Towards a Veluwe for all the future generations

Policy advice for Water board Vallei en Veluwe to improve the biodiversity and, at the same time, protect the citizens on the upper part of the IJssel river against floods.

Group 12

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Summary

The increasing impact of flooding on communities and the environment has become more pronounced, particularly in Europe where flood-related damages have risen by 10% over the past decade. The construction and elevation of dikes have been commonly used to mitigate these risks, but they often result in significant ecological disruption and biodiversity loss. In response, the Dutch government launched the "Room for the River" program, which focuses on nature-based solutions to create more space for rivers to overflow safely while enhancing ecological quality. However, integrating flood protection with nature conservation presents challenges due to diverse stakeholder interests and ecological uncertainties. This report by analysts for the Water board Vallei en Veluwe aims to develop policies for the IJssel River that balance flood risk mitigation with environmental preservation, considering the perspectives of various stakeholders.

To provide a policy, several analyses have been conducted. The process began with an Extra Trees analysis to examine sensitivity, followed by scenario discovery using PRIM. Five scenarios were selected, which led to various policies in the multi-scenario MORDM. These policies were then delineated and tested for robustness, leading to recommendations.

As for the recommended policies, a solution space is given with ranges for the policy choices, while also a more specific recommended single policy is given. The recommended approaches combine nature-based solutions (more specifically Room for River in the model), at Room for River locations 2 and 3, with moderate dike increases of about 2.6 - 2.7m. These policies demonstrate strong robustness and performance across scenarios. Although precise values are challenging to implement in reality, the broader solution space offers flexible, robust options that are economically viable, safe in terms of deaths and damages, and environmentally friendly.

The research involves significant assumptions or limitations. The most notable ones are as follows: The focus of this study is on the 10% worst-case scenarios. This approach is highly risk-averse. There are more ambitious approaches that could potentially perform better overall but might only score lower in the worst-case scenarios.

Additionally, the model does not generate outputs that measure nitrogen emissions or nature conservation. Incorporating such metrics could offer a more comprehensive perspective on policy outcomes, especially for stakeholders such as Waterschap Vallei en Veluwe, where environmental preservation holds significant value.

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1. Introduction

The impact of flooding on the environment and communities has become increasingly significant in recent years. Statistics reveal that Europe has experienced a 10% rise in flood-related damages over the last decade (European Environment Agency, 2023). Alongside this, biodiversity loss has accelerated, with a notable decline in species richness in riparian habitats due to human interventions such as dike construction (WUR, n.d.) In response, various flood protection measures, including the construction and elevation of dikes, have been implemented without adequate consideration for their ecological consequences. While these measures effectively reduce flood risks, they often disrupt natural habitats and biodiversity (Opperman, 2019).

To address these challenges, the Dutch government initiated the Room for the River (RFR) program, which emphasizes nature-based solutions. This approach aims to create more space for rivers to overflow safely, thereby reducing flood risks while enhancing ecological quality (Ministerie van Infrastructuur en Waterstaat, 2024). Despite the program's successes, the integration of flood protection and nature conservation remains a complex challenge due to diverse stakeholder interests and ecological uncertainties.

As analysts for the Water board Vallei en Veluwe, our objective is to provide strategic advice on flood risk management for the IJssel River. This report focuses on developing policies that not only mitigate flood risks but also keep the biodiversity and environmental quality in the region. Formulating an optimal policy is challenging due to the uncertainties inherent in predicting future flood scenarios and the need to balance the interests of various stakeholders, including transport companies, environmental groups, and governmental agencies.

Effective decision-making in flood protection requires a collaborative approach that ensures consensus among stakeholders. This is crucial for developing widely supported policies that address the dual objectives of minimizing flood risks and enhancing ecological quality. The Water board Vallei en Veluwe is particularly committed to environmentally friendly practices, such as reducing nitrogen levels in water bodies to improve ecosystem health. This is a given mandate by one of the lecturers.This leads to the following research question:

What are the optimal policies to manage and mitigate flood risks of the Ijssel River effectively, with as little impact on nature as possible, given the various perspectives of the stakeholders involved in the decision-making process.

The report begins with an introduction, discussing the increasing impact of flooding, the challenges of current flood protection measures, and the need for nature-based solutions. The problem framing section explores traditional flood protection approaches in the Netherlands and the need for innovative strategies like the RfR program. The political arena section identifies key stakeholders involved in policy formation for flood risk measures along the IJssel River. The approach section describes the methodology used to develop flood risk management policies, and the results section presents findings from the analysis. The report ends with a conclusion, that among other things, gives the answer to the research question.

2. Problem framing

Traditionally, flood protection in the Netherlands has relied heavily on constructing and maintaining dikes. This approach was guided by risk and cost-benefit analyses, balancing economic and safety indicators (De Bruijn et al., 2015; Nillesen & Kok, 2015). However, high water levels in 1993 and 1995 prompted experts to question the effectiveness of this strategy, especially in light of climate change, which increases flood risks through more rainfall, land subsidence, and sea level rise (Ministerie van Infrastructuur en Waterstaat 2024b; De Bruijn et al., 2015).

Experts argue that continuously raising dikes might exacerbate flood severity and overlook the broader impacts, such as societal disruption and environmental degradation (Klijn et al., 2013; Visscher, 2018). This led to the development of a new approach: Room for River (RfR).

2.1 Nature based solutions

Nature-based solutions play a crucial role in flood prevention and dike reinforcement in the Netherlands, particularly in managing nitrogen levels. Nature-based solutions include the creation of wetlands, restoration of floodplains, and the implementation of green infrastructures. These methods are designed to work with natural processes to manage water more effectively and reduce flood risks.

Wetlands restoration: Wetlands are of great importance for life on earth. All life on earth depends on the presence of water and as many as one in ten animal species worldwide lives in wetlands. Wetlands are therefore a source of biodiversity. Wetlands are also indispensable for humans: they provide drinking water and food and are important natural climate buffers. Wetlands provide protection against flooding, retain (fresh) water for periods of drought, help reduce heat stress in urban areas and store carbon. Wetlands are also natural water filters, and they play a role in nature experience and the economy (Krijger et al., 2022).

Floodplains: By allowing rivers to overflow into designated floodplains, the pressure on dikes is reduced. Floodplains are not only important for flood protection, they are used for many purposes: As hay and meadows or as nature and recreation areas, there are homes, businesses, paths and roads and sand, clay and gravel is extracted (Ministerie van Infrastructuur en Waterstaat, 2024a).

Green infrastructure: Traditionally, strengthening dikes involves raising and widening them, often using concrete and asphalt. This approach frequently damages the landscape and causes inconvenience for local residents, while also contributing to pollution and CO2 emissions. However, plant scientists propose an alternative: green, flower-rich dikes. These biodiverse dikes are not only beneficial for the environment but also for the dikes themselves. Flower-rich dikes could withstand pounding waves better and require less artificial reinforcement. (Redactie Vanafhier, 2021).

Room for river
RfR is a comprehensive program initiated by the Dutch government to manage flood risks and enhance environmental quality in river basins. The program aims to create more space for rivers to overflow safely, thus reducing the likelihood of flooding in populated and economically significant areas. This approach represents a shift from traditional flood protection methods that rely heavily on dike construction and elevation, towards more sustainable and integrated river basin management (Rijke et al., 2012). Key measures include widening riverbeds, excavating floodplains, relocating dikes, depoldering, deepening summer beds and creating flood retention zones, which adapt to the specific conditions of each location.

RfR is considered a nature-based solution because it leverages natural processes and landscapes to manage water flow and reduce flood risks. Unlike traditional engineering solutions that often involve extensive infrastructure and can disrupt natural ecosystems, RfR seeks to work with nature. Measures like floodplain excavation, dike relocation, and wetland restoration enhance the natural capacity of landscapes to absorb and manage water. This approach not only mitigates flood risks but also promotes biodiversity, improves water quality, and enhances the aesthetic and recreational value of riverine environments (Klijn et al., 2013).

By integrating flood risk management with environmental conservation, RfR exemplifies how nature-based solutions can provide sustainable, multifunctional benefits, addressing both safety and ecological quality (De Bruijn et al., 2015).

2.2 Political arena

2.2.1 Stakeholders

The political landscape, illustrated in Appendix B, identifies the key actors involved in the policy formation process for flood risk measures along the IJssel River. Among the thirteen actors, six have a direct impact on policy formulation: the Delta Commission, a transport company, the provinces of Overijssel and Gelderland, Rijkswaterstaat, and an environmental interest group. This means that the dike rings and water boards lack formal power and their interests are represented by the provincial governments and Rijkswaterstaat. Their interests are also described in this section because the water board Vallei en Veluwe needs to consider their opinions. Therefore, it is important to understand the positions of the water boards and dike rings on the issue.

Delta commission
The Delta Commission was established by the Dutch government to provide long-term recommendations on flood risk management and freshwater supplies for both coastal and inland areas (Ministerie van Infrastructuur en Waterstaat, 2024c). It plays a crucial role in the flood risk management plan for the IJssel River, acting as a consensus-builder to negotiate agreements among various stakeholders. The commission has veto power, allowing it to reject policy proposals if stakeholders' interests are not adequately considered. This ensures that the concerns of all involved parties are taken into account before final decisions are made (Given mandate, personal communications, 2024).

Rijkswaterstaat (National level)
Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Water Management, focused on improving quality of life, access, and mobility through effective water management to prevent floods (Rijkswaterstaat, n.d.). They are responsible for financial planning and covering the costs of investments in dike infrastructure and the RfR program, which includes measures to increase rivers' capacity to handle higher water levels. Additionally, Rijkswaterstaat creates final policy recommendations for projects in the IJssel area. In this region, flood risks require solutions that are safe, improve quality of life, protect ecosystem services, and enhance mobility, which is also important to transport companies (Ministerie van Infrastructuur en Waterstaat, 2024d).

Province of Gelderland (Local level)
The province of Gelderland, located upstream of the IJssel River, includes urban and rural areas susceptible to flooding. Similar concerns are relevant to the province of Overijssel.

Gelderland faces the challenge of balancing flood protection measures with other considerations, such as land usage and agricultural activities. Their role is to gather input from local actors and represent these interests at a broader level. These actors include the dike rings 1, 2, and 3, with rings 1 and 2 in rural areas and ring 3 in an urban area (Debate, personal communication, 2024).

