Managing flood risk of the IJssel River:

Advice for the province of Overijssel

GROUP 2

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Summary

Managing flood risk involves preventing a flood from happening and limiting the (financial) damage when a flood happens. This issue is relevant not only for areas along the Dutch coast but also for the province of Overijssel, as the downstream part of the IJssel River flows through the province. To get advice on what policies should be implemented to manage the flood risk of the IJssel River cost-effectively, the province of Overijssel commissioned this report.

A thorough analysis is performed due to the high complexity of this issue. This complexity is partly caused because multiple stakeholders are involved with diverse interests and different interpretations of the problem, resulting in often multiple conflicting objectives. Next to this, there is much uncertainty about how the flood risk will evolve over time, such as how fast the breach in a dike grows over time or what the exact shape of the flood will be.

Although the province of Overijssel prefers to meet all stakeholders' wishes, it realizes that there is no magic money tree, so the financial budget must be used cost-effectively. Therefore, proposed policies must preferably have low implementation costs. Nevertheless, a strict condition is that these policies should perform well in the worst-case future states of the world. That is, the province of Overijssel wants to prevent proposed policies from performing poorly in dramatic flooding events that are obviously out of the control of decision-makers.

Various robust policies are identified that perform very well (i.e., lowest total costs) for the province of Overijssel, especially in worst-case future states of the world. However, these policies performed worse for the neighbouring province of Gelderland. As it would not be realistic for the province of Gelderland to agree with these policy implementations, alternative policies are identified that perform well for both the province of Overijssel and Gelderland. These identified policies require decisions from the province of Overijssel on what aspects they consider most important. The policies have a different distribution of costs which means that there are political considerations to be made.

The province must first consider whether to invest in dike heightening. If the province does not invest in the dikes, the chances of flooding will be higher, so either the evacuation costs should rise, or the total death costs will rise. More flooding also means higher expected damage because of everything that gets destroyed by the flooding, so lower investments in dikes also mean higher expected damages. The second consideration is whether to expand the river (RfR). If the province chooses to expand the river, a lot of room is needed for the expansion, which means people will lose their homes. This means that if the province chooses to expand the river, it will also have to choose to evacuate more people who lose their homes, or the death costs will rise. The province can also choose to do nothing and evacuate most people, leading to higher expected damages because of the flooding.

These considerations depend on what de province deems important and how the province copes with the interests of other involved actors. The province will consider not only the costs, but also ethical considerations and the interests of actor actors involved. If the province opts to minimize the flooding and keep everyone satisfied, it will be a costly project, while if they select the cheapest option, it will result in people dying. With the different policy considerations presented in this analysis, the province of Overijssel can decide on what policy measures it wants to implement.

Table of Contents

1. Introduction

The Netherlands has a long history of protecting its citizens from devastating floods. During the night of January 31, 1953, a powerful storm coincided with a high tide, causing multiple breaches in the dikes along the Dutch coast. Tragically, the disaster claimed the lives of over 1,800 people, while thousands of homes were destroyed or severely damaged (Ellemers & Groenman, 1956). This calamity exposed the vulnerability of the Dutch coastline and highlighted the pressing need for enhanced flood protection.

Another significant event that influenced the public perception regarding flood protection was the flooding of the Meuse River in 1993. This flood resulted from prolonged heavy rainfall and snowmelt in the upstream areas of the Meuse River. As a result, comprehensive assessments of water management and protection measures were undertaken. These efforts involved reinforcing levees and establishing floodplain areas to better handle future flooding (Van Stokkom et al., 2005).

In response to devastating floods, several Room for the River projects were initiated (Rijke et al., 2012). The primary objective of these projects is to increase the water discharge capacity of rivers and create space for controlled flooding, thus minimizing the potential impact of future floods. Rather than relying solely on dike heightening, these projects focus on expanding the available area for water, both in floodplains and within the river channels.

Despite the remarkable progress that has been made in enhancing flood protection measures throughout the Netherlands, the province of Overijssel still faces significant challenges in effectively managing and mitigating the risks associated with potential floods of the IJssel River. Situated in a downstream area of the IJssel River, this province remains particularly vulnerable.

As analysts of the Province of Overijssel, the aim of this report is to provide advice to the province of Overijssel on the best course of action regarding flood risk management for the IJssel River. Developing an optimal policy is challenging due to various sources of uncertainty that play a role when it comes to predicting and planning for future flood risks. Next to this, effective decision-making in flood protection involves multiple stakeholders, such as local communities, interest groups, and government bodies. It is crucial to ensure effective collaboration and consensus-building among these diverse stakeholders to develop flood protection policies that are widely supported.

While keeping these challenges in mind, the comprehensive flood protection policy should also be specifically tailored to the concerns and objectives of the province of Overijssel. These mainly revolve around minimizing the risks associated with floods and promoting the overall resilience and safety of the region in a cost-effective way. This leads to the following research question:

> *'What are the optimal policies for the province of Overijssel to manage and mitigate flood risks of the IJssel River cost-effectively, given the uncertainties and the multiple perspectives of stakeholders involved? '*

The report is structured as follows. Section 2 describes how the decision problem is structured. Section 3 explains the approach to analyze the problem given the uncertainties and multi-objective nature of flood risk management of the IJssel River. Then, the results are presented in Section 4. Finally, Section 5 presents the conclusion and discussion.

2. Problem framing

This section describes how the decision problem concerning flood risk management of the upper branch of the IJssel River is structured. First, the political arena is discussed in Section 2.1. Then, the problem is structured in Section 2.2 using the XLRM framework proposed by Lempert et al. (2003). Finally, two problem formulations, considering the rival perspectives of several actors in the political arena and our own position as analysts for the province of Overijssel, are described in Section 2.3.

2.1 Political arena

The political arena, as displayed in *Figure 1*, shows which actors are involved in the policy formation process of flood risk measures for the IJssel River. Although ten actors are involved, only six directly influence the policy formulation: Delta Commission, transport company, Overijssel province, Rijkswaterstaat, Gelderland province and environmental interest group. In other words, the dike rings do not have formal power (and are not separately discussed), but the provincial governments and Rijkswaterstaat represent their interests.

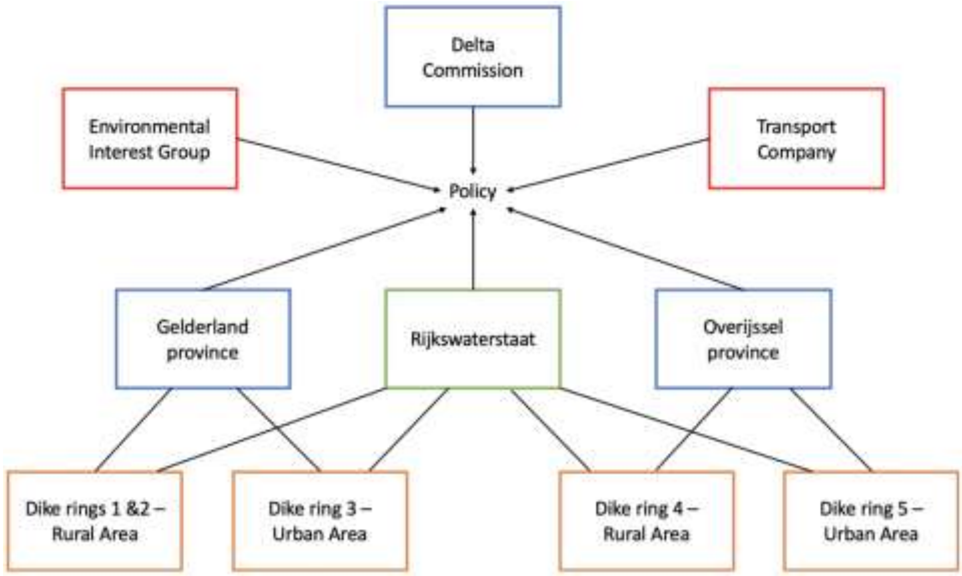

Figure 1 Political arena with actors involved in flood risk management of the IJssel River. Source: Kwakkel (2023).

2.1.1 Delta commission

The Delta Commission was established by the Dutch government to provide recommendations on flood risk management and freshwater supplies in the Netherlands (National Delta Programme, n.d.). It plays a crucial role in the flood risk management plan for the IJssel River as it acts as a consensus-builder looking to find a negotiated agreement among the different actors. It has a veto power, meaning that it can reject policy proposals when (some) stakeholder's interests are insufficiently considered.

2.1.2 Transport company

The transport company uses the IJssel River for the transportation of goods. Its primary interest lies in ensuring the continuity and efficiency of maritime transportation along the river. The transport company wants to avoid low water levels or shallow rivers. The reason is that the transport company fears a negative impact on its revenues when it is forced to limit its cargo capacity due to restrictions on how deep vessels can reach below the water surface.

2.1.3 Province of Overijssel

The interests and concerns of the province of Overijssel are influenced by its downstream position. It represents dike ring 4 (Gorssel) and 5 (Deventer). As dike ring 4 represents a rural area, stakeholders are likely to have specific concerns and priorities related to agriculture, rural infrastructure, and the preservation of natural landscapes. In contrast, dike ring 5 represents a predominantly urban area where people are concerned about the protection of their homes, business continuity and economic growth. Also, due to its downstream location, this province is aware that it should collaborate with the upstream province of Gelderland to manage the water volumes. Hence, one of the main challenges is balancing the diverse interests of all actors involved.

2.1.4 Rijkswaterstaat

Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Water Management, dedicated to improving the quality of life, access, and mobility through effective water management for flood protection (Rijkswaterstaat, n.d.). Rijkswaterstaat assumes accountability for financial planning and bears the expenditures associated with investments in dike infrastructure and the Room for the Rivers initiatives. The latter encompasses a series of measures implemented to augment the rivers' capability to handle elevated water levels.

