Flood risk prevention for the IJssel River in Gelderland

An exploratory modelling approach within a broader political frame

GROUP 22

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Executive Summary for Gelderland Province

Flooding has become a common danger in many river basins around the world. The IJssel river-basin in the eastern Netherlands is one such basin. Characterised by a multi-actor environment consisting of various administrative strata and other for-profit and non-governmental organisations, an already uncertain issue is made even more complex. Through use of a computational simulation model of the IJssel river basin, potential policy approaches are generated for Gelderland. This is accompanied by the use of novel deep uncertainty management methods, such as scenario discovery through patient rule induction method (PRIM). Candidate policies are discovered through use of the many objective evolutionary algorithm (MOEA) and then evaluated for robustness. Furthermore, the political context of the proposed policies are captured and reflected upon through stakeholder analysis. Throughout this process, limitations and shortcomings are identified of the model in used, the overall decision-making approach followed, as well as the eventual recommended policy. Recommendations are made for future decision-making approaches to iteratively include stakeholder analysis as a way of holistically including political considerations in the model-based policy recommendation.

1 Introduction and Framework

1.1 Problem summary

As the global climate changes, increased rainfall and shrinking floodplains create the perfect conditions for flooding in many river basins worldwide (Wilby and Keenan, 2012). In addition, the topography of the Netherlands makes it increasingly prone to flooding events (Lugeri et al., 2010). One of the major rivers in the country is the IJssel, a distributary of the Rhine river. Flooding has become a significant concern since many residential and productive urban and rural areas are lining the river.

Since the IJssel flows through the Overijssel and Gelderland provinces of the Netherlands, collaborative action is imperative to tackle the issue effectively. The decision-making arena comprises different stakeholders, often with diverging objectives and interests. This adds a layer of complexity to the problem arena since no singular solution exists. Consequently, the tool of discrete modelling under deep uncertainty is applied to reach a scientific foundation upon which the political arena will be navigated. As the concept of post-normal science delineates (Funtowicz and Ravetz, 1993):

"***Scientific practices cannot be separated from politics***"

This ideology encapsulates the relevant context for the complex problem at hand (Kwakkel, Haasnoot, and Walker, 2015). This report aims to offer policy advice to Gelderland to effectively mitigate flood risk in the region while managing challenges in a multi-actor decision arena.

1.2 Problem formulation

The IJssel flows through two Dutch provinces, Gelderland upstream and Overijssel downstream. In this region in particular, there are 5 existing dike rings located in Doesburg, Cortenoever, Zutphen, Gorssel and Deventer (see Table 2). Three policy measures are generally accepted to be effective in some or other form in flood prevention and mitigation. These measures are:

- Increasing the height of existing dikes or investing in new dike development,
- Implementing or creating **room for the IJssel river** at locations close to the dike rings,
- Implementing or investing in early warning systems that become active in case of floods.

These measures can be adopted in isolation or combination. Each of these measures has its benefits, consequences and associated costs, which different stakeholders might perceive differently. Different stakeholder values combined with no clear optimal solution form part of the complex nature of this issue,

Table 1: *Names of the Dike Rings*

Dike Name	Number
Doesburg	Dike Ring 1
Cortenoever	Dike Ring 2
Zutphen	Dike Ring 3
Gorssel	Dike Ring 4
Deventer	Dike Ring 5

which demands caution, adaptability and compromise to navigate effectively.

The stakeholder analysis below details the intricate nature of all stakeholders involved in the decision-making process. Gelderland is in a strategic position in its influence in this process. Not only does it have a significant impact on the Dutch economy, but it has direct links to Overijssel (to the north), transport companies which utilise the expanding port in Zutphen, and, ultimately, to the Rijkwaterstaat and Delta Commission, who will recommend a policy to the Dutch government. Therefore, a research question for this analysis must be determined:

Research Question

How can Gelderland develop an effective and efficient flood risk management plan to ensure the physical safety of its citizens, maintain its economy's prowess, and minimize expected damage to its assets?

As mentioned before, this entire project suggests decision-making under very uncertain conditions. Essentially, this would mean testing a variety of policies against a variety of scenarios, preferably ones that seem to be the most problematic, to ensure that Gelderland can recommend a preventive policy proposal. Given the many factors critical to Gelderland, the analysis employs robust multi-objective decision-making to develop and provide the testing grounds (Kwakkel, 2017). Thus, the following are **sub-research questions** that help form the framework for this analysis.

- Which uncertainties have **potentially critical impacts** to Gelderland's outcomes of interest?
- Which policies can potentially address these scenarios?
- How do these policies fare in **dire circumstances** that have been predetermined?
- How does Gelderland's proposed approach fare in the **larger political arena?**

1.3 Objectives of Gelderland

While regions surrounding the IJssel river have substantial defences against flooding, these events have become more frequent and violent (Klijn, Asselman, and Mosselman, 2019). Current predictions of flooding frequencies are being altered; as a result, and when combined with population growth and economic development, there is a need for evolving flood risk management solutions, perhaps with dynamic performance metrics to complement these solutions (Mens, Klijn, and Schielen, 2014). This sentiment is also expressed by the Dutch government, which has expressed interest in implementing reevaluation points in the Netherlands (Rijswick et al., 2016).

The three dike rings present in Gelderland vary greatly, with Doesburg and Cortenoever (dike rings 1 and 2) being primarily rural locations and Zutphen (dike ring 3) being an urban setting and one of the economic cornerstones of the province. As such, these regions may have localised interests that might, in execution, conflict with other regions' interests. As an overarching framework, the goals of Gelderland province are simple, listed below, in order of importance:

- **To uphold the physical safety and security of the people living in Gelderland province.** To preserve Gelderland's ideals and structure, the province has a moral obligation to prevent the loss of life to ever-increasing flooding events. While the analysis focuses on this metric in Gelderland, the province is committed to ensuring that loss of life in other provinces is mitigated.

- **To uphold the robustness of Gelderland's booming economy and ensure stability for the future.** Ensuring that businesses that utilise Gelderland's resources are a priority to provide a high standard of living for its residents and, by extension, all those in the Netherlands and Germany that enjoy services emerging from the province. Since the province also has a significant agricultural sector, this also includes preserving free enterprise of the farming population located, for sake of this analysis, in Dike Rings 1 and 2.

