FRAMEWORK FOR ADAPTIVE MANAGEMENT AND ITS RELATION TO THE DUTY OF CARE

A CASE STUDY TO THE PRIMARY FLOOD DEFENCES BETWEEN DEN OEVER AND DEN HELDER

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ABSTRACT

With increased dynamic processes as global warming and subsidence, future scenarios become very difficult to predict and account for. Managers and decision-makers of complex coupled systems face deep uncertainty in future scenarios and require flexible, adaptive management policies. Due to these future uncertainties, their demand for such adaptive policies increased significantly in the past decades, resulting in many available concepts and frameworks.

In the Netherlands, regional water authorities bear the responsibility to ensure national flood protection. This responsibility has been coined as the duty of care and is legally documented in the Water Act (2009). The regional water authority that is responsible for flood protection in North Holland is Hoogheemraadschap Hollands Noorderkwartier (HHNK).

In 2017, several test tracks of the flood defence trajectories 12-1 and 13-5, localized between Den Oever and Den Helder, have been assessed insufficient. Although the HHNK has been started to prepare reinforcement procedures, traditional policies would prescribe immediate reinforcement of insufficient tracks. To account for future uncertainty, the HHNK is willing to increase its resilience by implemented more flexible, adaptive policies. However, it was yet obscure what framework will most optimally fit the context of Flood Risk Management and how this adaptive framework is compatible with the duty of care. Therefore, this research aimed to determine a promising framework of Adaptive Management for the context of Flood Risk Management, while providing advice concerning the relation and compatibility between the adaptive framework and the safeguarding of the duty of care.

To realize this, three multidisciplinary literature studies have been conducted. First, the duty of care as referred to in the Water Act was examined. Four out of twelve relevant activities that are covered by the duty of care were distinguished. Moreover, legal processes and guidelines to assess primary flood defences; to determine hydraulic loads and to determine the safety have been investigated.

Next, promising frameworks of Adaptive Management were found that met the requirements set by both literature and the demands of the commissioner. The combination of two strong concepts, Dynamic Adaptive Policy Pathways (DAPP) (Haasnoot et al, 2013) and Passive Adaptive Management (PAM) (Prato T., 2016) eventually formed the preferred management policy. The roadmap element from DAPP and the TOPSIS decision-rule from PAM both contribute significantly to the demands for an adaptive flexible policy. The preferred policy has been evaluated using a method invented by (Dewulf & Termeer, 2015) that assesses the governance capacity using five fundamental variables. The third literature study provided both current and expected future technical specifications of the trajectories 12-1 and 13-5, and potential management actions. The preferred policy has been applied in a case study together with the information from the third literature study. The purpose of the case study was to expose and exhibit the frameworks' advantages, capacities and vulnerabilities.

Concluding, formally there is no formal space to deviate from the safety levels or other fundamental requirements stated by the duty of care, which might be just as well. However, this does not have to obstruct the implementation of an adaptive policy at all. Since the preferred management policy anticipates the safety levels by implemented them as ATP, legal standards are always guaranteed. Moreover, by adjusting the monitoring and assessment processes, for which there is formal room for, to more shelf-life oriented approaches, the manager's governance capacity of uncertain future scenarios will substantially increase.

PREFACE

Conducting this research has turned out quite different than previously expected. Honestly, it was hard not being able to be physically present at the organization I was commissioned working for, as within the aspects of communication and concentration I encountered several problems. Although my contingency planning as well as my planning was quite detailed, all contingencies came true and my planning lacked from day one. After all, I forced myself to concentrate and continue working since I experienced the moral plight to deliver quality research. Nonetheless, it was a very interesting period as I feel I've grown in several aspects. Besides all this drama, I have been helped by many and therefore I explicitly want to show my gratitude for the assistance I obtained.

At first, I would like to express my appreciation to Ruud Joosten, counsellor technical management (HHNK), for his help in searching and provisioning the stack of documents and information I required. He attended almost all meetings and provided me with general as well as specific advice, contextual as methodological.

Next, I want to thank both my external supervisors Jaap Kottier and Peter van den Horn, respectively project manager and department head (HHNK), for their guidance and assistance. Peter helped me connect with the organization, find the research subject, and connect with the concerned employees. Jaap, the project manager of the project I was interested in, helped me through the months of researching by staying in contact with me. He attended all meetings, helped me choose directions and come in contact as well.

I especially want to thank my internal supervisor, ir. Daan Poppema, Ph.D. candidate University of Twente. Daan has sincerely been a very polite and kind supervisor who provided me contextual as well as methodological advice. He has given me constructional feedback on my ideas and concepts and came with helpful insights.

Also, I want to thank Floor van der Heijden for her conversation as she attended me at several insights that I later on included and treated in my research.

TABLE OF CONTENTS

DEFINITIONS

The following technical terms and definitions will regularly emerge in the report:

EN	Definition/Explanation	NL
Primary Flood Defence (PFD)	A levee (system) that protects against flooding. *For instance the Amsteldiepdijk.*	Primaire Waterkering
Water Act	Fusion of several laws and regulations.	Waterwet
Trajectory	Part of a primary flood defence that is assessed separately. *For instance trajectory 12-1 (WZW).*	Dijktraject
Failure Probability	Probability of exceeding the ultimate threshold of the primary flood defence. *Expressed in once every X years.*	Faalkans
Section	Part of a trajectory with uniform characteristics. *Trajectory 12-1 is divided into twelve sections.*	Dijkvak
Ultimate Threshold	Flooding probability that represents the minimal level of security that the PFD is obligated to provide. *Expressed in once every X years.*	Ondergrens
Signaling Threshold	Flooding probability that represents the level of security provided by the PFD that is ment to initiate maintenance or reinforcement activities. *Expressed in once every X years.*	Signaleringswaarde
Test Track	The mechanism of a PFD that is subjected to an assessment. *For instance macroinstability.*	Toetsspoor (c.q. faalmechanisme)
(Legal) Standard	Acceptable probability of flooding, expressed in signaling- or ultimate thresholds. *Expressed in once every X years.*	Norm
Safety Assessment	Assessment concerning the safety a PFD provides. *Expressed in categories (I-VI).*	Veiligheidsoordeel
HWPP	High Water Protection Program.	HWBP
RSL Analysis	Remaining Shelf Life Analysis.	Restlevensduur Analyse
ATP	Adaptation Tipping Points.	-
APW	Adaptation Pathways.	-
APM	Adaptive Policymaking.	-
DAPP	Dynamic Adaptive Policy Pathways.	-
AM	Adaptive Management	-
CHANS	Coupled Human and Natural Systems	Gekoppeld mens-omgeving systeem
PAM	Passive Adaptive Management	-
SRPFD	Safety Regulation Primary Flood Defences	
FPB	Failure Probability Balance	Faalkansbegroting
FRM	Flood Risk Management	Beheer van overstromingsrisico's

Table A – Technical terms and definitions (EN, NL)

1 INTRODUCTION

1.1 CONTEXT

As approximately between one to two-quarters of the Netherlands lies below sea level, the entire landscape is often considered as one large delta. We thank our current existence to our advanced flood defence infrastructure. Due to the dynamic processes of primarily global climate change and subsidence, the probability of flood hazards occurring is continually increasing (Klijn, Asselman, Kruif, Bloemen, & Haasnoot, 2016). With thermal expansion as a result of climate change, global and local sea levels rose exponentially between 1901 and 2010, estimated as the fastest rise in 2800 years (United Nations, 2017). Glacier loss and thermal expansion account for at least three-quarters of the sea level rise, giving for example Antarctica alone the potential to raise global sea levels with approximately one meter by 2100 (Church, et al., 2013).

As a justification for flood protection, it appears that urban areas are relatively densely populated and show rapid economical growth due to their access to important seaports and other economical opportunities (Klijn, Kreibich, Moel, & Penning-Rowsell, 2015). These major developments urge governments; policymakers and water authorities to act adequately and develop policies that prevent large scale economic losses.

While national safety is depending on flood protection, a flood defence system has various owners and managers who might initially have different standards concerning the duty of care. In The Netherlands this historically led to the Water Act (2009), which is a fusion of multiple previous regulations and laws; prescribed guidelines for inspection and maintenance of freshwater and flood management to guarantee safety (Ministerie IL&T, 2017) (Ministerie IL&T, 2016). The first legal implementation of legal safety levels and the obligation to assess flood protection dates from 15 January 1996. The implementation was probably caused by two extreme high water situations in 1993 and 1995 with the evacuation of 200.000 residents.

The Water Act dictates that each flood defence system must be assessed by its manager every twelve years, to ensure it still meets the up-to-date legal safety standards, currently set by the WBI 2017 (Dutch: Wettelijk Beoordelings Instrumentarium 2017) (Rijksoverheid, 2017). As this applies to the defence system between Den Oever and Den Helder as well, the previous patrol conducted in 2017 assessed a large part of the trajectory to be insufficient on several test tracks. Therefore, the responsible manager, Hoogheemraadschap Hollands Noorderkwartier (HHNK), is obligated to initiate a large scale reinforcement project. (HHNK, 2018).

Due to future uncertainty, the need for governance arises. Flexibility for plans and management is desired by managers of all complex coupled systems in general. With many plausible future scenarios, likely, that one static policy will not fit all of them. For very complex systems whose development we cannot predict, policies based on estimation models could prove to be very fragile, especially for decades of extrapolation (Walker, Rahman, & Cave, 2001). With differences in the allocation of public responsibilities, even though the state is formally responsible for flood safety in the Netherlands, the decision-making process and thus Adaptive Management has been a rather open process where the responsibility is carried by the regional water authorities (Art Dewulf, 2015). With water authorities preliminary relying on guiding principles provided by the national government, in 2012, as a result, the Delta Programme launched an additive guidance for the development of adaptive strategies (Rhee, 2012). In general, these strategies are refferred to as Adaptive Management.

The flood defence trajectory between Den Oever and Den Helder will be the first reinforcement project for HHNK that operationalizes the concept of Adaptive Management. The area enriches additional natural, social and cultural values and is suitable for a pilot project with internal educational purposes. Moreover, the project will be the precursor for the HHNK that follows and handles the policies and regulations included in the Omgevingswet, which will operationalize in 2022. The Omgevingswet is a national displacement and simplification of many current institutions and laws. Both Adaptive Management and the Omgevingswet make this project very innovative in its kind.

1.2 PROBLEM DESCRIPTION

With Den Oever – Den Helder being the precursor for HHNK that operationalizes the concept of Adaptive Management, it is yet unclear how this new methodology will be shaped and applied. In the past few decades several frameworks and guidelines have been provided for an adaptive policy, most of them principally equal with solely different details. Because of the many available frameworks, it is obscure what framework will most optimally fit the given context in which the manager of a coupled system operates. For the context of this report, the manager HHNK operates in the ambiance of Flood Risk Management. Flood Risk Management analyzes the relationship between physical processes (sea level rise), institutional frameworks (flood control) and socio-economic (environmental) developments such as economic or damage and social or environmental disturbance.

Whenever the most optimal concept of Adaptive Management is determined and operationalized by the HHNK, the implementation of flood protection and flood management changes which might affect the duty of care. However, it is yet unknown how this policy transition relates to the duty of care. Ambiguities arise such as what is prescribed by government institutes concerning adaptive reinforcement and the duty of care; what are ultimate legal conditions that implicitly have to be met, and what opportunities are possible for adjusted assessments or monitoring.

1.3 RESEARCH AIM

Since it is uncertain what framework will most optimally fit the given context in which the manager operates, a promising concept for Adaptive Management has to be found for Dutch water authorities that operate in Flood Risk Management. In order to identify the most optimal concept, several available concepts will be analyzed, whereafter the most ideal solutions will be elaborated and exhibited. For each concept the strong and weak elements have to be highlighted, vulnerabilities and difficulties have to be explained and compared with alternative methods, and the different steps should be clarified.

A new flexible methodology to reinforce flood protection and execute maintenance activities raises the need for advice in safeguarding the duty of care. Comprehensive advice is required concerning what activities are currently covered by the duty of care, what legal and formal space is available and thus how the duty of care could still be guaranteed when adaptive policies are operationalized.

Obviously, each flood defence trajectory has different spatial and technical characteristics. As Adaptive Management will be applied to the flood defence systems between Den Oever and Den Helder, consisting of the trajectories 12-1 and 13-5, the specifications that grounded the assessment of the insufficiency of these trajectories are crucial. Therefore, the third aim of this report is to provide practical advice on how to operationalize an Adaptive Management policy between Den Oever and Den Helder, while safeguarding the duty of care. This advice is supported by a case study that combines the most optimal framework with the technical specifications of trajectories 12-1 and 13-5.

1.3.1 RESEARCH QUESTIONS

Besides the purpose and directive of scientific research, an advisory report will be established in which the commissioner of this research, HHNK, will be provided with several promising concepts of Adaptive

Management, a case study and insight in how the duty of care could still be ensured with the operationalization of this novel methodology. Following, the research questions that ought to be answered have been formulated in such a way that they serve both scientific and advisory purposes.

Clear main questions have been arranged that define the core of the research, whereafter several subquestions have been established that together support the answering of the main questions.

Main question	**How could the duty of care for managers of primary flood defences be guaranteed given Adaptive Management?**
Subquestion	What activities or responsibilities currently include the duty of care according to the Water Act?
Subquestion	What are the current legal standards and regulations for flood protection?
Subquestion	How and by who is the duty of care currently assessed and what space is available for own interpretation or adjustment?

Table 1.3.1.1 – Research Questions Water Act

The Water Act is a very comprehensive body of literature that covers many aspects, as the duty of care is just one of them. First, insight in what exactly is the duty of care and how it is prescribed in the Water Act is fundamental. Next, information concerning the legal standards and regulations will provide boundary conditions, whereafter information concerning the current methods for assessment and monitoring may yield space for an adjustment that might be filled by Adaptive Management.

Main question	**What is the most promising framework of Adaptive Management in the context of Flood Risk Management?**
Subquestion	What frameworks of Adaptive Management are currently available and how do they differ?
Subquestion	Which of those frameworks would best fit the context of Flood Risk Management?

Table 1.3.1.2 – Research Questions Adaptive Management

Adaptive policies have been studied for several decades in all different fields and disciplines. While one concept might be optimal for one field, this optimality does not necessarily apply to all fields.

At third, the information concerned the current and future technical state of the Den Oever – Den Helder (DODH) flood defence trajectory has to be obtained. The research focusses on this project area and therefore the advice on both the duty of care as Adaptive Management will be applied to DODH whenever possible.

Main question	**What is the current and expected state of the primary flood defences between Den Oever and Den Helder?**
Subquestion	What is the current and expected state of trajectory 12-1?
Subquestion	What is the current and expected state of trajectory 13-5?
Subquestion	What are the planned or expected reinforcement and maintenance activities in the short- and long term?

Table 1.3.1.3 – Research Questions Technical State

With in general the trajectory being assessed as insufficient in 2017, reinforcement procedures are initiated by HHNK. With the purpose to implement a new policy, insight is desirable in what activities and procedures are currently planned and expected by the manager.

2 METHODOLOGY

This research included a wide multidisciplinary literature study in three main subjects: The duty of care as documented in the Water Act, Adaptive Management and the technical reports for flood defence trajectories 12-1 and 13-5.

2.1 WATER ACT

To determine how water authorities could implement Adaptive Management under the restriction of ensuring their duty of care, the fundamental requirements and regulations have been examined in the Water Act. The Water Act includes many regulations and guidelines that account for several interests in the water ambiance, such as the duty of care, purified drinking water or the provisioning of water for agricultural purposes. With respect to the duty of care, the following has been examined:

At first, it is investigated what responsibilities and activities are covered by the duty of care as referred to in the Water Act and how these responsibilities are beared. Besides, it is investigated what ministry or organization supervises the compliance of these responsiblities and how this supervision is performed.

Next, to determine boundary conditions for the case study and to obtain perspective in the current and expected technical specifications, the legal safety levels for the primary flood trajectories 12-1 and 13-5 have been examined.

Last, to determine whether a flexible reinforcement policy would influence safety levels or formal responsibilities, and to determine what space is available for own interpretation or adjustment, the following three core subjects have been examined:

- The procedures that legally dictate the methods to assess primary flood defences.
- The determination of the hydraulic loads that primary flood defences are subjected to.
- The establishment of the safety assessment.

2.2 ADAPTIVE MANAGEMENT

To find a framework that optimally fits the context of Flood Risk Management, many frameworks have been investigated. To (dis-)approve them for having potential, first, information was provided on how and why managers and decision-makers could benefit from flexible policies and what elements could be advantageous in comparison with traditional policies. This has been provided in general context as well as in the ambiance of Flood Risk Management. Besides the general and more specific information concerning what elements and aspects of Adaptive Management could be advantageous for water authorities, the management of HHNK had established several preconditional variables that they desired to implement in an adaptive policy. These variables were documented in internal reports and have been accounted for in selecting frameworks.

Following, a large literature study was conducted that identified multiple available frameworks. All interesting frameworks have been exhibited in the report.

The available frameworks have been compared and analysed. Several studies were presented that conducted case studies with the available frameworks, to expose their strong elements, vulnerabilities and application. Also, a study has been presented that compared the operationalization of adaptive policies by water authorities and national governments in equal contexts to Flood Risk Management.

Next, the preferred management policy was determined, it included a combination of strong elements from two frameworks with one minor adjustment.

To assess the governance capability of the preferred management policy, an evaluation method was provided. The method is designed by two highly regarded dutch scientists that have decades of experience in the field of innovative governance frameworks in the fields of climate change and sustainability.

After the preferred management policy was established and evaluated, a case study was conducted that put the theory into practice. The case study went thoroughly through every step of the preferred policy to expose advantages, vulnerabilities, and capacities. The case study provided insight in the application of the policy in the context of the Den Oever – Den Helder project.

2.3 CURRENT AND EXPECTED STATE

To conduct the case study that applies the preferred management policy, technical information of the trajectories 12-1 and 13-5 between Den Oever and Den Helder was examined. The information was derived from several technical reports by HHNK and external organizations, dating from 2016 to 2020. Most of reports were underlying the assessment round in 2017 that eventually determined the insufficiency of the trajectories. These reports mainly described the current state of the flood defences. To determine the expected state and of the trajectories, two shelf life investigations were examined. For every test track that was determined to be currently or before 2100 insufficient, insight was provided in three different time perspectives: 2023; 2070 and 2100.

In the case study, potential management actions had to be established. These actions were a logical result of the current and expected state of the primary flood defences. To derive management actions, multiple internal conceptual reports of the HHNK provided information in addition to the current and expected state, as they proposed potential reinforcement and maintenance activities. To make the set of actions comprehensive, the project leader of the Den Oever – Den Helder project and a counselour of the technical department have been asked to provide additional management actions that were left out or haven't been documented. All potential management actions gathered provided a comprehensive set of actions for the case study.

3 RESULTS

3.1 WATER ACT

3.1.1 DUTY OF CARE

In the Netherlands primary flood defences have various managers, in most cases water authorities. Their responsibility towards the Dutch residents to preserve and ensure the functionality of flood defence systems, e.g. by the execution of periodic maintenance, is legally covered in the Water Act (2009). Since 2014 the supervision of the assessments of flood defence systems has been transferred from provincial authorities to the national Ministery of Infrastructure and Environment. As a result, the Inspectie Leefomgeving en Transport (Now: ILT) has been charged with the responsibility to examine and supervise this process. (Rijksoverheid, 2009)

In the Water Act the water managers are obligated by law to take responsibility and adequate measures in order to ensure safety and execute preventive management. At least every twelve years the primary flood defences are thoroughly assessed on whether their current shape meets the design requirements. (Inspectie Leefomgeving en Transport, 2016)

In 2015 the Ministery of Infrastructure and Environment constructed a framework for the duty of care (Ministerie I&M, 2015) consisting of twelve fundamental requirements that cover the duty of care. For certain activities several manuals and guides are provided that prescribe methods and processes, holding the purpose to be of advisory nature. Water authorities are initially responsible themselves to fulfill the duty of care, while the ILT supervises this with known, public requirements. Due to this opportunitity of own implementation, it is allowed to deviate from traditional methods whenever the manager has sufficient motivation to do so, under the restriction that the underlying accountability and documentation meets the requirements.

One very important note to consider is that the ILT doesn't assess or supervise the reinforcement projects included in the High Water Protection Program (Dutch: Hoog Water Beschermings Programma (HWBP)), since these activities are not legally included by the requirements from the duty of care. Reinforcement projects generally differ from managing and maintenance.