While Gelderland acknowledges the importance of dike heightening to save space, it is aware that this could shift flood risks downstream to Overijssel. Consequently, Overijssel prefers implementing the RfR program to ensure safety for all areas around the IJssel (Province of Gelderland, 2019). They prefer a co-creation approach to minimize differences and develop a consensus, which will inform the higher-level debate. The Province of Gelderland aims to ensure that flood risk management is both safe and conductive to maintaining the economic freedom of parties in the region (Debate, personal communication, 06-06-2024).

Province of Overijssel (Local level)
The downstream communities in the province of Overijssel benefit from flood management that aims to reduce the water volumes flowing from Gelderland to Overijssel. The interests and concerns of the province of Overijssel are influenced by its downstream position. Overijssel is concerned about the impacts of the RfR program on agricultural activities, fearing it will reduce available land for farmers and their income (Province of Overijssel, 2019). Overijssel, which includes dike rings 4 (Gorssel) and 5 (Deventer), faces unique challenges due to its downstream position. Dike ring 4, a rural area, has stakeholders focused on agriculture, rural infrastructure, and natural landscape preservation. In contrast, dike ring 5 is predominantly urban, with concerns centered on home protection, business continuity, and economic growth. The province recognizes the need to collaborate with Gelderland to manage water volumes effectively, balancing the diverse interests of all actors involved (Debate, personal communication, 06-06-2024).

Environmental interest group
The environmental interest group advocates for nature-based solutions like the RfR projects. They emphasize the importance of preserving and enhancing biodiversity, citing that the

Netherlands has experienced significant loss of animal and plant species over the past century. RfR supports biodiversity by using natural landscapes for flood protection, which aligns with its goals (Utrecht University, 2017).

The environmental interest group supports government mandates that consider RfR, as it allows nature to thrive while protecting areas from flooding. Conversely, they oppose dike heightening, which can harm natural areas, as seen with the Delta Works in Grevelingen, where dam construction negatively impacted local ecosystems and fish migration (Visscher, 2018).

The group also highlights the importance of ecosystem services, which provide cultural, provisional, and regulating benefits. They note that climate change has increased the demand for water storage and coastal protection in the Netherlands while reducing water supply and soil fertility (PBL, 2019).

Transport company

The transport company relies on the IJssel River for transporting goods and is primarily focused on maintaining the continuity and efficiency of maritime transportation. Their main concern is avoiding low water levels or shallow rivers, as these conditions force them to limit cargo capacity, negatively impacting revenues.

Representatives from Transport and Logistics Netherlands, KNV, NIWO, and Fenex advocate for the interests of transport companies using the IJssel for goods transportation. Over 30% of Dutch goods are transported via waterways, with the IJssel classified as a major route for national and international transport (CBS, 2009).

In 2018, extreme drought led to lower water levels, forcing maritime transport companies to reduce cargo loads, resulting in potential economic costs up to 345 million euros (Water board Rijn and IJssel, 2018; Hussen et al., 2019). Some configurations of the RfR program could also lower current water levels, further affecting transport sector revenues due to cargo restrictions (Water board Rijn and IJssel, 2019). To avoid these issues, the transport sector representatives prefer dike heightening, which is expected to prevent technical problems related to reduced water levels (Smienk, 2003).

Water board 3

Water board 3 oversees the Rijn IJssel region, which includes the eastern part of Gelderland and the southern part of Overijssel, covering dike rings 3, 4 and 5. Their primary focus is on environmental protection and continuous adaptation due to climate change. They are responsible for ensuring safe and clean water in the eastern part of Gelderland and the southern part over Overijssel. This involves maintaining and monitoring smaller organizations to ensure the stability of flood protection systems. Their key priorities are the safety and reliability of water systems to protect both environment and community (Debate, personal communication, 06-06-2024).

Dike rings 1 and 2: Doesburg and Cortenoever

These areas are primarily occupied by farmers and the farming population. Modern farming in these regions contributes significantly to the local economy. Protecting these farmers is crucial for the province of Gelderland. The current level of flood risk management is unequal between rural and urban areas in Gelderland, there is more focus on flood management in urban areas compared to rural areas(Debate, personal communication, 06-06-2024).

They are predominantly against the RfR policy due to its potential impact on reducing farming land, which constitutes the primary source of income for their areas. Their narrative perspective is focused on prioritizing the preservation of farming land and ensuring economic stability of the region (Debate, personal communication, 06-06-2024).

Dike ring 3: Region of Zutphen
Zutphen is represented as a small, urbanized town. Their main concern is that in the event of flooding, the expected damages and the number of affected people will be significantly larger. They have very little land available for reallocation for the RfR measures. They are therefore hesitant for the nature based solutions, as they seem more expensive and require more land. They have concerns about the feasibility and cost-effectiveness of implementing nature-based solutions and the RfR approach in urban areas with limited space (Debate, personal communication, 06-06-2024).

2.2.2 Key objectives and constraints

The Water board Vallei en Veluwe aims to enhance biodiversity and ensure flood protection that aligns with natural processes by implementing nature-based solutions like those proposed by the RfR program. These objectives include promoting wetland restoration and floodplain management to support diverse species, allowing rivers to overflow safely to reduce flood risks, and maintaining the long-term health of water systems for clean and safe water supplies.

Potential coalition partners include the Delta Commission, which supports nature-based solutions and plays a crucial role in integrating stakeholder interests, and the environmental interest group advocating for biodiversity and nature-based flood management strategies. The Province of Gelderland, despite challenges in balancing land use, shows willingness to collaborate on sustainable flood management, and Water board 3, which focuses on environmental protection and climate change adaptation, aligns with these goals.

However, opposition arises from Rijkswaterstaat, whose focus on traditional infrastructure solutions may conflict with the nature-based approach, and the Province of Overijssel, concerned about the impact on agricultural activities and land availability. Transport companies prioritize efficient maritime transport and prefer dike heightening to prevent low water levels, while the rural and agricultural areas of dike rings 1 and 2 oppose RfR measures due to potential reductions in farming land. Dike Ring 3, representing an urban area, is concerned about the feasibility and cost-effectiveness of nature-based solutions given their limited land and higher potential for flood damage.

Navigating these diverse interests will require careful negotiation and a commitment to collaborative, multi-benefit solutions that address both ecological and economic priorities.

2.3 Simulation model: XLRM framework

The flood simulation model helps to understand how floods move through the river and how dikes respond. At each location along the river, the model checks if the dike will fail and, if so, how the breach will widen over time. If a dike fails, the model estimates the resulting flood, economic damage, and casualties. By running the model with different flood risk management strategies, it can be seen how these measures affect risk reduction and risk distribution across different areas. The simulation model follows the XLRM framework (Brightspace, 2024), as can be seen in Figure 1.

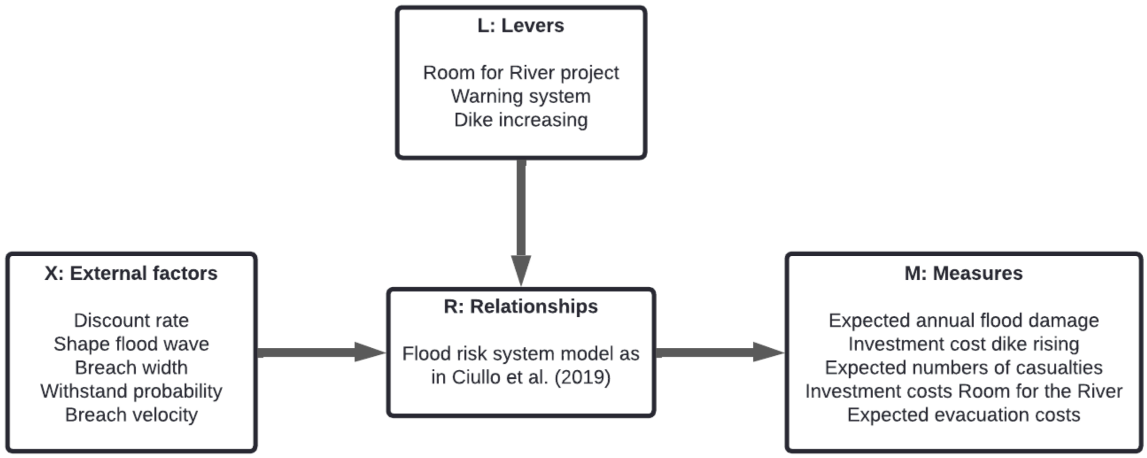


Figure 1, XLRM framework for the IJssel river flood case

2.3.1 External factors

The external factors represent the uncertainties affecting the system's performance over which the policymaker has no control. The external factors are given in Table 1. The five sources of uncertainty are: the discount rate, the flood wave shape, the breach width, the withstand probability of the dike and the breach growth rate.The analysis highlights which of these uncertainties are most critical and which uncertainties are most relevant to our actor.

According to Walker et al. (2012), there are several levels of uncertainty. In this case, the pfail and Bmax per dike are level 1 uncertainties: we are not absolutely certain, but it is known what values these variables in certain situations have, due to the constant monitoring and research. However, the flood wave shape has a high level of uncertainty. There is no known future for when a flood wave will happen. When the analysis shows that this uncertainty is indeed important, extra robust policies need to be developed to prepare for these situations.

Table 1, the external factors (X) of the simulation model explained

Type	Name in the simulation model	Description	Values	Dimension
Categorical	discount rate {timestep}	Discount rate for calculating present day	1.5, 2.5, 3.5, 4.5	dmnl

		values of damages		
Integer	A.0_ID flood wave shape	A normalized curve describing the shape of the incoming flood wave over time. There are 132 predefined curves.	0-132	dmnl
Real	A.{dike_ring}_pfail	Probability that the dike will withstand the hydraulic load	0-1	dmnl
Real	A.{dike_ring}_Bmax	The final extent of the breach width. The greater the width, the larger the volume of water that enters the floodplain per unit of time	30-350	meters
Categorical	A.{dike_ring}_Brate	How fast the breach grows over time	0, 1.5, 10	1/day

2.3.2 Levers

The possible ways to intervene in the system are as follows: an intervention takes place at a specific location, at a specific time step. An intervention can be either RfR, heightening the dikes, or implementing a warning system. From the perspective of Water board Vallei en Veluwe, RfR needs to be maximized. An overview of the described levers can be found in Table 2.