- **Promoting and implementing efficient solutions in terms of cost and application.** While Gelderland is open to investments to protect their citizens and assets, those investments must also provide a "return" in the form of viable solutions in the face of deep uncertainties regarding flooding events and, by extension, climate change effects.

These objectives can also be visualised in the following objectives tree:

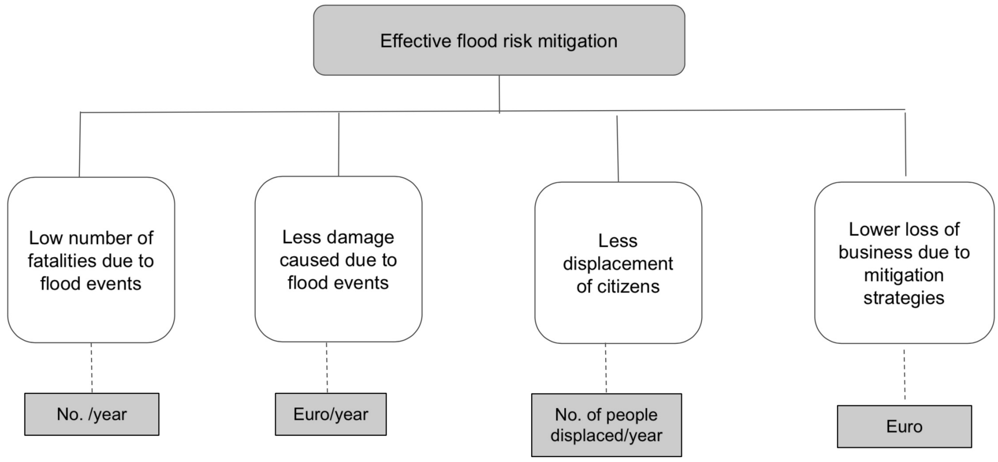


Figure 1: *Gelderland operationalized objectives tree*

1.4 Stakeholder dynamics

The complexity of the RfR project does not merely lie in the limited understanding of the natural/technical system potentially affected by the decision-making process. The interaction of multiple actors across different decision-making arenas and levels of governance, with their conflicting values, is, necessarily, a source of complexity (Nguyen, Mohamed, and Panuwatwanich, 2018) that must be adequately studied and accounted for. Such understanding and considerations will be crucial in two main aspects:

1. Understanding this multi-faceted actor arena will be necessary for Gelderland to safely navigate through the different stages of the decision-making process.

2. Objective-weighting or objective prioritisation is an important way through which Gelderland can capture and communicate the goals of the different stakeholders.

For these reasons, this subsection will try to shed light on the different participants involved in the decision-making process, together with their values, resources and objectives.

From a first analysis of the project, 10 main participants can be identified (see **Figure 2** for reference). As explained by Hermans and Cunningham (2018), to gain a qualitative understanding of this arena, we can initially follow two subsequent steps:

- Identification of resources that can be mobilised by each actor.

- Identification of participants' objectives and level of interest in the project

While a detailed analysis is attached in Appendix B (see **Table 28** and **Table 29**), these two steps, in turn, help us create a power-interest matrix 2 which can be used to visualise an approximate characterisation of different actors, and to guide Gelderland's first interactions in this arena (Bryson, 2004; Enserink et al., 2010).

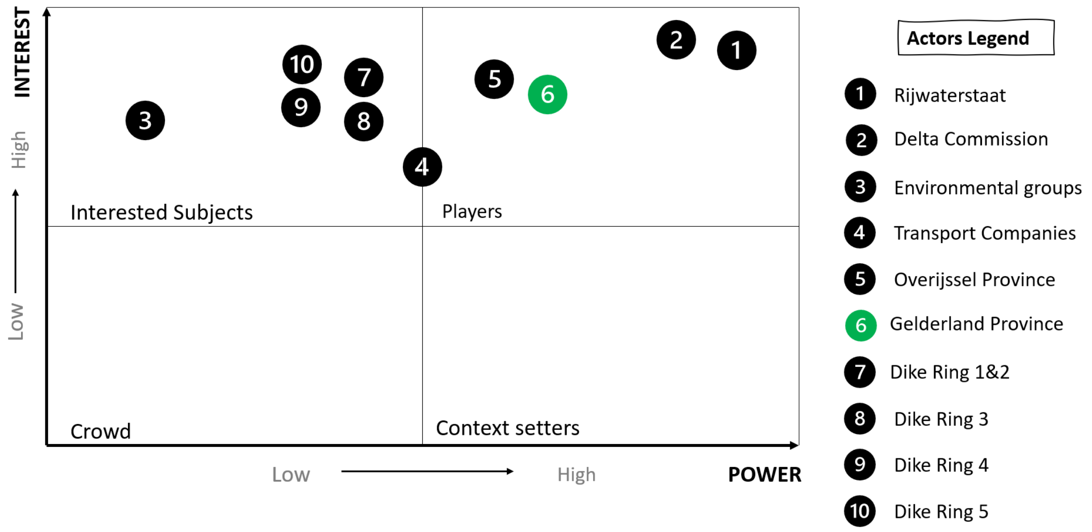


Figure 2: *Power-Interest Matrix*

To complement this first stakeholder analysis method, it will be essential to understand which actors are likely to support (or oppose) Gelderland's proposed policies. To achieve this, we can create a salience-position matrix developed by Aaltonen et al. (2015) in the context of complex nuclear projects drawing.