3.1.1.1 FUNDAMENTAL REQUIREMENTS

The duty of care is explicated in twelve different activities by the ILT (Inspectie Leefomgeving en Transport, 2016). For the purpose of this report not all activities are considered of equal relevance, since certain activities do not influence or are influenced by Adaptive Management in any way. These activities include: "Long term and crossing boundaries"; "Legally register primary flood defences"; "Informational management system"; "Knowledge management"; "Accountability for results"; "Licensing"; "Surveillance and enforcement" and "Operation of flood defence structures".

Activities that in turn are relevant in the application of Adaptive Management within the project DODH are scheduled and summarized in Table 3.1.1.1. Appendix X1 presents the extended table as documented in the Water Act.

Activity	Fundamental Requirements (Realisation Duty of Care)
Assessment	1. Assessment will be executed according to the corresponding schedule. 2. The obtained results of the assessment will be drocumented unambiguously.

	3. Follow-up actions will be made whenever the results of an assessment cause to do so. 4. The process of assessment will be periodically evaluated and adjusted.
Managing daily data	1. The management register contains charasteristic, physical data of the primary flood defence. 2. The data set will be validaded before it will be documented in the management register. 3. The water manager has adjusted the data set concerning the primary flood defence according to the legal standards for actuality and comprehensiveness. 4. The process of managing the daily data set will be evaluated periodically and adjusted if desirable.
Maintenance	1. The planned maintenance will be executed according to the schedule and maintenance plan. 2. For the unexpected maintenance (as a result from an assessment) the consideration for adequate (re)action is demonstrable and visible. 3. The predetermined follow-up actions for unexpected maintenance will be executed. 4. All relevant maintenance data will be actively documented in the management register or a comparable system. 5. The maintenance will be executed periodically and adjusted if desirable.
Emergency care	1. The presence and condition of emergency facilities needs to be assessed periodically. 2. Employees will practice and be trained according to an OTO-plan (Opleiden; Trainen en Oefenen). 3. Practices and/or emergencies will be evaluated in advance and will lead to active instructions.

Table 3.1.1.1 – Relevant Fundamental Requirements covered by the duty of care

3.1.2 LEGAL STANDARDS FLOODING PROBABILITY

Section 2.2 of the Water Act contains formal standards for primary flood defence systems, these standards determine the level of security the separate sections of the entire defence system have to provide. Security or safety levels represent the probability of flooding happening per year, and are distinguished in signaling thresholds and ultimate thresholds. Once the signaling threshold is reached, the water manager is supposed to start reinforcement or maintenance activities. The lowest threshold is the ultimate level of failure the flood defence may have. The standards are determinative for the scope of the duty of care the manager of the defence systems has. For the corresponding flood defence trajectories the signaling and ultimate probability levels are presented in Table 3.1.2.

Trajectory	Signaling Threshold	Ultimate Threshold
12-1, Wieringer Zeewering	1:1000	1:1000
13-5, Amsteldiepdijk & Balgzanddijk	1:3000	1:1000

Table 3.1.2 - Signaling & Ultimate values

Section 2.3 of the Water Act suggests that ministerial guidelines have been drawn for the security assessment, these guidelines assist in determining and calculating the corresponding hydraulic loads and strength of the system. In Safety Regulation Primary Flood Defences (Now: SRPFD) 2017 Appendix I, II and III (Ministry of Infrastructure & Environment, 2016a) (Ministry of Infrastructure & Environment, 2016b) (Ministry of Infrastructure & Environment, 2016c) guidelines and regulations are provided for procedures; the determination of hydraulic loads and the safety assessments of primary flood defences.

The following sections 3.1.3, 3.1.4 and 3.1.5 provide a brief overview of the most important and relevant aspects considering the application of Adaptive Management.

3.1.3 SAFETY REGULATION PRIMARY FLOOD DEFENCES – PROCEDURE SAFETY ASSESSMENT PFD

This section is based on Appendix I of Safety Regulation Primary Flood Defences (Water Act). Initially the procedure of a PFD safety assessment starts off with a general filter on both the section as the trajectory scope. The general filter isn't applicable for trajectories 12-1 and 13-5 so won't be treated in this report. (HHNK, 2020) (Tauw, 2017). Figure 3.1.3 visualizes the procedure for the assessment of primary flood defences:

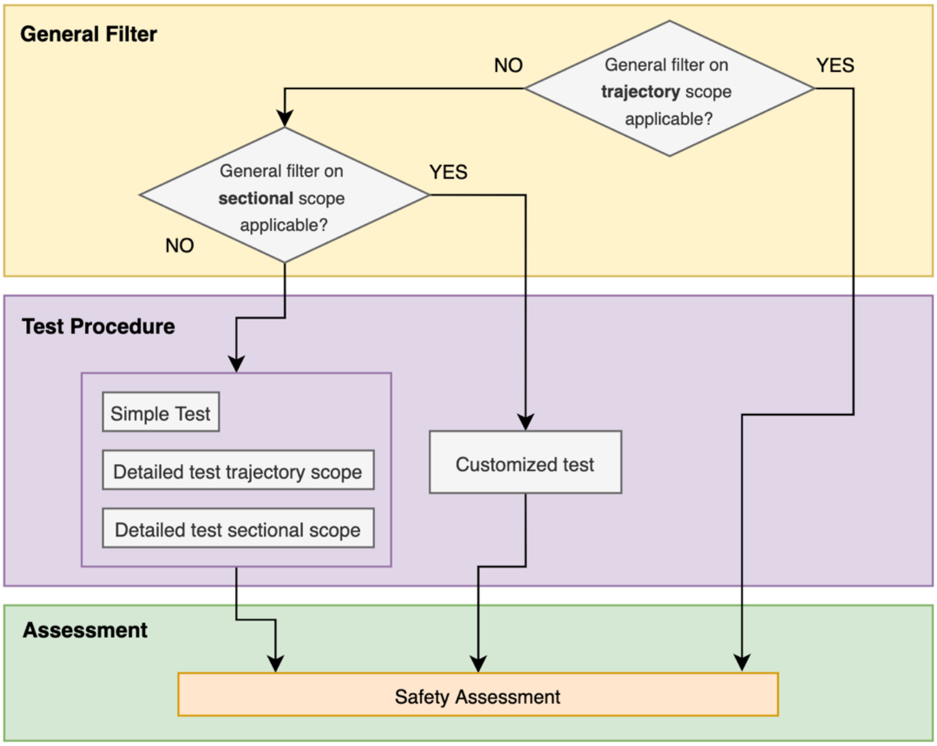

Figure 3.1.3 – Procedure Safety Assessment PFD (Ministry of Infrastructure & Environment, 2016a)

After the general filter, four different test levels are distinguished:

- Simple test > executed for each section and each track.
- Detailed section test > executed for each section and each track.
- Detailed trajectory test > executed for the entire trajectory with combined sections and tracks.
- Customized test > executed for each track, both for each section as for the trajectory.

Whenever the water manager substantiates that the simple and detailed tests don't provide valid and sufficient results, or whenver there is a general filter on the sectional scope available, the customized test may yield a more adequate assessment.

3.1.3.1 EXECUTION OF THE ASSESSMENT

Simple test

When both the general filter within trajectory and sectional scope are not applicable, the simple test procedure starts off. The simple test contains simple decision rules that determine whether the potential flooding contribution of a certain track is relevant compared to the other tracks and the legal standards. For some test tracks no simple test is available.*Detailed section test*

Within the detailed section test, the requirements for each section are deriviated from the requirements for the entire trajectory. The flooding probability will be allocated to all the different tracks. Due to this, the failure probability requirement for each test track on each section will be obtained. Grounded by this procedure, the ultimate probability that is allowed for the section can be compared with the flooding probability of each track for that section, to see whether the track is less or more likely to cause failure in comparison with the remainder tracks.

Detailed trajectory test
The detailed trajectory test represents an probabilistic approach applied to the entire traject. The assessments of each section and for each track will be combined with a failure probability balance (FPB) and a so-called length effect, which compensates for the influences of neighbouring sections on each other. The results from the detailed trajectory test provide insight into what tracks the assessed primary flood defence are most likely to contribute to or to cause flooding.

Customized test
Assessments based on the detailed tests presume generic regulations, the application is documented in Appendix III (section 3.1.5 of this report). The customized test offers further, unqiue quantifications:

- Location specific analysis.
- Advanced analysis.
- Empirical assessment based on expert knowledge.

No regulations or guidelines are available for the customized test, the manager is responsible for sufficient grounding and substantiation. This has to be reported according to chapter 4 in SRPFD Appendix I (Ministry of Infrastructure & Environment, 2016a). The ILT, a special department of the Ministry of Infrastructure and Enviroment, is responsible for supervision. At least the following elements, presented in Table 3.1.3.1, have to be included when the customized test is executed:

Analysis	Information
Location specific test	The executed analysis and the principles that have been used both have to be reported in the log.
Advanced analysis	Whenever the advanced analysis is executed according to WBI 2017, the anaylsis and the principles that have been used both have to be reported in the log. As a part of the substantiation existing technical guidelines and reports could be used for the execution. In these reports handles for the application of advanced analysis or models are available.
Application novel knowledge	Whenever fundamental novel knowledge is being applied, the water manager has to demonstrate that the knowledge is valided and applicable for the involved primary flood defence. Due to this the water manager is obligated to seek for advice by the ENW. The next step is to demonstrate that the knowledge is applied sufficiently.

Table 3.1.3.1 – Elements customized test

3.1.4 SAFETY REGULATION PRIMARY FLOOD DEFENCES – PRESCRIPTION DETERMINATION HYDRAULIC LOAD PFD

This section is based on Appendix II of Safety Regulation Primary Flood Defences (Water Act). The WBI 2017-software contains a strength function for every mechanism of the studied primary flood defence that defines the critical combinations of hydraulic parameters with limit function Z. This function compares **the hydraulic load S** with **the defences' strength R** and is therefore a determinant for the probability of failure.

3.1.4.1 RELATION FAILURE PROBABILITY REQUIREMENT, STANDARD AND HYDRAULIC LOAD.

The hydraulic load that will be used to calculate ultimate scenarios, is supposed to be derived from the same probability as the failure probability requirement. This may differ for each test or track. In (Ministry of Infrastructure & Environment, 2016b) Table 3-2, which visualizes the hydraulic load for each test track, presents the relation between each type of test, test track and the principles that ought to be used for the determination of hydraulic load.

3.1.4.2 POSSIBILITIES CUSTOMIZED TEST

The customized test offers the possibility to:

- Compose a substantiated managers assessment. *For hydraulic loads this could imply measurements that indicate less or more frequent hydraulic loads compared to what the formal models suggest.*
- Analyse local hydraulic effects. *A second possibility within the customized test is the analysis for local hydraulic effects.*
- Advanced analysis. *For hydraulic loads the WBI-2017 software uses a constant length-effect factor. This factor is positively correlated with the uniformity of the flood defence. This factor could be checked and controlled with Hydra-NL equations.*

3.1.5 SAFETY REGULATION PRIMARY FLOOD DEFENCES – PRESCRIPTION DETERMINATION STRENGTH AND SAFETY PFD

This section is based on Appendix III of Safety Regulation Primary Flood Defences (Water Act). All test tracks are distinguished in five different groups:

1. Test tracks in which the detailed test is conducted per section with a probabilistic analysis. *For these tracks, the FPB and the length effect influence the determination of the hydraulic load. The probability of failure per section is directly compared with the probability of failure per section.*

2. Test tracks in which a semi-probabilistic analysis is conducted per section for the detailed test, that provides insight in the current state relative to the standard, by extrapolation. *For these test tracks, the standard of the trajectory is used to derive the hydraulic loads. The corresponding value in the failure probability balance and the length effect for the relevant test track are taken into account in the calculation rules for determining the failure probability.*

3. Test tracks in which a semi-probabilistic analysis is conducted per section in the detailed test, that provides insight in the current state relative to the standard. *For these tracks the legal standard for the corresponding trajectory is used to derive the hydraulic load. The failure probability balance and the length effect for the corresponding test track are taken into account in the calculation rules for determining the failure probability.*

4. Test tracks that do not use a probabilistic approach. For these tracks the legal standard of the trajetory is used to derive the hydraulic loads. The failure probability, FPB and length effect will not be used in this group.

5. Test tracks that describe the assessment of indirect mechanisms that do not hold a failure probability. For the derivation of hydraulic loads the legal standard of the trajectory is used.

Depending on the group a test tracks belongs to, table 3.1.5.1 presents the available tests for each test track. DTs and DTt represents respectively sectional- and trajectorial detailed tests.

Track	Code	Group	ST	DTs	DTt
Macrostability Inward	STBI	2	X	X	X
Macrostability Outward	STBU	4	X	X	
Piping	STPH	2	X	X	X
Microstability	STMI	4	X	X	
Wave-Hit Asphalt Revetment	AGK	3	X	X	
Water Pressure Asphalt Revetment	AWO	4	X	X	
Erosion Grass Revetment Outer Embankment	GEBU	3	X	X	
Shearing Grass Revetment Outer Embankment	GABU	4	X		
Erosion Grass Revetment Inner Embankment	GEKB	1			X
Shearing Grass Revetment Inner Embankment	GABI	4	X		
Stability Concrete Block Revetmentq	ZST	3	X		

Table 3.1.5.1 – Available tests for test tracks (Ministry of Infrastructure & Environment, 2016c)

Following the categorization of each test track, all separated relevant tracks will be distinguished in the following categories on sectional level:

Category	Description
I	Widely meets signaling threshold.
II	Meets signaling threshold.
III	Meets ultimate threshold and possibly signaling threshold.
IV	Possibly meets signaling- and ultimate threshold.
V	Doesn’t meet ultimate threshold.
VI	Widely doesn’t meet signaling- and ultimate threshold.
IC	Irrelevant contribution to failure probability or FPB.

Table 3.1.5.2 – Different categories for each track on section level (Ministry of Infrastructure & Environment, 2016c)

After the assessment on sectional level, all sections will be combined and assembled in a category on trajectorial level. This process follows the procedures of chapter 28 in (Ministry of Infrastructure & Environment, 2016c).

3.2 ADAPTIVE MANAGEMENT

For managers and policymakers of complex coupled human-nature systems, uncertainties rose since both social-economical developments as global climate change became more unpredictable in the last decades and will continue to increase (Church, et al., 2013). Although sea-level rise calibration models may be acceptable for several decades of extrapolation according to (Bittermann, Rahmstorf, Perrette, & Vermeer, 2013), many strategies and investments rely on larger time periodes. Moreover, many variables and complex systems have proven to increase in both severinity and frequency, and are scenario-dependent. As a result of future ignorance, managers and policymakers have limited options to fulfill their responsibility. Assuming worst case scenarios in risk analyses or policy strategies will lead to extreme costs and measures, while awaiting certainty may be practically unfeasible and irresponsible in certain situations. (Botzen, Bergh, & Bouwer, 2009). Figure 3.2 presents global sea level rise according to the IPCC (Church, et al., 2013):

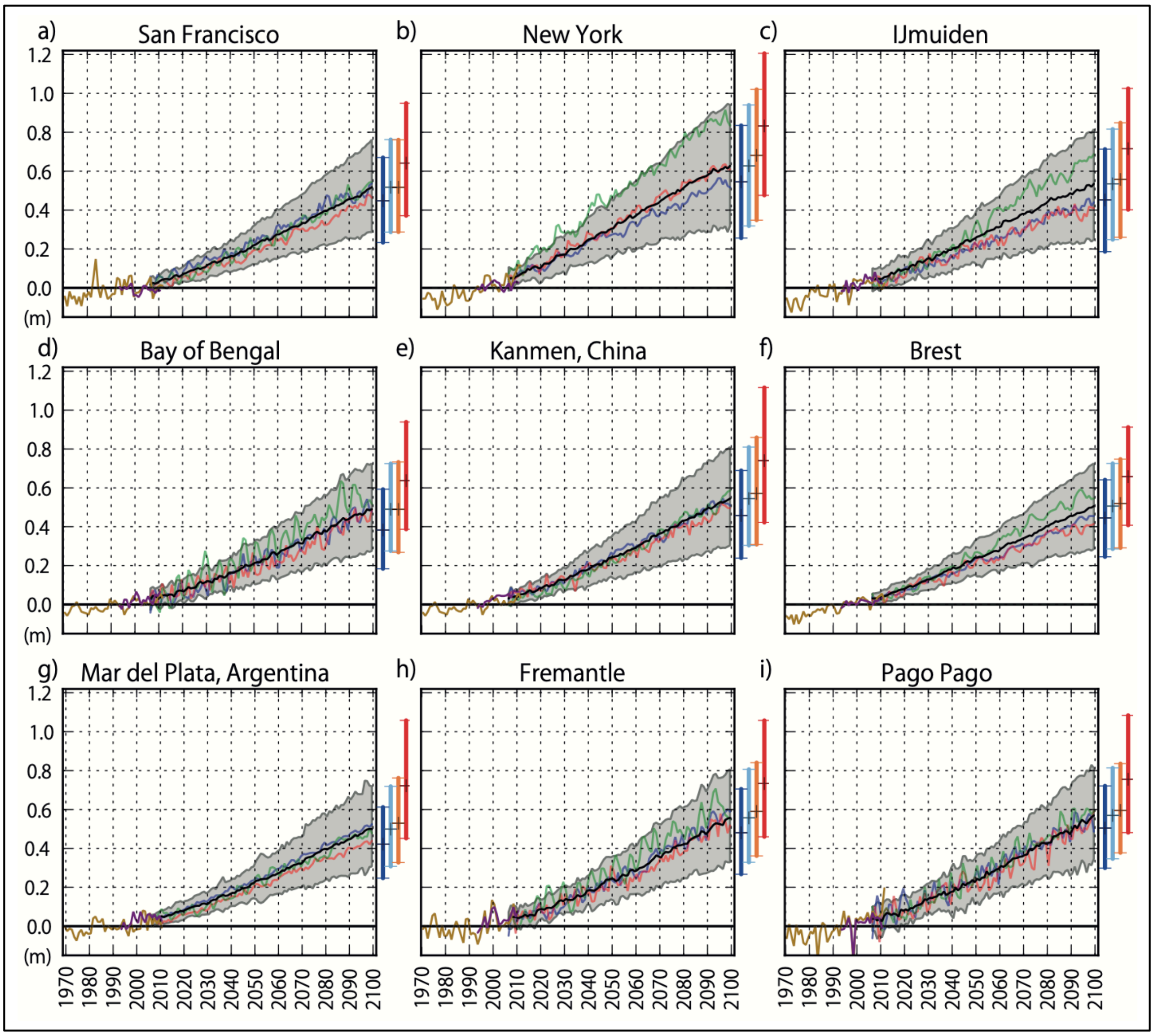

Figure 3.2 – Global Sea Level Rise IPCC (Church, et al., 2013)

Since the start of the 21st century, the paradigm shifted from traditional flood control into more integrated and adaptive frameworks in order to become resilient. According to (Massey, Biesbroek, Huitema, & Jordan, 2014) the number of recorded adaptation policy measures in the European Union grew with a factor of six between 2005 and 2010. The main narrative of this novel paradigm holds that nothing is considered certain except uncertainty itself. In line, huge efforts have been put into advanced protection programmes, as for example the Netherlands launched the national research programme "The Delta Programme" in 2014, following the English Thames Estuary 2100 Plan. The Delta Programme is ment to guide regional water authorities in building resilience, as this appears to be the key factor in governing the unknown, and could moreover be regarded to as a Dutch, adjusted version of the TE2100 Plan (Restemeyer, van den Brink, & Woltjer, 2018). The Delta Programme contains a commissioned guideline concerning Adaptive Management (Rhee, 2012), with implemented key elements from the Adaptation Pathways framework (Haasnoot, Middelkoop, Offermans, Beek, & Deursen, 2012).

In their 2018 study, Restemeyer and his colleagues compared both national initiatives and specifically identified their operationalization in flood risk management strategies (Restemeyer, van den Brink, & Woltjer, 2018). The analysis of the operationality of national strategy programmes as The Delta Plan is interesting, since the critique of applying knowledge and literature on resilience into practice, is growing (Chandler, 2014) (Cote & Nightingale, 2012) (Davoudi, Brooks, & Mehmood, 2013). In their comparison the area Rotterdam-Rijnmond within the Delta Programme is emphasized, since they wanted to ensure that they were able to compare regional implications. Restemeyer and his colleagues found that there is an inclination towards rather maintaining and improving current procedures instead of fundamentally transformatting them. As for instance in Rotterdam-Rijnmond the water authority intented to base their policy on the national guideline as referred to in the Delta Programme, the water authority couldn't identify tipping points, defined as the moments in which you need to fundamentally change strategy.