2.1.5 Province of Gelderland

The province of Gelderland is situated upstream of the IJssel River, encompassing significant urban and rural regions susceptible to flood events. It represents dike ring 1, 2 and 3. While dike rings 1 and 2 are in rural areas, dike ring 3 is positioned in an urban area. Comparable concerns to those of dike rings 4 and 5 in the province of Overijssel are relevant in this context. This province faces the challenge of balancing flood protection measures with other considerations, such as land usage and agricultural activities. While the Gelderland acknowledges the significance of dike heightening, it remains aware of the potential consequence of shifting flood risks downstream towards the province of Overijssel.

2.1.6 Environmental interest group

The environmental interest group strongly advocates for nature-based solutions, specifically endorsing initiatives such as Room for the River projects. The group opposes the implementation of dike heightening measures due to their detrimental impact on natural areas. Preserving and enhancing biodiversity is vital for this group; therefore, creating space for the river to protect the surrounding areas from flooding is the preferred option.

2.2 XLRM framework

The problem is framed using the XLRM framework as shown in *Figure 2* with exogenous factors (X), policy levers (L), system relationships (R) and measures (M) of performance or outcomes of interests (Lempert et al., 2003). These factors are further discussed below.

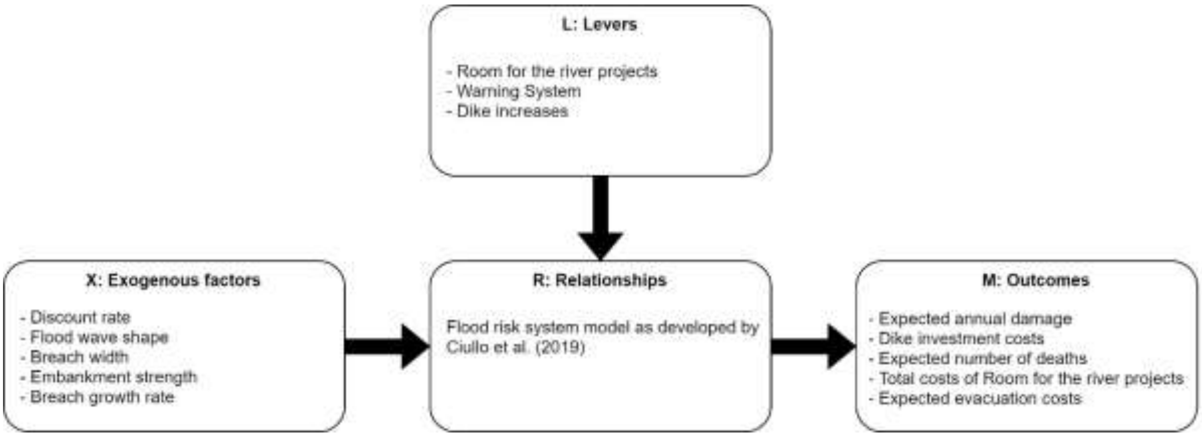

Figure 2 XLRM framework for the IJssel River case

2.2.1 Exogenous factors (X)

The exogenous factors (X) or model uncertainties involved with flood risk management are given in *Table 1*. Five sources of uncertainty are outside the control of the decision-maker: the discount rate, flood wave shape, breach width, embankment strength and breach growth rate. To use consistent terminology, any given parametrization over the uncertainties is defined as a scenario, and a scenario as a point in the uncertainty space.

Table 1: Description, range and unit of the exogenous factors (X)

Exogenous factors (X)	Description	Range	Units
Discount rate (per timestep)	Rate to calculate the present value of damages at a certain point in time.	{1.5, 2.5, 3.5, 4.5}	dimensionless
Flood wave shape	A pre-defined normalized curve describing the shape of incoming flood wave over time.	{0,1,2,...,132}	dimensionless
Breach width (per dike ring)	The maximum breach width of a specific dike ring.	[30,350]	meter
Embankment strength (per dike ring)	The probability that a specific dike ring will withstand the hydraulic load.	[0,1]	dimensionless
Breach growth rate (per dike ring)	Rate indicating how fast the breach grows over time for a specific dike ring.	{0, 1.5, 10}	1/day

2.2.2 Levers (L)

Policy levers (L) can be regarded as interventions of decision-makers. The specific levers for flood risk management are shown in *Table 2.* These three types of levers entail Room for the River, dike heightening and an early warning system. Again, for consistent terminology, any given parameterization of the levers is defined as a policy, and a policy as a point in the decision space.

Table 2: Description, range and unit of levers (L)

Levers (L)	Description	Range	Units
Room for the River project (per location and time step)	Whether to activate the Room for the River project at a specific location (total of five locations) or not at a certain point in time. Once activated, the project remains activated.	{0,1}, where 0 = not activated, 1 = activated	dimensionless
Warning system	Number of days prior to a threat to give a warning.	{0,1,2,3,4}	day
Dike increase (per dike ring and time step)	Amount of dike raising at a specific dike ring for a certain point in time.	{0,1,2,..,10}	decimeter

2.2.3 Relationships (R)

The relationships (R) in the systems indicate how the exogenous uncertainties (X), levers (L) and outcomes (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).

2.2.4 Outcomes (M)

The M (of measure) are the outcomes of interest as described in *Table 3.* A total of five (conflicting) objectives are part of the decision problem: expected annual damage, dike investment costs, the expected number of deaths, total costs for Room for the River projects and expected evacuation costs. The goal for each outcome is to minimize the value. Which outcomes are the key objectives for the province of Overijssel are specified in Section 2.3.

Table 3: Description and units of model outcomes (M)

Outcome (M)	Description	Units
Expected annual damage (per dike ring and timestep)	Discounted expected annual flood damage.	euro
Dike investment costs (per dike ring and timestep)	Investment costs of a specific dike ring heightening.	euro
Expected number of deaths (per dike ring per timestep)	The expected annual number of casualties due to flood for a specific dike ring.	person
Total costs of Room for the River projects (per timestep)	Investment costs for the Room for the River projects.	euro
Expected evacuation costs (per timestep)	Costs of evaluation based on the number of people and the duration they must leave their homes.	euro

2.3 Problem formulations

The analysts of the province of Overijssel primarily represent their principal's interests. However, Overijssel does not act in isolation but is part of a multi-actor political arena, as described in Section 2.1. As a result, there are many ways to frame the problem formulation. Both problem formulations specified in this study follow a cost-benefit analysis (CBA) approach. This approach aligns with the desire to allocate scarce economic resources efficiently. Furthermore, CBA is the dominant paradigm in risk policy (Hayenhjelm & Wolff, 2012). A significant problem with this approach is that intangible damages, including loss of human lives, must be monetized to include them in the analysis (Kind, 2014). All model outcomes in the XLRM framework, as shown in *Table 3*, are measured in euros, except the number of deaths. To translate this outcome to a monetary value, a human life is valued at 6.3 million euro based on extensive previous research (Schoeters et al., 2021).

To specify the measures (M) of performance for the two problem formulations, all five types of model outcomes (*Table 3*) are included because the province of Overijssel aims to balance the diverse interests of the actors in political arena. The two problem formulations differ in terms of which dike rings are included regarding the expected annual damage, dike investment costs and expected costs of casualties. For problem formulation 1, only the costs belonging to dike rings 4 and 5 are included since these are geographically positioned in the province of Overijssel. However, as the province of Overijssel realizes that this may result in policies with unreasonably high costs for the other dike rings, problem formulation 2 also takes the costs of the other dike rings (located in the province of Gelderland) into account. Important to note here is that problem formulation 2 is only used as a back-up when the optimal identified policies in problem formulation 1 would result in dramatic outcomes for the province of Gelderland.

The costs are aggregated over the dike rings for both problem formulations. As a result, it could be that a certain policy performs well for a certain dike ring at the expense of another dike ring. This is not a problem since the proposed policies must be cost-effective overall. Next, the total costs of Room for the River projects and expected evacuation costs are aggregated by design in the model of Ciullo et al. (2019). Finally, the values for the model outcomes are aggregated over time. Hence, a static policy implementation is chosen. The key objectives for both problem formulations are shown in *Table 4*. Following the CBA, the goal is to optimize (or minimize) these costs.

Table 4: Five key objectives of the two problem formulations

#	Chosen outcomes (M) for problem formulation 1 and 2	Unit
1.	Expected annual damage for dike ring 1*, 2*, 3*, 4 and 5	euro
2.	Dike investment costs for dike ring 1*, 2*, 3*, 4 and 5	euro
3.	Expected death costs for dike ring 1*, 2*, 3*, 4 and 5	euro**
4.	Total costs of Room for the River projects	euro
5.	Expected evacuation costs	euro

** Only included in problem formulation 2*

*** 1 death = 6.3 million euro*

All exogenous factors, as displayed in *Table 1*, are included in both problem formulations because there is no consensus among the actors in the political arena about which uncertainties are most important to consider. Next, all policy levers, as shown in *Table 2*, are included as well for both problem formulations. Although the province of Overijssel has no formal control over all levers (e.g., controlled by another actor), the aim is to strive for the best policy given the specified model outcomes for the two problem formulations as presented in *Table 4*. In other words, insights are given into what the best robust policies are, but whether these policies are viable and successful in the end depends on whether the province of Overijssel can find consensus among the actors in the political arena during the decision-making process.