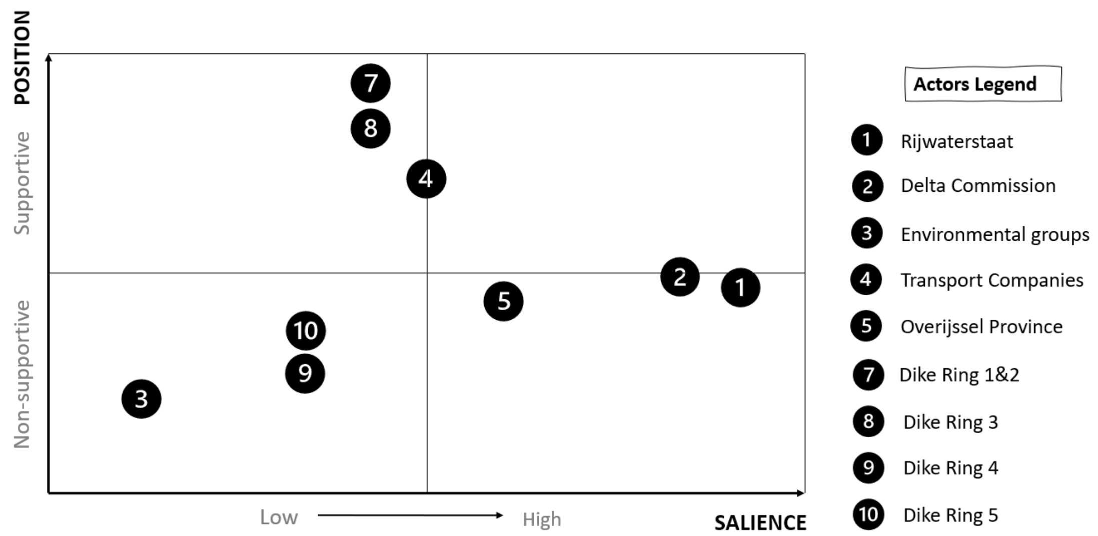


Figure 3: *Salience-Position Matrix*

While this kind of matrix can be helpful for Gelderland to grasp a broader picture of the decision-making arena in this preliminary stage, we still have to account for two key points:

- The position of different participants for the construction of this first matrix was deduced from their objectives. This means that, when a policy is chosen on the basis of the modelling outcomes, the perceptions (and thus the position) of the remaining participants can drastically change. Thus, a reevaluation of this first matrix will be needed as soon as a policy is created.

- As highlighted by Aaltonen and Kujala (2010), stakeholders' behaviour is dynamically shaped throughout the different phases of a complex project (e.g., conceptual, planning, execution, termination). This would imply that SA (stakeholder analysis) tools and results, like our salience-position and power-interest matrixes, should not be a one-time analysis product. Rather, they should be rediscussed and reevaluated throughout different phases of the decision-making process.

Nevertheless, the qualitative results of these initial SA methods should provide a valuable framework for Gelderland in understanding the policy-making arena and how to interact in it.

1.5 Alternative problem formulations

The above section sheds light on the different actors in the arena. Rijkswaterstaat and Overijssel have been identified as crucial actors whose problem formulations might be relevant for Gelderland's analysis.

Rijkswaterstaat

How can the Netherlands develop effective long-term flood risk mitigation strategies to minimise fatalities due to such events while promoting biodiversity and minimising the investment costs?

Overijssel

How can Overijssel develop flood risk mitigation strategies to minimise the threat to its citizens while safeguarding the economic interests of their region?

2 Modelling Approach and Theory

The approach followed in this report is visualised in **Figure 4**, while utilising novel approaches to modelling under deep uncertainty (Saltelli et al., 2019, Bryant and Lempert, 2010) and striving towards responsible modelling (Saltelli et al., 2020). The initial step requires quantification and prioritisation of Gelderland's goals. This is a necessary step as, at least from the modelling perspective, many outcomes can potentially be of interest. This is then followed by *Exploratory modelling* - which involves exploring the model, its required inputs and outputs, as well as its general overall behaviour. Subsequently, *Open exploration* is conducted, which serves to dive deeper into understanding the model's relationship with uncertainties, while already identifying some general trends. With this deeper model understanding, policies are ready to be identified through several potential *Directed search* methods. These candidate policies are then subject to a *Robustness evaluation* to determine how well these policies fare in less-than-ideal or even worst-case scenarios. With the number of candidate policies reduced through this analysis, three potential policies are finally presented as candidate solutions. Based on numerous factors, such as the political arena and stakeholder network, a final *Policy recommendation* is selected. This is then subject to *Political reflection* based on how this policy might be implemented in practice, especially when taking the complex multi-stakeholder environment into account.

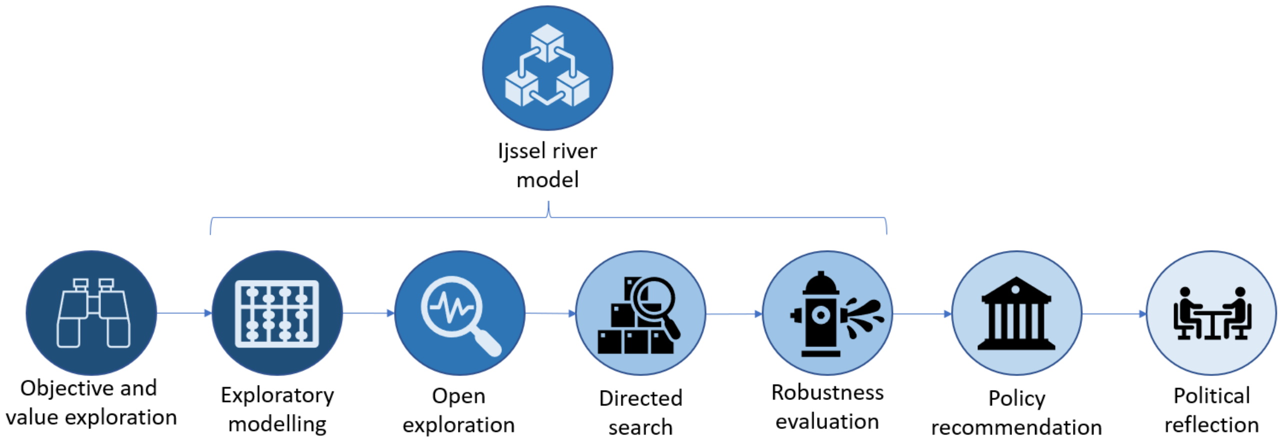


Figure 4: *Modelling and decision-making approach*

2.1 Decision-making under deep uncertainty

Exacerbating climate patterns in the region along the IJssel River will continue to inflict random and often violent events in surrounding regions. Solutions that may help alleviate this problem and protect citizens are debated under the constraints of bounded rationality and contextualised in an economic perspective. When combined with the intricate interactions between, for example, a province's social and economic responsibilities, decision making becomes even more complicated, all while these flooding events continue to grow in frequency and devastation. Thus, decision making for the IJssel River problem is rooted in uncertainty and complexity, and this ultimately impacts the state of knowledge on this problem, as predictability of the absolute impacts of the IJssel River floods are inherently limited (Walker, Marchau, and Kwakkel, 2012).