Situations may occur in which adjustments or changing strategies in general might be difficult, in example due to previous investments. These situations are referred to as *lock-in* and *lock-out* situations (Rhee, 2012). The subsidence currently happening in The Netherlands is one prime example of a lock-in situation. For the purpose of agricultural profits, peatlands have been milled dry untill a point the average exceeded sea levels in a negative relation. As a result the dry milling has to continue infinite, with subisdience continuing to happen. Lock-outs in their turn disturb potential solutions. As urbanization surrounds existing rivers, the available physical space of the river decreases as well as the volume and amount of management opportunities.

Adaptive planning emphasises the acknowledgement that certain important and prominent spacial developments happen to be out of control for government institutions and cannot be controlled. The attempt to do so is not considered reasonable. Therefore, this basically means that future environmental developments will account for as well planned- as spontaneous acitivities and attempts to unite these. Firstly, adaptive planning accounts for the conscious organization, planning and structure of the adaptive capacity of an environmental system. Second, it assumes that the adaptive capacity concerns as much physical systems as organization- and policy acitivities. (Rauws, Zuidema, & de Roo, 2018)

The commissioner of this report, HHNK, identified several variables that ought to support important additional values they require in reinforcement activities through culture, nature and sustainability. The potential frameworks of Adaptive Management, have to account for at least these determined variables. According to internal reports (Marjoke Hoeve, 2020), the variables include:

Time (postponement of reinforcement activities)
Durability (lifespan of reinforced trajectories, moment of recurrence)
Initiative & Alliances (cooperate with or profit from autonomous activites)
Scope (boundaries & restrictions of projects)
Experiments (opportunities to explore novel methodologies & alliances)

When promising Adaptive Management frameworks are found, the capacity of governance has to be evaluated. In 2015 two Dutch scientists, highly regarded when it comes to the analysis of innovative governance frameworks in the fields of climate change and sustainability, investigated the concept of Adaptive Delta Management (ADM) as referred to in the Delta Programme (Dewulf & Termeer, 2015).

They assessed the potential of ADM by five governance capabilities, explained as the ability of policymakers to identify wicked problems and the ability of the operating governance system to enable adequate acting. While the scientists already did the evaluation for Adaptive Delta Management, the preferred methodology will probably deviate from ADM on at least certain elements and will therefore be evaluated separately. The five governance capabilities Dewulf and his colleague distinguished include the following:

i. Reflexivity, the capacity to examine and deal with frame conflicts. When there is no consensus or agreement on what exact the problem is, it is essential to deal with this variety of possible perspectives on wicked problems and to prevent both tunnel vision and intractable controversies.

ii. Resilience, capability of the governance system to ensure that the social-ecological system is able to adapt to unpredictable, changing circumstances without losing its identity and reliability.

iii. Responsiveness, there is the need to develop a governance capability to respond wisely to continuously changing demands.

iv. Revitalization, when people are no longer able to critically reflect upon their actions, policy deadlocks arise. It refers to the capability of actors in a governance system to recognize and unblock counterproductive patterns in policy processes, thus to reanimate actors and to enhance processes of innovation needed to cope with wicked problems.

v. Rescaling, capability to observe and address cross-scale and cross-level issues.

They concude that ADM could potentially contribute substantially in governance capabilities to its reflexivity and responsiveness, which is obvious since elements as the elaborated roadmap provide a broad overview of future situations and enables transition between different strategies.

Next, several concepts of adaptive policies and adaptive management frameworks are elaborated and compared, whereafter the most promising one or combination of multiple frameworks is presented as the preferred methodology. The evaluation and case study are available in the appendices.

3.2.1 ADAPTATION PATHWAYS

In 2010, Kwadijk and her colleagues assessed the vulnerability of policy-making management systems (Kwadijk, et al., 2010) with the use of Adaptation Tipping Points (ATP). ATP could be defined as the points at which the current management strategy can no longer meet its objectives and additional actions or stategies are necessary. Following ATP, in 2012 Haasnoot and her colleagues (Haasnoot, Middelkoop, Offermans, Beek, & Deursen, 2012) tested a method to identify pathways by including dynamics from natural variability and the interaction between the water system and society. They did so by implementing an Integrated Assessment Meta Model that provided multiple realisations of transient scenarios.

One of the approaches that followed as a logical product of adaptation concepts and key elements such as ATP is Adaptation Pathways (APW). The approach has been widely studied and applied in hypothetical case studies.

As mentioned before, one key element in the Adaptive Pathways approach is the use of ATP, with these points representing technical conditions or thresholds under which an predetermined action or strategy no longer meets its specified objectives. The *sell-by-date*, characterizes the moment in time the tipping point is exceeded, and is often scenario-dependent. Whenever one action is near to reaching its tipping point, pathways arise through alternative actions, in order to still meet the general objective(s). The Adaptive Pathways approach could therefore be visualized as a metro road-map that presents multiple adaptation pathways through time. (Figure 3.2.1)

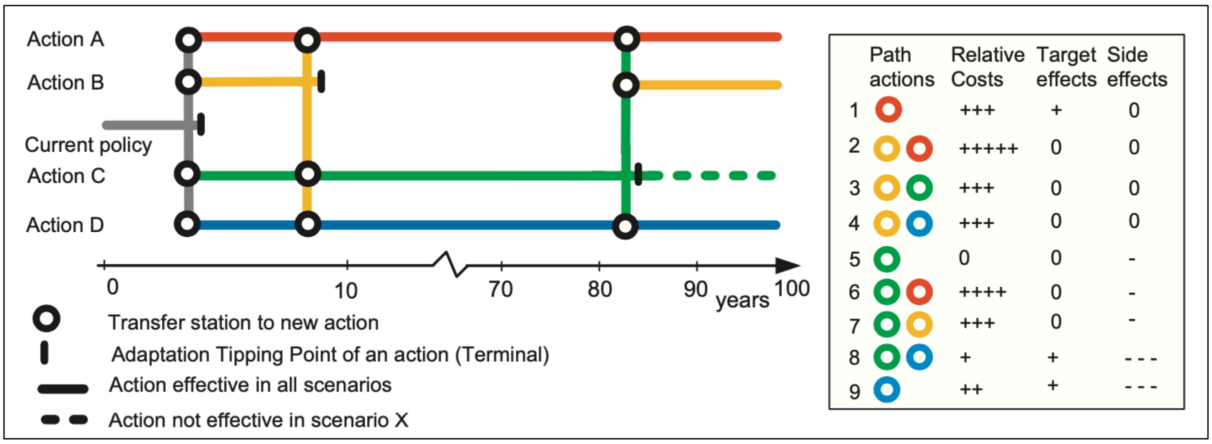

Figure 3.2.1 – Adaptive Pathways (Haasnoot et al, 2013)

As Figure 3.2.1 shows, the currently policy is considered to be insufficient within four to five years. This moment is characterized as a decision-making moment, in total nine pathways are available to reach the objective within the time frame. Actions A and D should be able to achieve the targets for the next 100 years; Action B will most likely reach its tipping point within eight to nine years, whereas action C will perform unacceptable (dashed line) within 80 to 90 years. The moment a strategy or action becomes ineffective and reaches its ATP is scenario dependent.

For all possible paths, proxies and objectives such as relative costs, effectiveness or side effects can potentially be analysed with the purpose to assist decisionmakers in their preference for certain pathways. These specifications can be visualized in a scorecard, presented in Figure 3.2.1. Scorecards could be constructed for several scenarios and multiple time frames. This example considers one time frame and one scenario.

3.2.2 ADAPTIVE POLICYMAKING

In 2001, Walker and his colleagues proposed an "adaptive" approach that allowed policymakers to cope with uncertainties by creating policies that allow them to adjust and change over time (Walker, Rahman, & Cave, 2001). Therefore policy changes became part of a recognized iterative dynamic process instead of a repeated ad hoc decision model. In 2011, Kwakkel et al. conducted a case study called Adaptive Airport Strategic Planning (Kwakkel, Walker, Marchau, & W.J., 2010) in which they explore three adaptive concepts. They suggest that the concepts are complementary and that it would be worthwile to combine them into one new comprehensive approach. In their study they used key concepts of the framework provided by Walker et al. (2001). This new framework has later been coined as Adaptive Policymaking (APM), a generic structured approach for designing an adaptive, dynamic robust plan (Haasnoot et al, 2013). The approach consists of five fundamental steps. (Figure 3.2.2)

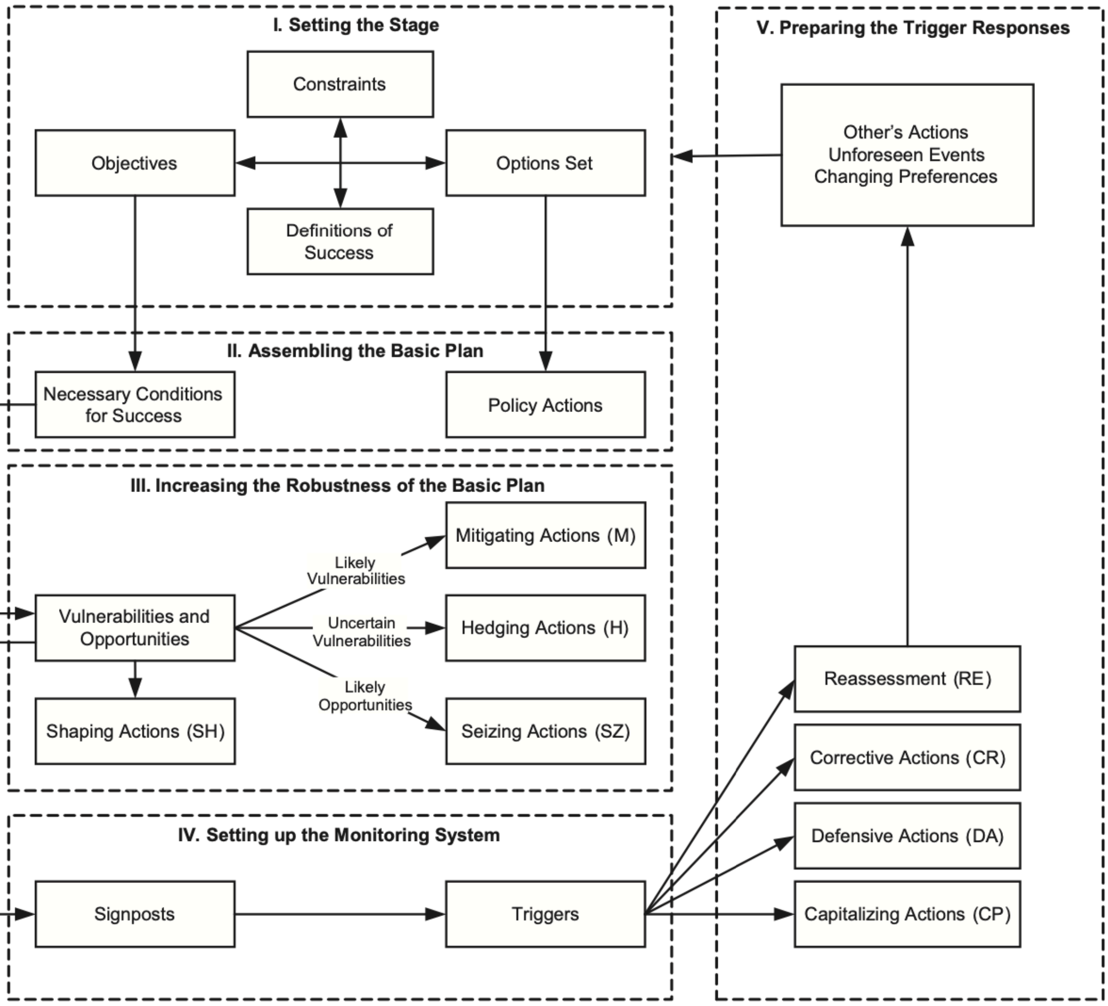

Figure 3.2.2 – Adaptive Policymaking approach to designing a dynamic adaptive plan (Kwakkel, Walker, Marchau, & W.J., 2010)

The fundamental steps in the Adaptive Policymaking approach have been scheduled and summarized below in Table 3.2.2:

Step	Description; Explanation
I	Analyse existing conditions and specify objectives for future development.
II	Assemble a basic plan to achieve the objectives. (Policy actions and necessary conditions)
III	Make basic plan more robust through four types of actions > *Mitigating actions* > Actions to reduce the likely adverse effects. *Hedging actions* > Actions to spread or reduce the uncertain adverse effects. *Seizing actions* > Actions to seize likely available opportunities. *Shaping actions* > Actions taken to reduce failure or enhance succes.
IV	Monitor the plan's performance > Contigency planning (take actions if necessary). *Signposts* specify information that should be tracked, in order to determine whether the plan is meeting the conditions for its success. In addition, *critical values* of signpost variables (triggers) beyond which additional actions should be implemented are specified.
V	Four types of actions that can be triggered by a signpost. *Defensive actions* > Actions taken to clarify the basic plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan unchanged.

		Corrective actions > Adjustments to the basic plan. *Capitalizing actions* > Actions to take advantage of opportunities that can improve the performance of the basic plan. *Reassessment* > Initiated when the analysis and assumptions critical to the plan's succes have clearly lost validity.

Table 3.2.2 – Steps of Adaptive Policymaking

After the immediate steps (II + III) are implemented, the monitoring (IV) of signposts begins. Actions are started, altered, stopped or suspended in response to the information that is gathered concerning the signposts. The implementation of diferent actions (V) is postponed until a critical value is exceeded.

3.2.3 DYNAMIC ADAPTIVE POLICY PATHWAYS

APM provides a very comprehensive stepwise approach for designing a plan, and offers many types of actions that can be taken. In comparison, APW explicitly consideres the multiplicity of future planning process through transient scenarios, and does not provide categorizations of actions. Whether this is positive or negative in terms of building resilience depends on the perspective, while the categorization of actions may provide structure and grip, it may rule out future actions that are not covered by any of the predetermined categories and therefore limit its adaptive capacities. In addition, APW does not emphasize on how to identify promising pathways when many actions or strategies are present.

In general the two approaches provide quite different support for decisionmakers. APM provides a stepwise approach that accounts for a wide variety of uncertainties through the monitoring system and associated actions. However, actions that should be initiated right after critical values are reached, are not explicitly treated. APW provides clear insight in the sequencing of actions or strategies, and supports the overview of future developments through their adaptation map. In a 2013 study, Haasnoot and their colleagues compare the two above mentioned approaches (Haasnoot et al, 2013). They eventually combine both approaches into Dynamic Adaptive Policy Pathways (DAPP), which integrates strong elements from both methods. It includes transient scenarios representing a variety of relevant uncertainties and their development over time; different types of actions to handle vulnerabilities and opportunities; adaptation pathways describing sequences of promising actions and a monitoring system with related contigency actions to keep the plan on the track of a preferred pathway.

The concept of Dynamic Adaptive Policy Pathways has been scheduled in Table 3.2.3:

Step	Description
1 – Describe Study Area	Describe the system's characteristics; (main) objectives; constraints in the current situation; potential constraints. This includes *lock-ins* and *lock-out*s as well. Define the defintion of a succesful plan. The description of the study area includes a specification of the relevant uncertainties and vulnerabilities of the entire system. This can as well relate to future scenarios as the lack of data or models.
2 – Problem Analysis	In this step the current situation and possible future situations are compared with the specified objectives in order to identify whether there are any gaps. Possible future situations are "reference cases" assuming no new policies are implemented. A gap indicates that actions are needed. The identification of opportunities and vulnerabilities can be based on the analysis of the reference case, which can best be accomplished using computational models or empirical data.
3 – Identify Actions	The actions could be specified in the light of opportunities and vulnerabilities previously identified, and moreover could be categorized according to the four

	types of actions specified in the Adaptive Policymaking framework. The aim of this step is to assemble a rich set of possible actions or strategies.
4 – Evaluate Actions	Assess all actions on their (expected) performance and specifications. For each actions this holds the impact(s); sell-by-dates and costs, for each scenario. With the impacts of actions in mind, vulnerabilities and opportunities have to be reassessed.
5 – Develop Pathways	Once the set of actions from the previous step is adequate, pathways can be created. A pathway consists of a combination of actions, where a new action is activated once its predecessor is no longer able to meet the definition of succes and reaches its ATP. Analysts could explore all possible routes and evaluate performances of these routes. To do this, additional information such as urgency; severinity or uncertainty could be used to support promising pathways. If sell-by-dates for certain actions will possibly increase significantly, additional lines can be added. Illogical actions could be eliminated by making their appearance more transparant untill the point they become relevant.
6 – Preferred Pathways	Preferred pathways are pathways that fit well within a specified perspective. It could be useful to specify two to four pathways that reflect different perspectives in order to identify socially robust pathways. The preferred pathways form the basic structure of a *dynamic adaptive plan*. Different stakeholders and decisionmakers have different preferred pathways. The point at which different preferred pathways start to diverge can be considered as decision points.
7 – Contingency Planning	These are actions to anticipate and prepare for one or more preferred pathways (e.g. keep options open) and moreover corrective actions to stay on track in case the future turns out differently than expected. *(Corrective-, Defensive- and Capitalizing actions of APM)*
8 – Dynamic Adaptive Plan	This step holds the translation from all previous steps into a *dynamic adaptive plan* that provides support onto what actions/decisions should be taken and what could be postponed. The plan summarizes the results from previous steps, such as the objectives, problems and preferred pathways. The challenge is to draft a plan that keeps relevant preferred pathways open for as long as possible. It specifies the monitoring system.
9 – Implementation and monitoring	Finally, the actions to be taken immediately are implemented and the monitoring system is established. When time starts running, signpost information related to the triggers is collected; actions are started, altered, stopped, or expanded in response to this information. After the implementation of the initial actions, the activation of additional actions is postponed until a trigger event occurs.

Table 3.2.3 – Process of Dynamic Adaptive Policy Pathways

3.2.4 PASSIVE ADAPTIVE MANAGEMENT

While managers face the challenging task of controlling Coupled Human And Natural Systems (CHANS) with increasing future uncertanty, adaptive frameworks have considerable support to address decision making under uncertainty. However as Tony Prato claims, the applicability in all desired scenarios is not feasible, nor the only way to account for uncertainty (Prato T. , 2016)

Adaptive Management (AM) is an integrated learning process that acknowledges and accounts for surprising future events within the management outcomes as the driver proxies. Williams (2011) distinguishes two kinds of AM. Active AM entails the emphasis and evaluation of the influence of management actions on uncertainty of ecological processes, while passive AM (PAM) focuses on resource management (Williams, 2011). (Nyberg, 1998) and (Prato T. , 2012) have different definitions, as they state that active AM conducts and tests management hypotheses concerning the efficacy of actions and adapts management actions based on these findings. Passive AM does not involve the testing of hypotheses and is therefore less expensive.

The framework presented by (Prato T. , 2016) is based on the interpretation of passive AM by (Nyberg, 1998) and (Prato T. , 2012), as it provides information concerning the influence of management actions on objectives for CHANS, selects preferred management actions and employs monitoring data to revise models parameters. The passive AM framework presented identifies acceptable management actions in terms of cost relative to a planning period budget and compliance with standards for multiple biophysical and social objectives. Moreover it determines the preferred management action for each driver scenario using the fuzzy Technique for Order Preference by Similarity to Ideal Solutions (fuzzy TOPSIS).

The application of the framework is disntinguished in seven fundamental steps: (Table 3.2.4)

#	Step	Description; Explanation
1	Select management actions and objectives.	In this step the management selects all relevant actions; requirements and objectives for the system. As for instance all actions need to be consistent with national regulations.
2	Establish standards for objectives.	Specify the level above or below which the value of the objective is considered unacceptable or insufficient to managers. (Based on scientific knowledge, management goals etc.) The value(s) vary or be constant over periods of time.
3	Choose budgets, drivers and driver scenarios.	Estimate future budgets to evaluate financial acceptability and sufficiency of management actions.
4	Estimate management objectives.	In this step the management estimates the values of the selected objectives in different climate scenarios and planning periods using meta-analyses; data or models.
5	Identify acceptable management actions.	Identify actions that are affordable, satisfy most standards, and do not exceed the budget available. Two decision rules could be applied to determine whether management actions are sufficient concerning their standards for management objectives. (1)
6	Determine preferred management actions.	The proposed framework uses a fuzzy decision rule to determine preferred management actions. Fuzzy decision rules are based on fuzzy logic, a mathematical way of representing the imprecise or approximate nature of decision-making under uncertainty. One fuzzy deicision rule provided by Prato is the Technique for Order Preference by Similarity of Ideal Solutions (TOPSIS). (2)
7	Evaluate whether or not passive AM is adantageous.	-

Table 3.2.4 – Steps of Passive AM

(1) > The first rule entails that estimated means of all positive objectives exceed their respective minimum acceptable levels and the estimated means of all negative objectives fall belo their respective maximum acceptable levels. The second rule holds the same requirements as the first rule, however applied to probabilities instead of nominal levels. This requires probability distributions for both the values as the objectives.