3. Method

Given the aim of identifying robust policies that achieve satisfactory performance across multiple uncertainties and (competing) objectives in flood risk management, a four-step approach based on the Many-Objective Robust Optimization (MORO) framework is followed, as shown in *Figure 3* (Bartholomew & Kwakkel, 2020). In the first step, the model is specified using the XLRM framework (Section 3.1). Then, robust candidate policies are identified under a pre-defined set of scenarios in the second step (Section 3.2). In the third step, the performance of these policies is stress-tested under uncertainty (Section 3.3). Finally, vulnerabilities of the identified policies are examined in the fourth step (Section 3.4). The analysis is carried out using the Exploratory Modelling and Analysis (EMA) Workbench in the Python programming language (Kwakkel, 2017).

The main advantage of this approach, in contrast to other robust decision-making approaches, is that the MORO framework makes the most effort to include robustness considerations in the search phase (step 2). In this phase, the robustness of candidate policies is calculated over a pre-specified set of scenarios. Usually, a rather simple sampling technique is used to generate this set of scenarios. However, in this study, a more sophisticated approach is considered by using open exploration to specify a set of scenarios that is highly relevant to the province of Overijssel. Hence, by using robust values in the search process to determine the effectiveness of a potential policy, it is more likely that set of policies is built that meet the robustness criteria that are targeted by the province of Overijssel.

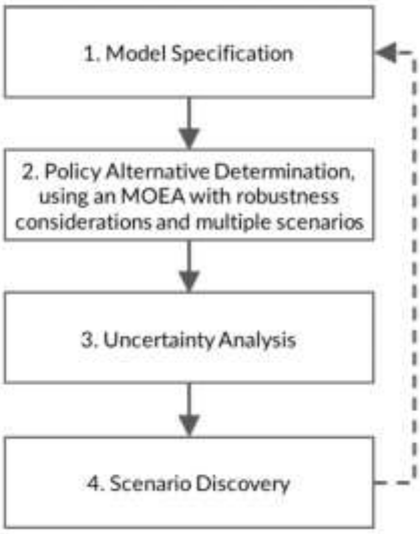

Figure 3: Four steps of the Many-Objective Robust Optimization (MORO) framework

3.1 Model specification

In the first step, the components of the decision-making problem are determined. The model specification follows the same XLRM framework format, as shown in *Figure 2*, but is slightly adjusted to align with the problem formulation of Section 2.3. That is, all exogenous factors (X) and levers (L) are included, but only the model outcomes (M), as specified in *Table 4*, are considered.

3.2 Policy alternative determination

In this step, robust optimization takes place through a Many-Objective Evolutionary Algorithm (MOEA) (Coello Coello et al., 2007) called ε-NSGAII (Kollat & Reed, 2005) to determine a Pareto-approximate set of policies. This means that policies are compared based on the outcomes of defined robustness metrics, leading to a Pareto non-dominated set of policies. The robustness metric for this step is the mean square deviation (MSD), which is robust by considering both the functional expectancy and the dispersion (Moritz Göhler et al., 2016). The MSD is defined in this study as: $MSD = \mu^2 + \sigma^2$.

To enable the calculation of a robustness metric, each policy identified in the MOEA search is evaluated against a set of pre-specified scenarios. This study determines the pre-specified set of scenarios with open exploration. As the province of Overijssel is risk-averse, a precondition is that the policies perform at least well in worst-case scenarios. In other words, after the search phase is completed, the resulting policies are robust for worst-case scenarios. To determine these worst-case scenarios, 10,000 scenarios are generated first using Latin hypercube sampling (LHS) without the implementation of any specific policy (zero policy or no action). This sampling technique efficiently divides the uncertainty space evenly with a relatively small sample size (Helton et al., 2006). Also, LHS ensures that the entire range of each exogenous factor is equally represented in the sample set (McKay et al., 1979). The results from this analysis yield the total costs for each scenario. Subsequently, the total costs are ranked from highest to lowest total costs, and the top 20 highest costs scenarios are chosen as the worst-case scenarios.

To track the progress and stabilization of the search progress, ε-progress is considered. This metric indicates whether new policies are being added to the set of non-dominated policy alternatives as the search progresses (Ward et al., 2015). If the slope of the epsilon progress line flattens, this means that fewer policies are being added to the set of non-dominated alternatives. Enough function evaluations are needed to reach the point that the slope of the epsilon progress line flattens out, and hence, convergence is reached. In this study, 30,000 function evaluations are used as testing of different values showed that this number was large enough to ensure consistent convergence. The epsilon value settings were set to 0.01 for all metrics after balancing the computational cost of having smaller epsilon values with the added benefit that smaller values may yield a closer approximation of the Pareto front. Although there is an element of randomness to the MOEA's process, a seed analysis is not performed due to computational constraints. A preliminary attempt showed that performing the run multiple times using a different seed within a reasonable running time would not be feasible.

3.3 Uncertainty analysis

In this step, the non-dominated set of policy alternatives (resulting from the previous step) is stress-tested under uncertainty to evaluate performance across a much wider range of scenarios. To do this, a large ensemble of 10,000 scenarios is built first by using LHS across the uncertainty space as defined in the model specification. Then, each policy from the non-dominated set of alternatives is tested against the generated ensemble of scenarios. This results in a large data set that describes each policy's performance across a broad set of scenarios. This information is used to calculate the robustness of each policy. Again, the mean square deviation is used as the robustness metric. Each outcome of interest has a separate robustness metric value, which makes it easier to communicate conflicts and trade-offs among the outcomes.

3.4 Scenario discovery

Scenario discovery methods aim to develop easy-to-understand descriptions of which areas of the uncertainty space remain vulnerable or perform poorly, despite the search for policies that are meant to be most successful (Kasprzyk et al., 2013). For this goal, the scenario discovery Patient Rule Induction Method (PRIM) is used to identify a range of values that best predict the behaviour of a subset of cases from the entire data set that fails to meet a specific goal (Friedman & Fisher, 1999). To accomplish this, PRIM optimizes along three different axes: density, coverage, and interpretability. While density refers to the fraction of cases in an identified cluster where failure is recognized, coverage concerns the fraction of identified failure cases constrained within that cluster. A further explanation of density, coverage plot can be found in Appendix A.3. Interpretability incorporates the ease with which users can understand what is discovered by the algorithm (Lempert, 2013). The advantage of the PRIM algorithm over the Classification and Regression Tree algorithm is that it provides more opportunity for interaction and requires less initial configuration (Bryant & Lempert, 2010). Scenario discovery is executed for the set of non-dominated policy alternatives resulting from step 2. The implementation of PRIM for this study involved defining robustness thresholds for each outcome of interest. These are set to 0.75 for all metrics. Further, peeling alpha is set to 0.05.

3.5 Summary of adjusted MORO framework

Figure 4 displays the four steps of the adjusted MORO framework as applied in this study. The main novelty is the use of open exploration to determine the set of scenarios for the second step (policy alternative determination) of the MORO framework. To highlight this, the second step of the original MORO framework is divided into two consecutive steps: open exploration and MOEA.

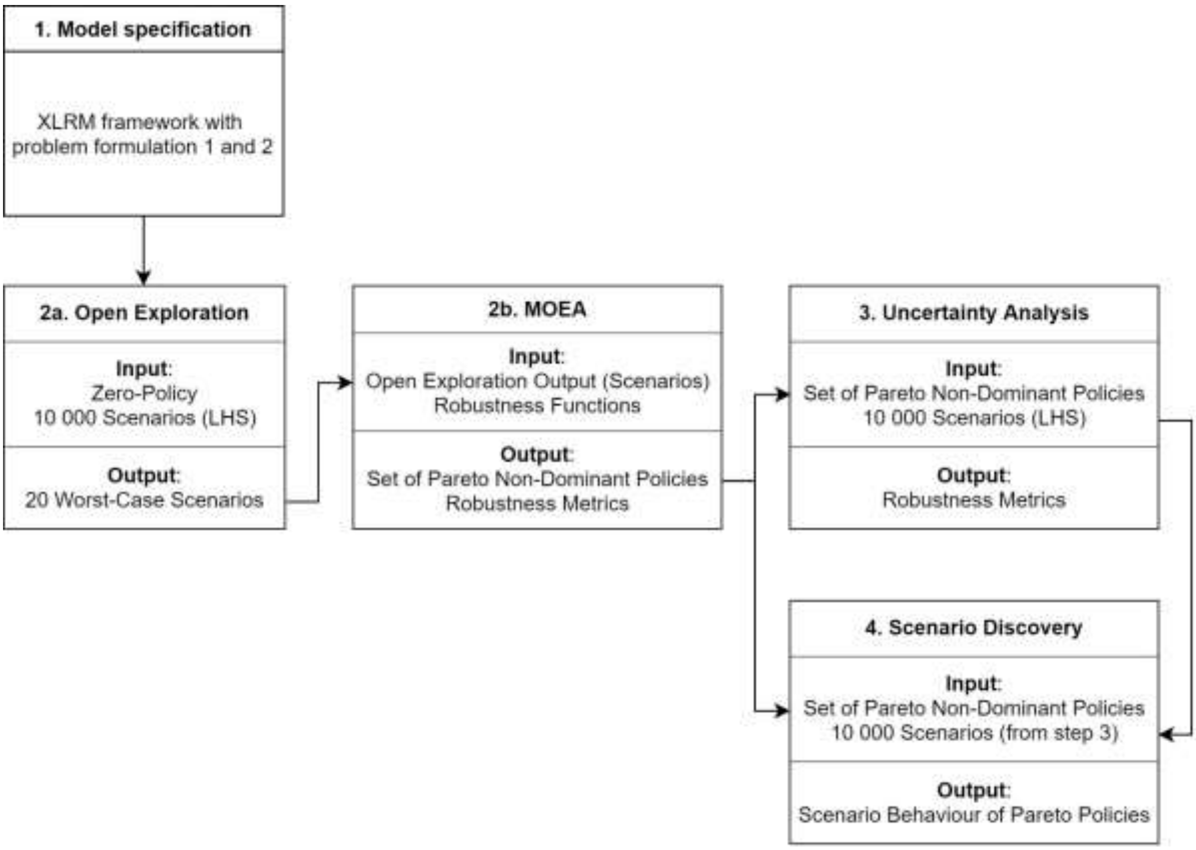

Figure 4: Adjusted MORO framework for the IJssel River case

4. Results

This section presents the results in three stages belonging to the first problem formulation, corresponding to steps 2, 3 and 4 of the MORO framework: policy alternative determination in Section 4.1, uncertainty analysis in Section 4.2, and scenario discovery in Section 4.3. As step 1 of the MORO framework does not produce any direct results, this step is not discussed. Additionally, the results of applying the adjusted MORO framework for the second problem formulation are also presented and compared with the first problem formulation in Section 4.4.