Table 2, The levers of the simulation model described

Type	**Name in the simulation model**	**Description**	**Values**	**Dimension**
Integer	{location}_RfR{timestep}	Whether to activate the RfR project at the specified location or not. Once activated, the project remains active	0-1	dmnl
Integer	EWS_DaysToThreat	Number of days prior to threat to give a warning. False warnings can undermine trust in the system. The earlier the warning the more time to evacuate, but also the more chance of a false warning.	0-4	days
Integer	A.{dike_ring}_DikeIn	Amount of dike raising	0-10	decimeter

	crease {timestep}			

2.3.3 Relationships

The relationships (R) in the systems indicate how the external factors (X), levers (L) and measures (M) are tied together and relate to each other. The simulation model considered in this study is the model developed by Ciullo et al. (2019).

2.3.4 Measures

There are five outcomes that are part of the decision problem: expected annual damage, dike investment costs, the expected number of deaths, total costs for RfR projects and expected evacuation costs. All relevant outcomes have to be minimized for Water board Vallei en Veluwe. The measures are described in Table 3

Table 3, The measures of the simulation model described

Type	**Name in the simulation model**	**Description**	**Dimension**
Array	a.{dike_ring}_Expected Annual Damage	Discounted expected annual flood damage	euro
Array	a.{dike_ring}_Dike Investment Costs	Investment costs of dike raising	euro
Array	a.{dike_ring}_Expected Number of Deaths	Expected annual number of casualties due to floods	person
Array	RfR Total Costs	Investment costs for all Room for the River projects	euro
Array	Expected Evacuation Costs	Costs of evaluation based on number of people and the duration they have to leave their home	euro
Array	RfR {RfR_project} Individual Costs	Investment costs per individual Room for the River project	euro

2.4 Problem formulation

The model outcomes are based on a new problem formulation, number six. This problem formulation is created to make it possible to only focus on dikes and RfR projects in the area of the water board. Therefore, the problem formulation focuses on dike ring 2 and RfR project 2 and 3. Furthermore, costs per RfR project are also added, to be able to specify for the costs of RfR project 2 and 3.

The variable Total Costs is splitted into “Expected Annual Damage” and “Dike Investment Costs”. Thereby, it is possible in the analysis to focus on the annual damage, and not take the dike investment costs into account. It is more important that the damage is as low as possible, than that the dike investment costs are zero.

Due to the split of costs per dike and RfR projects, it has been decided to use ScalarOutcomes instead of ArrayOutcomes. This way, a data overload is prevented.

3. Approach

To arrive at a well-informed policy recommendation in this context, it is important to consider the uncertainties involved. These uncertainties are represented in the model and can thus be used for analyses. This process involves several steps to obtain a comprehensive understanding of potential future scenarios for the dike.

3.1 Open Exploration with Extra Trees analysis

Firstly, there is an intent to utilize open exploration through a sensitivity analysis using Extra Trees. This approach does not limit itself to predefined hypotheses or constraints. Extra Trees is an ensemble of decision trees, each trained in a randomized manner. The model builds multiple trees and combines their results to enhance the robustness and accuracy of predictions (Sharaff & Gupta, 2019).

The outcome of this analysis, through feature scores, indicates the extent to which uncertainties in the model impact its results. The uncertainties include the seven uncertainties listed in table 1 regarding external factors. The dike-specific variables are applied solely to dike ring 2, as it falls within our jurisdiction. The outcomes being examined are the expected annual damage and the expected number of deaths, as these align most closely with the values of the Vallei and Veluwe water board. Latin Hypercube Sampling is used to fully explore the parameter and uncertainty space, as specific policies have not yet been determined.

It was decided to conduct an Extra Trees analysis instead of Sobol because it is less computationally intensive, yet through the use of multiple trees, Extra Trees can provide robust estimates of variable importance. One consideration for choosing Sobol could be that it provides more clarity on interaction effects (Jaxa-Rozen & Kwakkel, 2018). However, at the beginning of the research, we are more interested in an initial analysis that gives us a broad overview of the uncertainties to better understand the model and its context. The analysis will be performed multiple times to ensure that there are sufficient samples for the graph to converge.

3.2 Open Exploration with Patient Rule Induction Method

Now that a general understanding has been established regarding which uncertainties have the most significant impact on our output and are thus most relevant to our case, it is time to proceed to the next step in open exploration; scenario discovery.

PRIM will allow us to systematically explore the input space and isolate critical regions where extreme negative outcomes occur (Chong & Jun, 2008). By analyzing these regions, we can gain deeper insights into the key drivers of risk and the interaction between different variables. This information will enable us to identify risk-averse policies and better prepare for the future developments of the dike.

In contrast to the Extra Trees analysis, the uncertainties of all dikes are considered here. This was done to gain better insight into how the outcomes related to dike ring 2 depend on uncertainties surrounding all dike rings, including those located in the territories of other stakeholders. This way, it can be identified whether the Water Authority Vallei and Veluwe is dependent on other stakeholders.

The process begins by identifying the 10% worst-case scenarios that result in the highest damage and casualties. All uncertainties are considered in this process, and the model has run for 15.000 scenarios. When performing this step, the base case is used with no policies, meaning all levers are set to 0. The 10% worst-case outcomes for deaths and damages are selected.

Next, these 10% worst-case outcomes are used as input for the two PRIM analyses. This analysis reveals which ranges of uncertainties lead to the highest damage and number of casualties.

According to Bryant and Lempert (2010), it is possible that the PRIM boxes do not provide a correct shape of the underlying scenarios. Therefore, resampling will be done, to be sure the analysis is valid and correct scenarios are identified (Bryant and Lempert, 2010). Furthermore, dimensional stacking is used to make sure the number of input scenarios is sufficient. Both validation methods can be seen in Appendix A2.

From the set of uncertainty spaces derived from the PRIM analysis, 5 scenarios are manually selected. These scenarios are chosen to ensure they are widely spread across the resulting range of uncertainties, as shown in Appendix A2.

This provides a set of 5 scenarios with variations in uncertainties. The score of each scenario's uncertainty falls within the range identified in the PRIM analysis. These scenarios will be further used in the directed search to develop appropriate policies for this set of worst-case scenarios.

3.3 Directed policy search with Multi Scenario MORDM

The aim is to identify policies that mitigate the impact of the uncertainties identified, particularly focusing on reducing damage and casualties in the worst-case scenarios. Therefore, the model optimizes for a minimal expected annual damage and expected number of deaths for dike ring 2. Furthermore, costs should be minimized for RfR and dike investment, since water boards do not have an endless budget (Unie van Waterschappen, 2022).

When looking at the preferred outcomes, there is an Arrow's paradox (Kasprzyk et al., 2016): minimizing the RfR and dike investment costs, will probably not lead to the least damages and deaths. Therefore, multi-scenario MORDM will be used to find the best policies under these circumstances.

According to Eker and Kwakkel (2018), MORDM is an analysis which can be used to create robust solutions under a scenario. With using multi-scenario MORDM, it is possible to use various predefined scenarios, identified earlier in the PRIM. Multi-scenario MORDM has been conducted instead of MORO, since MORO is more computationally intensive (Eker & Kwakkel, 2018). It was also possible to implement MOEA instead of multi-scenario MORDM. However, when doing a multi-scenario MORDM, different MOEAs are combined with other robust decision making techniques (Watson & Kasprzyk, 2017). Since we aim for robust solutions, Multi-scenario MORDM will be conducted instead of MOEA.

Using Multi-scenario MORDM, the model will run with five different scenarios and three seeds to find a wide range of policies. The optimization will run on DelftBlue, to ensure sufficient computing capacity. To reduce the number of policy outcomes, and to find pareto optimal solutions, non-dominated sort will be used.

3.4 Robustness metrics

The first step is to filter the optimum solutions for RfR project 2 and 3. Thereby, the eventual policy will be a nature based solution, which is preferred by water board Vallei and Veluwe. The second step is to filter the solutions on least damages and deaths, since it is not preferred to have damages and deaths due to floodings. Lastly, the set of "perfect" solutions is put into the robustness metrics.

The signal to noise ratio is used as robustness metrics. Since we had focused on worst-case scenarios in previous analyses, it has now been decided to take a broader view instead of only considering the worst case. Therefore, signal to noise has been used instead of regret.

It is preferred to minimize the outcomes, and therefore, the signal to noise ratio should be as low as possible. A low signal to noise ratio indicates that a policy is robust under the different scenarios. This one will be recommended.

4. Results

4.1 Extra Trees analysis

Figure A.1.1, in the appendix shows the results of the Extra Trees analysis. It can be seen that a change in the uncertainty A.2_pfail has the highest impact on the expected annual damage. This is also reflected in the heatmap in Figure y in the appendix. In terms of policy or advice, it is important to consider this uncertainty.

What stands out is that the results on the expected number of deaths show similar results to the analysis on the expected annual damage, as can be seen when comparing figure A.1.1 and A.1.2 to figure 5 and 6 in the appendix. A.2_pfail has the highest impact on the output expected number of deaths. Additionally, it can be observed that the graph does not fully converge to a straight line. However, there is no further improvement, so increasing the number of samples further is not necessary.

4.2 PRIM

The PRIM results are in line with the results of the Extra Trees analysis. Firstly, there is only little difference between the analysis focussing on damages and the analysis focussing on deaths.

Secondly, both analyses have as key determinants A.1_pfail and A.2_pfail. That means that they are important in the worst case scenarios. All worst case scenarios occur when dike ring 1 has an A.1_pfail higher than 0.31, and A.2_pfail is lower than 0.14. In other words, when A1 has a higher chance it will withstand a hydraulic load, there will be negative consequences for A2.

Both of the PRIM analyses have a high coverage and density. A visualization of their boxes can be seen in Appendix A.2.

