreasing forest health and putting the communities behind the levees at risk (Venema et al., 2013). Also, the maintenance of the forest is carried out by trimming alternate patches of trees at different years to provide a mixture of developmental stage of the trees.

Modularity

This principle implies that a solution consists of individual, modular components. This configuration is at odds with a solution that is build-up of components that are fully integrated. Modularity gives flexibility as it allows to adapt the solution to changing circumstances. A levee is a solution consisting of fully integrated components where the components (inner layer, outer layer and grass cover) are designed such that they together provide the water retaining function. On the other hand, dunes consist of individual sand particles. This makes it easy to adapt the size of dunes with additional nourishments.

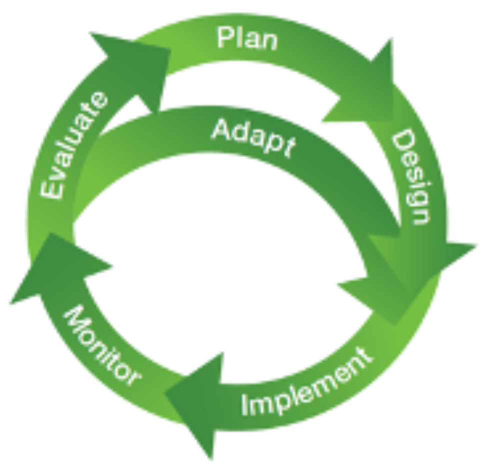
Working with uncertainties by modularity – Example mangrove restoration

The mangrove restoration pilot in the Province of Central Java is an example where modularity can be applied in relation to the required width of the mangrove belt to be an effective coastal protection barrier. Although the pilot itself was geared to optimizing the strategy to restore the mangrove forest as such, theoretically it is possible to optimize the settings of the permeable walls by adding more modules of them to be in line with the required width for a mangrove belt to provide protection during extreme conditions.

3.3.2 Monitoring and maintenance

The adaptive character of Building with Nature comes with a need for continuous monitoring and maintenance to ensure their effectiveness. The process of adaptive management and maintenance is an iterative systematic approach that facilitates flexible decision making (CEDA, 2015). Targeted monitoring, evaluation and adaptation are part of the project's adaptive management cycle (Figure 3.3). In this way, refinement of the cycle is possible. In addition, collecting data helps to grow an evidence base and record lessons-learned. Guidebooks with a specific focus on Building with Nature projects fitted this cycle into a Building with Nature context (e.g. PIANC, 2018; Van Wesenbeeck et al, 2017). A monitoring and maintenance framework should be created in an early stage of the project (before choosing between alternatives, as maintenance costs can play a role in the selection process). Upfront there should be agreement on the content (indicators, trigger levels, actions), processes (roles and responsibilities of involved parties, communication of results) and financing.

Figure 3.3
Adaptive monitoring and maintenance cycle (CEDA, 2015) based on (Fischenich and Vogt, 2012).



1. **Plan**: Defining the desired goals and objectives, evaluating alternative actions and selecting a preferred strategy with recognition of sources of uncertainty;
2. **Design**: Identifying or designing a flexible management action to address the challenge;
3. **Implement**: Implementing the selected action according to its design;
4. **Monitor**: Monitoring the results or outcomes of the management action;
5. **Evaluate**: Evaluating the system response in relation to specified goals and objectives; and
6. **Adapt**: Adapting (adjusting upward or downward) the action if necessary to achieve the stated goals and objectives.