4.1 Policy alternative determination results

Applying open exploration techniques resulted in 20 worst-case scenarios. Visualizations and detailed results of this open exploration analysis can be found in Appendix A. Solving the multi-objective optimization problem with MOEA produced a final set of 45 non-dominated Pareto policies. *Figure 5* shows the resulting robustness scores of the five outcomes as defined in problem formulation 1 for these identified policies. The lower the score for the robustness metric, the better, since the goal is to minimize the costs. As can be seen in *figure 5*, many policies score a zero for the robustness metric for expected costs of casualties and Room for the River investment costs. A generally high robustness score is obtained for the dike investment and evacuation costs for most policies. Regarding the damage costs, the score is relatively low for most policies. These results suggest that there is a trade-off between expected costs of casualties, Room for the River investment costs and damage costs on the one hand, and dike investment and evacuation costs on the other hand.

The first trade-off option is investing in the construction and maintenance of dikes. Neglecting these investments would increase the likelihood of flooding, consequently leading to higher evacuation costs or a rise in total death costs. Furthermore, inadequate dike investments result in more frequent and severe flooding, causing extensive damage to infrastructure and property. Therefore, lower investments in dikes also translate to higher expected damage.

The second trade-off option involves the expansion of the river through the Room for the River (RfR) project. Opting for river expansion requires a significant amount of space, potentially resulting in the displacement of residents from their homes. Consequently, if the province decides to proceed with river expansion, they will face the choice of either evacuating a larger number of people who have lost their homes or accepting potential increases in death costs. Alternatively, the province can choose to take no action and rely on mass evacuation during flood events. However, this passive approach would likely result in high expected damage due to the extensive flooding and its destructive consequences.

As a limited number of policies perform well with relatively low dike investment and evacuation costs, there is a relatively high chance that a lot of money will be spent on the dike investment and evacuation costs in the final advice.

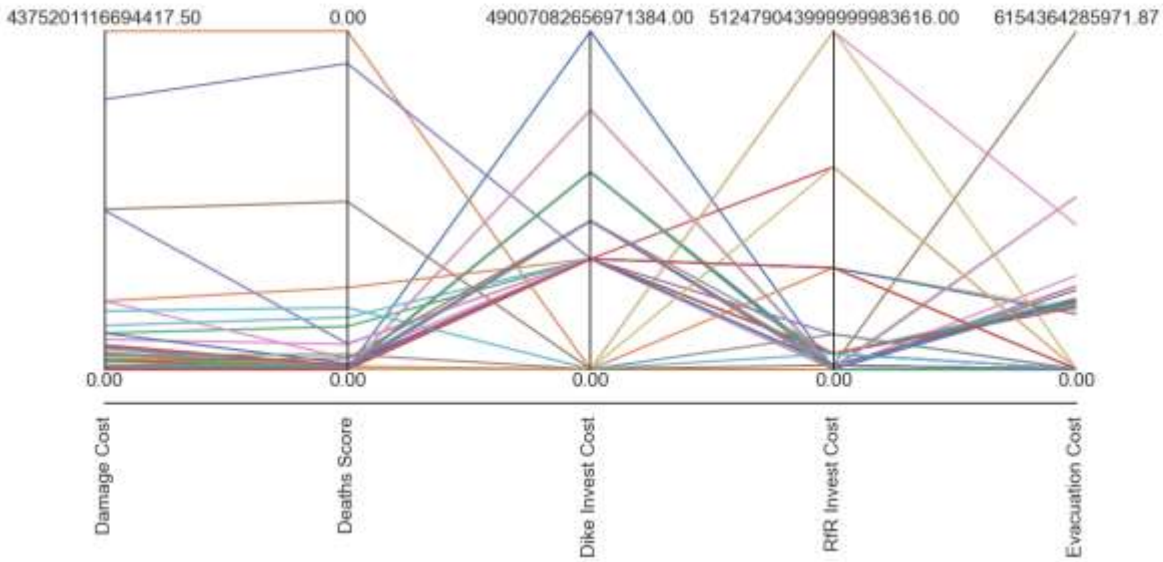

Figure 5: Robustness scores for the five outcomes in problem formulation 1 for the non-dominated policies

4.2 Uncertainty analysis results

For the uncertainty analysis, robustness scores are calculated using the mean square deviation (MSD) that indicates each policies' behaviour across relatively broad range of 10,000 scenarios. *Figure 6* shows the robustness of each set of non-dominated policy alternatives. Unlike in *Figure 5*, the behaviour of individual policies becomes much clearer for the robustness scores in *Figure 6* because only the top 5 best-performing (that is, policies with the lowest total costs) policies are presented. The following can be concluded from *Figure 6* and *Table 5*:

- The first policy (**blue**, policy 26 in *Table 5*) shows that the total expected evacuation costs are not exceptionally high or low, while the investment costs and the death costs are relatively low. This policy entails that only few investments are made for the dike heightening or Room for the River projects, implying that much land will get flooded. This lack of investments results in a relatively high value for the total expected annual damage.
- The second policy (**orange**, policy 11 in *Table 5*) exhibits a comparable pattern as the first policy, albeit without incurring any costs associated with evacuation. Consequently, a considerable number of individuals cannot be evacuated, resulting in the highest cumulative death cost when comparing across the other policies. Additionally, not much is invested in dike heightening or Room for the River projects.
- The third policy (**green**, policy 5 in *Table 5*) shows a policy in which relative maximum investments in dikes, Room for the River projects and evacuation are made. As a result, this policy yields a relative minimal cumulative death cost, effectively minimizing the number of individuals who succumb to flooding incidents. In this case, the expected annual damage is average, indicating that the measurements taken do not necessarily prevent damage.
- In the fourth policy (**red**, policy 44 in *Table 5*), there is a low investment cost made in dikes but very high investment cost in Room for the River projects. In this case, the total expected evacuation costs are zero, which explains the high number of deaths. The evacuation costs for this policy cannot be seen in this figure due to overlapping policies, but the fact that it is zero for this policy can be traced from the output values in Appendix A.

- In the fifth policy (**purple**, policy 9 in *Table 5*), there is a relative minimum total expected damage as a just below-average investment is being made for the dikes, and a very high investment is being made for Room for the River projects. The downside is that there are no evacuation costs involved in this policy, resulting in a high number of deaths.

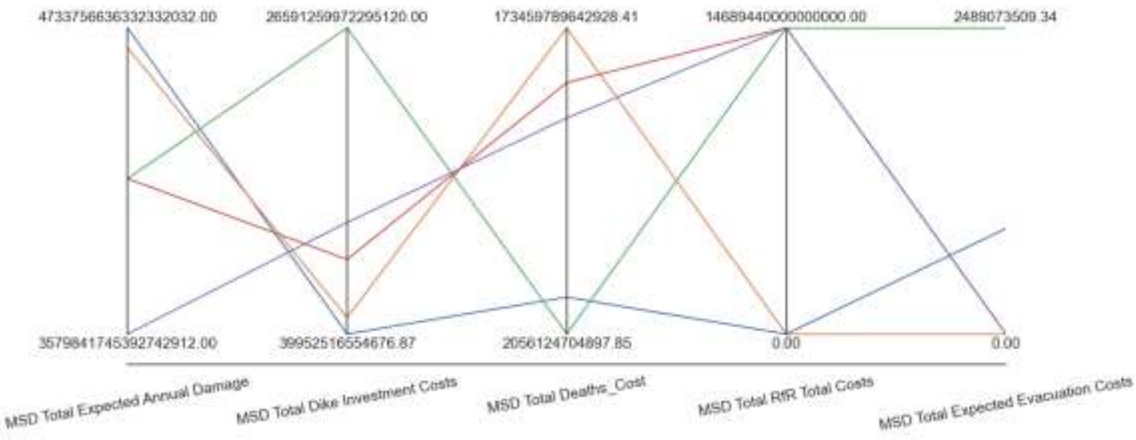

Figure 6: Robustness scores for the five outcomes in problem formulation 1 for the top 5 best-performing policies

The top 5 policies with the lowest costs are shown in *Table 5*. The levers and results of these policies are shown in Appendix C. The optimal policy would be policy number 26, where a warning system is implemented that issues a warning one day before a threat, and the dike height at dike ring 4 (Gorssel) must be increased by 1 decimetre at timestep 0. The second policy (number 11) in the top 5 suggests only a dike increase at dike ring 2 (Cortenoever), a Natura 2000 area in the province of Gelderland. There is a slight difference in costs for the Province of Overijssel between policy number 26 and 11, but a significant advantage is gained regarding workload since policy 11 only requires action in the province of Gelderland.