4.3 Multi Scenario MORDM

The algorithm has converged for all scenarios, which can be seen in Appendix A.3. Out of the non-dominated solutions that came out of the optimization, the top 10 solutions with lowest deaths are considered the solution space. Below, the ranges of the lever values for the top 10 are plotted in Figure 2. Because in reality, specific policies are hard to implement, having insights in the ranges of lever values that lead to the best outcomes can be insightful. This makes for interesting conclusions. First of all, and to no surprise as it was the filter condition, every solution has RfR 2 and 3 turned on. It was decided to use them as filter conditions, as nature based solutions proved to be important for the water board and these specific locations are linked to dike A2. There are some differences in which timestep RfR is introduced. For RfR 2, it seems that in most solutions it is introduced in timestep 0 or 2, as indicated by the higher mean of the lever values in these timesteps. For RfR 3, however, timestep 1 seems to be the popular option. Unfortunately, in our problem formulation, the outcomes are aggregated over time so the model cannot provide specific insights in how outcomes change through timesteps. RfR 0 and 1 remain off in all policies, which means that they don't seem important in preventing floods at A2. Finally, RfR 4 is only introduced in some policies, which also indicates less importance for dike ring A2.

Furthermore, due to the low mean and max of EWS_DaysToThreat, it seems like warnings beforehand don't have much influence on outcomes, which could be due to potential false warnings leading to less effectiveness. As for the dike increases, on average across all dikes, there is a dike increase of 2.7m. This is quite moderate, and it is something that is preferred by the water board as dike increases lead to emissions and nature-based solutions are preferred to protect the quality of nature, which is further described in the Problem Framing. However, there are large differences between the ranges of dike increases of different dikes. In all policies, dike ring 1 doesn't get an increase, which can be explained by the conclusion of the PRIM analysis. If dike ring 1 becomes too strong, the water force will increase at dike ring A2, potentially leading to a dike failure. As for the increase of dike ring A2 itself, an increase of around 3 meters is recommended, at timestep 0. Due to the small range of this variable across the different solutions, it can be considered important for the outcomes. The ranges of the other dike increase variables are larger, indicating that the specific values that they take on are less critical to the outcomes and vary a lot across the candidate policies. A complete list of the candidate policies can be found in Appendix A.3.

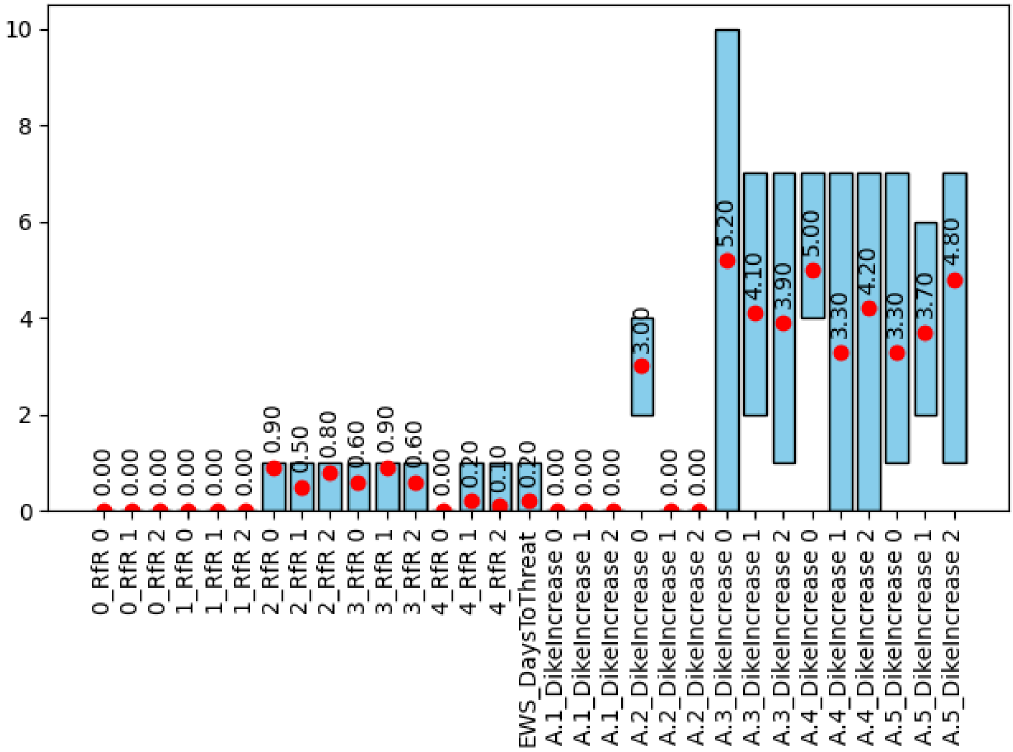


Figure 2, ranges for the levers in the top 10 policies.

4.4 Robustness

From the multi-scenario MORDM, it seemed that policy 52 and 54 were favorite, as they led to zero deaths in their respective worst case scenarios. When tested with a 1000 newly generated scenarios though, there seems to be a slightly higher expected number of deaths in some scenarios for these policies. The policies still seem to be very robust though as only policy 65 and 79 are more robust in terms of deaths. There are more deaths, however, in general with these policies, which is why policy 52 and 54 remain better options. The final recommendation is policy 52, as it is more robust than 54 in terms of expected number of deaths and expected annual damage. Finally, something to note is that Room for River costs and dike investment costs all have a signal to noise ratio of zero. This is expected, because these costs are directly linked to the levers and are therefore not influenced by different uncertainties across scenarios. Below, the scores are visualized using parallel coordinate plotting in Figure 3, and a list of the scores can be found in Appendix A.4.

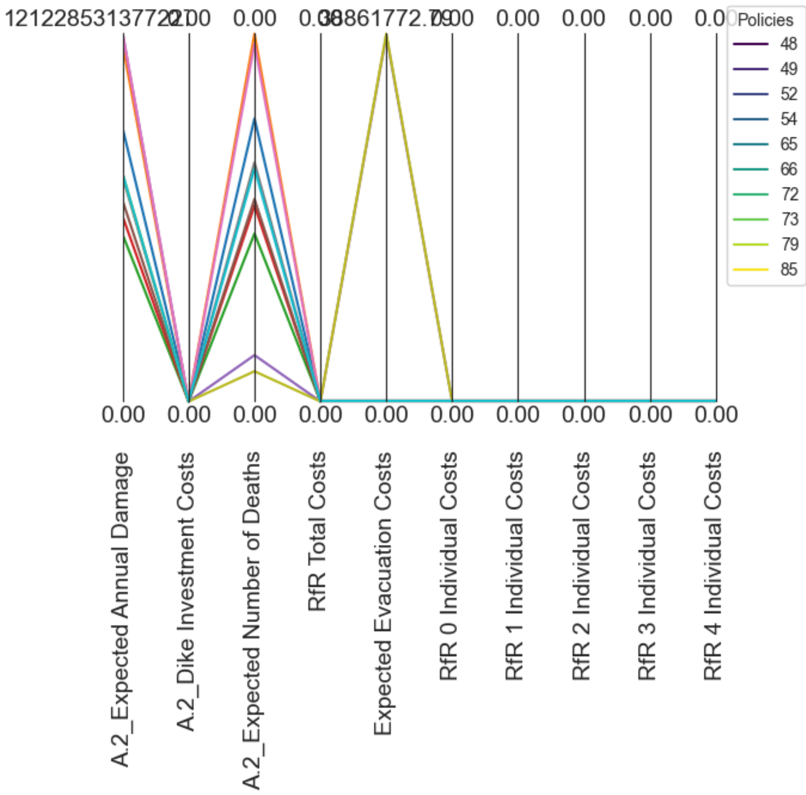


Figure 3, robustness scores for the top 10 policies

As said before, policy 52 outperforms most other policies, which is why it is the final recommendation and described in Table 4. In this policy, RfR 2 is introduced at timestep 0, while RfR 3 is introduced at timestep 1. Furthermore, EWS_DaysToThreat remains 0. Next to that, A2 gets increased by 3 meter, A1 doesn't get a dike increase, while other dikes are increased with varying amounts. The average dike increase is about the same as in the whole solution space, with a 2.66 m average. For our actor, this specific policy leads to the best performance across different scenarios as pointed out by the analysis. However, in the real world, it is hard to adhere to very specific values, which means that the whole solution space can still be taken into account and all policies in the space should perform relatively well and robust as well, as most robustness scores were similar. Table 4 is also visualized in a different way in Appendix A.4.

Table 4, the final policy recommendation

Time step	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease
0	0	0	1	0	0	0	0	3	7	4	2
1	0	0	1	1	0	0	0	0	2	5	2

2	0	0	1	1	0	0	0	0	3	5	7

5. Discussion

In the PRIM analysis, the focus is on the 10% worst-case scenarios, reflecting a highly risk-averse approach (Breuer, 2006). The findings of this study suggest policies that limit significant losses. However, this may not necessarily represent the policy that performs best overall. There could potentially be a policy that scores slightly lower in worst-case scenarios but yields significantly better results in other scenarios. Adopting such an ambitious approach could lead to improved insights and consequently better advice.

Within the current model, specific variables serve as outputs for policy performance. However, the model does not generate outputs that measure nitrogen emissions or conservation. Including such metrics could provide a more comprehensive view of policy outcomes, particularly for stakeholders like water board Vallei en Veluwe, where environmental preservation holds significant value (Jabro et al., 2006).

In our analyses, we prioritize minimizing RFR costs under the assumption that lower costs are beneficial for water board Vallei en Veluwe. This approach conflicts with the goal of maximizing RFR solutions. Initially, it was unclear that RFR solutions are not uniformly costly, which could be a valuable refinement for future research.

In the extra trees analysis, 1500 samples were utilized to ensure the graph converged to a consistent result. However, as shown in Figure A.1.1 in the Appendix, the line does not converge tightly and shows no improvement as the number of samples increases. There remains an uncertainty margin of approximately ±0.5.

We have selected problem formulation with scalar outcomes. This decision was made to mitigate data overload from our customized model, where variables are segmented by dike. As a consequence, we are only informed of damages and fatalities at the conclusion of the model run, lacking intermediate insight into the model's behavior. Consequently, our ability to pinpoint the exact timing of damage occurrence is limited

In this study, the focus was on the outcomes of dike A2, as it is the only dike within the jurisdiction of Waterschap Vallei en Veluwe. However, in future research, it may be relevant to conduct specific analyses for other stakeholders to gain a more comprehensive understanding of their positions, strengths, weaknesses, and dependencies, enabling informed responses. This could strengthen water board Vallei en Veluwe's position in the debate (Branham, 2013).