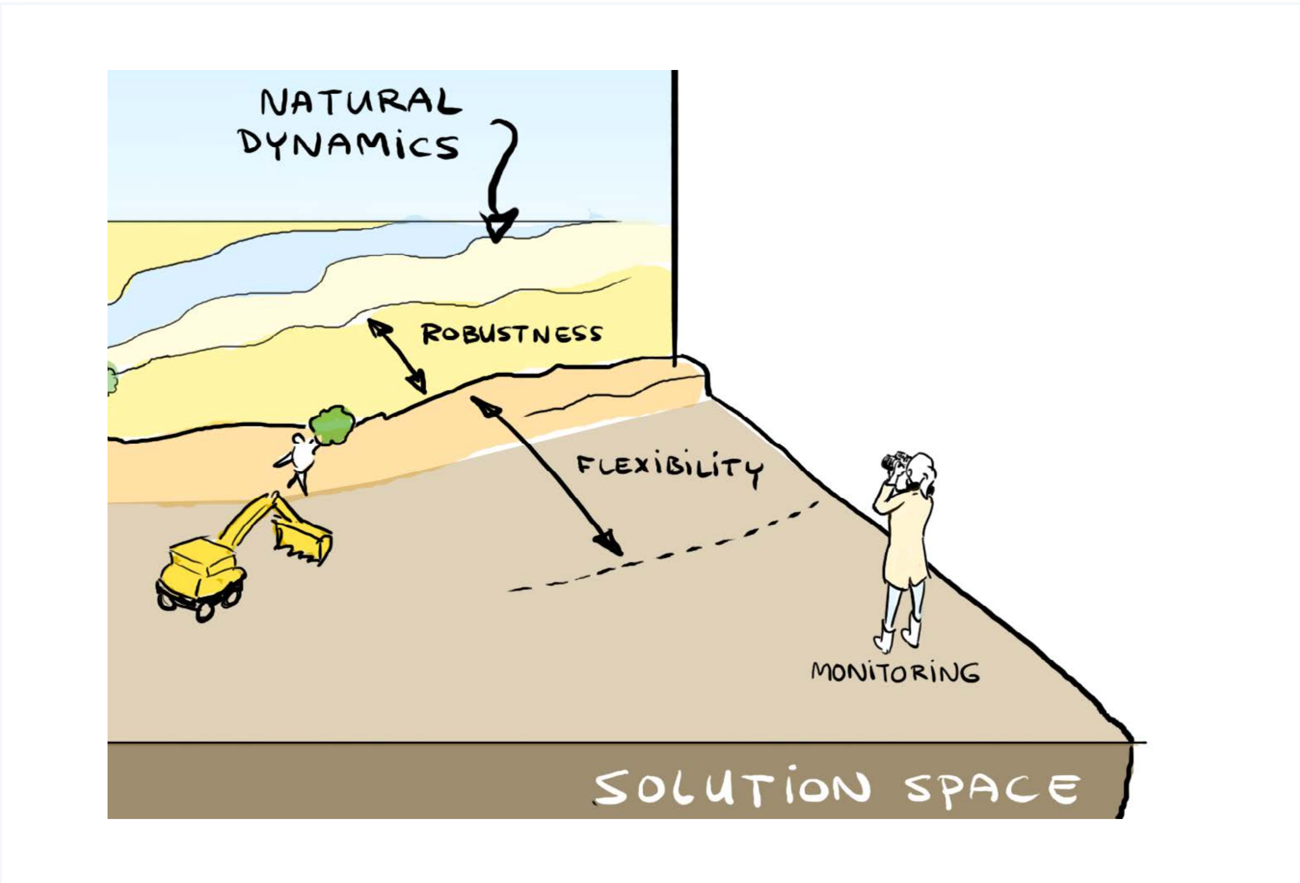
An adaptive monitoring and maintenance set-up includes:
- the baseline (eco)system functioning and monitoring;
- the objectives of the Building with Nature solution;
- short-term (during implementation) and long-term monitoring plan to assess functioning of the solution;
- the key indicators and signal values at which adaptation is required;
- description of possible adaptations.

1. Baseline system function
Prior to intervention, data should be gathered to set a baseline. The monitoring efforts (intensity and duration) that are required to establish a reliable baseline depend on the level of dynamics in the system. Target groups with multi-year trends (e.g. sediment dynamics) require a long monitoring campaign to establish such a baseline.

2. Solution's objective
The framework should contain a description of the objective of the solution. This objective is often the main target of the design cycle. For Building with Nature projects that have the purpose to reach an effect at shift system scale, mile stones can be set for the solution's functioning. For example, the objective to reduce turbidity on a system scale is not achieved overnight. In contrast to traditional infrastructure, the objective directly after construction might differ from the longer-term objective, because the solutions develop in time. A monitoring and maintenance plan should be set in place upfront and not once things are about to move in the wrong direction.