(2) > Fuzzy TOPSIS has three advantages:

i. It requires decisionmakers to state their preferences for the values and objectives in linguistic variables (very hard, simply, etc.).
ii. It does not assume utility independence in comparison with different methods, as they employ additive utility functions.
iii. It does not impose restrictions on risk preferences of the decision maker.

The steps in the TOPSIS decision rule are summarized below: (Table 3.2.2.b)

#	Description
1	The manager assigns linguistic variables to the estimated values of the objectives. Examples are “very low”; “low”; ”medium”; “high” and “very high”. The variables can be assigned collectively or individually.
2	Assign (triangular) numbers to the linguistic variables. Whenever linguistic variables are assigned collectively, the numbers corresponding to the collective variables are used. When individual actors assign variables, the numbers correspondig to the variables are averaged.
3	After calculation, the preferred management action for a planning period or scenario is the top-ranked action. The step-by-step calculation and other relevant detail are elaborated and provided in Appendix X2.

Table 3.2.2.b – Three main steps TOPSIS decision rule

The concept framework provided by (Prato T. , 2016) could be interesting to apply in several contexts due the generic set-up. The concept of the first step of the PAM approach is quite equivalent in comparison with the DAPP approach, as it selects all actions and objectives. However, the DAPP approach provides more thorough guiding in its first four steps. Step 2 could be considerd as the adressing of ATP. Step 3; 4 and 5 could be considered as constructing and identifying the scorecard.

Step 6 however, has potential in its compatibility with previous approaches, which makes it relatively interesting. The use of the TOPSIS decision rule as well as the minimax regret choice may potentially support the interpretation of the scorecard within the DAPP approach.

3.2.5 PREFERRED MANAGEMENT POLICY

Within the PAM framework, the identification of the current system; the selection of management actions and objectives and the determination of standards/thresholds/ATP is treated in two distinctive steps. The DAPP framework provides the double amount of steps, as it first identifies the system and the problem analysis before potential management actions are established. In addition, the development and representation of the available pathways is one very strong element that enables managers and policymakers to physically oversee alternative long-term strategies, decision points and potential *lock-ins* and *lock-outs*.

When the roadmap with all available pathways has been constructed, preferred pathways have to be established for each climate scenario. The framework supposes that different stakeholders develop their preferred pathway. When different pathways overlap, these solutions or strategies are know as **socially robust** pathways, and represents multiple perspectives. Whenever preferred pathways do not overlap, the Fuzzy TOPSIS approach by (Prato T. , 2016) will be used. This approahc is an alternative for a Multi-Criteria-Analysis, and offers an adequate selection process in comparison with the scorecard from the DAPP framework. The Fuzzy TOPSIS approach has to be performed by one or multiple analysts that are able to objectively examine all pathways.

With both the DAPP framework and the TOPSIS-decision rule from the PAM framework gathered, Figure 3.2.5 visualizes the process in a flowchart of the preferred Adaptive Management:

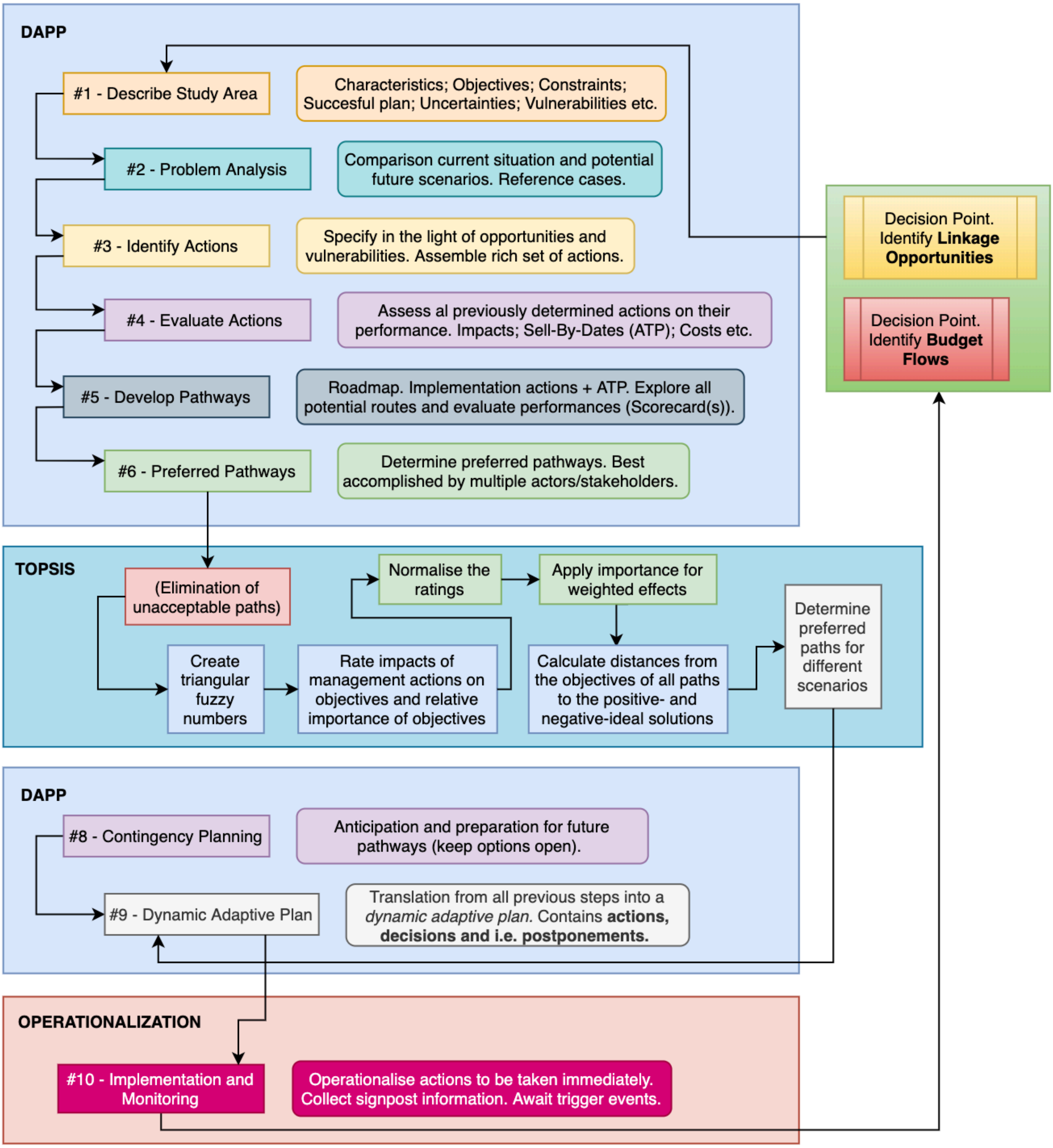

Figure 3.2.5 – Flowchart Preferred Management Policy

Considering the flowchart, the core processes are explained in advance, being both the DAPP and the TOPSIS decision rule. However, two unique loops stand out and might need further explanation.

First, in the fifth step, the roadmap is constructed based on all available management options and corresponding ATP (sell-by-dates). Each potential change of strategy, caused by the exceeding of a ATP, characterizes a **decision point** (In Figure 3.2.1 indicated as a transfer point). Every decision point creates the opportunity for the management to implement both **linkage opportunities** as a novel indentification of **budget flows** (subsidies and fundings), when initiading a new pathway. This holds that the identification of both linkage opportunities and budget flows has to be executed before decision points present themselves. Logically, both linkage opportunities as budget flows could be implemented and monitored in **step 10**.

Next, after the TOPSIS-decision rule has been applied, the preferred paths for the corresponding climate scenarios are known. Together with the contingency planning this makes up the Dynamic Adaptive Plan (DAP). This loop needs to be emphasized since the **preparation of alternative pathways** is very important for water authorities. Exploration phases of reinforcement projects could take up for several years before realisation is approved and executed, therefore the preparation of pathways should be initiated in advance, depending on the likeliness that a pathway is indeed chosen as strategy. As a result, this is implemented in the contingency planning and thus in the DAP.

Appendix X3 includes an extensive evaluation of the preferred management policy. The evaluation is based on the five governance capabilities distinguished by (Dewulf & Termeer, 2015). Table 3.2.5 summarizes the evaluation report:

Governance Capability	Score
Reflexivity, the capacity to examine and deal with frame conflicts. When there is no consensus or agreement on what exact the problem is, it is essential to deal with this variety of possible perspectives on wicked problems and to prevent both tunnel vision and intractable controversies.	9
Resilience, capability of the governance system to ensure that the social-ecological system is able to adapt to unpredictable, changing circumstances without losing its identity and reliability.	10
Responsiveness, there is the need to develop a governance capability to respond wisely to continuously changing demands.	9
Revitalization, when people are no longer able to critically reflect upon their actions, policy deadlocks arise. It refers to the capability of actors in a governance system to recognize and unblock counterproductive patterns in policy processes, thus to reanimate actors and to enhance processes of innovation needed to cope with wicked problems.	6
Rescaling, capability to observe and address cross-scale and cross-level issues.	7
Overall Score	8,2

Tabel 3.2.5 – Summarized Evaluation Report

3.2.5.1 – CASE STUDY

In Appendix X4 case study has been conducted in which the preferred management policy is applied to the project area Den Oever – Den Helder. The case study combines sections 3.2.5, 3.3, and Appendix X2. The software that has been used to generate the pathways is free available at the public site of Deltares: https://publicwiki.deltares.nl/display/AP/Pathways+Generator. The software used for the performance of the TOPSIS decision rule is Microsoft Excel 2020.

The case study comprehensively walks through the steps according to Figure 3.2.5. The first step includes describing a succcesful plan and the system's characteristics, objectives, vulnerabilities and potential constraints, whereafter the problem is analysed.

A plan:

> **Is considered succesful whenever the manager is able to ensure the obligated safety standards, while both provide and obtaining more resilience for uncertain future developments. Moreover, it is important the plan contributes to the next subjets:**

i. Provide social added value. The postponement of activities creates opportunities to combine autonomous activities by consciously not locking the planning-horizon for several decades but instead keeping multiple options open (avoid lock-out & lock-in situations).
ii. Minimalise the impact on the environment and other natural values. Within the perspective of frequent maintenance activities, the potential environmental costs must be consciously outweighted and compared by all benefits.
iii. Realize sustainable profits.
iv. Reduce the likeliness and volume of unnecessary investment.

In the second step the main problem is identified. The main problem in the case study basically holds that the trajectories 12-1 and 13-5 are insufficient regarding several test tracks (Table X4.1 and X4.2), and that multiple actions are possible to respond on this insufficiency. For all insufficient test tracks the expected shelf life has been examined (Table X4.6).

In the third step, all possible management actions have been established based on internal reports and feedback of a technical management counsellor and the project leader of Den Oever – Den Helder. Table X4.9 provides a clear overview of all actions that will be implemented in the pathway map and the corresponding test tracks they are related to.

In step four, all available management actions are assessed regarding the objectives that have been determined in the previous steps (Figure X4.1):

Action	Impacts					
Flood Management Actions	**Safety**	**Nature**	**Social**	**Sustainability**	**Sell-By-Date**	**Costs**
Aggravation of the embankment with novel stones	+++	-	-	-	2070-2090	++
Immediate reinforcement 300m of grass-sods	++	0	0	0	2030-2050	0
Optimize grass management for currently sufficient trajectory	+++	+	+	+	2040-2100	+
Reinforce grass sods for the entire trajectory	++	-	-	+	2050-2080	+++
Partially replace concrete block revetment at insufficient locations	+	-	0	++	2035-2045	+
Replacement of concrete block revetment by similar revetment for the entire trajectory	++	---	--	+	2080-2100	+++
Continue with current asphalt layers	-	0	0	+	2025-2035	0
Reinforcement solely outer asphalt layers ADD	++	-	-	+	2040-2050	+
Reinforcement of all outer asphalt layers (ADD + BZD)	+++	--	--	++	2070-2100	+++
Reinforcement of outer asphalt layers BZD	+	--	--	+	2080-2100	++
Replacement of top asphalt layers (WZW; 3,2km)	+	-	-	++	2060-2080	+
Reinforcement of all top asphalt layers	++	--	-	+	2090-2100	+++
Reinforcement of top asphalt layers remainder trajectory	++	--	--	+	2090-2100	++

Figure X4.1 – Assessment of the impact of all management actions on each objective.

In this case study, two scenarios are distinguished. The mild scenario represents an advantageous outcome of future uncertainties, such as a moderate sea level rise and an impaired subsidience. The extreme scenario considers the inverse of the mild scenario. The sell-by-dates or ATP for all management actions are determined for each scenario.

Step five guided the development of all possible pathways using the pathway generator provided by Deltares. First, all separate management actions and corresponding ATP (scenario-based) derived from the fourth step, are implemented in the program. To be clear, these actions include all actions from Figure X4.2 that have an <u>empty</u> “type of pathway” section. The next step is to point out "combined" and "sequence" pathways, which are either combinations or sequences of two preceding actions.

ID	Color	Action or Pathway	Type of pathway	Mild	Extreme
-->1		Current Situation		2025	2020
2		Aggravation (novel stones)		2090	2070
3		Immediate reinforce grass-sods (300m)		2030	2025
4		Optimize grass management		2035	2030
15		Grass-sods (300m) + Optimize grass management	Combine	2070	2040
16		Grass-sods (Entire Trajectory)		2035	2030
17		Optimize grass management + Grass-sods (Entire Tracjectory)	Combine	2090	2070
18		Grass-sods (300m) + Optimize grass management + Grass-sods (Entire Trajectory)	Combine	2090	2070
6		Partial Reinforce CBV (Insufficient Loc)		2045	2035
19		Reinforce CBV (Entire Trajectory)		2100	2090
20		CBV (Insufficient Loc) + CBV (Entire Trajectory)	Sequence	2100	2090
8		Continue Current Asphalt		2035	2030
9		Reinforce Asphalt ADD		2050	2040
21		Current Asphalt + Reinforcement ADD	Sequence	2065	2050
10		Reinforce Asphalt ADD + BZD		2100	2070
22		Current Asphalt + Reinforcement ADD + BZD	Sequence	2100	2070
11		Reinforce Asphalt BZD		2100	2080
12		Top-Asphalt WZW (3,2km)		2080	2060
13		Top-Asphalt Remainder Trajectory		2100	2090
14		Top-Asphalt Entire Trajectory		2100	2090
23		Reinforce Asphalt ADD + Top-Asphalt Entire Trajectory	Sequence	2100	2090
24		Partial Reinforce CBV (Insufficient Loc) + Reinforce Asphalt BZD	Sequence	2100	2080
25		Current Asphalt + Reinforcement ADD + Reinforce Asphalt BZD	Sequence	2100	2080
26		Reinforce Asphalt ADD + Top-Asphalt Remainder Trajectory	Combine	2100	2090
27		Current Asphalt + Reinforcement ADD + Top-Asphalt Remainder Trajectory	Combine	2100	2090

Figure X4.2 – Management Actions and corresponding ATP.

Figure X4.3 (Appendix X4) visualizes the roadmaps for both the extreme and the mild scenario, whereas sequences and combinations are made using the roadmap-view.

Step six focusses on the preferred pathways, defined by different perspectives. Within this case study, two different perspectives have been distinguished. The first perspective represents the **social actor** that values social impacts. Frequent reccurance of maintenance activites disturbes his social wellbeing as this actor lives nearby the project area. His perspectives justifies increased project budgets with a decrease in such an impact. The second perspective is core-project based and represents the **financial actor**. The purpose of such Adaptive Management is to support in the governance of future uncertainties, reduced project costs align with the preferences of this actor.

Figure X4.4 visualizes the preferred pathways of both stakeholders. The green line represents the social actor, while the blue line represents the financial actor. As derived from the roadmap, pathways #1, #4 and #5 overlap for both actors. While the collision of pathway #1 is obvious, since no other management actions have been determined within this test track, pathways #4 and #5 could be interpret as **socially robust pathways**.

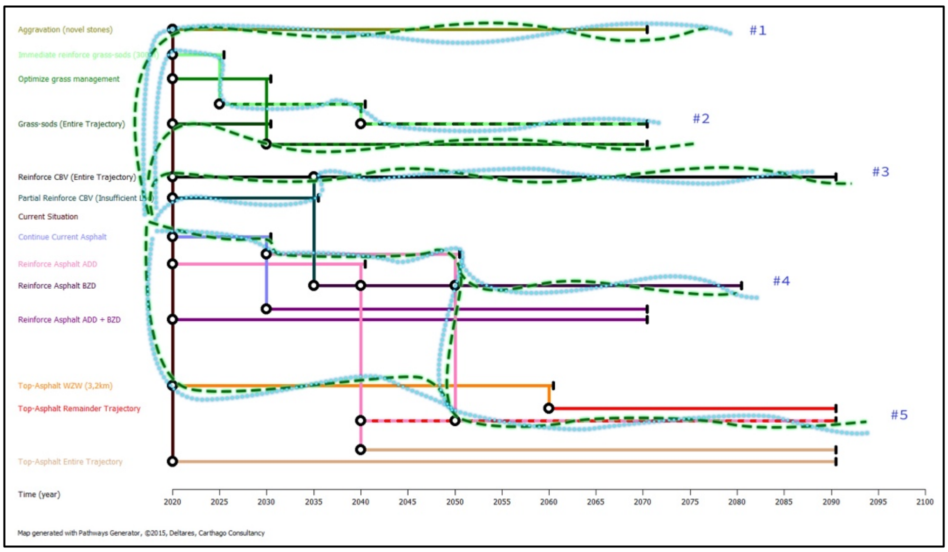

Figure X4.4 – Preferred Pathways; Extreme Scenario

After step six the TOPSIS decision selects the pathways out of the multiple non-socially robust pathways. Appendix X2 explains the TOPSIS proces separately in detail. After all linguistic variables have been assigned and the calculations have been performed, vertex distances and closeness coefficients are obtained.

For each management action, vertex distances have been calculated to every previosuly determined objective. The vertex distance values the normalised distance from the [influence of management action on the objective] to the [ideal solutions]. For negative objectives such as social, which ought to be as low as possible, the positive ideal solution holds (0; 0; 0) whereas the negative ideal solution holds (1; 1; 1). As Figure X4.6 presents, the vertex distance to the positive ideal solution (pathway #2 green) is smaller (0,58) in comparison with the vertex distance to the negative ideal solution (0,79). This means that the influence of pathway #2 green on the social objective is closer to its positive ideal solutions than to its negative ideal solution.

The closeness coefficient averages and determines the closeness to all ideal solutions for any pathway (in this case pathway #2 green). A closeness coefficient of 0,9 would therefore signify that the pathway is very ideal.

	Safety			Nature			Social			Sustainability			Costs		
Fuzzy effects	7,00	9,00	10,00	0,05	1,00	3,00	0,05	1,00	3,00	7,00	9,00	10,00	7,00	9,00	10,00
Normalised weights	0,90	0,90	1,00	0,30	0,50	0,70	0,70	0,90	1,00	0,30	0,50	0,70	0,70	0,90	1,00
Normalised fuzzy effects	0,700	0,900	1,000	0,017	0,333	1,000	0,017	0,050	1,000	0,700	0,900	1,000	0,700	0,778	1,000
Weighted normalised fuzzy effects	0,630	0,810	1,000	0,005	0,167	0,700	0,012	0,045	1,000	0,210	0,450	0,700	0,490	0,700	1,000
Vertex Distance to Positive		0,24			0,77			0,58			0,58			0,76	
Vertex Distance to Negative		0,82			0,41			0,79			0,49			0,34	
Positive Ideal Solution	1	1	1	1	1	1	0	0	0	1	1	1	0	0	0
Negative Ideal Solution	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1

Figure X4.6 – Fuzzy Effects, (Weighted) Normalised FE, Vertex Distances and Closeness Coefficient.
// Extreme Scenario; Pathway #2 Green.