Part of model based decision making can benefit a lot from increased (parallel) computational power, which is why we have decided to make use of the capabilities of the DelftBlue supercomputer. However, ensuring smooth operations of DelftBlue posed to be quite challenging, mainly due to the queue for student usage. Running our Python scripts involved a lot of trial and error with the task and CPU configuration and installation of specific versions of dependencies and because of the queue, every try would take several hours. Unfortunately, we couldn’t get the MPIEvaluator to work with our code and claiming an exclusive node for the MultiprocessingEvaluator took too long. A workaround was running several SequentialEvaulator in parallel for each scenario, but therefore we couldn’t run the scenarios with as many seeds as initially. However, we have run the model with sufficient nfe, as can be concluded from the convergence metrics.

Finally, we ourselves chose which analyses to conduct and in what sequence. Any alteration to this plan may impact the outcomes and the direction of the policy recommendations. Each sequence of different analyses can yield different insights, meaning that there is inherent subjectivity in model based decision making. There is no perfect and definitive way to capture uncertainty in a proper analysis, which is why transparency and being conscious of this is important for the quality of the analysis.

6. Conclusion

In this report, an analysis of measures making the Ijssel flood resistance at dike ring A2 was conducted for the water board Vallei en Veluwe. A lot of different stakeholders, with sometimes conflicting interests, are involved which complicate decision making. For the water board, it is important that environmental interests are taken into account. To further find out what a good policy would be several analyses were done, which take uncertainty into account at every step.

First, Extra Trees was conducted to gain a clearer understanding of which uncertainties surrounding dike A2 are most relevant to the expected annual damage and the expected number of deaths. For both outcomes, it has been found that A.2_pfail is the most important uncertainty to consider.

Second, a scenario discovery was conducted using PRIM. The most important discovery was that all worst case scenarios occur when dike ring 1 has an A.1_pfail higher than 0.31, and A.2_pfail is lower than 0.14. The third and last steps were the multi-scenario MORDM and robustness. From this, a solution space could be derived. It was found that, in the candidate policies, when RfR 2 and 3 are introduced, other RfRs aren't introduced and the dikes are increased with 2.7 meters on average. The most important dike to increase is A2 itself, and that should happen in the first timestep (timestep 0).

Two policies (52 and 54) were favorite as they led to zero deaths and damages in their respective worst case scenarios. Testing with the 1000 newly generated scenarios showed a slightly higher expected number of deaths for these policies in some scenarios, but they remained highly robust, with only two other policies showing slightly better robustness in terms of deaths but with a higher overall death count. The final recommendation (Policy 52) was recommended due to its superior robustness in both the expected number of deaths and expected annual damage. In this policy, just as in the other policies in the solution space, RfR is combined with a slight dike increases.

Answering the research question: w*hat are the optimal policies to manage and mitigate flood risks of the Ijssel River effectively, with as little impact on nature as possible, given the various perspectives of the stakeholders involved in the decision-making process,* it is found that a combination of nature-based solutions (RfR) and moderate dike increases is the recommended policy direction. The analysis provided a broader solution space, and a more specific solution, so there is more flexibility when decisions have to be made. The whole solution space provides robust policies, while taking the different perspectives into account: it being economically viable by minimizing costs, it being safe by minimizing deaths and damages and it being environmentally-friendly by introducing RfR.

References

Branham, R. J. (2013). Debate and Critical Analysis. In *Routledge eBooks*. https://doi.org/10.4324/9780203812846

Breuer, T. (2006). Providing against the worst. *Managerial Finance*, *32*(9), 716–730. https://doi.org/10.1108/03074350610681934

Bryant, B. P., & Lempert, R. J. (2010). Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. *Technological Forecasting & Social Change/Technological Forecasting and Social Change*, *77*(1), 34–49. https://doi.org/10.1016/j.techfore.2009.08.002

CBS (2009, November 11). Nederlandse vaarwegen belangrijk voor goederentransport. Retrieved from: https://www.cbs.nl/nl-nl/nieuws/2009/48/nederlandse-vaarwegen-belangrijk-voor-goederentransport

Chong, I., & Jun, C. (2008). Flexible patient rule induction method for optimizing process variables in discrete type. *Expert Systems With Applications*, *34*(4), 3014–3020. https://doi.org/10.1016/j.eswa.2007.05.047

Ciullo, A., de Bruijn, K.M., Kwakkel, J.H., & Klijn, F. (2019). Accounting for the uncertain effects of hydraulic interactions in optimising embankments heights: Proof of principle for the IJssel River. Journal of Flood Risk Management, 12(S2), e12532.

De Bruijn, H., De Bruijne, M., & Ten Heuvelhof, E. (2015). The politics of resilience in theDutch 'Room for the River'-project. Procedia Computer Science, 44(C), 659–668.

European Environment Agency. (2023, 6 oktober). *Economic losses from weather- and climate-related extremes in Europe*. https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related?activeAccordion=546a7c35-9188-4d23-94ee-005d97c26f2b\

Eker, S., & Kwakkel, J. H. (2018). Including robustness considerations in the search phase of Many-Objective Robust Decision Making. *Environmental Modelling & Software*, *105*, 201–216. https://doi.org/10.1016/j.envsoft.2018.03.029

Geurts, P., Ernst, D., & Wehenkel, L. (2006). Extremely randomized trees. *Machine Learning*, *63*(1), 3–42. https://doi.org/10.1007/s10994-006-6226-1

Hussen, K., Velde, I. van D., Läkamp, R., Kooij, S. van D., & Alex Hekman, Sweco. (2019). Economische schade door droogte in 2018. In Ministerie van Infrastructuur en Waterstaat, *Ministerie van Infrastructuur en Waterstaat*. https://www.ecorys.com/app/uploads/files/2019-10/20190221%20Rapport%20Economische%20schade%20door%20droogte%20in%202018.pdf

Jabro, J. D., Jabro, A. D., & Fox, R. H. (2006). Accuracy and Performance of Three Water Quality Models for Simulating Nitrate Nitrogen Losses under Corn. *Journal Of Environmental Quality*, *35*(4), 1227–1236. https://doi.org/10.2134/jeq2005.0413

Jaxa-Rozen, M., & Kwakkel, J. (2018). Tree-based ensemble methods for sensitivity analysis of environmental models: A performance comparison with Sobol and Morris techniques. *Environmental Modelling & Software*, *107*, 245–266. https://doi.org/10.1016/j.envsoft.2018.06.011

Kasprzyk, J. R., Reed, P. M., & Hadka, D. M. (2016). Battling Arrow's paradox to discover robust water management alternatives. *Journal of Water Resources Planning and Management*, *142*(2). https://doi.org/10.1061/(asce)wr.1943-5452.0000572

Klijn, F., de Bruin, D., de Hoog, M. C., Jansen, S., & Sijmons, D. F. (2013). Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team). International Journal of River Basin Management, 11(3).

Krijger, C., Simons, H., & Verwer, C. (2022). Moerassen en andere wetlands zijn onmisbaar. *Waterbeheer*. https://www.iucn.nl/app/uploads/2023/02/Moerassen-en-andere-wetlands-zijn-onmisbaar_LandWater-2022.pdf

Ministerie van Infrastructuur en Waterstaat. (2024, juni 12). *Room for the River*. https://www.rijkswaterstaat.nl/en/projects/iconic-structures/room-for-the-river

Ministerie van Infrastructuur en Waterstaat. (2024a, mei 13). *Uiterwaarden voor een veilig rivierengebied*. https://www.rijkswaterstaat.nl/water/waterbeheer/bescherming-tegen-het-water/maatregelen-om-overstromingen-te-voorkomen/beheer-van-uiterwaarden-voor-een-veilig-rivierengebied

Ministerie van Infrastructuur en Waterstaat. (2024b, januari 30). *Maatregelen tegen overstromingen*. Water | Rijksoverheid.nl. https://www.rijksoverheid.nl/onderwerpen/water/maatregelen-tegen-overstromingen

Ministerie van Infrastructuur en Waterstaat. (2024c, april 25). *Home - Deltaprogramma*. https://www.deltaprogramma.nl/

Ministerie van Infrastructuur en Waterstaat. (2024d, januari 12). *Waterbeheer in Nederland*. Water | Rijksoverheid.nl. https://www.rijksoverheid.nl/onderwerpen/water/waterbeheer-in-nederland

Nillesen, AL., & Kok, M. (2015). An integrated approach to flood risk management and spatial quality for a Netherlands' river polder area. *Mitigation and Adaptation Strategies for Global Change*, *20*(6), 949-966. https://doi.org/10.1007/s11027-015-9675-7

Opperman, J. (2019). *Working with Nature to Reduce Climate Risk in Europe on World Wetlands*. https://wwf.panda.org/wwf_news/?359040/World-Wetlands-Day-NBS

PBL (2019). Ecosystem services. Retrieved from: https://www.pbl.nl/en/topics/nature-landscapes-and-biodiversity/introduction-ecosystem-services

Province of Gelderland (2019). Strijd tegen het water. Retrieved from: https://mijngelderland.nl/inhoud/specials/de-ijssel-in-beeld/strijd-tegen-het-water

Province of Overijssel., (2019). Ruimte voor de Rivier IJsseldelta. Retrieved from: https://www.ruimtevoorderivier.nl/project/ruimte-voor-de-rivier-ijsseldelta/

Redactie Vanafhier. (2021, 10 februari). Bloeiende dijken bieden meer bescherming | Vanaf Hier. *Vanafhier*. https://www.vanafhier.nl/natuur/bloeiende-dijken-bieden-meer-bescherming

Rijke, J., van Herk, S., Zevenbergen, C., & Ashley, R. (2012). Room for the river: Delivering integrated river basin management in the netherlands. International Journal of River Basin Management, 10(4), 369–382.