3. Short-term and long-term monitoring
For traditional infrastructure monitoring is mainly limited to during and around the construction phase to satisfy regulations. Building with Nature comes also with long-term monitoring to keep an eye on development of the solution and the environment. Adaptive monitoring and maintenance should be based on the entire system (physical, natural, social) and not solely the solution itself. Thorough understanding of the ecosystem and its dynamics is required. Monitoring of the social system is sometimes forgotten, but is important to get insight in public perception and the multiple benefits Building with Nature projects often bring. For example, community benefits, employment and economic opportunities.

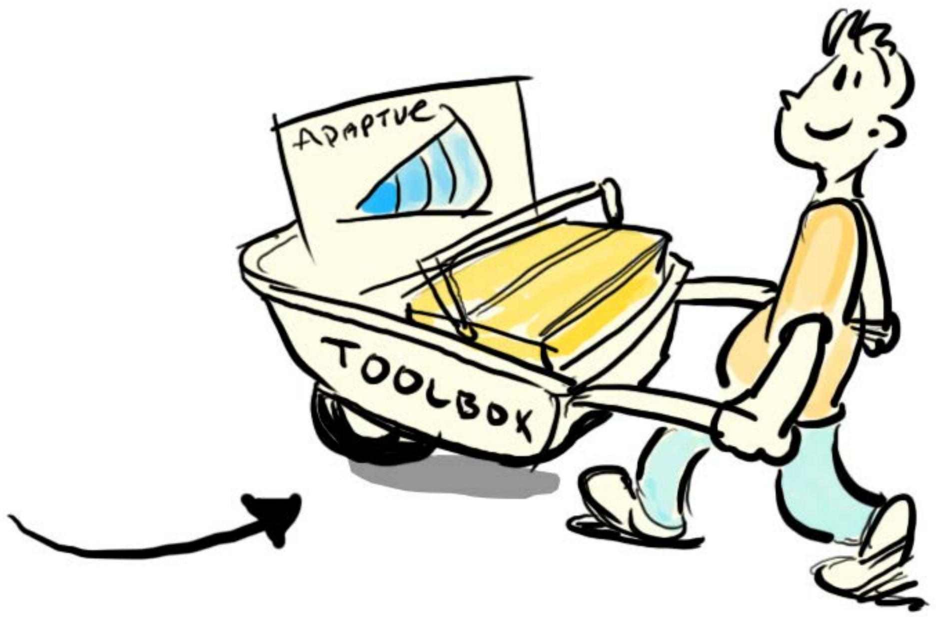
Figure 3.4
Adaptive monitoring is needed to help in the adaptive management of the solution.



4. Key indicators and corresponding signal values
The monitoring scope (what to measure/where/frequency) should be focused on the intended objective of the solution, but also on a set of plausible scenarios that might negatively influence the solution. The first, focusses on monitoring of the development of the solution to ensure it meets/develops towards the design requirements. The latter addresses potential tipping points. Tipping points can lead to collapse/transition towards a different system state and demand a change in strategy, due to the high impact of tipping points these should receive special attention.

Monitoring of performance objectives focusses on the development of the solution after construction and implementation. Determining the appropriate variables to monitor for tipping points can be challenging, but the aim is to find signals that provide an early, yet reliable indicator of the direction and magnitude of future changes. Note that these variables may not necessarily be the same metrics used to determine performance objectives but could describe completely different phenomena. For example, a stronger signal regarding the emergence of extreme peak river discharges may be found by monitoring low discharges rather than annual peaks (Haasnoot et al, 2015). This exemplifies that monitoring variables should be chosen carefully, keeping in mind that the monitored variables should provide advanced signals of the direction and the magnitude of future changes. Next, corresponding values of these variables that act as 'triggers' should be chosen. These signal values should trigger maintenance of implementation of new interventions or even a change in strategy.

5. Possible adaptations
Ideally the adaptions following exceedance of a signal values are agreed and documented upfront. In case of deep uncertainty this might not always be possible, however organizational actions can be set in place upfront (e.g. gathering of an expert group). For (extreme) events that take place on a rather short timescale (e.g. a high intensity storm, fire) a back-up action plan should be set in place upfront, as direct action will required. This allows for adequate decision-making in case of emerging events that endanger the solution's effectiveness.