After the TOPSIS analyses, pathways or management strategies in the extreme scenario for all tracks have been established:

Track	Preferred Pathway	Type
STBI	Aggravation of novel stones.	Socially Robust
GEBU	Immediate reinforcement grass sods > Optimize grass management > Reinforcement entire trajectory.	TOPSIS
ZST	Partial reinforcement concrete block revetment > Reinforcement concrete block revetment entire trajectory.	TOPSIS
AGK	Continue current asphalt > Reinforce asphalt ADD > Reinforce asphalt BZD.	Socially Robust
Asphalt	Top asphalt WZW > Top asphalt remainder trajectory.	Socially Robust

Table X4.10 – Preferred Pathways // Extreme Scenario.

Step 7 holds the establishment of a contingency planning. The main purpose of a contingency planning is to safeguard strategy transitions by preparing necessary elements. Doing this, options are kept open to provide resilience for future uncertainty.

Step 8 translates all previous steps in a Dynamic Adaptive Plan (DAP). The DAP contains all emenents of the previous steps, including the contingency planning and a M.E.R. (Dutch: Milieu Effecten Rapportage). The DAP could be explained as the entire project plan for which a permittance or license is granted by the supervisor.

Step 9 guides the implementation and monitoring of the adaptive policy. In addition to the monitoring system, the proactive loop explained in Figure 3.2.5 in the report should be established as well. This holds that before every decision point, which are characterized by all circles in Figure X4.3, linkage opportunities and budget flows should be identified.

3.3 CURRENT & EXPECTED STATE PFD

The flood defence system between Den Oever and Den Helder has been partially rejected because it does not meet the legal standards according to WBI 2017. This system consists of the trajectories 12-1, Wieringer Zeewering and 13-5, Amsteldiepdijk & Balgzanddijk. The manager of these trajectories, HHNK, is supposed to reinforce the systems within the context of the National Flood Protection Program (HWBP).

3.3.1 TRAJECTORY 12-1

The Wiering Zeewering (WZW) spans 11,7 kilometers and is located from Den Oever up until the Amstelmeer. The hinterland of the WZW is the former island Wieringen and mainly consists of rural nature. The foreland is the Wadden Sea, an area with high natural values. Along the WZW towns as Den Oever and Hippolytushoef are located (HHNK, 2018). Both the signaling threshold as the ultimate threshold are numerically equivalent and have a probability of 1/1000.

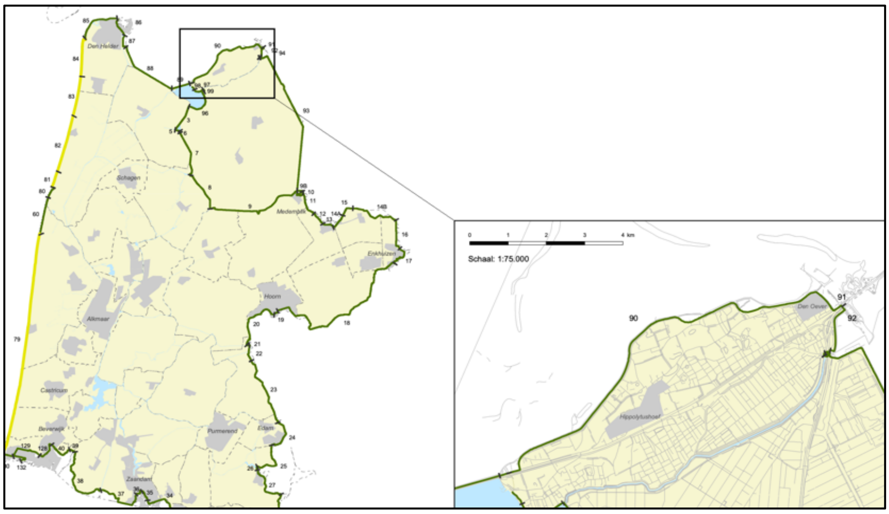

Figure 2.5.3 - Study Area WZW (90) (HHNK, Legger Primaire Waterkering 90, 2008a)

The general filter isn't applicable for trajectory 12-1. In the next phase the water manager conducted a relevance test which excluded irrelevant test tracks from the further assessment, i.e. dune erosion.

3.3.1.1 SAFETY ASSESSMENT

The safety assessment for trajectory 12-1 is **C**: Both the signaling and the ultimate threshold are exceeded. This means the flooding probability is currently larger than 1/1000.

After the assembly of all test tracks for each section, an safety assessment is determined for the flooding probability of the entire trajectory.

Track	Type	Cat	Assessment
STBI	ST+DT	II	For +- 2km category II holds (3/21) sections, the remaining 8,8km holds category I. Section 21 isn't assessed.
STBU	ST+DT	II	Every section holds category II. Section 11 isn't assessed.
STPH	ST+DT	II	Every section holds category II. Section 4 isn't assessed.
STMI	ST+CT	II	Every section holds category II. Section 4 isn't assessed.
AGK	ST+CT	V	Sections 1, 2, 3 and 6 hold category II. Sections 4, 5 hold category V and are together with section 6 estimated to be at the end of their

			shelf life. Due to foreland at section 6 the local hydraulic load is relatively low.
AWO	ST+CT	II	Every section holds category II, while 22 sections haven't been assessed.
GEBU	ST+CT	V	Every section holds category II, while DP21.7, DP22.2 hold category IV and sections DP23.3 and DP24.1 hold category V.
GABU	ST+DT	II	All sections hold category II.
GEKB	DT	I	All sections hold category I
GABI	ST	I	For this track the Simple Test suggested that the corresponding flooding contribution is irrelevant.
ZST	CT	V	In total 29 sections (2,9km) hold category II, while 12 sections (1,2km) hold category V due to the instability of the top layer. The remaining 6,6km of the WZW doesn't apply to ZST.

Table 3.3.1.1 – Scheduled assessment 12-1

The remaining indirect mechanisms as *Foreland, Non Water Retaining Objects* and *Dams* have been assessed with a simple test and turn out to be of irrelevant contribution into potential failure.

Track	Length	Condition
AGK	1,6 km	-
GEBU	0,4 km	While aiming at closed sods, some sections are being rented and the enclosement of these section can not be guaranteed. As a result for these sections an open sod is assumed.
ZST	1,2 km	-

Table 3.3.1.1-2 – Summary insufficient tracks 12-1

3.3.1.2 PERSPECTIVE OF ACTION

The following actions perspectives have been derived from internal management documents of HHNK (HHNK, 2018) (HHNK, 2020), and will contribute in determining management actions in the case study.

Wave hits on asphalt revetment
The two patches between DP22.2+80 till DP23.1 and DP24.1+70 till DP24.9+70 include a major maintenance activity. This has been confirmed in an investigation on the remaining lifespan of the asphalt revetment (KIWA, 2018).

Erosion grass revetment outer embankment
The sections DP21.7; DP22.2; DP23.3 and DP24.1 with assessments IVv and Vv include the application of a harsh revetment on the lower embankment.

Stability of the concrete block revetment
The three patches between DP16.0 till DP16.2, DP18.5 till DP18.7 and DP18.8 till DP19.6 include a major maintenance activity. Further investigation into the HWBP exploration suggested that the maintenance task increases for the scope of 2073.

3.3.2 TRAJECTORY 13-5

Trajectory 13-5 contains both the Amsteldiepdijk as the Balgzanddijk. The Balgzanddijk (BZD) spans 8,0 kilometers and is located south-east of Den Helder. At the inner side of the BZD two bird-rich Natura-2000 areas are located: the Balgzandpolder and the Balgzandkanaal. The Balgzand has the function of being a large mudflat and is therefore an important forage- and rest place for birds (HHNK, 2018). More technically, the Balgzandkanaal carries the function of an important drainage channel up until the Spuissluis Oostoever.

The Amsteldiepdijk (ADD) spans 2,3 kilometers and has been constructed in 1924 as the pilot for the Afsluitdijk, causing the Amstelmeer to arise at the inner side. It connects the Wieringer Zeewering (WZW) and the Van Ewijcklsuis. The ADD is enclosed on both sides with the Amstelmeer and the Wadden Sea at the outer side. (HHNK, 2018)

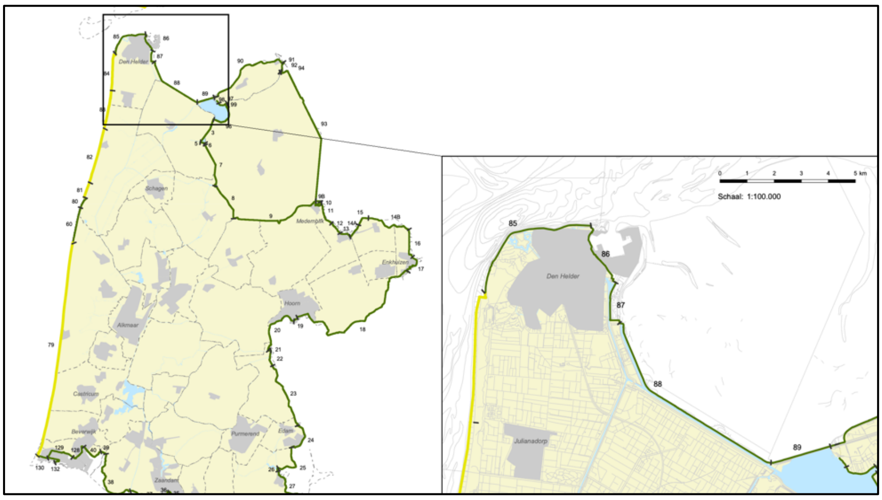

Figure 3.3.2 - Study Area BZD (88) and ADD (89) (HHNK, Legger Primaire Waterkeringen 85-89, 2008b)

3.3.2.1 SAFETY ASSESSMENT

In Table 3.3.2.1 scheduled safety assessments for all different test tracks of trajectory 13-5 are presented:

Track	Type	Cat	Assessment
STBI	ST+DT	VI	Both signaling and ultimate threshold do widely not meet during 7,8 km. This holds for sections 13005.1 till 13007.2
STBU	ST+DT	V	Both signaling and ultimate threshold do not meet during 2,0 km. This holds for sections 13006.2, 13006.8, 13007.1 and 13007.2.
STPH	ST+DT	II	For section 13005 the threshold doesn't meet in run 2 of the assessment (undeep sand layers), however the length of the cross-section might be incorrect due to insufficient information.
STMI	ST+DT	II	Sections 13005, 13006, 13008 and 13010 hold category I as their contribution is considered irrelevant (ST). Section 13007 has been subjected to two detailed tests (sand and clay layer) and holds category II.
AGK	ST+CT	-	All sections hold category I, while HHNK awaits further analysis and application requirements concerning ground water levels.
AWO	CT	-	HHNK awaits further analysis for application requirements. Entire trajectory holds category FPI (Failure Probability Irrelevant).

GEBU	DT	II	Most insufficient locations have been assessed (DP7.9, DP9.5 & DP11.5 BZD // DP12.9, DP13.2 & DP13.9 ADD). All locations hold safety factors higher than required.
GABU	CT	I	Grass coverage located significantly higher than maximum water level so the contribution of this track is considered irrelevant.
GEKB	DT	I	The trajectory holds open sods at the top and the inner side, while even then the failure probability is many times lower compared with the requirement.
GABI	ST	I	Failure probability contribution irrelevant.
ZST	DT	VI	Both signaling and ultimate threshold do not meet during 4,9 km: 3300-5500; 5600-6000, 6200-6400, 6600-6700, 6800-6900, 7300-7400, 7500-7600, 8100-8300, 8400-8600, 9000-10307.

Table 3.3.2.1 – Scheduled assessment 13-5

Track	Length	Condition
STBI	7,8 km	-
STBU	2,0 km	-
ZST	4,9 km	-

Table 3.3.2.1-2 – Summary insufficient tracks 12-1

Trajectory 13-5 contains forelands at certain locations, there forelands had to be assessed as well:

Track	Type	I	Assessment
VLGA	ST	IC	Areas B and C contain a large enough foreland. The height of the foreland in Area A is low enough. Contribution of all three areas is irrelevant.
VLAF	ST	IC	Irrelevant contribution.
VLZV	CT	-	The ST and DT suggested a CT is necessary. Still needs to be conducted (June 2017)

Table 3.3.2.1-3 – Foreland tracks 13-5

3.3.3 EXPECTED SHELF LIFE

In early 2018 HHNK requested HKV to conduct an analysis into the remaining shelf life of the Wieringerzeewering, Amsteldiepdijk and Balgzanddijk. (HKV, 2018) In this report the tracks STBI, STPH, GABU, ZST and AWO have been analysed. The tracks STBU and GEKB the remaning shelf life is analysed by Deltares (Breteler, 2018).

3.3.3.1 STBI

Due to the fact that de BZD is insufficient concerning STBI, this tracks is implied in the scope of the HWPP (Dutch: HWBP). Therefore no remaining shelf life analysis has been conducted for the BZD.

The ADD is assessed sufficient, as a result the RSL is calculated for the weakest cross-section.

The WZW is assessed sufficient as well, therefore two trajectories (DP19.1 – 20.9 and DP22.3 – 23.4) have been analysed.

For all sections a further check is conducted to determine what cross-section is most likely to burst, whereafter the inner macro stability for the corresponding cross-section is calculated.

Topic	BZD & ADD	WZW
Burst	Except for cross-section 13008.2 all considered cross-sections have turned out to be insufficient in 2023, and reduce through the years.	Only relevant within the first trajectory. First trajectory is widely sufficient.
Inner Macrostability	For the weakest cross-section (13008.1a) the signaling threshold is expected to be slightly exceeded in 2100.	Both trajectories are widely sufficient until at least 2100.

Table 3.3.3.1 – STBI

3.3.3.2 STPH

As a result from the assessment, 1,2 km of the trajectory 13-5 (BZD & ADD), section 13005, is insufficient since it does not meet the signaling threshold. In this analysis it is determined whether when the ultimate threshold is expected to be exceeded. Based on the assessment of the WZW piping is excluded from this trajectory since its contribution is considered irrelevant. (HKV, 2018)

For this track two different runs have been conducted. The first run represents piping through undeep sand layers, calculted from the outer toe untill the inner toe. The second run represents deeper layers, calculated from the foreland untill the bottom of the Balgzandcanal.

Perspective	
2023	Entire trajectory is sufficient.
2070	Three cross-sections (13005, 13007.1 and 13007.2 exceed signaling threshold, but maintain ultimate safety threshold.
2100	Cross-section 13005 exceeds ultimate threshold.

Table 3.3.3.2 – STPH

3.3.3.3 GEBU

For the RSL analysis of this track the same loactions have been assessed as for the assessment round (HHNK, 2018). The weakest sections, section 6 and 9, have been assessed.

Topic	2023	2070	2100
Wave Run-Up	Both closed as open sods sufficient.	Closed grass sods sufficient. Two analysed locations are insufficient considering open sods.	Closed grass sods sufficient. Open grass sods insufficient.
Wave Hit	Section 6 insufficient for closed sods.	Both section 6 as section 9 insufficient for closed sods.	-

Table 3.3.3.3 – GEBU

Potentially new safety assessment concerning GEBU in 2070 for the wave run-up. Concerning the wave hit, nearby DP22.2 the profile transfers from foreland with grass coverage into asphalt without foreland. An easy solution for this safety assessment may hold to continue the asphalt coverage up untill DP22.2.

3.3.3.4 ZST

For the RSL of this track sections of 100m have been used similar as in the assessment round. Results represent either stable or unstable sections. Table 12 in (HKV, 2018) presents detailed results, while table 3.3.3.4 presents scheduled results.

Topic	2023	2070	2100
BZD	A few sections are insufficient, around 5%	A few sections are insufficient, around 10%	Many sections are insufficient.
ADD	Half of the sections are insufficient.	Around 75% of the sections are insufficient.	Around 75% of the sections are insufficient.
WZW	Except for three sections, all sections are insufficient	Except for two sections, all sections are insufficient	Except for one section, all sections are insufficient.

Table 3.3.3.4 – ZST

For more specific RSL analysis, Deltares is currently conducting research into wave conditions (2070 and 2100. Reference for this questions at Helpdesk Water: #18022584.

3.3.3.5 AGK & AWO

Coverage of asphalt is present at the entire length of the BZD (8,0 km), during 2,3km of the ADD and at three sections of the WZW (8,4 km). Cross-sections of 100 m have been used in this analysis. One of the assumptions that has been made is that the internal strength of the asphalt doesn't reduce over the years.

The results of the RSL analysis concerning the track Water Pressure are sufficient for all trajectories and for all perspectives (2023; 2070 & 2100).

The results of the RSL analysis concerning the track Wave Hit is considered of irrelevant contribution into the flooding probability.

3.3.3.6 SUMMARY

Table 3.3.3.6 summarizes the current and expected scope for the analysed test tracks:

Track	Safety Scope (2023) and Shelf Life Analysis (2070)			
	Balgzanddijk / Amsteldiepdijk (BZD/ADD)		Wieringerzeewering (WZW)	
	2023, based on signaling threshold	*2070, based on ultimate threshold*	*2023, based on signaling threshold*	*2070, based on ultimate threshold*
STBI	BZD = 7,8 km	BZD = 7,8 km	-	-
STBU	BZD = 2,0 km	BZD = 2,5 km	-	-
STPH	-	-	Irrelevant	
GEKB	-	-	-	-
GEBU	-	-	4,5 km	4,5 km
ZST	BZD = 3,2km; ADD = 1,7 km	BZD = min 3,2 km; ADD = min 1,7 km	3,8 km	3,8 km
AWO	-	-	-	-
AGK	Further investigation		Irrelevant	

Table 3.3.3.6 – Summary RSL for each test track (HKV, 2018).

4 DISCUSSION

As the purpose of this report serves in-depth advice concerning Adaptive Management, it answers the quest for a contextual promising frameworks of Adaptive Management and its compatibility with the duty of care.

At first, the duty of care has been thoroughly studied and eventually elaborated in current legal standards, fundamental requirements, guidelines for assessment and restrictions in terms of what opportunities present themselves when reinforcement and maintenance activities differ from conventional methodologies. The results cover all relevant aspects to answer the concerned research question.

Although formally there is no opportunity to deviate from legal standards, the misconception may arise that adaptive policies go together with postponement that exceeds safety levels. An adaptive policy offers support in governing uncertain future scenarios as it guides managers and decision-makers to identify e.g. all vulnerabilities and decision points (ATP). In fact, the static safety levels could easily be implemented as a preconditional value that triggers strategy transitions.

To closely monitor the processes underlying safety levels, frameworks such as DAPP both facilitate and require a new form of frequent monitoring, reporting and more future-oriented assessments. These future-oriented assessments might hold inspection sessions that thoroughly determine shelf lives instead of current states. Frequent monitoring refers to the managing of daily data, as certain entities (state of grass-sods; moist levels in the ground layers) could change significantly in short periods and therefore need frequent care.

The literature study on the several available promising concepts of Adaptive Management might have lacked comprehensiveness by missing one or more available concepts. The subject has been widely studied for the past decades and therefore a very large body of literature is available. Although the most cited works have been treated, this still is a possibility. Moreover, although the preferred management policy has been evaluated by an evaluation method constructed by two highly regarded (Dutch) scientists, the evaluation method itself might have been executed with colored interpretation since the researcher himself conducted the evaluation.

Several technical reports that have been used to determine the current and expected state of trajectories 12-1 and 13-5 are not up-to-date or include (internal) concept versions, as the WBI Assessment Report Trajectory 12-1 (HHNK, 2020) is an internal concept version. Moreover, the safety assessments of both trajectories are not entirely equal since the Wieringerzeewering has partially been implemented in the HWBP, while both the Amsteldiepdijk and the Balgzanddijk are assessed following traditional methods. Whether the inconsistency and fact that reports are of significant relevance for the outcome of the research are up to debate. Eventually, the technical content has been used to provide customized advice concerning the duty of care, and to conduct a case study with the preferred Adaptive Management framework. Optimal values will probably not change anything significant.