Understanding various different uncertainties within a problem will help decide how to approach the problem as well as provide valuable insight into potential limitations and valuations of important outcomes (Walker, Marchau, and Kwakkel, 2012). Even with the added value of models, remnants of uncertainty will remain and will need to be explored further to also provide conditions for appropriate solutions (Malekpour et al., 2020). To aid decision making under these circumstances, decision making under deep uncertainty (DMDU) is utilised. This archetype of decision making is divided into exploratory modelling, adaptive planning, and final decision support. Exploratory modelling involves utilising computational resources to generate insight onto how the simulated real world will react as a result of a set of combinations of uncertainties and policy options (Kwakkel and Haasnoot, 2019). Adaptive planning ensures the flexibility of resilient policies; uncertainties themselves change in time, so being adaptive in solutions is necessary to retain efficiency and, from an economic perspective, continue to provide a benefit to society. Finally, through the archetype of DMDU, decision support shift to an *a posteriori* approach to decision making, where the tendency for policymakers to initially place weights on different objectives are now motivated to analyse trade-offs from different policies (Tsoukiàs, 2008). Together, these parts merge together to form a structured method for analysis and, by extension, governance under deeply uncertain conditions.

2.1.1 Multi-objective robust decision making

Multi-objective robust decision making (MORDM) is the primary process for providing data-driven policy recommendations. It is an extension of the RDM framework and, due to the prevalence of multiple objectives and intricate subsystems in simulations, incorporates evolutionary algorithms and policy visualisations to show trade-offs and perform evaluations on viable solutions (Kasprzyk et al., 2013). **Figure 5** shows the workflow that was introduced in Kasprzyk et al., 2013 paper.

MORDM was used for a variety of reasons. From a practical point of view, the EMA Workbench only supports the MORDM framework for DMDU (Kwakkel, 2022). From an application perspective, researchers have recently been noted MORDM's ability to greatly improve decision making in environmental systems that have many subsystems at work, similar to the IJssel River boundaries and the foreseen impacts on the river's movement. As a result, this can provide to be a valuable tool in assessing potential solutions in the broader political arena. The IJssel River model has a fixed set of outcomes of interest, with each stakeholder having different motivations and interests. The incorporation of evolutionary algorithms into MORDM allows for optimisation of the solution

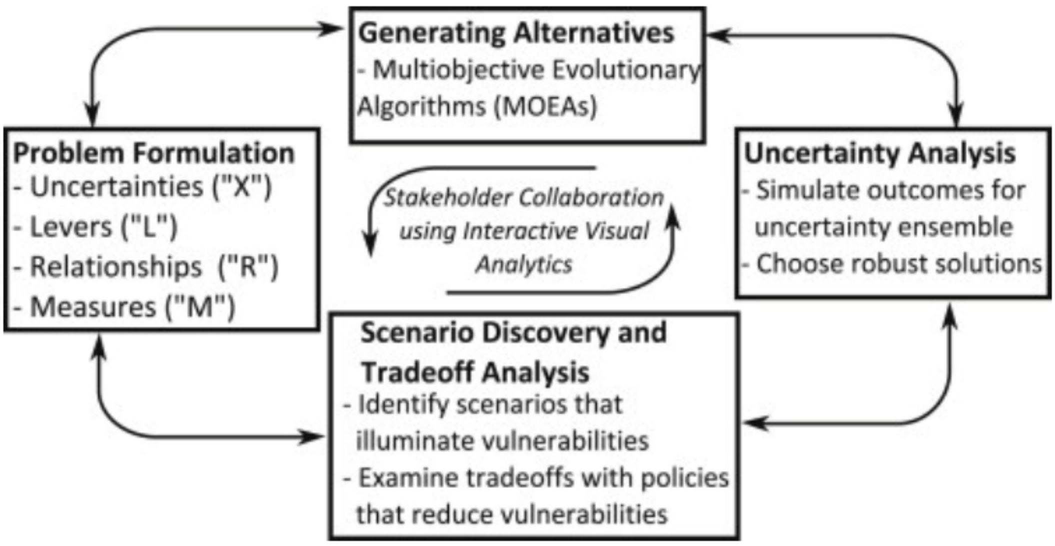


Figure 5: *The main steps of the MODRM framework for decision-making under deep uncertainty. Note that this is an iterative process in ultimately finding and testing all solutions for policies (Kasprzyk et al., 2013)*

space to account for these politically interesting scenarios, where solutions are chosen for the Pareto front space and then discussed by policymakers (Hadka et al., 2015).

2.1.2 Operationalization of MORDM

To put forth a method to perform decision-making under deep uncertainty, the Exploratory Modelling and Analysis (EMA) Workbench is used. Developed by Jan Kwakkel of TU Delft, the EMA Workbench is a revolutionary Python-based computational approach to analyse high complexity systems within the larger realms of deep uncertainty (Kwakkel, 2017). Finally, it also provides tools for decision support by incorporating robustness tools and vulnerability analysis to validate proposed decisions and set limitations or worst-case scenarios. The IJssel River model, which is debriefed following this section, is connected to the workbench to allow for analysis to occur.