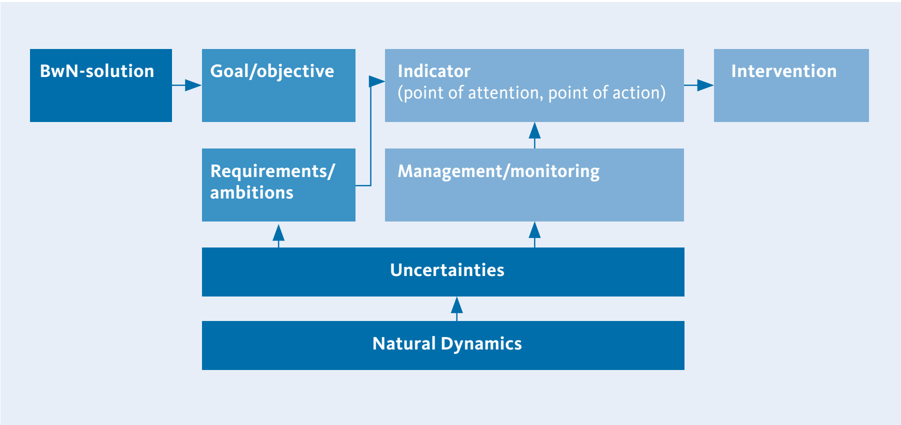
Box 2

Working with uncertainties through adaptive management – Example of mangrove restoration in Indonesia

The pilot case in Indonesia offers an example of successful adaptive management. “The design in this pilot used permeable structures from local natural materials to attenuate incoming waves and trap sediment. Thus, the structures create abiotic conditions that are favourable for mangrove seedling settlement.

Since the start of the project early 2015 every autumn permeable structures are constructed by the local community and a lot is learned by doing that and monitoring the construction and the effects afterwards. As natural materials are used, they degrade due to the presence of particular species of worms living off the material and general decomposition. Frequent inspection and maintenance are required and are carried out by the local communities. The natural dynamics and related uncertainties are thereby reduced to a level that is manageable through timely intervention in repair of the structures and that ensures the functioning of the structures as a wave attenuating barrier and trap sediments.

Figure 3.5
Building with Nature uncertainty model related to monitoring, maintenance and adaptation.



To enable adaptive management, funding to cover the adaptive management cycle should be allocated upfront and become available over time. This necessity can add uncertainties in procurement and contracting. In regular flood risk infrastructure, it is common practice that construction is contracted separately from operation & maintenance, often also funded from different budgets. Construction/ initial investment often comes from more centralized budgets, whereas operational expenditures usually come at the cost of local asset management budgets. As Building with Nature typically has lower capital expenditures and possibly more uncertain operational expenditures (due to natural dynamics), more long-term contracts combining the building and maintenance phase and transferring risk to the project developer may be attractive.