Considering the operationalization of the preferred management policy, available in Appendix X4, certain points might need further attention.

i. **Computational models are crucial and necessary for the detailed determination of sell-by-dates and thereby ATP**. When the framework is implemented to support decision-making processes in more complex systems such as flood protection, many decision-points are characterized by complex variables as well. These variables, e.g. sea-level rise, subsidence or precipitation, should be derived from models and other signposts instead of expert estimates as the case study may suggest.

ii. Depending on the context in which the framework is applied, **one or more management actions could be executed synchronously**. In the case study, most of the test tracks need different reinforcement activitires. Two or more activites could be combined with the advantage that surrounding nature or residents only experience disturbance once. In this sense, the framework provides a detailed overview and a step-by-step approach, with the purpose to support decision-making. Indeed, it should not limit any rational decision-making.

iii. **The Dynamic Adaptive Plan should be iterated before every decision-point is about to be reached.** As emphasized in section 3.2.5, this iteration process has been constructed on the side to align with both the management demands as the Omgevingswet which operationalizes in 2022. Linkage opportunities constantly present themselves during the performance of the current management action(s). The process to identify such opportunities should be implemented in the current DAP. Besides, subsidy flows are roughly estimated for the current management action(s) and are therefore obviously part of the current DAP. Since every decision-point offers new opportunities to change strategy (and combine linkage opportunities), the budget demand for the novel strategy might differ.

iv. **The framework itself is not static.** Although the current DAP considers multiple (climate) scenarios, with every decision-point characterizing the change of current management action(s), new information and opportunities might arise, as appears from point iii. The implementation of new information and thereby the construction of a new DAP forces the manager to maintain a dynamic decision-making model and is crucial in safeguarding the resilience for future changes. The consideration of multiple scenarios within one DAP significantly supports this process as it potentially accounts for a large part of the change.

Concluding, the application of the roadmap concept differs from the original application by (Haasnoot et al, 2013). The roadmap includes multiple activities that fundamentally are noninterdependent and not related due to their different test tracks. However, the execution of these activities could indeed be combined to significantly reduce project costs and social disturbance. Because of these benefits, while Haasnoot and her colleagues would most probably establish separate roadmaps for each test track, the roadmap in this case study combines all test tracks in one figure.

The preferred management policy guides the manager in identifying the entire system with all vulnerabilities, restrictions and opportunities. A rich set of management actions is designed right after the identification. So far these steps are quite commonly shared in alternative frameworks. The roadmap that is established, however, provides a significant advantage in comparison with alternatives as it enables the manager to physically oversee all combinations, pathways and future lock-ins and lock-outs. Also, the TOPSIS approach is a very strong element in the selective process of non-socially robust pathways as it statistically determines preferred pathways using triangular distributions.

The variables that have been distinguished by the commissioner, HHNK, have been accounted for in advance through finding the adaptive frameworks. The variables included **time** (postponement of reinforcement activities); **durability** (lifespan of reinforced trajectories, the moment of recurrence); **initiative & alliances** (cooperate with or profit from autonomous activities); **scope** (boundaries & restrictions of projects) and **experiments** (opportunities to explore novel methodologies & alliances). The capacity to make a well-considered postponement of activities has been significantly increased by the first steps of the approach in which all future opportunities and vulnerabilities are identified.

Moreover, the roadmap enables the manager to foresee pathways and solutions that are advantageous and increase durability, while ATP guarantees that boundaries and restrictions are met. The identification of linkage opportunities before every decision point appears enables the manager to anticipate or cooperate with autonomous activities.

The fact that an equal framework is recommended and guided by the Delta Programme, suggests that the preferred policy of this research is adequate. The studies that analyzed the operationalization of adaptive policies however concluded that managers may tend to traditional static policies. It is important to distinguish two different perspectives here. As traditional static policies result in traditional reinforcement or maintenance activities, an adaptive policy might eventually result in the same. The actual strategies that are realized (by an adaptive policy) do not depend in any way on the adaptive policy itself, as adaptive policies only support and contribute to a more deliberate consideration and provide guidance in the decision-making process. It is there possible that the preferred strategy of an adaptive policy would be traditional reinforcement.

The establishment of the Dynamic Adaptive Policy Pathways approach in combination with the TOPSIS analysis should be conducted by experts that constitute a professional project group. Constructing a pathway roadmap for complex projects is a multidisciplinary task and requires professional analysts that identify all possible opportunities; combinations and sequences. Note here that the purpose of this case study was to shine a light on the capabilities and benefits the preferred management policy provides.

5 CONCLUSION AND RECOMMENDATIONS

While this research contains three main questions, the third question concerning the current and expected technical state serves the first and second question rather than it is fundamental itself. Therefore no conclusion will be provided for the third research question.

Main question	**How could the duty of care for managers of primary flood defences be guaranteed given Adaptive Management?**
Subquestion	What activities or responsibilities currently include the duty of care according to the Water Act?
Subquestion	What are the current legal standards and regulations for flood protection?
Subquestion	How and by who is the duty of care currently assessed and what space is available for own interpretation or adjustment?

Table 2.3.1.1 – Research Questions Water Act

The Water Act supposes twelve fundamental requirements that are covered by the duty of care. Four of those activities are considered relevant in the given context of Flood Risk Management and include **Assessment**; **Managing daily data**; **Maintenance** and **Emergency care**. As a part of the assessment, legal standards have been examined that prescribe the level of safety primary flood defences must meet, these are static and can not be deviated from.

For the assessment procedures, guidelines and regulations are offered in which default assessment processes are described. These suggest that whenever traditional or default assessment methods prove to be insufficient or incomprehensive, managers bear the responsibility and liberty to conduct customized tests under the condition that those are properly substantiated and correctly executed.

Concluding, formally there is no formal space to deviate from the safety levels, which might be just as well. However, this does not have to obstruct the implementation of an adaptive policy at all. Since the preferred management policy anticipates the safety levels by implemented them as ATP, legal standards are always guaranteed. Moreover, by adjusting the monitoring and assessment processes, for which there is formal room for, to more shelf-life oriented approaches, the manager's governance capacity of uncertain future scenarios will substantially increase.

Additional research in these monitoring and assessment processes is highly recommended whenever the manager has yet decided how to implement and operationalize an adaptive policy. Depending on the ATP, which could be safety levels or i.e. local subsidence, frequent monitoring of the quantities would prove itself very advantageous in operationalizing an adaptive policy. Research into how this monitoring could best be aligned with the policy is recommended.

Main question	**What is the most promising framework of Adaptive Management in the context of Flood Risk Management?**
Subquestion	What frameworks of Adaptive Management are currently available and how do they differ?
Subquestion	Which of those frameworks would best fit the context of Flood Risk Management?

Table 1.3.1.2 – Research Questions Adaptive Management

Although several concepts have been provided (Kwadijk, et al., 2010) (Haasnoot, Middelkoop, Offermans, Beek, & Deursen, 2012) (Walker, Rahman, & Cave, 2001) (Kwakkel, Walker, Marchau, & W.J., 2010), the most promising framework of Adaptive Management for Flood Risk Management directly follows from the results and the case study. It includes a combination of the Dynamic Adaptive Policy Pathways framework (Haasnoot et al, 2013) and the TOPSIS analysis (Prato T., 2016).

It is recommended to optimize the adaptive framework when it is implemented and operationalized, potentially facilitated by scientific research. The manager should be aware of the fact that every policy requires customization and adjustments due to dynamic circumstances.

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APPENDICES

APPENDIX X1 – FUNDAMENTAL REQUIREMENTS

Activity	Fundamental Requirements (Realisation Duty of Care)
Assessment	1. Assessment will be executed according to the corresponding schedule. *The water managers themselves determine the frequency at which the assessment schedule will be realised. It is conceivable that this follows the planning & control and/or the budget cycle and is demonstrably. It is asssumed that primary flood defences that currently do not meet legal standards will be inspected with relatively more care and focus.* 2. The obtained results of the assessment will be documented unambiguously. *Unambiguously can be interpreted as internally consistently, however the water manager gives own interpretation into how unambiguously is realised. It may be expected that at least the following points will be documented:* • *Overview of damage + classification.* • *Details: coordinates, location, measurements, quantities and resolution.* • *Enviromental characteristics.* • *General data.* 3. Follow-up actions will be made whenever the results of an assessment cause to do so. *How and by whom follow-up actions will be executed is predetermined in the process organization of the water manager. Depending on the damage and various other relevant cases a decision will be made on what measures to take. It could potentially occur that the reinforcement of noticed damaged will be deliberately posponed. For each claim the consideration for postponement needs to be demonstrable and visible.* 4. The process of assessment will be periodically evaluated and adjusted. *Part of the evaluation could be the comparison of the assessment results with the risk analysis leading to a judgment concerning the safety situation, which is input for the safety report as well.*
Managing daily data	1. The management register contains charasteristic, physical data of the primary flood defence. At least the following points must be included: • *The context of the data set is predetermined by the water manager.* • *The physical shape infers the current shape.* • *Current shape implies cables, pipes, permits, maintenance measures etc.* 2. The data set will be validaded before it will be documented in the management register. 3. The water manager has adjusted the data set concerning the primary flood defence according to the legal standards for actuality and comprehensiveness. 4. The process of managing the daily data set will be evaluated periodically and adjusted if desirable.
Maintenance	6. The planned maintenance will be executed according to the schedule and maintenance plan. *This implies the maintenance executed by the water manager himself.*

	7. For the unexpected maintenance (as a result from an assessment) the consideration for adequate (re)action is demonstrable and visible. 8. The predetermined follow-up actions for unexpected maintenance will be executed. 9. All relevant maintenance data will be actively documented in the management register or a comparable system. *It is up to own interpretation to determine what maintenance data is considered relevant and how actual this data needs to be. The policy concerning this point will be secured in the process report of this activity.* 10. The maintenance will be executed periodically and adjusted if desirable. General: Certain types of maintenance can be distinguished: • *Expected regular maintenance, with the purpose to extend its lifespan.* • *Expected variable maintenance, emphasized to ensure its functionality.* • *Unexpected maintenance as a result from natural disasters, high water, accidents or non-permitted activities.* *The logical cause from the assessment of a primary flood defence is that observed damages need to be repaired. The steps between observation and repairment or reinforcement are predetermined. The ILT supervises whether the process is executed sufficiently and comprehensive.*
Emergency Care	1 The presence and condition of emergency facilities needs to be assessed periodically. *Emergency facilities may include i.e. sandbags and demountable walls.* 2 Employees will practice and be trained according to an OTO-plan (Opleiden; Trainen en Oefenen). *The water manager registers an OTO-plan who/how and when practices occur.* 3 Practices and/or emergencies will be evaluated in advance and will lead to active instructions. *The water manager himself decides the interpretation of "in advance", for instance before each high water season.* General: Certain types of emergencies can be distinguished: • Default management • Management under special circumstances, i.e. when the objects need to be prepared in order to protect against extreme weather. • Emergencies in which the primary flood defences tend to fail and emergency measures need to be taken.

Table X1 – Extended Fundamental Requirements

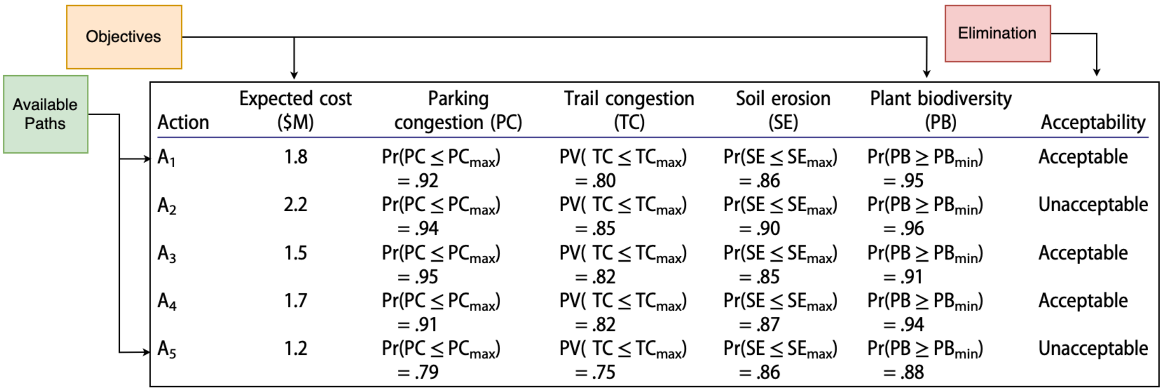
APPENDIX X2 – DETERMINE PREFERRED MANAGEMENT ACTIONS, PAM

This appendix explicates the determination of preferred management action(s) through a Fuzzy TOPSIS method according to (Prato T. , 2016). The procedure is applied by Prato to a highway corridor through a hypothetical national park. Eventually the procedure to determine preferred pathways will be apended to the Dynamic Adaptive Policy Pathways procedure (Haasnoot et al, 2013) in order to compare different paths in more detail and make the consideration of multiple paths more comprehensive.

As shown in Table X2.1, five management actions or pathways (A1 to A5) have been distinguished. All actions are evaluated on four objectives for the highway corridor:

Minimising congestion at the visitor centre parking lot (PC)
Maximising plant biodiversity along hiking trails (PB)
Minimising soil erosion along hiking trails (SE)
Minimising congestion on hiking trails (TC)

Several models, visitor surveys and monitoring data are used and conducted to estimate and/or determine the values of all objectives in all action pathways. Moreover standards have been set for all objectives, following a minimum acceptable level of PB, and maximum acceptable levels of PC, TC and SE. Reliability levels have been arranged for all objectives (PB&PC=0.90; SE=0.85; TC=0.80). The available budget has been set at two million USD.



Action	Expected cost ($M)	Parking congestion (PC)	Trail congestion (TC)	Soil erosion (SE)	Plant biodiversity (PB)	Acceptability
A_1	1.8	$Pr(PC \leq PC_{max}) = .92$	$PV(TC \leq TC_{max}) = .80$	$Pr(SE \leq SE_{max}) = .86$	$Pr(PB \geq PB_{min}) = .95$	Acceptable
A_2	2.2	$Pr(PC \leq PC_{max}) = .94$	$PV(TC \leq TC_{max}) = .85$	$Pr(SE \leq SE_{max}) = .90$	$Pr(PB \geq PB_{min}) = .96$	Unacceptable
A_3	1.5	$Pr(PC \leq PC_{max}) = .95$	$PV(TC \leq TC_{max}) = .82$	$Pr(SE \leq SE_{max}) = .85$	$Pr(PB \geq PB_{min}) = .91$	Acceptable
A_4	1.7	$Pr(PC \leq PC_{max}) = .91$	$PV(TC \leq TC_{max}) = .82$	$Pr(SE \leq SE_{max}) = .87$	$Pr(PB \geq PB_{min}) = .94$	Acceptable
A_5	1.2	$Pr(PC \leq PC_{max}) = .79$	$PV(TC \leq TC_{max}) = .75$	$Pr(SE \leq SE_{max}) = .86$	$Pr(PB \geq PB_{min}) = .88$	Unacceptable

Figure X2.1 – Acceptability of management actions (Prato T. , 2016)

Following the estimates of all objectives and their corresponding reliabilities, both A2 and A5 are unacceptable, since A2 exceeds the budget and A5 is not reliable to meet three out of four.

The elimination of unacceptable management paths could potentially be skipped given the fact that the TOPSIS-decision ruled is an additive of the original frameworks and therefore all actions have already been run through the first steps of the DAPP approach.

Next, for all acceptable paths, linguistic variables with corresponding trangular (fuzzy) numbers have to be set (Table X2.2). The first number is the minimum value, the second second number is the mode and the third number is the maximum value for a triangular probability distribution.

Linguistic variable	Triangular fuzzy number[a]
Very low	(0.05, 0.05, 1)[b]
Low	(0.05, 1, 3)
Moderate	(3, 5, 7)
High	(7, 9, 10)
Very high	(9, 10, 10)

Table X2.2 – Linguistic variables and corresponding triangular fuzzy numbers. (Prato T. , 2016)

The linguistic variables will be assigned by the management to all objectives for all acceptable management paths, and for the importance of the objectives (Table X2.3).

Management action	Parking congestion (PC)	Trail congestion (TC)	Soil erosion (SE)	Plant biodiversity (PB)
A_1	Moderate	Moderate	Very low	Moderate
A_3	High	Very high	Moderate	Moderate
A_4	Moderate	Moderate	Low	High
Importance	Moderate	Moderate	High	Very high

Table X2.3 – Manager's linguistic ratings

Using TOPSIS to determine preferred management actions requires calculated distances of each acceptable management action to the fuzzy positive- (d_i^+) and negative-ideal solution (d_i^-):

$$d_i^+ = \sum_{j=1}^{4} \mathrm{d}(w_j r_{ij}, v_j^+)\ (i = 1, 3, 4)\ (1)$$

$$d_i^- = \sum_{j=1}^{4} \mathrm{d}(w_j r_{ij}, v_j^-)\ (i = 1, 3, 4)\ (2)$$

$d(w_j r_{ij},\ v_j^+)$ = vertex distance between the weighted normalised fuzzy effect of management action i on objective j and the positive-ideal solution for objective j

$d(w_j r_{ij},\ v_j^-)$ = vertex distance between the weighted normalised fuzzy effect of management action i on objective j and the negative-ideal solution for objective j

> w_j > The normalised triangular fuzzy number corresponding to the linguistic variable assigned to the **importace of objective j;**
>
> r_{ij} > The normalised triangular fuzzy number corresponding to th linguistic variable assigned to the **effect of management action i on objective j.**

Basically this implies that the effects of the management action on each objective is multiplied by the relative importance of that objective in order to make the assessment weighted. Next the distance between the weighted effect ($w_j r_{ij}$) to its ideal vectors (v_j^+ or v_j^-) will be calculated using the equation below.

The vertex distance between two triangular fuzzy numbers $z_1 = (e_1, e_2, e_3)$ and $z_2 = (k_1, k_2, k_3)$ is:

$$d(z_1, z_2) = \{0.33[(e_1 - k_1)^2 + (e_2 - k_2)^2 + (e_3 - k_3)^2]\}^{0.5}\ (3)$$

For the constructed example $z_1 = w_j r_{ij}$ and $z_2 = v_j^+$ or v_j^-.

The fuzzy positive- and negative-ideal vectors for the four objectives in the example are:

$v_j^+ = (0, 0, 0)$ and $v_j^- = (1, 1, 1)$ for $j = PC; TC\ \&\ SE$
$v_j^- = (0, 0, 0)$ and $v_j^+ = (1, 1, 1)$ for $j = PB$

Following the distances between each action and its ideal solution, the closeness coefficient (E_i) is determined by:

$$E_i = \frac{d_i^-}{d_i^+ + d_i^-}\ (i = 1, 3, 4; 0 \le E_i \le 1)\ (4)$$

As E_i approaches 0 the values of the objectives move farther away from (or closer to) the values of the objectives for the fuzzy negative-ideal solution and closer to (or further away from) the values of the objectives for the fuzzy positive-ideal solution. The desirability of a management action decreases (or increases) as its closeness coefficient approaches zero (or one).

Acceptable management actions are ranked based on the values of E_i.

Applied to the management path A1 constructed example, in the first row of Table X2.4 the fuzzy effects of each objective are scheduled according to their corresponding linguistic variable. The second row presents the values corresponding to the linguistic variable assigned to their relative importance.

Effect of management action i on objetive j → Fuzzy effects

Importance of objective j → Norm. weights

	Negative (aj-)	Negative (aj-)	Negative (aj-)	Positive (cj+)
	PC	SE	TC	PB
Fuzzy effects	(3, 5, 7)	(.05, .05, 1)	(3, 5, 7)	(3, 5, 7)
Norm. weights	(.3, .5, .7)	(.7, .9, 1)	(.3, .5, .7)	(.9, 1, 1)
	PC	SE	TC	PB
Normalised fuzzy effects	(.429, .6, 1)	(.05, 1, 1)	(.429, .6, 1)	(.333, .556, .777)
Weighted normalised fuzzy effects	(.129, .3, .7)	(.035, .9, 1)	(.129, .3, .7)	(.3, .555, .777)

Table X2.4 – Fuzzy effects; normalised fuzzy effects & weighted normalised fuzzy effects management path A1 (Prato T. , 2016)

Fuzzy effects are normalised following equations (5) and (6).

$$\text{Negative objectives: } r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ where } a_j^- = \min a_{ij} (j = PC, SE, TC) \ (5)$$

$$\text{Positive objectives: } r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right) \text{ where } c_j^+ = \max c_{ij} (j = PB) \ (6)$$

In order to obtain weighted normalised fuzzy effects, the normalised fuzzy effects have to be multiplied by the corresponding weight.