2.2 IJssel River Model

The IJssel River model, developed by researchers at TU Delft, forms the foundation of the decision-making process for this specific problem (Ciullo et al., 2019). To give a brief overview of the model, it is helpful to overlay the model's components on the XLRM process flow diagram from above, shown in **Figure 6.**

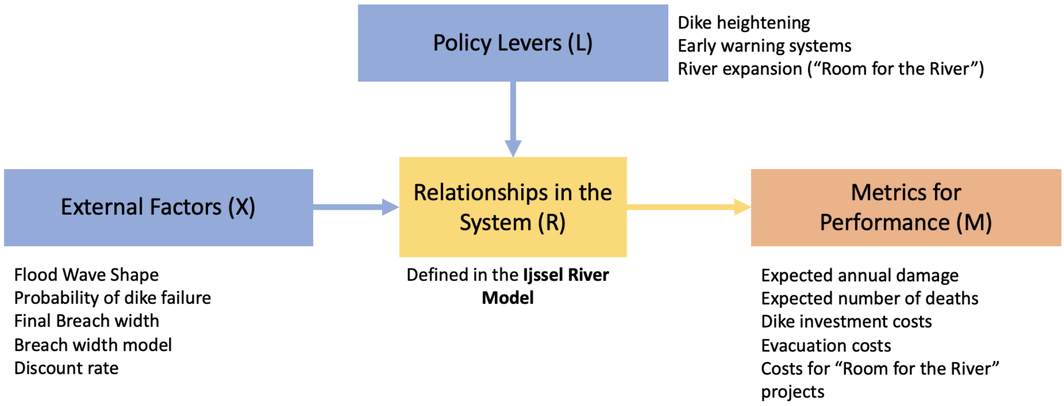


Figure 6: *The XLRM process flow specific to the IJssel River model with relevant variables, modified from the original diagram from Kwakkel, 2017.*

The model's base is a hydrodynamic function, which simulates a flood wave that will impact regions in proximity to the dike rings. The flood wave combines with other factors, like the movement of water into floodplains and the probability of dike failure, to create a unique scenario. While uncertainties are out of the direct control of policymakers, they have an opportunity to implement solutions through variations in policies levers. Combinations of scenarios and policies are then simulated and validated using the IJssel model to provide an output of recommended policies, the effect and impact of which are determined from the problem metrics (or outcomes). The model's time frame can also be varied to analyze temporal changes on outcomes. The model's external variables are detailed in the following sections.

2.2.1 External Factors Space

External factors are influential to overall efficacy of the proposed solution. They are not directly controlled by policymakers; this is done to develop independent scenarios. However, variations in policies can help influence the impact that some external factors impose on the dike rings (Ciullo et al., 2019). This dynamic strengthens the effectiveness of the MORDM framework. The external factors are:

- The ***flood wave shape***, which is a quantitative description of temporal changes in the flood wave that will trigger a release of river water at Doesburg's dike ring (the most upstream of the dike rings). The flood wave shape is determined randomly from 140 unique shapes, and the feasibility of each curve is implemented through a normal distribution.
- The ***dike failure probability***, denoted as p_{fail}, is the probability that a dike ring can withstand the hydraulic load imposed by a flood wave. This value ranges between [0-1], where a higher value signifies a stronger dike.
- The ***breach width model*** is a submodel that describes the development of a breached width over time. The uncertainty in this model is through

the growth rate of the breach, denoted as B_{rate}, which can vary between 1, 3, or 5 days. Depending on this, the model values can be 1, 1.5, or 10, respectively (with units of $\frac{1}{day}$).

- The ***final breach width***, denoted as B_{max}, is the final extent of the breach of the flood plain. It ranges between $[30 - 350]$ meters, with a higher value indicating a greater volume of water that has broken into the flood plain.
- The ***discount rate*** is the present value of future damages. It can be either $1.5, 2.5, 3.5, or 4.5$, with a lower value indicating that future damages are valued more.

2.2.2 Policy Lever Space

The policy lever space are a set of actions taken by policymakers to define the aggregated strategy to deal with the IJssel River issue. These are the areas of direct control that, in part, will also affect uncertainties and, by extension, the performance metrics. The policy levers are:

- ***The heightening of dikes***. Increasing a dike's height can help fortify current dikes to withstand higher hydraulic loads from flood waves. Note that implementation of dike height increases can differ in amount by dike location. Dike heightening can range between $[1 - 10]$ decimeters.
- ***Early warning systems***. These are systems in place to provide notice to inhabitants of a region that will be flooded. The early warning system is intricate, however, because a false alarm (which could end up with a very early warning) for flooding will instill distrust in the system, perhaps leading to catastrophe later. This can range from $[0 - 4]$ days.
- "***Room for the River*" *or RfR***. The widening of the river beds to allow for a greater volume of water. This, similar to dike heightening, could vary by dike location and by the planning step, which is the reassessment period that could lead to additional actions defined in the policy. In the model, it is a binary definition; a 0 means that RfR will not be implemented, while 1 indicates a RfR approval.

2.2.3 Performance Metric Space

The performance metrics space are outcomes of interest to analyse, as these will help determine to attraction of different policy options. Within the MORDM framework, performance metrics are critical in all steps, and can be interpreted as absolute or relative measurements when performing robustness and vulnerability analysis (Marchau et al., 2019). The following are the IJssel River model's performance metrics:

- ***Expected annual damage***, measured in $[Euros]$, are cost of the expected annual damage due to flooding in a given planning period.
- ***Dike investment costs***, measured in $[Euros]$, is the total investment costs specifically for heightening dike levels.
- "***Room for the River*" *investment costs***, measured in $[Euros]$, which is the total investment costs specifically for RfR river bed expansion projects.

- ***Expected number of casualties***, are the expected deaths caused by flood in given planning period.
- ***Expected evacuation costs***, measured in $[Euros]$, is a function of the number of people evacuated in an area and how long they must stay evacuated, with estimations derived from data from the 1995 flood evacuations in the Netherlands.

2.2.4 Operationalization of problem formulation

The relationships in the model, in part, are defined by the problem formulation. A variety of problem formulations are integrated into the model, with each one having a different combination of performance metrics. Differences in problem formulation are critical for stakeholders to understand the problem and, by extension, define the approach to the problem and formulations. The choice of problem formulation also differs on ethical grounds; the choice of problem formulation specific to Gelderland's objectives will be discussed later. **Figure 7** provides a general overview of all available problem formulations for the model.