Table 5: Total costs and policy levers used for the top 5 best-performing policies in problem formulation 1

Policy number	**Total costs (in euro)**	**Policy levers used**
26	8.331391e+07	- Warning system 1 day before threat - Dike ring 4 increase by 1 decimetre at timestep 0
11	8.407651e+07	- Dike ring 2 increase by 1 decimetre at timestep 1
5	1.760816e+08	- Room for the River project 3 at timestep 2 - Warning system 3 days before threat - Dike ring 2 increase by 6 decimetres at timestep 1 - Dike ring 2 increase by 7 decimetres at timestep 2 - Dike ring 4 increase by 7 decimetres at timestep 0
44	1.763057e+08	- Room for the River project 3 at timestep 0 - Dike ring 2increase by 7 decimetres at timestep 1 - Dike ring 4 increase by 2 decimetres at timestep 0
9	1.764013e+08	- Room for the River project 3 at timestep 2 - Dike ring 1 increase by 1 decimetre at timestep 2 - Dike ring 2 increase by 1 decimetre at timestep 1 - Dike ring 3 increase by 1 decimetre at timestep 2 - Dike ring 4 increase by 2 decimetres at timestep 0

4.3 Scenario discovery results

PRIM is used to discover vulnerabilities after the initial search for robust policies. In other words, the goal is to identify subspaces in the uncertainty space where the implemented policies perform poorly. This is being done in different steps which are further explained in Appendix A. Once the uncertainty analysis has been completed, the data set generated is used for scenario discovery. In *Figure 7,* the probability of withstanding hydraulic load for each of the five dike rings can be seen as the uncertainty parameters. The coverage is 0.172, and the density is 0.828, which shows that the quite some cases of interest are outside the selected ranges, but that almost all cases selected are cases of interest. As the quasi-p value of all the parameters is lower than 0.05, they are all significant. *Figure 7* also shows that the fifth dike has the lowest range in probability of withstanding the hydraulic load. The first and the third dike have an extensive range in the probability of withstanding the hydraulic load, and the second and fourth dikes almost have a full range between 0 and 1, meaning that scenarios with these exogenous factor values are most problematic. A further explain of the interpretation of the box limits plot can be found in Appendix A.2. The trade-off curve is shown in Appendix B.

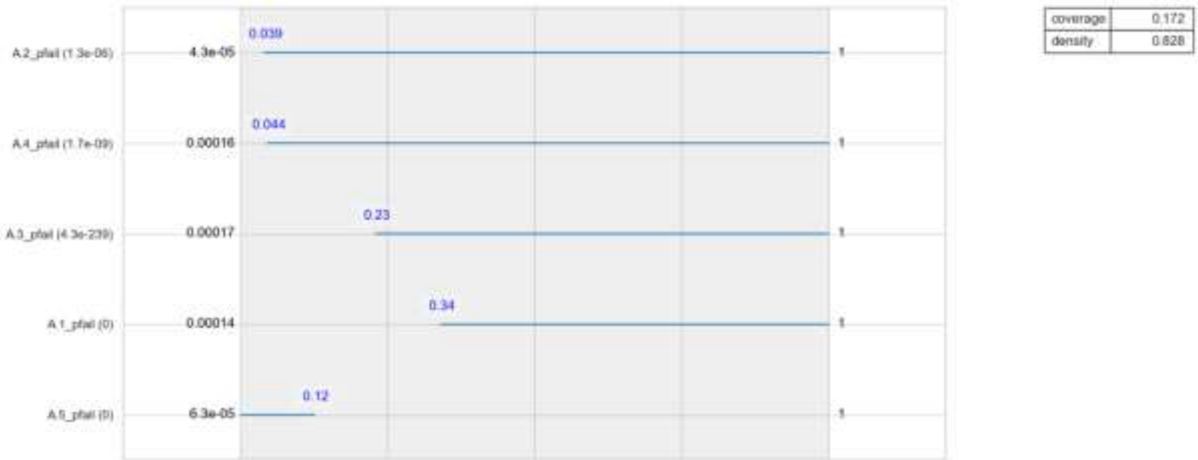

Figure 7: Box limits for each significant exogenous factor in the scenario discovery

4.4 Results of problem formulation 2

Considering the collaborative nature of decision-making in real-life, it is crucial to acknowledge that the province of Overijssel would not make decisions in isolation without consultation or collaboration with other actors. This section gives the results when considering problem formulation 2. That is, the outcomes for the dike rings located in the province of Gelderland are additionally considered in this problem formulation.

The robustness scores for the outcomes of the five best policies for the provinces of Gelderland and Overijssel combined, by considering problem formulation 2, are shown in *Figure 8*. The total costs and policy levers used for these top 5 are given in *Table 6*. The levers and results of these policies are shown in Appendix C. The following can be concluded from both *Figure 8* and *Table 6*:

- Policy 25 (**red**) shows a policy with the highest total expected annual damage. This policy entails the lowest investment cost in dikes among top 5 policy alternatives, with no costs allocated for Room for the River projects. Furthermore, no provisions are made for evacuation costs, leading to a considerable number of casualties.

- Policy 10 (**green**) shares similarities with the first policy. However, the expected annual damage is slightly lower, dike investment costs are somewhat higher, and the total death costs are significantly higher compared to the first policy.
- Policy 1 (**purple**) involves below-average investment costs for dikes and substantial investments in the Room for the River project. Although no evacuation costs are incurred, the extensive investments implemented to mitigate flood risks contribute to a relatively low number of total death costs.
- Policy 2 (**orange**) represents a policy where the total expected annual damage is minimized. This policy also entails substantial investment in both total dike costs and evacuation measures, resulting in minimal death costs.
- Policy 36 (**blue**) closely resembles the fourth mentioned policy (number 2) with slightly lower dike investment costs. Nevertheless, the total expected annual damage and death costs remain relatively low.

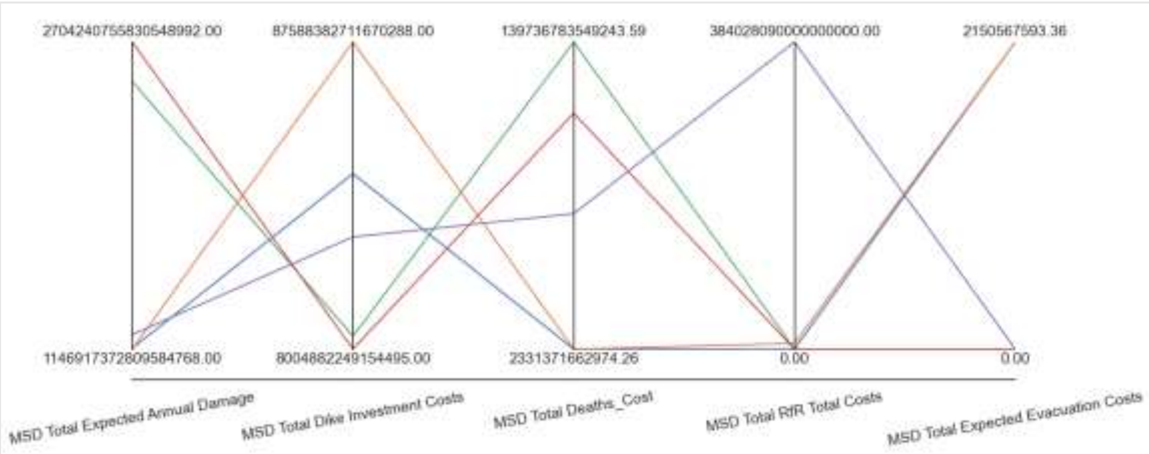

Figure 8: Robustness scores for the five most dominant policies for Overijssel and Gelderland

Table 6: Total costs and policy levers used for the top 5 best-performing policies in problem formulation 2

Policy number	Total costs (in euro)	Policy levers used
36	1.033884e+09	- Warning system 2 days before threat - Dike ring 1 increase by 8 decimetres at timestep 0 - Dike ring 1 increase by 1 decimetre at timestep 1 - Dike ring 1 increase by 6 decimetres at timestep 2 - Dike ring 3 increase by 1 decimetre at timestep 2 - Dike ring 4 increase by 4 decimetres at timestep 0
2	1.181345e+09	- Room for the River project 1 at timestep 1 - Warning system 2 days before threat - Dike ring 1 increase by 8 decimetres at timestep 0 - Dike ring 1 increase by 7 decimetres at timestep 1 - Dike ring 1 increase by 6 decimetres at timestep 2 - Dike ring 3 increase by 1 decimetre at timestep 2 - Dike ring 4 increase by 4 decimetres at timestep 0
10	1.373723e+09	- Dike ring 1 increase by 1 decimetre at timestep 0 - Dike ring 1 increase by 6 decimetres at timestep 2 - Dike ring 4 increase by 5 decimetres at timestep 0
25	1.422984e+09	- Dike ring 1 increase by 6 decimetres at timestep 2 - Dike ring 3 increase by 1 decimetre at timestep 0 - Dike ring 4 increase by 3 decimetres at timestep 0
1	1.481486e+09	- Room for the River project 3 at timestep 0 - Room for the River project 3 at timestep 1 - Room for the River project 3 at timestep 2 - Room for the River project 4 at timestep 0 - Dike ring 1 increase by 2 decimetres at timestep 0 - Dike ring 1 increase by 1 decimetre at timestep 1 - Dike ring 1 increase by 1 decimetre m at timestep 2 - Dike ring 2 increase by 1 decimetre m at timestep 0 - Dike ring 2 increase by 1 decimetre at timestep 1 - Dike ring 4 increase by 1 decimetre at timestep 0

5. Conclusion and discussion

5.1 Conclusion

A four-step approach based on the Many-Objective Robust Optimization (MORO) framework was followed to identify robust policies regarding flood risk management for the province of Overijssel. The policies are designed to address the unique needs and vulnerabilities of the province of Overijssel while considering the potential impacts of flood events. Five policies are identified that exhibit robustness and satisfactory performance across multiple uncertainties and often competing objectives. The policy with the lowest total costs entails activating a warning system one day prior to the threat and increasing the dikes belonging to dike ring 4 by one decimetre at timestep 0. While steering on lowest costs was important for the province of Overijssel, ethical objections may arise as preventing deaths should maybe be prioritized.