Rijkswaterstaat. (n.d.). Our organisation. https://www.rijkswaterstaat.nl/en/about-us/ourorganisation

Sabino, J. (z.d.). *RF_Patanal_garcia_sabino_wetlands_wealth_040-scaled-1-1800x1198*. Dialogue Earth. https://dialogue.earth/content/uploads/2021/01/RF_Patanal_garcia_sabino_wetlands_wealth_040-scaled-1-1800x1198.jpg

Sharaff, A., & Gupta, H. (2019). Extra-Tree Classifier with Metaheuristics Approach for Email Classification. In *Advances in intelligent systems and computing* (pp. 189–197). https://doi.org/10.1007/978-981-13-6861-5_17

Smienk, H. (2003). Verbeteren van de Beneden- en Midden-IJssel als scheepvaartweg. TU Delft, Faculty of Civil Engineering and Geosciences, Hydraulic Engineering. Retrieved from: http://resolver.tudelft.nl/uuid:e63b74de-2159-4ee8-b6f6-778c89edf0a5

Unie van Waterschappen. (2022, November 14). *Belastingen en financiën - Unie van Waterschappen*. Unie Van Waterschappen. https://unievanwaterschappen.nl/themas/belastingen-en-financien/#:~:text=De%20waterschappen%20betalen%20dit%20grotendeels,de%20taken%20van%20de%20waterschappen

Utrecht University (2017, November 8th). Higher biodiversity due to river-expanding measures. Retrieved from: https://www.uu.nl/en/news/higher-biodiversity-due-to-river-expanding-measures

Vallei en Veluwe. (n.d.-a). *Over onze Organisatie*. https://www.vallei-veluwe.nl/over-ons/onze-organisatie/

Vallei en Veluwe. (n.d.-b). *Wat doet het waterschap*. https://www.vallei-veluwe.nl/wat-doet-waterschap/

Visscher, R. (2018). ‘Dijken hebben op de lange termijn nadelige gevolgen’. Retrieved from: https://www.nemokennislink.nl/publicaties/dijken-hebben-op-de-lange-termijn-nadelige-gevolgen/

Walker, W. E., Marchau, V. a. W. J., & Kwakkel, J. H. (2012). Uncertainty in the framework of policy analysis. In *International series in management science/operations research/International series in operations research & management science* (pp. 215–261). https://doi.org/10.1007/978-1-4614-4602-6_9

Water board Rijn and IJssel (2019). Evaluatie Droogte 2018. Retrieved from: https://www.wrij.nl/thema/kennis-informatie/waterthema'-0/klimaat/droogte/droogte-nieuws/evaluatie-droogte/

Watson, A. A., & Kasprzyk, J. R. (2017). Incorporating deeply uncertain factors into the many objective search process. *Environmental Modelling & Software*, *89*, 159–171. https://doi.org/10.1016/j.envsoft.2016.12.001

WUR. (n.d.). *Biodiversity and climate change*. https://www.wur.nl/en/research-results/themes/biodiversity/biodiversity-and-climate-change.htm

Appendix

Appendix A: Results

A.1 Extra Trees analysis

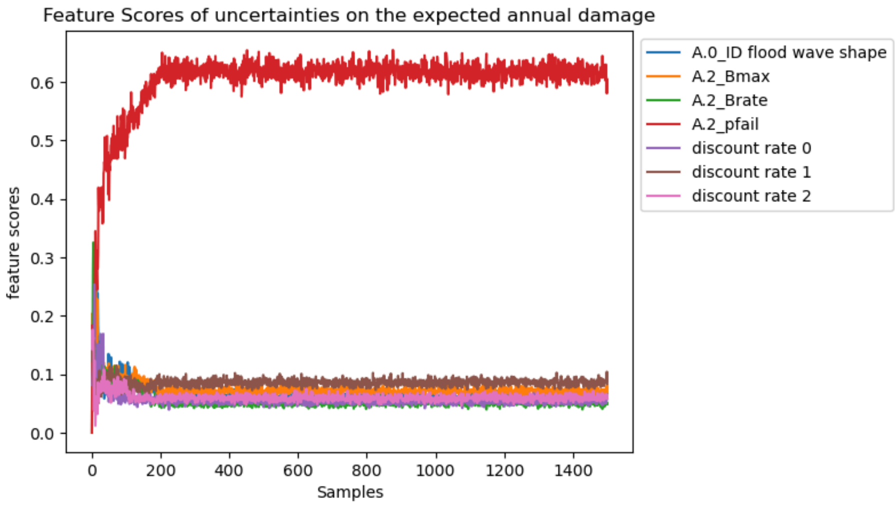


Figure A.1.1, A visualization of the impact of a change in uncertainties on the expected annual damage.

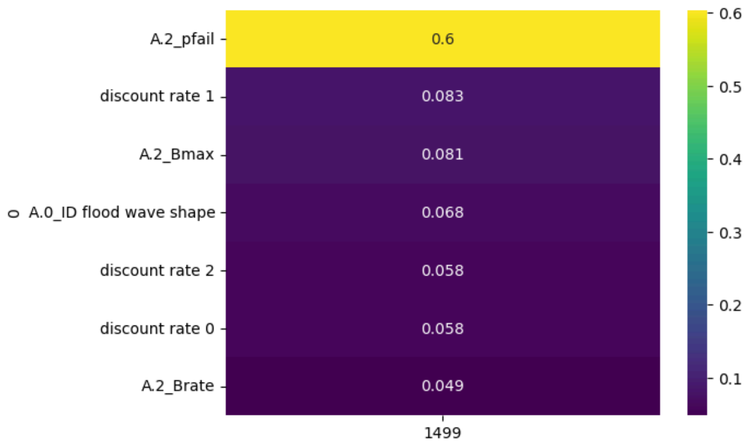


Figure A.1.2, A heatmap illustrating how the impact of changes in various uncertainties correlates with the expected annual damage.

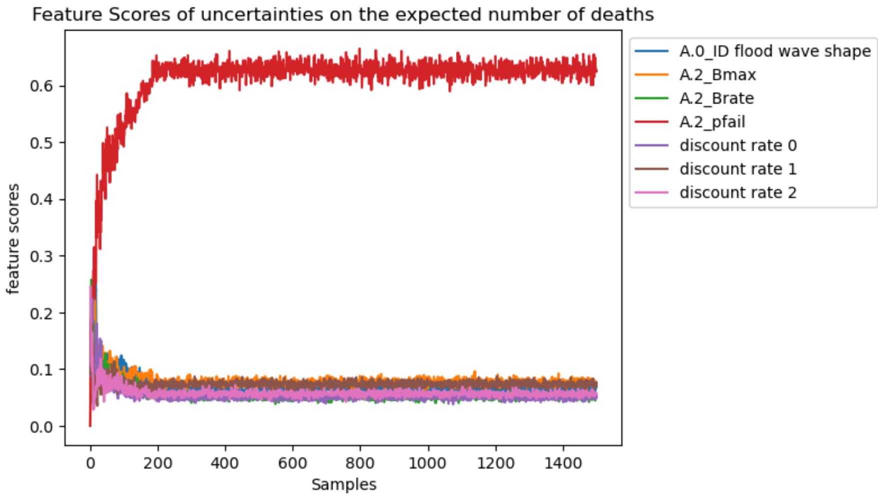


Figure A.1.3, A visualization of the impact of a change in uncertainties on the expected number of deaths.

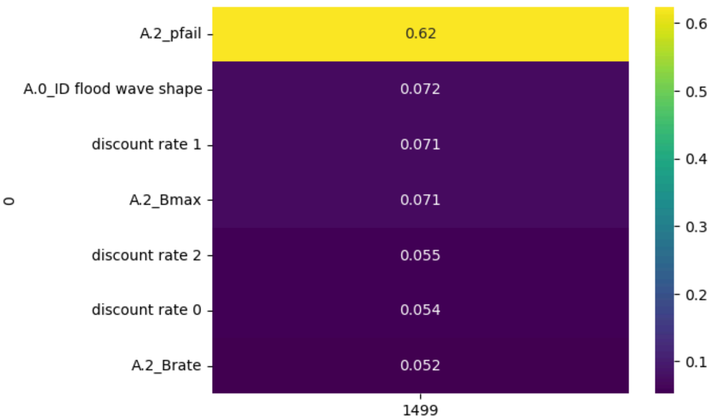


Figure A.1.4, A heatmap illustrating how the impact of changes in various uncertainties correlates with the expected number of deaths.

A.2 PRIM

PRIM boxes

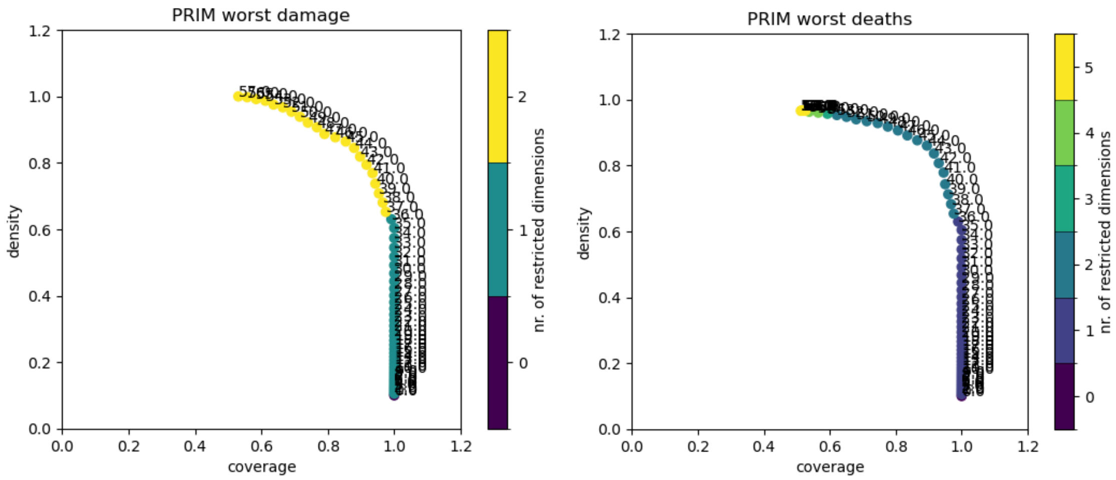


Figure A.2.1, PRIM boxes for worst damage (left) and worst deaths (right).