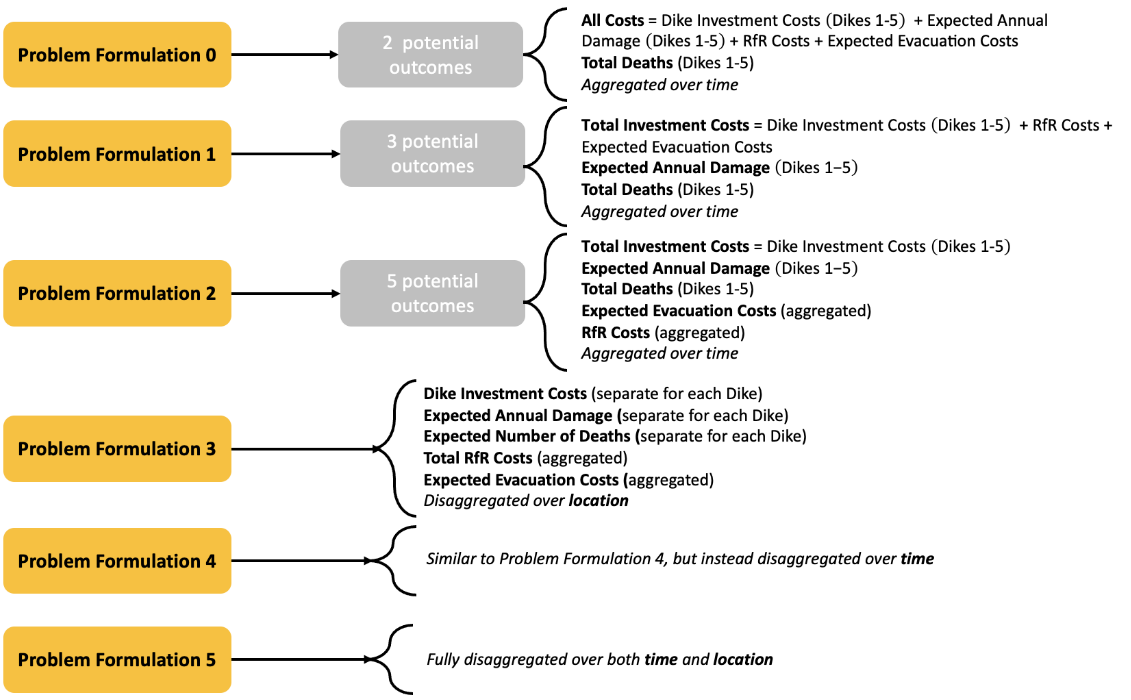


Figure 7: *A figure of available problem formulations in the IJssel River Model. These will be used to define performance metrics.*

3 Modelling Analysis and Results

All models are wrong. The key to making them useful, however, is understanding where and how they can be wrong, and how closely they resemble the system they model (Saltelli et al., 2020). This section is dedicated to understanding this model's behaviour under deep uncertainty , discovering potential policies, and optimising these policies along with evaluating their robustness.

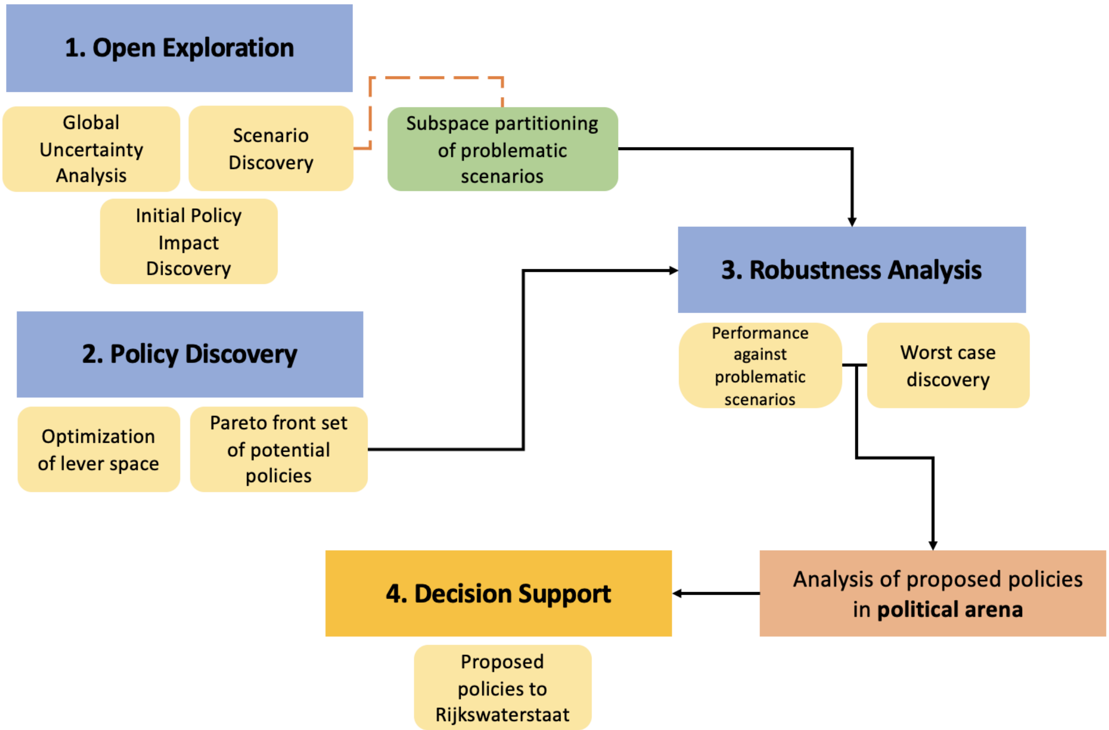


Figure 8: *A simplified workflow for the modelling and policy determination process, specific for this model.*

3.1 Open exploration

The model that is used for simulating the IJssel River environment contains many uncertain factors. These factors might at best lead to inaccurate or uncertain model outputs, or at worst conceal potentially dangerous and severe outcomes. In order to better understand the role of uncertainties in this model, two approaches are followed in this report: **scenario discovery** and **global sensitivity analysis**, further supported by dimensional stacking and feature scoring. Using such a broad range of methods, introduces more computational complexity in return of The uncertain factors in this model, and their accepted ranges of variations, are given in Appendix A.