The optimal policies identified resulted in financially adverse outcomes for the province of Gelderland. Therefore, an additional set of five policies were identified that effectively address the shared challenges and objectives of both provinces. The total costs of these five policies demonstrate less variability than those specific to the province of Overijssel alone. Again, the policies show very different considerations based on the robustness scores.

In the end, it is up to the province of Overijssel to choose the most suitable policy out of the set of proposed policies. The recommended policies offer valuable insights into the performance and tradeoffs associated with each policy. Investing in dike heightening and in Room for the River projects seem most promising based on the two problem formulations in this study. However, the province of Overijssel should also cope with the interest of the other actors in the political arena, like the environmental interest group that strongly favours implementing Room for the River projects or transport companies who are firmly against Room for the River projects.

By identifying promising policies for the province of Overijssel, this study makes a meaningful contribution to the ongoing efforts in flood risk management. It demonstrates the commitment to creating a more resilient and sustainable future for the province of Overijssel. The advice allows decision-makers to make informed choices that align with their goals and priorities.

5.2 Discussion

In the IJssel River case, only objectives related to flooding are considered. In real life, however, decision-makers would also care about other indicators, such as indicators related to recreation, water use for industry, agriculture, et cetera. Although the approach employed in this study can be extended to accommodate these additional criteria, incorporating more indicators will likely increase the required computational power. Moreover, converting human life into a monetary value, as the cost-benefit analysis approach requires, may raise some ethical questions.

For the multi-objective optimization problem, the NSGAII algorithm was used. Although this algorithm is well-known for solving this kind of problem, other algorithms, such as auto-adaptive algorithms like Borg (Hadka & Reed, 2013), could also be suitable and might lead to better performance. Furthermore, the definition of robustness in this study was specific to a particular operationalization. Employing alternative definitions of robustness could result in a distinct set of non-dominated Pareto policies. 16 Thus, future research could explore the influence of algorithm choice and robustness operationalization on performance and the identified set of policies.

Stakeholder involvement is crucial in scoping the decision problem, including indicating the significant uncertainties and outcomes of interest. As analysts for the province of Overijssel, the precise key objectives and major uncertainties, as perceived by the province, were not entirely clear. Consequently, a decision was made to explore robust policies while considering a wide range of potential levers and diverse uncertainties. For future research, it would be beneficial to narrow the scope to align robust policies more precisely with the long-term goals of the province of Overijssel. This can be achieved by engaging decision-makers more extensively at various stages of the process, facilitating improved ‘deliberation with analysis’ (National Research Council, 2009).

Within the Multi-Objective Evolutionary Algorithm (MOEA) framework, an assumption is made regarding the occurrence of a flattening phenomenon in the convergence curve after the 28th generation. The escalation of the epsilon progress value does not display a substantial increase as the number of generations increases. However, complete certainty regarding the flattening of the curve remains elusive, as the epsilon progress value also appears to reach a stable state between the 10th and 15th generations. As stated in the method description, MOEA is influenced by randomness. Therefore, it is best practice to perform the analysis multiple times and perform seed analysis. However, this was not a realistic option to perform due to a computational power constraint. Future research could include a seed analysis, making the outcomes more reliable. Finally, in the scenario discovery phase, problematic exogenous factor ranges are identified. These are, however, not further investigated due to time constraints. Future research could focus on these factor ranges, exploring possibilities to mitigate some of the negative effects in these scenarios.

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Appendix A. Open exploration Visualizations

A.1 Costs of scenarios

Figure A1 illustrates the anticipated annual damage, costs of deaths, and dike investment costs for multiple scenarios in the absence of policy intervention. Notably, the expected annual damage surpasses the costs attributed to deaths by a factor of 100, as depicted along the horizontal axis.

Analysis of the figure further reveals that approximately 50% of the scenarios demonstrate expected annual damage ranging from roughly one to three billion units. Similarly, the costs associated with fatalities span a range of approximately 4 to 14 million units across half of the scenarios.

Notably, the baseline case, characterized by the absence of any policy measures, demonstrates a complete absence of costs pertaining to dike investments, effectively registering a value of zero.
In the histogram, the 'Count' represents the number of scenarios out of the total 10,000 scenarios. It provides an overview of the distribution of scenarios based on their total cost, measured in billion euros of expected damage. The histogram reveals that a significant portion of scenarios have a total cost exceeding one billion euros, but more than half of the scenarios fall below the two-billion mark. Additionally, the histogram demonstrates that over 80% of the scenarios have total costs below four billion euros.

Complementing the information presented in the histogram, the boxplot provides further insights into the range and distribution of total costs. It shows that the majority of scenarios fall within the range of half a billion to three billion euros. Although the histogram appears to reach a maximum total cost of just below six billion euros, the boxplot identifies four scenarios as outliers, depicted by the diamond-shaped figures. These outliers represent scenarios with total costs exceeding six billion euros, indicating that they are considered worst-case scenarios due to their significantly higher costs.

Furthermore, it is worth noting that the visual representation of the total costs in *Figure A1* resembles the visualization of Expected Annual Damage costs. This similarity arises because death costs constitute a relatively small proportion of the overall expected annual costs.

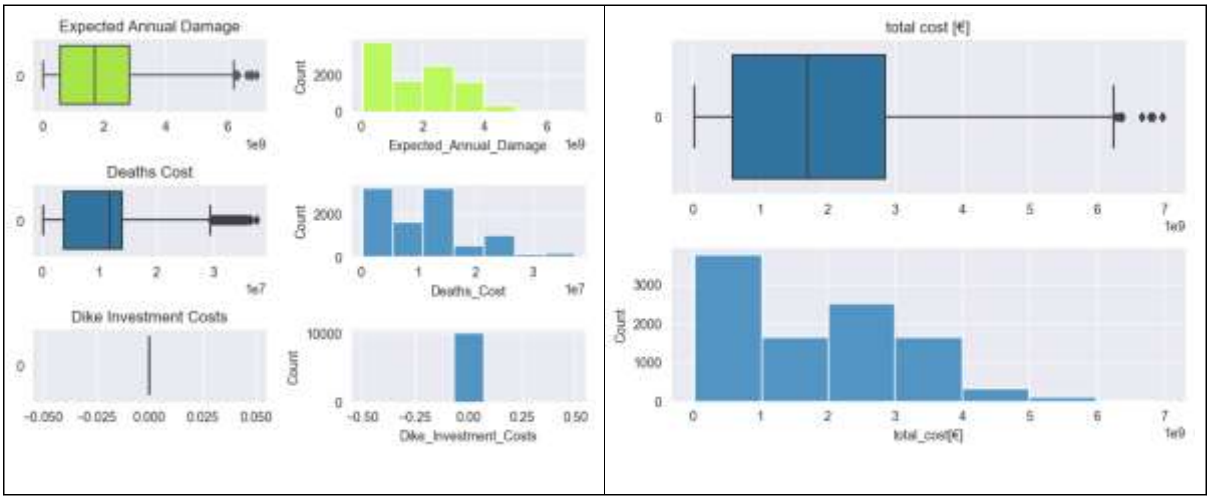


Figure A1. Boxplot and histogram of total costs

A.2 Box limit plot

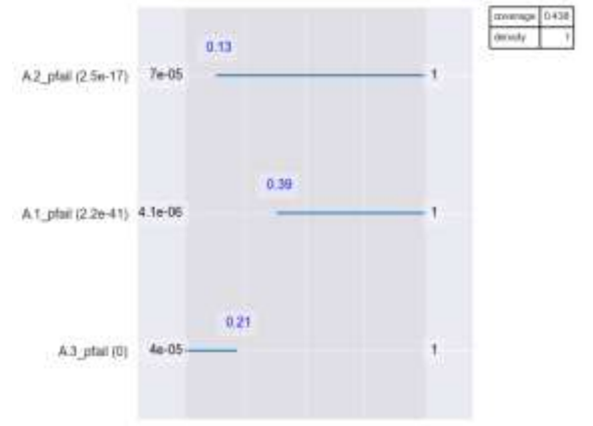
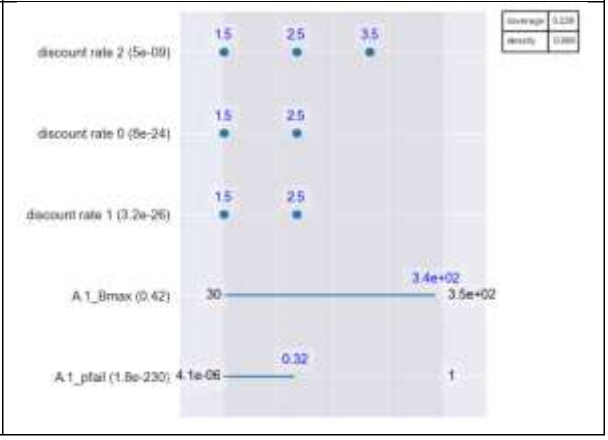
Death cost	*Expected annual damages*
	

Figure A2. Results box limits plot for Death cost and expected annual damages

In *Figure A2*, the patient rule induction method (PRIM) has been applied to the death costs and total expected damage. Only these outcomes are considered here because the investments will always be zero at the zero-policy scenarios.

The two figures in *Figure A2* show the box limits. The horizontal blue lines represent the bandwidth for each parameter's uncertain dimension, while the grey area represents the uncertainty space. These limits indicate the acceptable range or threshold values for the parameters. Any value falling outside these limits may be considered undesirable or beyond the acceptable range. Each number in blue represents a limit.