Resampling

Table A.2.1, Resampling of PRIM.

	reproduce coverage	**Reproduce density**
A.1_pfail	100.0	100.0
A.2_pfail	100.0	100.0
A.0_ID flood wave shape	0.0	0.0
A.1_Bmax	0.0	0.0
A.1_Brate	0.0	0.0
A.2_Bmax	0.0	0.0
A.2_Brate	0.0	0.0
A.3_Bmax	0.0	0.0
A.3_Brate	0.0	0.0
A.3_pfail	0.0	0.0
A.4_Bmax	0.0	0.0
A.4_Brate	0.0	0.0
A.4_pfail	0.0	0.0
A.5_Bmax	0.0	0.0
A.5_Brate	0.0	0.0
A.5_pfail	0.0	0.0
discount rate 0	0.0	0.0

discount rate 1	0.0	0.0
discount rate 2	0.0	0.0

It can be seen that A.1_pfail and A.2_pfail do still have a coverage and density of 100. Therefore, it is possible to reproduce the exact coverage and density, and it confirms the significance of the values.

Dimensional stacking

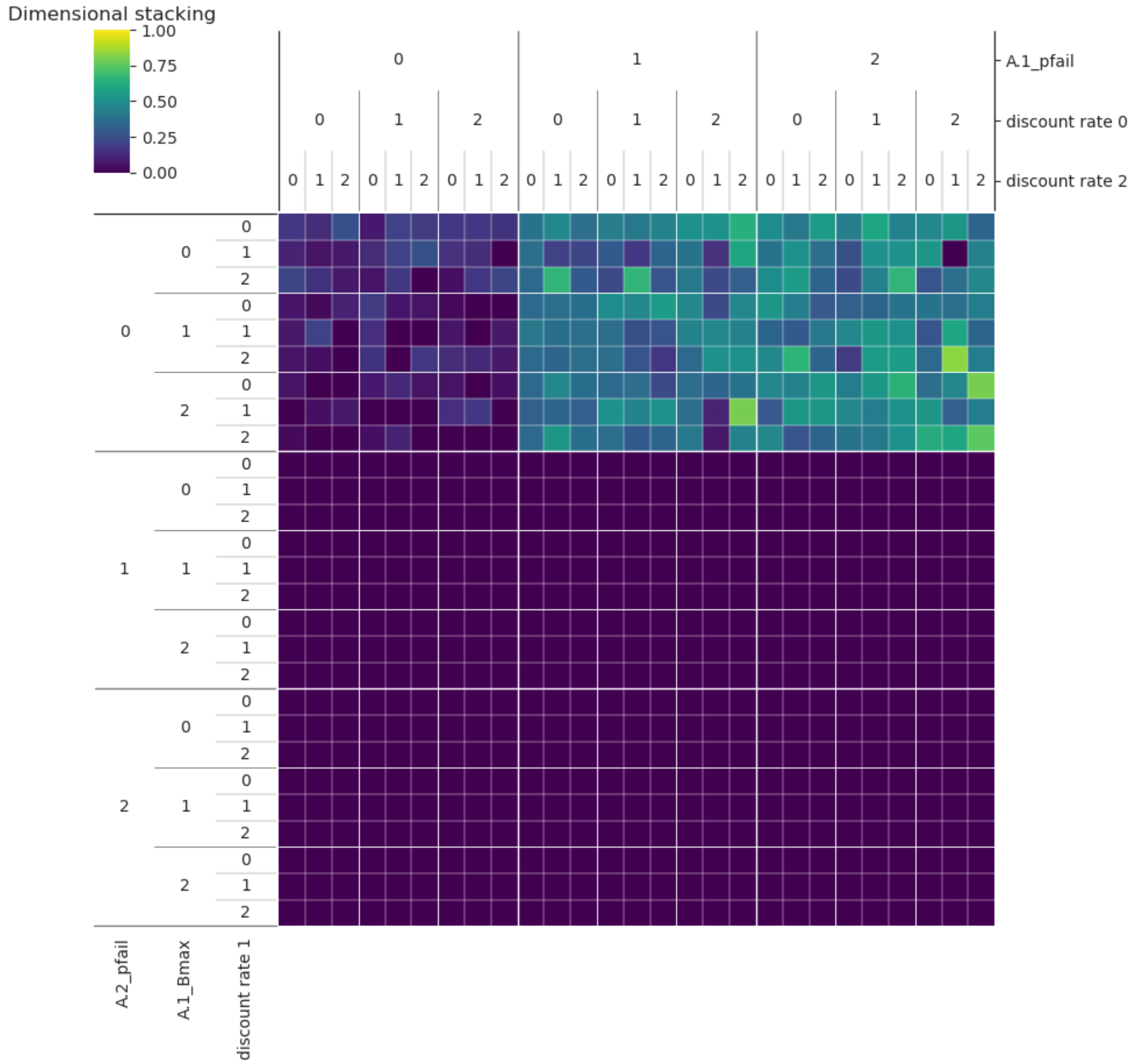


Figure A.2.2, plot for dimensional stacking

It can be seen that there are no white spaces left. Therefore, it can be indicated that the number of scenarios is sufficient, and there is good coverage of the total space.

Selecting scenarios

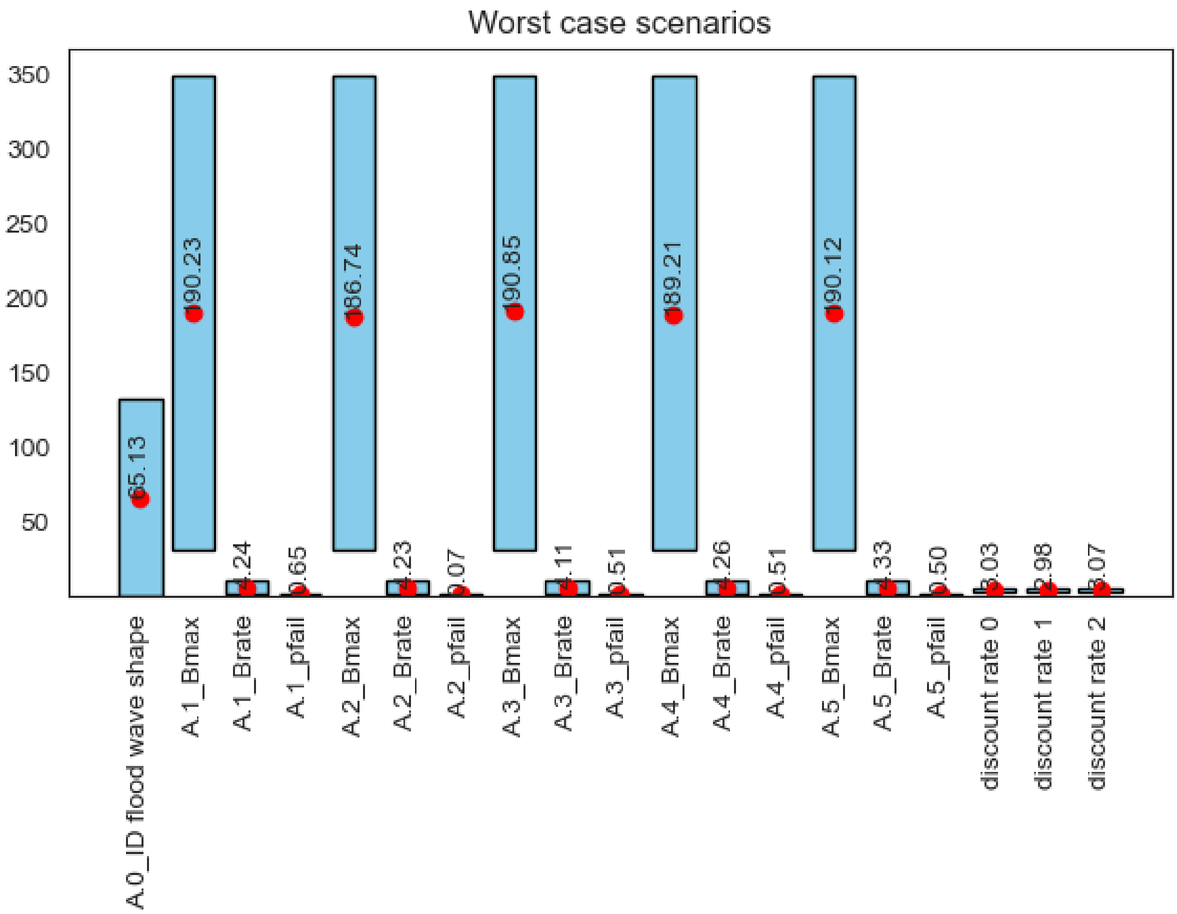


Figure A.2.3. Ranges for each value in the worst case scenarios

The red dots represent the mean values for each uncertainty. The blue bars show the ranges of the uncertainties. These are of the 10% worst case scenarios earlier defined.

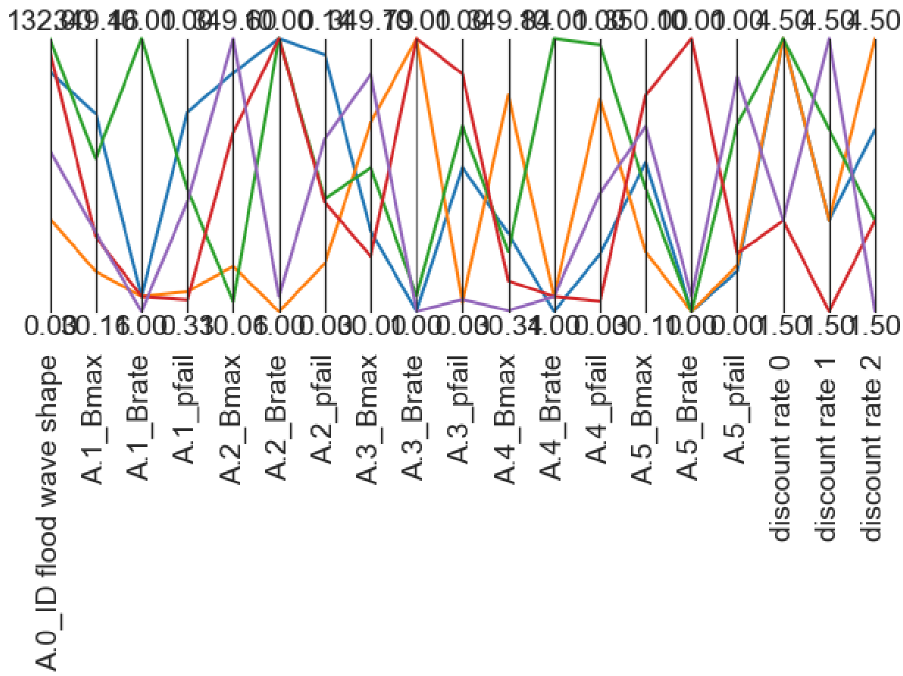


Figure A.2.4: Eventual scenarios

The 5 eventual scenarios are plotted to see if they cover the total space. These five scenarios are the input for the Multi-Scenario MORDM.