3.1.1 Scenario Discovery

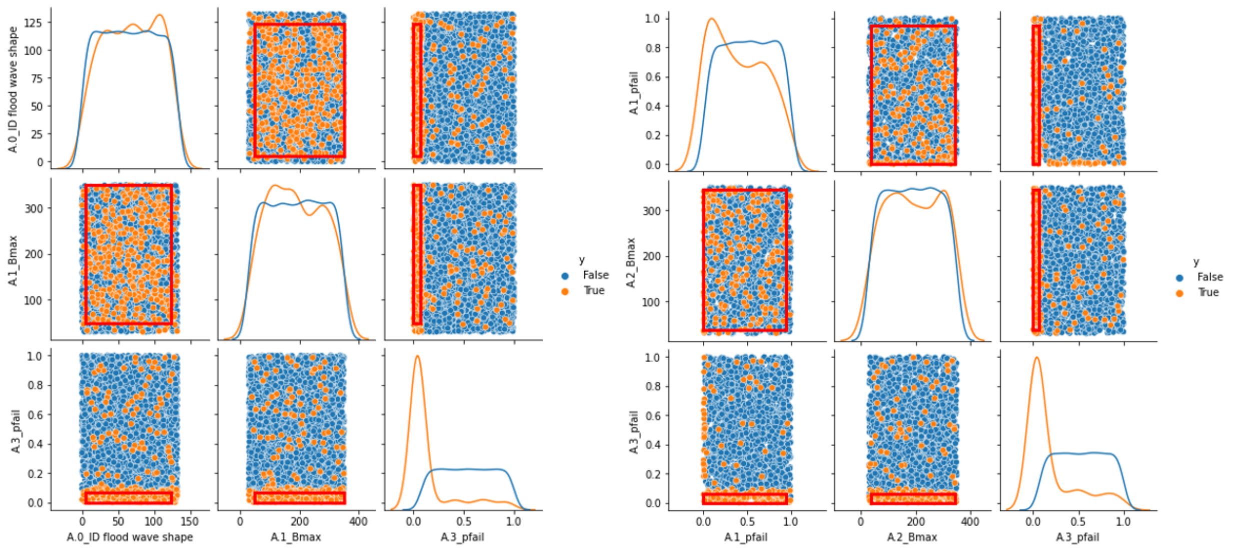
Scenario discovery involves generating random samples over a range for the uncertainties in the model. These sets of random uncertainties represent different *scenarios* that are easier to interpret in real-life context (Bryant and Lempert, 2010). Scenarios that are easier to interpret help in clarifying the performance of a potential policy in more realistic terms. These different scenarios are fed into the model to generate an outcome that is measured against a certain threshold for interest classification. Of the uncertainties that were previously mentioned (and tabulated in Table 3), the probability of dike failure p_{fail}, the final breach width B_{max}, as well as the breach width model B_{rate} were different for each dike ring, increasing the total number of uncertainties in the model to 18. Depending on the time-aggregation used by the model, more uncertainties were potentially added to based on the amount of time passed.

The outcomes that are most critical for Gelderland, *estimated number of fatalities* and *estimated damage cost*, are used to classify scenarios as being of interest or not. After scenarios are classified based on their outputs, a bounding box that encapsulates these scenario outputs is created using the Patience Rule Induction Method (PRIM). This algorithm allows for determining which range of uncertain inputs correspond to which change in the outputs of interest (Kwakkel and Jaxa-Rozen, 2016). Due to the differing geographical regions at play in this problem arena, two different scenario discovery approaches are undertaken to understand all possible dynamics that might become apparent. Firstly, a larger scale analysis is done across the whole IJssel area to determine the impact of some uncertainties on damage and fatalities across multiple dike rings. Secondly, we take a closer look into dike rings within Gelderland itself (which are dike rings 1 to 3). In all cases, 4000 scenarios were generated and analysed.

A note on problem formulation

In order to accurately analyse scenarios according to the outcomes of interest, the earlier described **Problem Formulation 3** was modified to disaggregate total costs into the expected annual damage as well as the dike investment cost. This new modified problem formulation was used for the rest of this analysis. Additionally, for open exploration, only Gelderland dike rings were then aggregated again.

In **Figure 9**, the PRIM-box is drawn for the expected number of deaths using both problem formulation 1 (**Figure 9 (a)**) and the local problem formulation 3 (**Figure 9 (b)**). From both we see relatively similar results, with only the probability of dike 3 failure significantly affecting outputs - as is evident by the rectangle's biggest dimension orthogonal to this variable. It is particularly dangerous to both Gelderland and the larger IJssel river area when the probability of dike 3's failure is lower than 0.1. Dike 3 breaking thus represents a significant *worst-case scenario*.

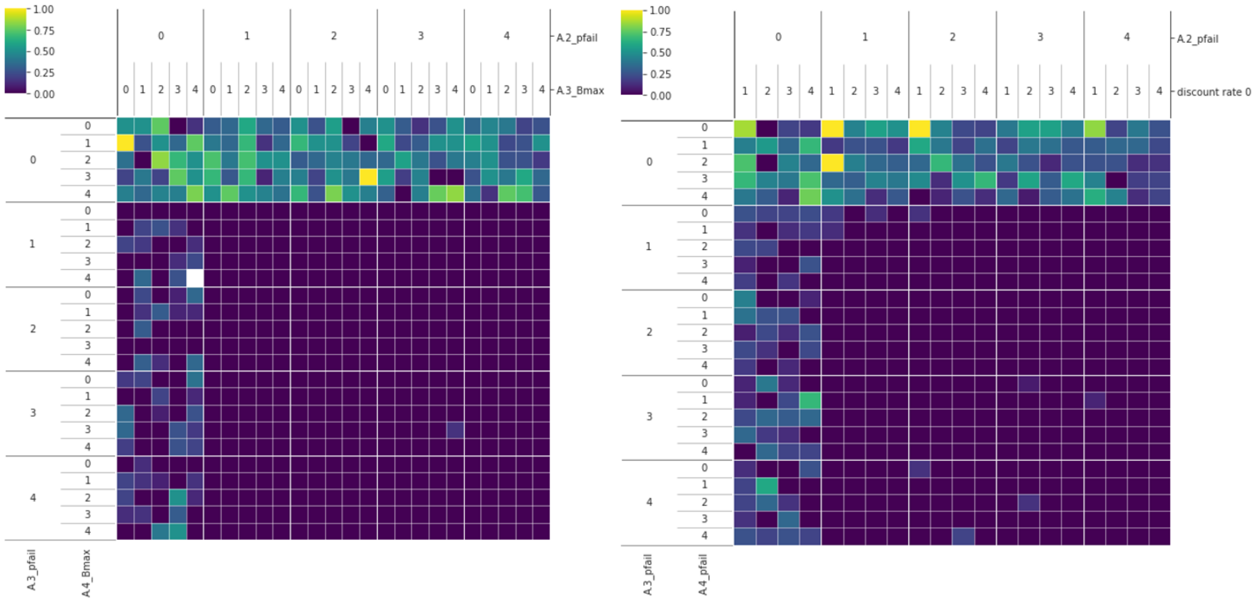


(a) Ijssel river area outcomes (b) Gelderland-specific outcomes

Figure 9: *Scatter plot results of PRIM analysis on expected number of deaths for different geographical aggregations*