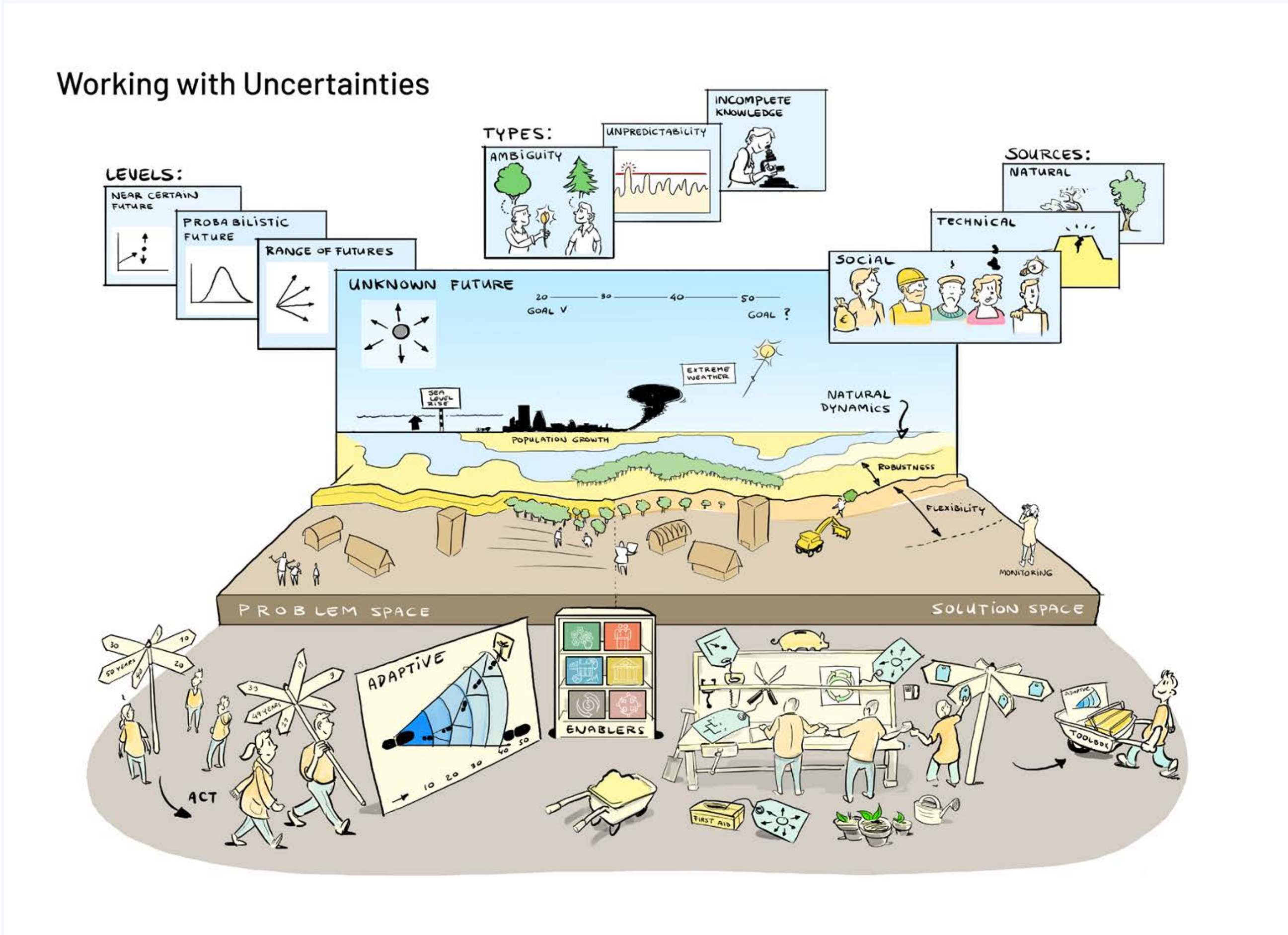
4. Epilogue

Responding to questioning the effectiveness of Building with Nature.

In this white-paper we have introduced the various types, sources and levels of uncertainty that prevail in both the problem and solutions space of water management challenges around the world. We show how a Building with Nature approach is a suitable method to deal with these uncertainties and what types of tools can be used to better frame and handle these uncertainties. An often-posed question with regards to the choice for a Building with Nature or a more traditional solution is the following: 'What do I tell an engineer when they say they are confident about calculating the safety of a levee, but that a Building with Nature solution is too uncertain to be quantified?'.

With the help of the explained principles it is possible to give a well-founded answer, and unravel this important question that lumps a whole lot of different uncertainties into a single 'bad feeling…': there's the ambiguity that levees are better than a Building with Nature solution, the lack of knowledge on the tools available for the quantification of Building with Nature functioning (while many exist, they may not be known to all), the incomplete knowledge that we might not yet have all the proof in the world on how a solution withstands an extreme event (which is valid both for the functioning of levees and Building with Nature), the deep uncertain future and risk of lock-in if you design your dikes for only 20 years instead of taking into account a larger time horizon, while a Building with Nature solution can adapt better to such deeply uncertain changes.

So, a good answer to this frequently asked question is to open the dialogue to unravel all the different types, sources and levels of uncertainty and to assess together what aspects can be solved by further research, monitoring, adaptive management and where this dialogue shapes the overall decision, what benefits different solutions bring and how these can best be financed. Only with open minds, a willingness to learn and attention to this dialogue we can sincerely evaluate and assess the best options to deal with the great global challenges that lie in our near yet uncertain future.



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