A.3 Multi scenario MORDM

Epsilon Progress

For each optimization run, the epsilon progress is recorded. In the graph below, we can see that the epsilon progress for every scenario has stabilized, which means that the optimization reached a 'plateau' in its performance, so higher nfe values are not necessary for better solutions. There are slight differences between the scenarios though. It seems that scenario 2 converges slower than the other scenarios, and it seems that for this scenario, more stabilization may occur with a slightly higher nfe. However, the nfe value seems more than sufficient for every other scenario as indicated by the early convergence.

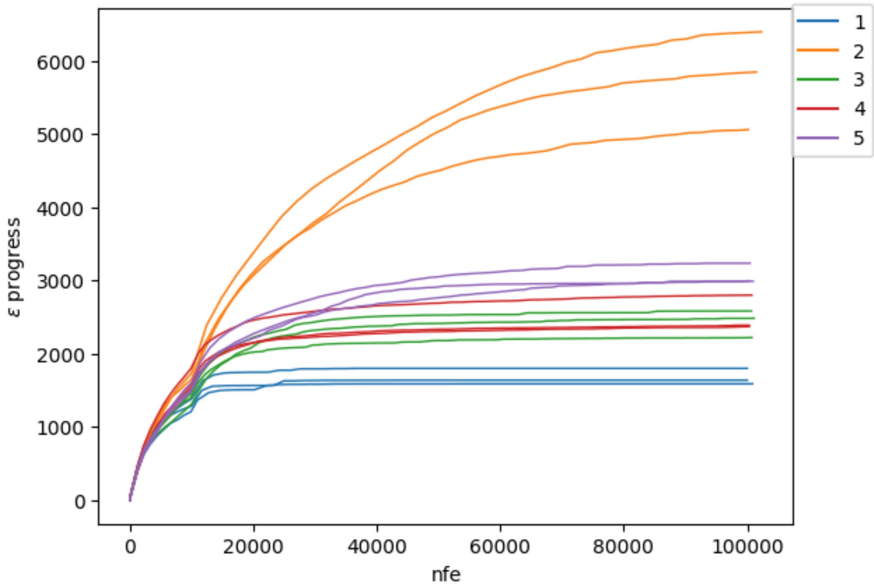


Figure A.3.a, epsilon progress for each scenario

Complete List of Candidate Policies

Table A.3.a, complete list of candidate policies

Policy	Timestep	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease
52	**0**	0	0	1	0	0	0	0	3	7	4	2
	1	0	0	1	1	0	0	0	0	2	5	2
	2	0	0	1	1	0	0	0	0	3	5	7
54	**0**	0	0	1	1	0	0	0	4	0	6	2
	1	0	0	0	1	0	0	0	0	3	1	6
	2	0	0	1	0	0	0	0	0	5	7	1

79	**0**	0	0	1	1	0	1	0	3	2	7	1
	1	0	0	1	1	0	0	0	0	5	5	5
	2	0	0	1	1	0	0	0	0	2	0	5
66	**0**	0	0	1	0	0	0	0	3	6	5	7
	1	0	0	1	1	0	0	0	0	2	6	5
	2	0	0	1	0	0	0	0	0	7	2	5
85	**0**	0	0	1	1	0	0	0	3	3	4	2
	1	0	0	1	1	1	0	0	0	5	0	2
	2	0	0	1	0	0	0	0	0	1	4	4
73	**0**	0	0	0	0	0	0	0	4	6	4	6
	1	0	0	1	1	0	0	0	0	4	7	4
	2	0	0	1	0	0	0	0	0	2	7	4
65	**0**	0	0	1	1	0	1	0	2	10	4	5
	1	0	0	1	1	0	0	0	0	5	3	3
	2	0	0	1	0	0	0	0	0	5	3	7
48	**0**	0	0	1	1	0	0	0	3	7	5	5
	1	0	0	1	1	0	0	0	0	5	0	2
	2	0	0	1	0	0	0	0	0	4	0	4
49	**0**	0	0	1	1	0	0	0	3	6	6	2
	1	0	0	0	0	0	0	0	0	3	1	6
	2	0	0	1	1	0	0	0	0	3	5	7
72	**0**	0	0	1	1	0	0	0	2	5	5	1
	1	0	0	1	1	1	0	0	0	7	5	2
	2	0	0	1	1	1	0	0	0	7	5	4

A.4 Robustness

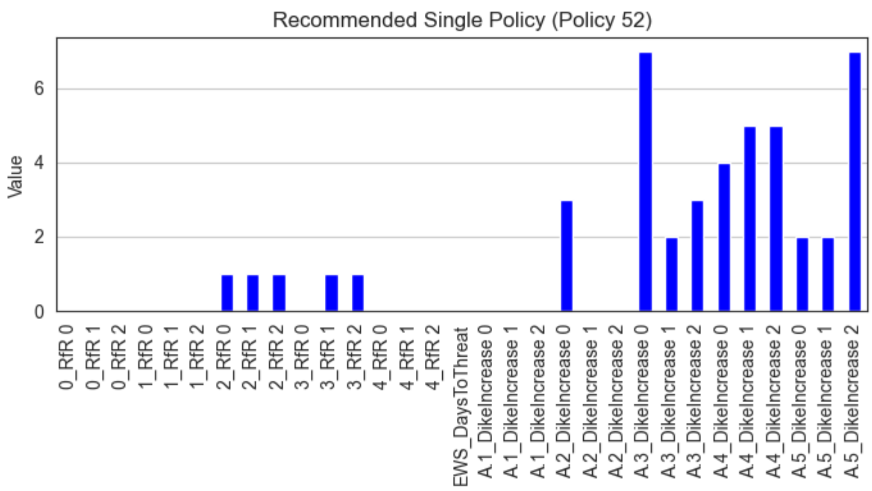
Table A.4.a, all signal to noise scores for the candidate policies

Policy	A.2_Expected Annual Damage	A.2_Dike Investment Costs	A.2_Expected Number of Deaths	RfR Total Costs	Expected Evacuation Costs	RfR 0 Individual Costs	RfR 1 Individual Costs	RfR 2 Individual Costs	RfR 3 Individual Costs	RfR 4 Individual Costs
48	8.997866e+14	0.0	0.000666	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0

49	1.175632e+15	0.0	0.000866	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
52	5.495198e+14	0.0	0.000395	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
54	6.093961e+14	0.0	0.000461	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
65	1.212285e+15	0.0	0.000109	0.0	3.868741e+07	0.0	0.0	0.0	0.0	0.0
66	6.610617e+14	0.0	0.000476	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
72	1.212285e+15	0.0	0.000842	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
73	7.395648e+14	0.0	0.000562	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0
79	7.499978e+14	0.0	0.000071	0.0	3.886177e+07	0.0	0.0	0.0	0.0	0.0
85	7.499978e+14	0.0	0.000548	0.0	0.000000e+00	0.0	0.0	0.0	0.0	0.0

Final Policy Recommendation

Figure A.4.a, lever values for final policy recommendation visualized in a bar graph



Appendix B: Political Arena

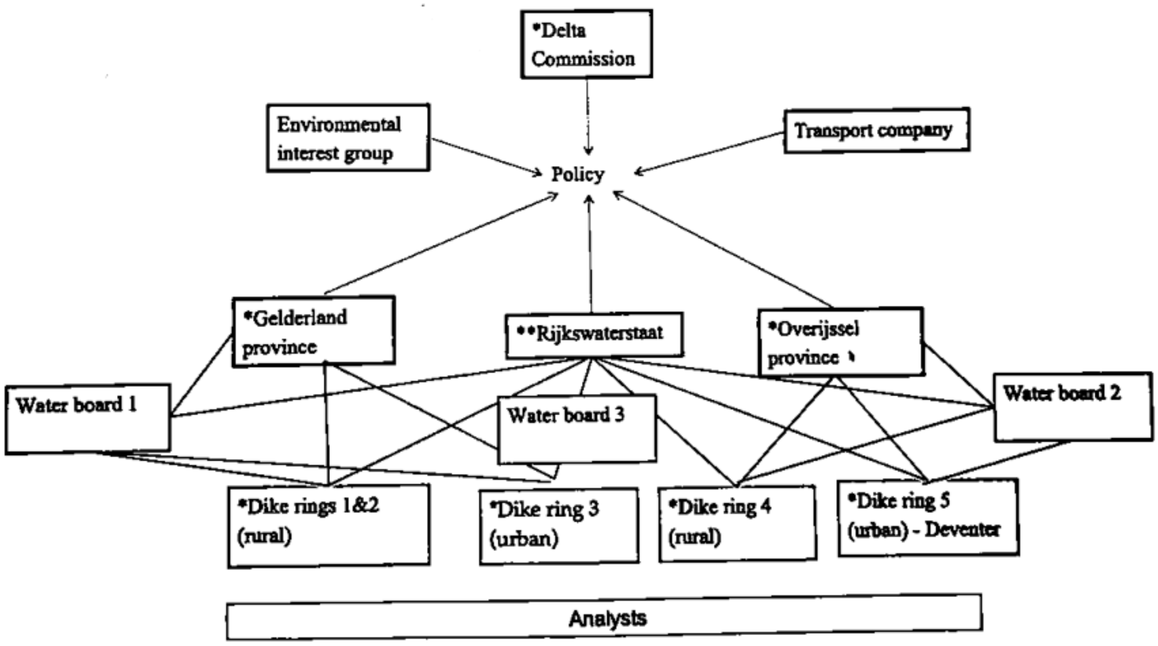


Figure B. 1, overview political arena with actors involved in flood risk management of the IJssel river (Kwakkel, 2024).