Now that all objectives contain weighted normalised fuzzy effects, distances to postive- and negative-deal solutions could be calculated using equations (1) and (2). Equations (3) and (4) will provide average vertex distances from all acceptable management paths. Table X2.5 visualizes the results:

	Distances from positive- and negative-ideal solutions											
Action	d^+_{PB}	d^-_{PB}	d^+_{PC}	d^-_{PC}	d^+_{SE}	d^-_{SE}	d^+_{TC}	d^-_{TC}	d_i^+	d_i^-	Vertex dist.	Rank
A_1	0.493	0.575	0.444	0.665	0.773	0.557	0.444	0.665	2.154	2.462	0.533	3
A_3	0.493	0.575	0.211	0.804	0.172	0.901	0.101	0.916	0.977	3.197	0.766	1
A_4	0.184	0.867	0.444	0.665	0.575	0.790	0.188	0.857	1.390	3.179	0.696	2

Table X2.5 – Vertex distances; Distances of management paths A1; A3 and A4 to all positive- and negative-ideal solutions.

Now that we're able to calculate vertex distances and distances between ideal-solutions and weighted normalised fuzzy effects for all management paths, the same entire process could be repeated for multiple climate scenarios. Table X2.6 presents preferred actions for all considered climate scenarios.

Climate scenario	C_1	C_2	C_3	C_4
Preferred action	A_3	A_4	A_4	A_2
Maximum loss index	45	58	65	72

Table X2.6 – Maximum Loss Indices for preferred management paths in all climate scenarios.

APPENDIX X3 – EVALUATION

Score	Governance Capability
-	**Reflexivity**, it is essential to deal with this variety of possible perspectives on wicked problems and to prevent both tunnel vision and intractable controversies.
8	While the core of the DAPP framework operates neutral when it comes to the implementation of different perspectives, still a lot of reflexivity could be provided. During the application of the framework, different perspectives could be very well implemented by suggesting different stakeholders to determine their respective preferred pathway in different climate scenarios (Step #6 of DAPP). Several preferred pathways walk through the TOPSIS decision-rule, all represented different perspectives. Moreover, when different pathways overlap, this characterizes socially robust solutions.
-	**Resilience,** capability of the governance system to ensure that the social-ecological system is able to adapt to unpredictable, changing circumstances without losing its identity and reliability.
10	Since the concept is built upon future failure through defining ATP, it definitely ensures that the social-ecological system is able to adapt to unpredictable changing circumstances. By construction pathways that walk through several management actions to reach the objective, and thereby defining transition points for several scenarios, the system considers fundamentally anticipates future failure.
-	**Responsiveness**, there is the need to develop a governance capability to respond wisely to continuously changing demands.
9	Although this governance capability might slightly be equal to the previous one when considering this framework, the responsiveness to changing demands is guaranteed by the transition between management actions. Whenever circumstances change, ATP are reached and additional actions is initiatlised.
-	**Revitalization**, when people are no longer able to critically reflect upon their actions, policy deadlocks arise. It refers to the capability of actors in a governance system to recognize and unblock counterproductive patterns in policy processes, thus to reanimate actors and to enhance processes of innovation needed to cope with wicked problems.
6	One potential problem concerning this governance capability might hold that most managers and decision-makers carry responsibility for several years, while the time-frame of (difficult) actions might stretch multiples. This conflict of interests might cause managers to postpone difficult decisions which ultimately reduces the flexibility to change strategy. As derived from (Restemeyer, van den Brink, & Woltjer, 2018), an inclination was found towards rather maintaining current policies instead of fundamentally transformatting them. This could potentially imply such postponements of difficult decisions.
-	**Rescaling,** capability to observe and address cross-scale and cross-level issues.
7	The capability to identify cross-scale issues is certainly implemented since the framework accounts for an detailed overview of short- mid- and long term developments and their associated uncertainties. Cross-level issues are solved by letting multiple actors and stakeholders construct preferred paths. However, as treated in the previous governance capability, political decision-making cycles, as where budgets partially depent on, play out shorter than the process of climate change. This might hold for the capability of rescaling that conflicts of interests arise.

Table X3 – Evaluation Preferred Management Policy

APPENDIX X4 – CASE STUDY

This appendix contains a case study in which the preferred framework, Dynamic Adaptive Policy Pathways (Haasnoot et al, 2013), has been applied to the project area Den Oever – Den Helder. The TOPSIS analysis from the framework Passive Adaptive Management (Prato T. , 2016) has been added as a filter to support the selection of one out of multiple preferred non-socially robust pathways.

The case study has the purpose to illustrate and elaborate the coverage; opportunities; ease of use; shortcomings; advantages and depth of the proposed framework. Note that in reality the details such as impacts, sell-by-dates and the TOPSIS-analysis deserve way more profession and care.

1 – Describe Study Area	Describe the system's characteristics; (main) objectives; constraints in the current situation; potential constraints. Define the defintion of a succesful plan. The description of the study area includes a specification of the relevant uncertainties and vulnerabilities of the entire system. This can as well relate to future scenarios as the lack of data or models.

In the complex project between Den Oever and Den Helder the system is subjected to several influences and perspectives. However, the main objective of the flood defence system is **to ensure legal safety standards and fulfill duty of care.** Besides the main goal the purpose of this novel methodology is **to increase natural, social, cultural and sustainable values.**

Current and future constraints would hold **changeable legistlation** such as the Omgevingswet; **the lack of insight in the shelf life of currently sufficient trajectories** since some developments or test tracks are hard to monitor and therefore difficult to determine significantly. Moreover the **nearby support base** for follow-up projects will drop significantly whenever maintenance activities are executed relatively frequently as a result to adaptive management.

A plan:

Is considered succesful whenever the manager is able to ensure the obligated safety standards, while both provide and obtaining more resilience for uncertain future developments. Moreover, it is important the plan contributes to the next subjets:

i. Provide social added value. The postponement of activities creates opportunities to combine autonomous activities by consciously not locking the planning-horizon for several decades but instead keeping multiple options open (avoid lock-out & lock-in situations).
ii. Minimalise the impact on the environment and other natural values. Within the perspective of frequent maintenance activities, the potential environmental costs must be consciously outweighted and compared by all benefits.
iii. Realize sustainable profits.
iv. Reduce the likeliness and volume of unnecessary investment.

The following relevant uncertainties and vulnerabilities have been identified:

The current state of the grass coverage is obscure. **Additional investigation concerning the stability and grass coverage** of the flood defence system is desirable. This clarifies the combination of seveveral measures with future activities. This is particularly important since mudflat birds in nearby nature areas appear to be disturbed by maintenance or reinforcement activities.

During an field observation with several experts it became clear that the dynamic process within **the mudflat soil cause ground level rise in the Wadden Sea**, which positively influences safety assessments of the primary flood defences. Their advice was to digest this knowledge into potential opportunities.

The current state concerning **spacious quality and regulation.** Visions and the planning from different stakeholders that require long-term agreements or contracts might interfere with adaptive management and present themselves as typical *lock-outs*.

Certain documents have limited shelf lives so will have either to be extended or conducted anew. Therefore further investigation is desirable concerning the **limited "shelf life" of investigations; assessments; reports and i.e. the MER.**

2 – Problem Analysis	In this step the current situation and possible future situations are compared with the specified objectives in order to identify whether there are any gaps. Possible future situations are "reference cases" assuming no new policies are implemented. A gap indicates that actions are needed. The identification of opportunities and vulnerabilities can be based on the analysis of the reference case, which can best be accomplished using i.e. a computational model.

The flood defence trajectories between Den Oever and Den Helder, 12-1 and 13-5, have been assessed and labeled insufficiently corresponding multiple test tracks during the twelve-year test round in 2017.

Conventional policies would prescribe static reinforcement activities with an estimated average shelf life of for instance 50-70 years. However, due to future uncertainties such as subsidence and climate change, such huge reinforcement activities might result in unnecessary costs; potential lock-outs or inadequate measures. Tables X4.1 and X4.2 visualize the insufficient trajectories and test tracks. The following tables X4.3; X4.4 and X4.5 provide future insight into the test tracks STBI, GEBU and ZST in terms of expected shelf lives, dervied from (HHNK, Analyse Levensduur DODH, 2020):

Track	Type	Cat	Assessment
AGK	ST+CT	V	Sections 1, 2, 3 and 6 hold category II. Sections 4, 5 hold category V and are together with section 6 estimated to be at the end of their shelf life. Due to foreland at section 6 the local hydraulic load is relatively low.
GEBU	ST+CT	V	Every section holds category II, while DP21.7, DP22.2 hold category IV and sections DP23.3 and DP24.1 hold category V.
ZST	CT	V	In total 29 sections (2,9km) hold category II, while 12 sections (1,2km) hold category V due to the instability of the top layer. The remaining 6,6km of the WZW doesn't apply to ZST.

Table X4.1 – Insufficient test tracks trajectory 12-1.

Track	Type	Cat	Assessment
STBI	ST+DT	VI	Both signaling and ultimate threshold do widely not meet during 7,8 km. This holds for sections 13005.1 till 13007.2
STBU	ST+DT	V	Both signaling and ultimate threshold do not meet during 2,0 km. This holds for sections 13006.2, 13006.8, 13007.1 and 13007.2.
ZST	DT	VI	Both signaling and ultimate threshold do not meet during 4,9 km: 3300-5500; 5600-6000, 6200-6400, 6600-6700, 6800-6900, 7300-7400, 7500-7600, 8100-8300, 8400-8600, 9000-10307.

Table X4.2 – Insufficient test tracks trajectory 13-5

Topic	BZD & ADD (13-5)	WZW (12-1)
Burst	Except for cross-section 13008.2 all considered cross-sections have turned out to be insufficient in 2023, and reduce through the years.	Only relevant within the first trajectory. First trajectory is widely sufficient.
Inner Macrostability	For the weakest cross-section (13008.1a) the signaling threshold is expected to be slightly exceeded in 2100.	Both trajectories are widely sufficient until at least 2100.

Table X4.3 – Expected shelf life STBI.

Topic	2023	2070	2100
Wave Run-Up	Both closed as open sods sufficient.	Closed grass sods sufficient. Two analysed locations are insufficient considering open sods.	Closed grass sods sufficient. Open grass sods insufficient.
Wave Hit	Section 6 insufficient for closed sods.	Both section 6 as section 9 insufficient for closed sods.	-

Table X4.4 – Expected shelf life GEBU.

Topic	2023	2070	2100
BZD	A few sections are insufficient, around 5%	A few sections are insufficient, around 10%	Many sections are insufficient.
ADD	Half of the sections are insufficient.	Around 75% of the sections are insufficient.	Around 75% of the sections are insufficient.
WZW	Except for three sections, all sections are insufficient	Except for two sections, all sections are insufficient	Except for one section, all sections are insufficient.

Table X4.5 – Expected shelf life ZST.

According to section 3.3.3.5 of this report, the results of the RSL analysis concerning Water Pressure and Wave Hit (test tracks AGK & AWO) confirmed that the coverage of asphalt is sufficient untill at least 2100.

The test tracks STBU and GEKB have been analysed by Deltares (Breteler, 2018). All test tracks that are assumed to be insufficient by 2073 or 2100 have been implemented in Table X4.6 below:

	< BZD + ADD (13-5) >			< WZW (12-1) >		
	2023	2070	2100	2023	2070	2100
STBI	Burst: All cross-sections expect one.	DP8.7 – DP11.7+50.	13008.1a (weakest) slightly exceeded.			
GEBU				Wave Hit: Section 6 insufficient (closed sods)	Wave Run-Up: Two locations insufficient (open sods). Wave Hit: Sections 6 + 9 insufficient (closed sods)	Wave Run-Up: Open sods insufficient.

ZST	BZD: Around 5% insufficient. ADD: Half of the sections insufficient.	BZD: Around 10% insufficient. ADD: Around 75% insufficient.	BZD: Many sections insufficient. ADD: Around 75% of sections insufficient.	Except for three sections, all insufficient.	Except for two sections, all insufficient.	Except for one section, all sections insufficient.
AGK	ADD: Currently sufficient: Additional analysis is necessary BZD: Sufficient	ADD: Currently sufficient: Additional analysis is necessary BZD: Most probable insufficient	ADD: Currently sufficient: Additional analysis is necessary			

Table X4.6 – Summary expected shelf lives of relevant test tracks for each trajectory.

3 – Identify Actions	The actions could be specified in the light of opportunities and vulnerabilities previously identified, and moreover could be categorized according to the four types of actions specified in the Adaptive Policymaking framework. The aim of this step is to assemble a rich set of possible actions or strategies.

In april 2020 the manager, HHNK, already provided a brief overview of the considered actions and urgencies for the specified expected life services (HHNK, Analyse Levensduur DODH, 2020). Based on this report all actions dervied from the corresponding test tracks are distinguished and identified in Table X4.7:

	Event	Solutions	Priority	Proposal HHNK
STBI	Shearing of the flood defence system by softening due to high internal ground water level.	Aggravation of the embankment with stones.	High – Insufficient on both short and long term.	Immediate reinforcement.
GEBU	Damage by wave hits.	Asphalt with grass layer on top. Optimize grass management.	High – Around 300m needs immediate reinforcement. Low – Wherever Wave Run-Up is determinant.	A – Immediate reinforcement for 300m. B – Optimize management of remainder trajectories.
ZST	Damage by wave hits.	Replace concrete block revetment by similar revetment.	Low – Priority differs for each cross-section when sanding in foreland is considered.	Reinforcement could potentially be postponed due to robust models. Field experiments could contribute to this.
AGK	Damage caused by ground water pressure under the asphalt layer.	Replacement of asphalt layers by new (possible recyclable) asphalt.	ADD: High – However uncertain whether application requirements or	ADD: Further investigation and possible urgent reinforcement.

			real factors cause insufficiency. BZD: Low – Sufficient for 15y.	BZD: Explore novel insight.
Asphalt	End of shelf life present asphalt coverage.	Replacement of asphalt layers by new (possible recyclable) asphalt.	WZW: High (3,2km) WZW; ADD & BZD: Very Low – Sufficient for 50y.	A – Immediate reinforcement for 3,2km. B – Additional investigation remaining trajectories.

Table X4.7 – Preferred management actions based on internal reports (HHNK, Analyse Levensduur DODH, 2020)

In addition to the internal reports, Ruud Joosten, counsellor technical management HHNK, has been asked to provide insight concerning the several management actions that are currently actively considered. Moreover he included feedback on all management actions concerning safety, sustainability, costs, social disturbance and impact on nature. Table X4.8 summarizes his insights and feedback:

Track	Context
STBI	Pouring concrete with the purpose to improve inner macro stability might not be very sustainable in terms of purchasing and producing concrete, while once the concrete is located it remains sufficient for many years. Overall quite sustainable.
ZST	Replacement of concrete block revetment negatively impacts nature since it disturbes local bird populations. Social impact or disagreement is assumed to be shallow.
AGK	When it comes to the asphalt layers (applies to the top asphalt layers as well), several options are available. With asphalt not being built-up in multiple layers as done with roads, one option is to replace to entire layer. A second option is to break the old asphalt layer and to use it as a foundation layer, which reduces the amount of new asphalt is necessary. At third, existing asphalt layers could be recycled for the new layers, with could add up to a 30% new – 70% recycled ratio. Fourth, milling the upper top layer of the asphalt and add a new layer with iron reinforcement in between. All options are quite sustianable when it comes to flood safety, remaing sufficient for multiple decades. The social impact is dependent on the reccurance time of maintenance activities. Five years is not acceptable, while a return within thirty years has a substantially support base.

Table X4.8 – Input Ruud Joosten (Counsellor Technical Management HHNK)

Table X4.9 provides a clear overview of all actions that will be implemented in the pathway map and the corresponding test tracks they are related to:

Action	Track
Aggravation of the embankment with novel stones.	STBI
Immediate reinforcement of 300m of grass-sods.	GEBU
Optimize grass management for currently sufficient trajectory.	GEBU
Reinforce grass sods for the entire trajectory.	GEBU
Partially replace concrete block revetment at insufficient locations.	ZST
Replacement of concrete block revetment by similar revetment for the entire trajectory.	ZST
Continue with current asphalt layers.	AGK
Reinforcement of outer asphalt layers ADD.	AGK

Reinforcement of all outer asphalt layers (ADD+BZD).	AGK
Reinforcement of outer asphalt layers BZD.	AGK
Replacement of top asphalt layers (WZW; 3,2km).	Asphalt
Additional investigation remaining trajectories.	Asphalt
Reinforcement of top asphalt layers remainder trajectory.	Asphalt

Table X4.9 – Management actions

4 – Evaluate Actions	Assess all actions on their (expected) performance and specifications. For each actions this holds the impact(s); sell-by-dates and costs, for each scenario. With the impacts of actions in mind, vulnerabilities and opportunities have to be reassessed.

The actions derived form the previous step have been assesed on all important (sub-) objectives derived from the first step. In this case study the assessment has been made using expert estimates and electronic sources. To make the DAPP more comprehensive and solid, it is desirable to execute computational models; field observations and empirical studies to determine the influence of all possible actions on their objectives. Figure X4.1 represents the assessment.

Two scenarios are distinguished. The mild scenario represents an advantageous outcome of future uncertainties, such as a moderate sea level rise and an impaired subsidence. The extreme scenario considers the inverse of the mild scenario. The sell-by-dates or ATP for all management actions are determined for each scenario.

The information concerning the sustainability, impact on nature and social disturbance and relative costs of aggravating the embankment with novel stones has been obtained from a guide made by Deltares in 2015 (Deltares, 2015). The information concerning the impact of management actions for novel concrete block revetment layers on above mentioned objectives has been obtained from (Betonproducten, 2016).

The aggravation of the embankment with novel stones is a very expensive activity that negatively impacts natural and social values by disturbance. However, the standards for STBI are currently insufficient on both the short- and long-term, so postponement or lighter alternatives are illogical. Still, this action needs to be implemented equal to all other actions since urgency isn't treated in this step. In the next step preferred pathways will be arranged, which are subjected to urgency.

Action	Impacts					
Flood Management Actions	Safety	Nature	Social	Sustainability	Sell-By-Date	Costs
Aggravation of the embankment with novel stones	+++	-	-	-	2070-2090	++
Immediate reinforcement 300m of grass-sods	++	0	0	0	2030-2050	0
Optimize grass management for currently sufficient trajectory	+++	+	+	+	2040-2100	+
Reinforce grass sods for the entire trajectory	++	-	-	+	2050-2080	+++
Partially replace concrete block revetment at insufficient locations	+	-	0	++	2035-2045	+
Replacement of concrete block revetment by similar revetment for the entire trajectory	++	---	--	+	2080-2100	+++
Continue with current asphalt layers	-	0	0	+	2025-2035	0
Reinforcement solely outer asphalt layers ADD	++	-	-	+	2040-2050	+
Reinforcement of all outer asphalt layers (ADD + BZD)	+++	--	--	++	2070-2100	+++
Reinforcement of outer asphalt layers BZD	+	--	--	+	2080-2100	++
Replacement of top asphalt layers (WZW; 3,2km)	+	-	-	++	2060-2080	+
Reinforcement of all top asphalt layers	++	--	-	+	2090-2100	+++
Reinforcement of top asphalt layers remainder trajectory	++	--	--	+	2090-2100	++

Figure X4.1 – Assessment of the impact of all management actions on each objective.

Since 300 meter of the grass sods is damaged, the reinforcement of this small stroke is relatively inexpensive and contributes to the overall safety level of the grass layer. However sustainability is hard to determine since grass layers could deteriorate very fast. An adequate grass management is very desirable since this could significantly increase the percentage of closed sods for the long-term, however does not guarantee closed sods. The reinforcement of grass-sods is currently illogical and doesn't guarantee closed sods for even short-term horizons (Ruud Joosten, 2020).

The decision to continue with the current stack of concrete block revetment raises the opportunity to further investigate the effect of sanding into the foreland, and moreover to investigate the robustness of the models that have been used to assess the sufficiency of the current revetment layers. Novel revetment layers have been proven to be very sustainable and potentially even recyclable. Concrete block revetment layers could have multiple opportunities, depending on the way and place they are located (Betonproducten, 2016).

The current outer asphalt layers of the ADD are assessed insufficient and therefore needs immediate reinforcement. However, if application requirements cause the insufficiency, which is still unclear, postponement would provide a sustainable cost-free strategy for the next 10 years. Reinforcement activities of all outer asphalt layers is expensive an yet not necessary. When this strategy is applied, recyclable asphalt could be preferred to contribute to sustainable values. Reinforcement of only BZD is currently illogical, however when the strategy is chosen to initially reinforce the ADD, this is a logical following step in the time period 2035-2045.