Furthermore, the Quasi-p values, denoted by the numbers shown in brackets next to the parameters, provide insights into the statistical significance of the restrictions imposed by the box limits. These values indicate the probability of observing a parameter value less than or equal to the specified limit. In other words, Quasi-p values reflect the likelihood of the parameter falling within the defined range. The significance of the Quasi-p values is determined by a threshold, typically set at 0.05 (or a significance level of 5%). If the Quasi-p value is greater than 0.05, it implies that the observed restrictions on the parameter are not statistically significant, and they can be disregarded as random variations. However, if the Quasi-p value is below 0.05, it suggests that the observed restrictions are statistically significant, indicating a meaningful boundary for the parameter.
Overall, the box limits and Quasi-p values provide valuable information about the acceptable parameter range, the significance of restrictions, and the probability distribution of each parameter, aiding in the analysis and interpretation of the uncertainty space in the context of the decision-making problem.
In *figure A2* the patient rule induction method (PRIM) has been applied to the death costs and total expected damage. Only these outcomes are considered here because the investments will always be zero at the zero-policy scenarios.

Box limit for Death Costs
For the probability of dike 1 withstanding hydraulic load, the limits are 0.39 to 1. This means the probability should be between 0.39 and 1 for dike 1 to withstand the hydraulic load.

The quasi-p value for dike 1 is 2.2e-41, indicating an extremely low probability of observing a value below the lower limit (0.39) based on the distribution.
For the probability of dike 2 withstanding hydraulic load, the limits are 0.13 to 1. This indicates that the probability should be between 0.13 and 1 for dike 2 to withstand the hydraulic load.
The quasi-p value for dike 2 is 2.5e-17, which is under the 0.05 value and means it is significant. This suggests a very low probability of observing a value below the lower limit (0.13) based on the distribution.
For the probability of dike 3 withstanding hydraulic load, the limits are 4e-05 to 0.21. This indicates that the width should be between 4e-05 to 0.21 for dike 3 to withstand the hydraulic load.
The quasi-p value for dike 3 is 0, suggesting a low probability of observing a value below the lower limit (4e-05) based on the distribution.

Box limit for Expected Annual Damage
For the expected annual damage, the parameter of the uncertainty of the discount rate has been added. This is the discount rate for calculating the present-day value of damages. The discount rate can either have the value 1.5, 2.5, 3.5 or 4.5, which means in the box limit plot, there will be no line present because the discount rate cannot take any value outside of these four values. This results in the fact that the box limit plot only shows certain points of the values which are relevant for the analysis.
For discount rate 0, the limits for the discount rate at timestep 0 are 1.5 and 2.5, so the values of 3.5 and 4.5 will not be used.
For discount rate 1, the limits for the discount rate at timestep 0 are 1.5 and 2.5, so the values of 3.5 and 4.5 will not be used.
For discount rate 2, the limits for the discount rate at timestep 0 are the values 1.5, 2.5 and 3.5.
For the probability of Dike 1 Withstanding Hydraulic Load, limits for the probability are 4.1e-06 to 0.32. This means that the probability should be between 4.1e-06 and 0.32 for dike 1 to withstand the hydraulic load.
For the final extent of the breach width of dike 1, the limits are 30 to 3.4e+02. This indicates that the width should be between 30 and 3.4e+02 for the dike breach.
Here the quasi-p value for the breach width of dike 2 is 0.42, which is rather high and certainly higher than 0.05, making it insignificant. For all the other parameters, the quasi-p values are below 0,05, which means they are significant.

A.3 Trade off curve

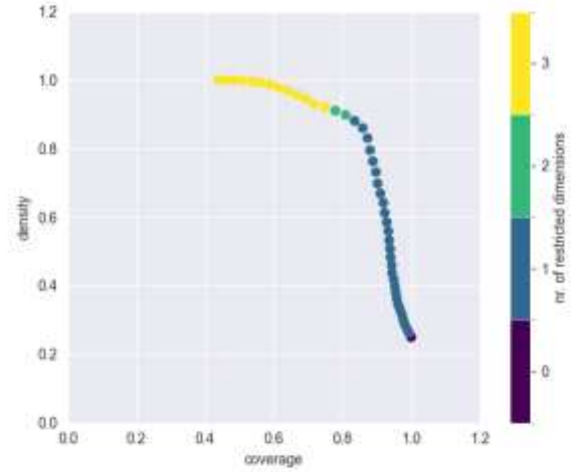
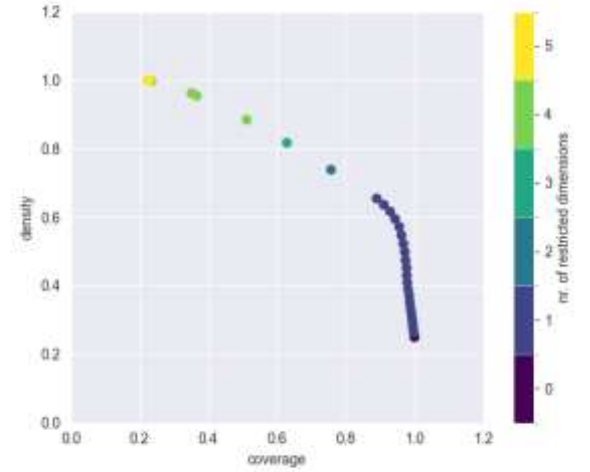
Death cost	Expected annual damages
	

Figure A3. Trade off curve between coverage and density

Figure A3 shows the trade-off between density and coverage made with the patient rule induction method (PRIM) for each death cost and the expected annual damages. Each point on the curve represents a specific combination of input parameter settings and the corresponding values of the performance measures. In the graph, the coverage refers to the proportion of the worst-case scenarios covered by a particular policy. It indicates how well a policy performs under extreme or unfavourable conditions. A higher coverage value suggests that the policy effectively addresses a larger number of worst-case scenarios. The density represents the number of distinct policy alternatives found within a specific region of the trade-off curve. This is also shown in *Figure A4* as the fraction of cases in the box which is of interest. It indicates the diversity or variety of available policies with varying levels of coverage. The points on the trade-off curve represent different policy alternatives with their corresponding coverage and density values. Each point represents a specific policy configuration or set of input parameter settings. The graph shows that the higher the coverage gets, the lower the density of the policy gets

The number of restricted dimensions is an additional factor that indicates the complexity or specificity of the policy alternatives. It represents the extent to which specific dimensions or variables are restricted or constrained in the policies. This measure helps capture the diversity of policy options by considering the variations in the number of dimensions that are restricted across different points on the trade-off curve. The more dimensions, the more the colour is headed towards yellow, while the fewer dimensions, the darker the points get.

A.4 Pair-wise scatterplot

Figure A4 shows the patient rule induction method (PRIM) used to form a pair-wise scatterplot for the death costs and the expected annual damages. This is used to measure the impact of the different uncertainties on expected annual damage. The scatterplot displays two sets of data points: cases of interest are represented in orange, while cases not of interest are shown in blue. The red square indicates the determined boundaries for each pair of parameters. The plot is used to identify parameter boundaries. The figure shows that the uncertainties significantly affect the different scenarios.

For the plot on the death costs, the parameters Probability of Dike 1 Withstanding Hydraulic Load and Probability of Dike 2 Withstanding Hydraulic Load show almost only orange points. In the other combinations, many blue points are shown in the plot.
For the plot on expected annual damage, all the combinations with the final extent of breach width of dikes 2, 3 and four show a lot of orange points, while the combinations with probability of dike 1 withstanding hydraulic load show a fair distribution between orange and blue points.

The presence of mostly orange points in the first plots involving the parameters suggests that specific combinations of these uncertainties strongly impact the death costs. The first plots involving the "Probability of Dike 3 Withstanding Hydraulic Load" show a mixture of orange and blue points, indicating that the impact of this uncertainty on the expected annual damage is less pronounced. The points are less well separated, suggesting a lower sensitivity or importance level than the other parameters.

The predominantly orange distribution in the second plot implies that the final extent of the breach width of the dikes is a critical factor in determining the expected annual damage when combined with these parameters. Here, the probability of dike 3 withstanding hydraulic load suggests a lower sensitivity or importance level than the other parameters.

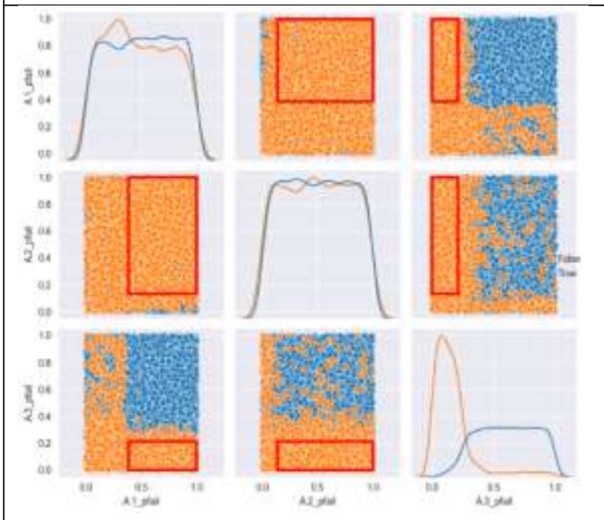
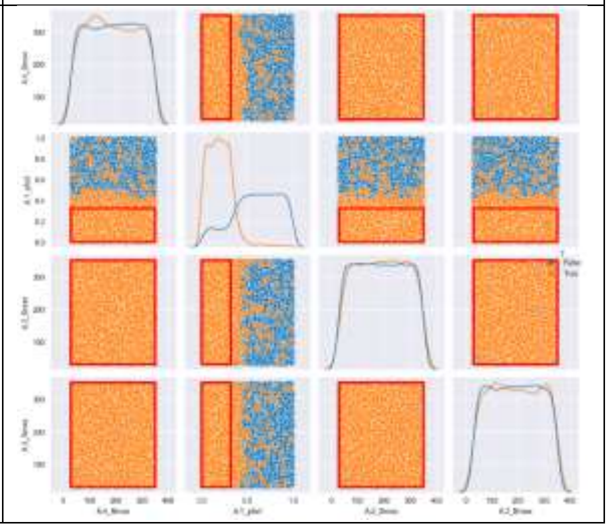
Death cost	*Expected annual damages*
	

Figure A4. Pair-wise scatterplot Death cost and expected annual damage

A.5 ε-progress

Figure A5 shows the ε-progress of MOEA. As can be seen, the ε stabilizes, indicating that MOEA has converged for the 30,000 function evaluations. However, more function evaluations could be useful in future research, as this would show whether the ε is definitely stabilized. For this analysis, however, this level of stabilization is sufficient, as it results in proper outcomes.

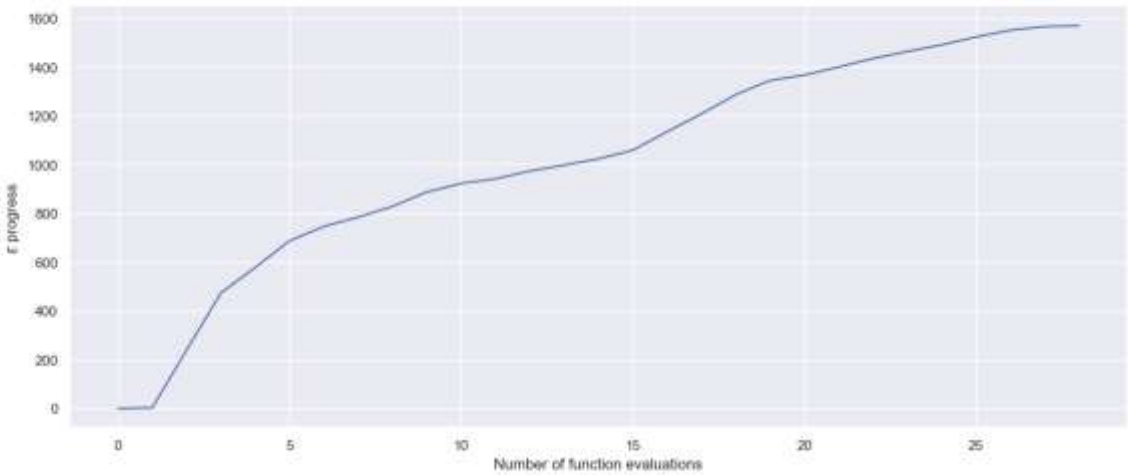


Figure A5. ε-progress of MOEA.

Appendix B. Scenario discovery visualizations

The trade-off curve between coverage and density shows a negative exponential distribution (or an inverse relationship) between the density and coverage. The inverse relationship in the trade-off curve shows that the density quickly decreases at a high low point in coverage, and the higher the coverage gets, the slower the density decreases.

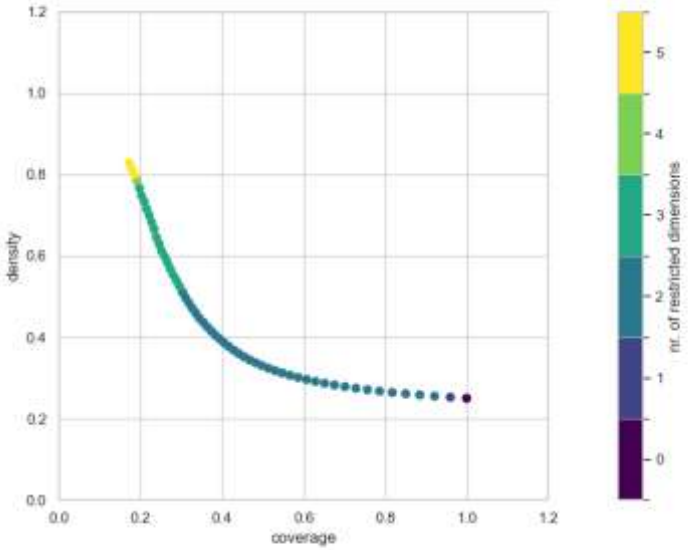


Figure B. Coverage and density function

Appendix C. Detailed policies

Top 5 policies Overijssel:

Table C1. Top 5 policies Overijssel

Policy → Lever ↓	26	11	5	44	9
0_RfR 0	0.0	0.0	0.0	0.0	0.0
0_RfR 1	0.0	0.0	0.0	0.0	0.0
0_RfR 2	0.0	0.0	0.0	0.0	0.0
1_RfR 0	0.0	0.0	0.0	0.0	0.0
1_RfR 1	0.0	0.0	0.0	0.0	0.0
1_RfR 2	0.0	0.0	0.0	0.0	0.0
2_RfR 0	0.0	0.0	0.0	0.0	0.0
2_RfR 1	0.0	0.0	0.0	0.0	0.0
2_RfR 2	0.0	0.0	0.0	0.0	0.0
3_RfR 0	0.0	0.0	0.0	1.0	0.0
3_RfR 1	0.0	0.0	0.0	0.0	0.0
3_RfR 2	0.0	0.0	1.0	0.0	1.0
4_RfR 0	0.0	0.0	0.0	0.0	0.0
4_RfR 1	0.0	0.0	0.0	0.0	0.0
4_RfR 2	0.0	0.0	0.0	0.0	0.0
EWS_DaysToThreat	1.0	0.0	3.0	0.0	0.0
A.1_DikeIncrease 0	0.0	0.0	0.0	0.0	0.0
A.1_DikeIncrease 1	0.0	0.0	0.0	0.0	0.0
A.1_DikeIncrease 2	0.0	0.0	0.0	0.0	1.0
A.2_DikeIncrease 0	0.0	0.0	0.0	0.0	0.0
A.2_DikeIncrease 1	0.000000e+00	1.000000e+00	6.000000e+00	7.000000e+00	1.000000e+00
A.2_DikeIncrease 2	0.000000e+00	0.000000e+00	7.000000e+00	0.000000e+00	0.000000e+00
A.3_DikeIncrease 0	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.3_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.3_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	1.000000e+00
A.4_DikeIncrease 0	1.000000e+00	0.000000e+00	2.000000e+00	2.000000e+00	2.000000e+00
A.4_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00

A.4_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 0	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
Damage Cost	8.815847e+14	4.375201e+15	2.665745e+13	2.665745e+13	3.636926e+13
Deaths Score	4.696797e-06	1.501234e-04	1.722509e-08	1.196187e-06	1.592133e-06
Dike Invest Cost	1.598101e+16	0.000000e+00	2.150376e+16	2.150376e+16	2.150376e+16
RfR Invest Cost	0.000000e+00	0.000000e+00	5.875776e+18	5.875776e+18	5.875776e+18
Evacuation Cost	1.705403e+12	0.000000e+00	6.154364e+12	0.000000e+00	0.000000e+00

Top 5 policies Gelderland and Overijssel combined:

Table C2. Top 5 policies Overijssel and Gelderland

Policy → Lever ↓	36	2	10	25	1
0_RfR 0	0.0	0.0	0.0	0.0	0.0
0_RfR 1	0.0	1.0	0.0	0.0	0.0
0_RfR 2	0.0	0.0	0.0	0.0	0.0
1_RfR 0	0.0	0.0	0.0	0.0	0.0
1_RfR 1	0.0	0.0	0.0	0.0	0.0
1_RfR 2	0.0	0.0	0.0	0.0	0.0
2_RfR 0	0.0	0.0	0.0	0.0	0.0
2_RfR 1	0.0	0.0	0.0	0.0	0.0
2_RfR 2	0.0	0.0	0.0	0.0	0.0
3_RfR 0	0.0	0.0	0.0	0.0	1.0
3_RfR 1	0.0	0.0	0.0	0.0	1.0
3_RfR 2	0.0	0.0	0.0	0.0	1.0
4_RfR 0	0.0	0.0	0.0	0.0	1.0
4_RfR 1	0.0	0.0	0.0	0.0	0.0
4_RfR 2	0.0	0.0	0.0	0.0	0.0
EWS_DaysToThreat	2.0	2.0	0.0	0.0	0.0
A.1_DikeIncrease 0	8.0	8.0	1.0	0.0	2.0
A.1_DikeIncrease 1	1.0	7.0	0.0	0.0	1.0

A.1_DikeIncrease 2	6.0	6.0	6.0	6.0	1.0
A.2_DikeIncrease 0	0.0	0.0	0.0	0.0	1.0
A.2_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	1.000000e+00
A.2_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.3_DikeIncrease 0	0.000000e+00	0.000000e+00	0.000000e+00	1.000000e+00	0.000000e+00
A.3_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.3_DikeIncrease 2	1.000000e+00	1.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.4_DikeIncrease 0	4.000000e+00	4.000000e+00	5.000000e+00	3.000000e+00	1.000000e+00
A.4_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.4_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 0	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 1	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
A.5_DikeIncrease 2	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
Damage Cost	0.000000e+00	0.000000e+00	0.000000e+00	1.317461e+13	1.124352e+11
Deaths Score	0.000000e+00	0.000000e+00	0.000000e+00	6.096035e-07	1.860414e-09
Dike Invest Cost	3.759873e+16	3.759872e+16	4.900708e+16	2.858404e+16	1.598101e+16
RfR Invest Cost	0.000000e+00	2.862864e+18	0.000000e+00	0.000000e+00	1.536112e+20
Evacuation Cost	3.142106e+12	3.141952e+12	0.000000e+00	0.000000e+00	0.000000e+00