Replacement of the top asphalt layer during 3,2 kilometer at the WZW is urgent and therefore directly contributes to the corresponding safety level. This strategy could contribute to the sustainability of the WZW since this relatively small activity significantly stretches the shelf life and is quite inexpensive. Meanwhile the remainder trajectory could await maintenance for another 50-60 years, depending on the scenario, which is in fact a sustainable cost-free adaptive strategy.

5 – Develop Pathways	Once the set of actions from the previous step is adequate, pathways can be created. A pathway consists of a combination of actions, where a new action is activated once its predecessor is no longer able to meet the definition of succes and reaches its ATP. Analysts could explore all possible routes and evaluate performances of these routes. To do this, additional information such as urgency; severinity or uncertainty could be used to support promising pathways. If sell-by-dates for certain actions will possibly increase significantly, additional lines can be added. Illogical actions could be eliminated by making their appearance more transparant untill the point they become relevant.

The pathways will be created with the Pathway Generator, the software is downloadable at the public site of Deltares: https://publicwiki.deltares.nl/display/AP/Pathways+Generator. Running the Pathway Generator, either a condition-based approach or a time-based approach can be chosen. The condition-based approach could be very helpful for situations in which most management actions are depending on one or two conditions (subsidence per year i.e.). For the purpose of this case study, the time-based approach is chosen.

First, all separate management actions and corresponding ATP (scenario-based) derived from the fourth step, are implemented in the program. To be clear, these actions include all actions from Figure X4.2 that have an empty "type of pathway" section. The next step is to point out "combine" and "sequence" pathways, which are either combinations or sequences of two preceding actions.

ID	Color	Action or Pathway	Type of pathway	Mild	Extreme
-->1		Current Situation		2025	2020
2		Aggravation (novel stones)		2090	2070
3		Immediate reinforce grass-sods (300m)		2030	2025
4		Optimize grass management		2035	2030
15		Grass-sods (300m) + Optimize grass management	Combine	2070	2040
16		Grass-sods (Entire Trajectory)		2035	2030
17		Optimize grass management + Grass-sods (Entire Tracjectory)	Combine	2090	2070
18		Grass-sods (300m) + Optimize grass management + Grass-sods (Entire Trajectory)	Combine	2090	2070
6		Partial Reinforce CBV (Insufficient Loc)		2045	2035
19		Reinforce CBV (Entire Trajectory)		2100	2090
20		CBV (Insufficient Loc) + CBV (Entire Trajectory)	Sequence	2100	2090
8		Continue Current Asphalt		2035	2030
9		Reinforce Asphalt ADD		2050	2040
21		Current Asphalt + Reinforcement ADD	Sequence	2065	2050
10		Reinforce Asphalt ADD + BZD		2100	2070
22		Current Asphalt + Reinforcement ADD + BZD	Sequence	2100	2070
11		Reinforce Asphalt BZD		2100	2080
12		Top-Asphalt WZW (3,2km)		2080	2060
13		Top-Asphalt Remainder Trajectory		2100	2090
14		Top-Asphalt Entire Trajectory		2100	2090
23		Reinforce Asphalt ADD + Top-Asphalt Entire Trajectory	Sequence	2100	2090
24		Partial Reinforce CBV (Insufficient Loc) + Reinforce Asphalt BZD	Sequence	2100	2080
25		Current Asphalt + Reinforcement ADD + Reinforce Asphalt BZD	Sequence	2100	2080
26		Reinforce Asphalt ADD + Top-Asphalt Remainder Trajectory	Combine	2100	2090
27		Current Asphalt + Reinforcement ADD + Top-Asphalt Remainder Trajectory	Combine	2100	2090

Figure X4.2 – Management Actions and corresponding ATP.

The construction of combinations and sequences could best be done using the roadmap-view. Combinations and sequences (verticals) are derived from logical, empirical opportunities, which could as well be constructed by managers as by different stakeholders. Figure X4.3 visualizes the Adaptive Pathways Roadmap for the case study. Both scenarios have been presented together using Adobe Photoshop CC 2020. The extreme scenario is represented by the dimmed roadmap with low opacity, whereafter the mild scenario follows the colourful roadmap with full opacity. The current situation is immediately insufficient in the extreme scenario, while the mild scenario considers the current situation to be sufficient for another five years. Normally two or more climate scenarios would be considered, and the respective roadmaps do not have to be collided.

As Figure X4.3 visualizes, most actions operate independent since the corresponding activities are related to a certain test track. Therefore the type of activities can not be combined or sequenced. However, several combinations could be made with the purpose to reduce the social impact on neighbouring residents or to reduce project costs.

One remarkable combination could hold the synchronous reinforcement of the outer asphalt layers at the BZD with the top-asphalt layer of the remainder trajectory.

Dashed lines represent the combination of multiple actions, as for instance the immediate reinforcement of grass sods at currently insufficient locations could be combined with the optimization of grass management. When this combination is estimated to be insufficient, around 2040 in the mild scenario the option arises to change strategy into a new combination. This new combination includes the grass sod reinforcement of the entire trajectory with the optimization of grass-management. Although it is almost impossible to determine sell-by-dates for grass sods, this test track has been implemented to elaborate and explain the capabilities of the framework.

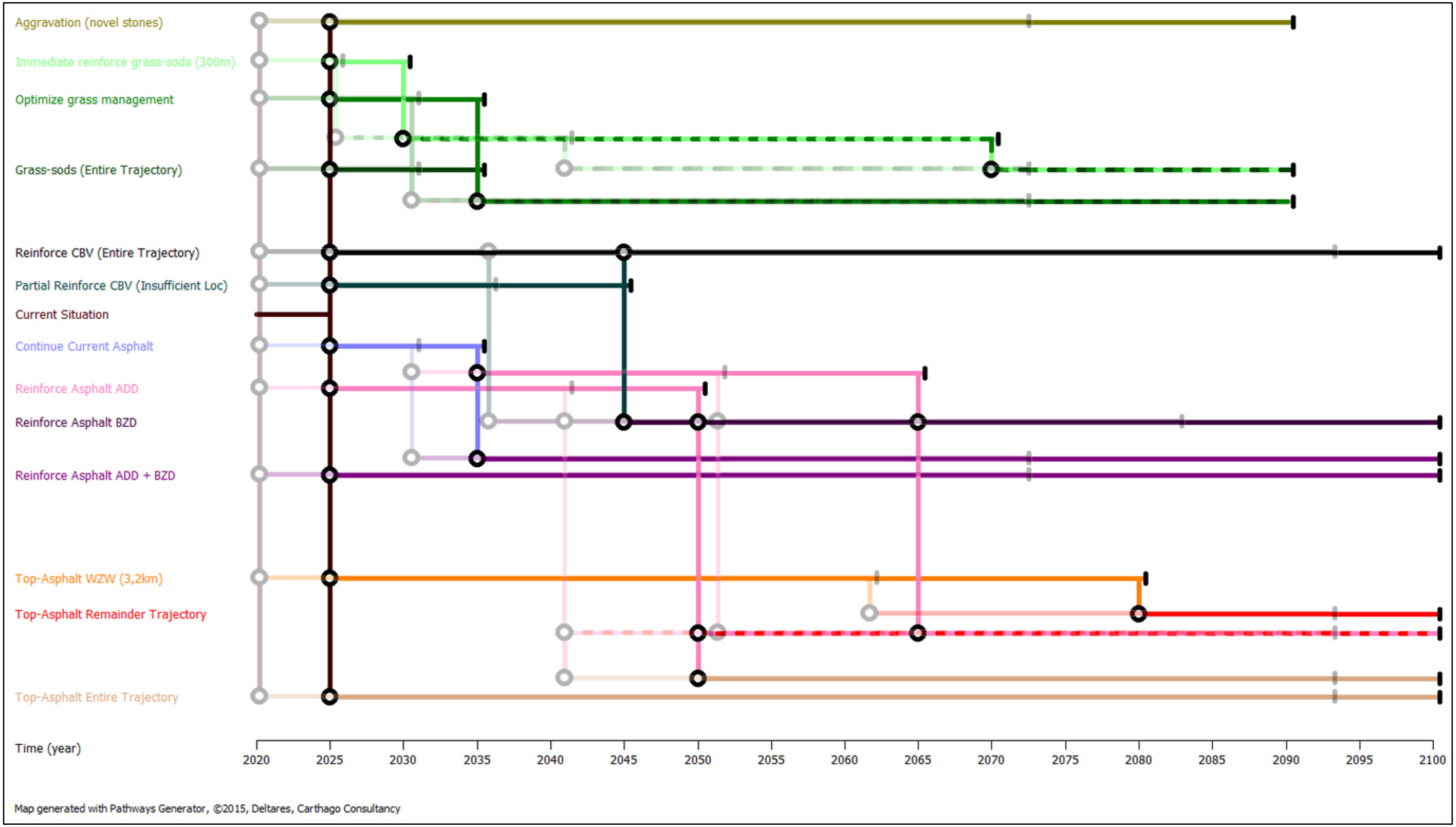


Figure X4.3 – Adaptive Pathways Roadmap (Extreme Scenario dimmed)

6 – Preferred Pathways	Preferred pathways are pathways that fit well within a specified perspective. It could be useful to specify two to four pathways that reflect different perspectives in order to identify socially robust pathways. The preferred pathways form the basic structure of a *dynamic adaptive plan*. Different stakeholders and decisionmakers have different preferred pathways. The point at which different preferred pathways start to diverge can be considered as decision points.

Two different perspectives have been distinguished. The first perspective represents the **social actor** that values social impacts. Frequent reccurance of maintenance activites disturbes his social wellbeing as this actor lives nearby the project area. His perspectives justifies increased project budgets with a decrease in such an impact. The second perspective is core-project based and represents the **financial actor**. The purpose of such Adaptive Management is to support in the governance of future uncertainties, reduced project costs align with the preferences of this actor.

Figure X4.4 visualizes the preferred pathways of both stakeholders. The green line represents the social actor, while the blue line represents the financial actor. As derived from the roadmap, pathways #1, #4 and #5 overlap for both actors. While the collision of pathway #1 is obvious, since no other management actions have been determined within this test track, pathways #4 and #5 could be interpret as **socially robust pathways**.

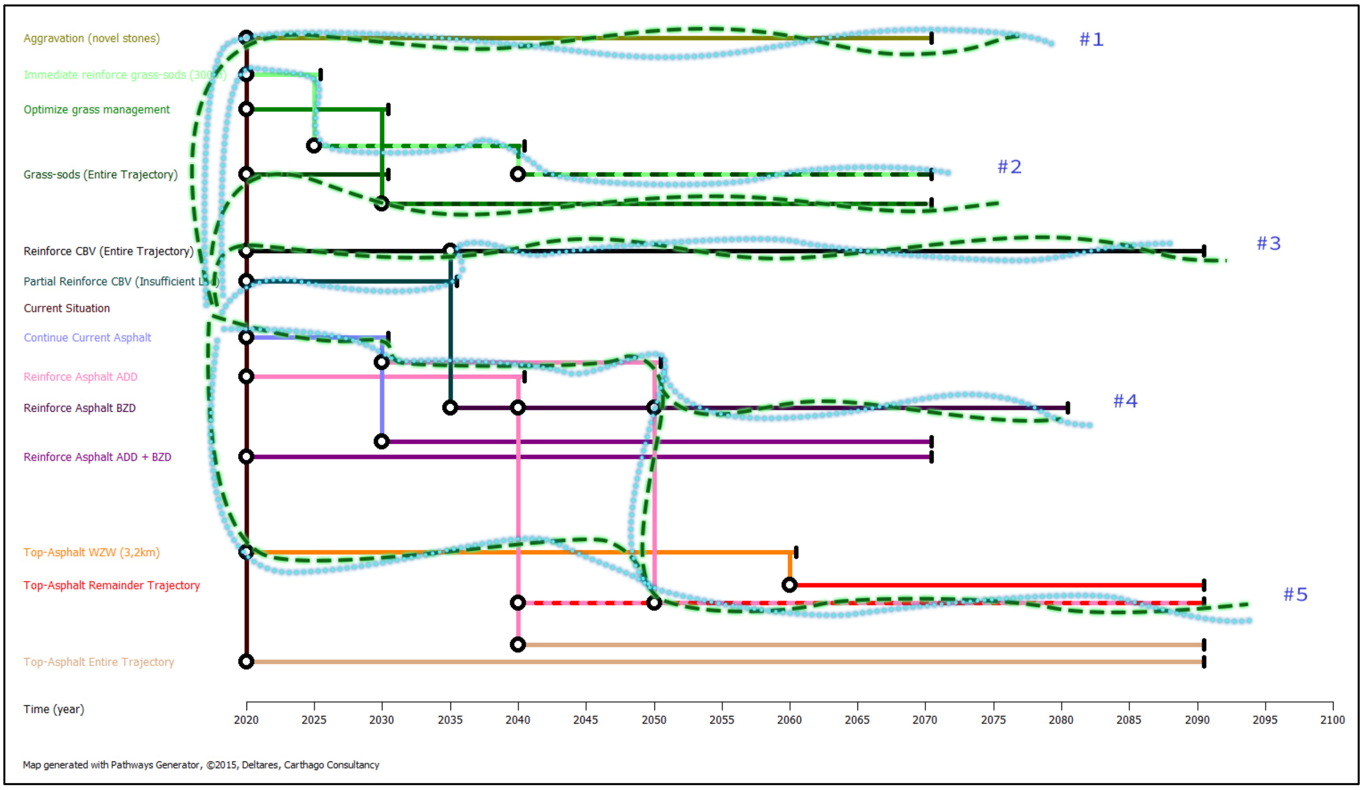


Figure X4.4 – Preferred Pathways; Extreme Scenario

The first actor benefits from the least reccurance of maintenance activities, combining the reinforcement of the BZD outer asphalt layers together with the remainder top asphalt layers around 2050 is in his favour. For this combination to happen, first the ADD outer asphalt layer and the WZW top asphalt layer have to be reinforced.

Summarized, this would result in one relatively small maintenance activity in 2020 (ADD + WZW 3,2km), and one larger task around 2050 (BZD + remainder trajectories). Since this combination is financially the most suitable, the second actor prefers this pathway as well.

TOPSIS	When preferred pathways for all involved stakeholders have been constructed, the TOPSIS decision rule supports the management in determining the strategies for pathways #2 and #3.

The same linguistic variables and corresponding numbers according to Table X2.2 will be used. For the remainder two management actions, four different pathways have been distinguished. Figure X4.5 visualizes the linguistic rating of all possible pathways on their corresponding objectives or impacts. Both **social** and **costs** include negative objectives, while **safety**, **nature**, and **sustainability** include positive objectives.

Management Action	Safety	Nature	Social	Sustainability	Costs
#2 Green	Very High	Low	High	Moderate	Moderate
#3 Green	High	Moderate	High	Moderate	Moderate
#2 Blue	Very High	High	Moderate	High	High
#3 Blue	High	Low	Low	High	High
Importance	Very High	Moderate	High	Moderate	High

Figure X4.5 – Linguistic Ratings // Extreme Scenario

The next step is to calculate the normalised fuzzy effects for all management paths using equations (5) and (6) from Appendix X2. The normalised fuzzy effects have been weighted by multiplying them with the normalised weights. Figure X4.6 presents the outcome of these calculations for management pathway #2 green in the extreme scenario.

	Safety			Nature			Social			Sustainability			Costs		
Fuzzy effects	7,00	9,00	10,00	0,05	1,00	3,00	0,05	1,00	3,00	7,00	9,00	10,00	7,00	9,00	10,00
Normalised weights	0,90	0,90	1,00	0,30	0,50	0,70	0,70	0,90	1,00	0,30	0,50	0,70	0,70	0,90	1,00
Normalised fuzzy effects	0,700	0,900	1,000	0,017	0,333	1,000	0,017	0,050	1,000	0,700	0,900	1,000	0,700	0,778	1,000
Weighted normalised fuzzy effects	0,630	0,810	1,000	0,005	0,167	0,700	0,012	0,045	1,000	0,210	0,450	0,700	0,490	0,700	1,000
Vertex Distance to Positive		0,24			0,77			0,58			0,58			0,76	
Vertex Distance to Negative		0,82			0,41			0,79			0,49			0,34	
Positive Ideal Solution	1	1	1	1	1	1	0	0	0	1	1	1	0	0	0
Negative Ideal Solution	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1

Figure X4.6 – Fuzzy Effects, (Weighted) Normalised FE, Vertex Distances and Closeness Coefficient. // Extreme Scenario; Pathway #2 Green.

After the weighted normalised fuzzy effects have been determined, vertex distances to the positive- and negative-ideal solutions have been calculated using equation (3). Note that the triangular fuzzy numbers of positive- and negative-ideal solutions depend on the colour of the objective. The positive-ideal solutions for negative objectives holds vector (0, 0, 0) whereas for positive-ideal solutions it holds the opposite. The last two rows of Figure X4.6 contain the corresponding vectors for all objectives.

Using software such as Microsft Excel eases the process to develop vertex distances for all management paths. Equation (4) provides closeness coefficients for all pathways. Figure X4.7 presents the vertex distances and closeness coefficients for all paths in the extreme scenario.

As explained in Appendix X2, *when E_i approaches 0 the values of the objectives move farther away from the values of the objectives for the fuzzy negative-ideal solution and closer to the values of the objectives for the fuzzy positive-ideal solution. As E_i approaches 1 the opposite holds.*

	Safety		Nature		Social		Sustainability		Costs		E
	-	+	-	+	-	+	-	+	-	+	
#2 Green	0,15	0,87	0,77	0,41	0,76	0,34	0,65	0,46	0,68	0,48	0,540394973
#2 Blue	0,15	0,87	0,58	0,49	0,68	0,48	0,58	0,49	0,58	0,49	0,476808905
#3 Green	0,24	0,82	0,65	0,46	0,76	0,34	0,65	0,46	0,68	0,48	0,537906137
#3 Blue	0,24	0,82	0,77	0,41	0,58	0,79	0,58	0,49	0,76	0,34	0,506920415

Figure X4.7 – Vertex Distances and Closeness Coefficients of all paths. // Extreme Scenario

Concluding, **the green pathways**, based on the preference from the social actor, have been determined most advantageous based on the five management objectives in the extreme scenario.

Table X4.10 presents the preferred pathways and respective management strategies for the extreme scenario:

Track	Preferred Pathway	Type
STBI	Aggravation of novel stones.	Socially Robust
GEBU	Reinforcement entire trajectory of grass sods > Optimize grass management.	TOPSIS
ZST	Reinforcement concrete block revetment entire trajectory.	TOPSIS
AGK	Continue current asphalt > Reinforce asphalt ADD > Reinforce asphalt BZD.	Socially Robust
Asphalt	Top asphalt WZW > Top asphalt remainder trajectory.	Socially Robust

Table X4.10 – Preferred Pathways // Extreme Scenario.

Note that the process should be repeated for all scenarios.

7 – Contingency Planning	These are actions to anticipate and prepare for one or more preferred pathways (e.g. keep options open) and moreover corrective actions to stay on track in case the future turns out differently than expected. *(Corrective-, Defensive- and Capitalizing actions of APM)*

Now that the initially preferred pathways have been established using the TOPSIS decision rule, changing strategies as a result from future uncertainty in different scenarios should be safeguarded by an adequate contingency planning.

Due to the fact that only one scenario has been elaborated in preferred pathways, accurate case study examples can not be provided. However, when i.e. the immediate reinforcement of 300 meter grass-sods turns out to be difficult due to permittance, the manager should anticipate such events by establishing his contingency planning.

8 – Dynamic Adaptive Plan	This step holds the translation from all previous steps into a *dynamic adaptive plan* that provides support onto what actions/decisions should be taken and what could be postponed. The plan summarizes the results from previous steps, such as the objectives, problems and preferred pathways. The challenge is to draft a plan that keeps relevant preferred pathways open for as long as possible. It specifies the monitoring system.

The DAP contains all (relevant) elements, with special emphasis on the all the preferred pathways for all climate scenarios; the contingency planning; budget flows and policy for the identification of linkage opportunities.

9 – Implementation and monitoring	Finally, the actions to be taken immediately are implemented and the monitoring system is established. When time starts running, signpost information related to the triggers is collected; actions are started, altered, stopped, or expanded in response to this information. After the implementation of the initial actions, the activation of additional actions is postponed until a trigger event occurs.