3.1.2 Dimensional Stacking

In **Figure 10**, the results based on the dimensional stacking were visualised to see which uncertainties most greatly impacted the outcomes of interest. In **Figure 10 (a)** the outcome of interest was *estimated damage cost* and in **Figure 10 (b)** the outcome of interest was *estimated number of fatalities*.

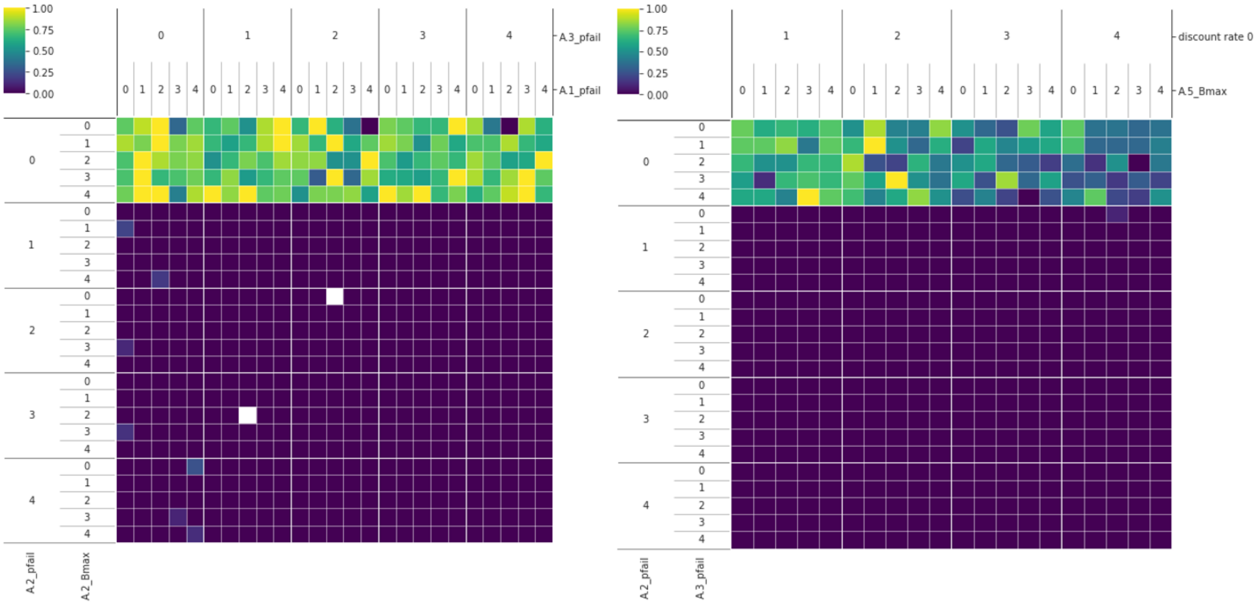


(a) Expected number of deaths (b) Expected annual damage

Figure 10: *Dimensionality of uncertainty factors for larger IJssel river area*

From **Figure 10** it is clear that the two factors that affect total damages in the IJssel area the most are the dike failing probability for dikes 2 and 3 - for both outputs of interest (given by *A2's* p_{fail} and *A3's* p_{fail}. This means that variation within these dike-breaking probabilities can potentially lead to the most adverse effects in damage costs and casualties. Thus, if both these values are lower than 0.25, it may be more likely to obtain undesired outputs. It is important to note that, as can be seen from the number of white cells in the grids in **Figure 10**, the analysis should ideally be reconducted with more scenarios. In the case of this report, this was not done in favour of doing a broader analysis on more factors and different geographical aggregations.

In **Figure 11**, the dimensionally stacked uncertainties are plotted for *estimated damage cost* and *estimated number of fatalities* as output of interest respectively. This represents the effect these uncertainties have over dike rings exclusively within Gelderland.



(a) Expected number of deaths (b) Expected annual damage

Figure 11: *Dimensionality of uncertainty factors for Gelderland dikes.*

When looking more in-depth at the dike rings contained within Gelderland, we see that here the most significant uncertainty is the probability of dike failure for dike 2. We also see the relatively minor issue of an insufficient number of samples as shown by the empty cells.

When comparing the different geographic aggregations, it is clear that the uncertainties affect Gelderland dikes less significantly than all dikes in the region.

3.1.3 Global Sensitivity Analysis

The second approach used to evaluate the impacts of input variance on the model and its behaviour is Global Sensitivity Analysis. In interest of adequately exploring the input parameter space, global sensitivity analysis is preferred over other commonly used methods such as One-at-a-Time analysis (Saltelli et al., 2019). This process helps in understanding the relationship between uncertainty in model inputs and outputs. This sensitivity analysis is done here using the SOBOL method (Saltelli et al., 2010), which describes how variations in model outputs are influenced by variations in the different model inputs. This method makes use of samples sampled in a SOBOL sequence to ensure that the parameter space is covered uniformly by the created samples.

Even though this specific SA method is computationally complex, the ease of which it can be used (particularly through the *SALib* and *EMA workbench*-libraries, as well as is relative accuracy, renders it the optimal method for this application. Both model uncertainties and input levers were analysed for global sensitivity to determine their impacts on the model output.

Initially, the effects of variance among the uncertainties on the estimated annual damages were investigated (**Figure 12**) and the estimated number of fatalities (**Figure 13**) were investigated. Using the SOBOL sampling method, 1000 random scenarios were generated. For SOBOL sampling, the number of experiments run can be calculated as

$$E = N \times (2k + 2),$$

with E the number of experiments, N the number of scenarios and k the number of uncertainties. Thus, for this initial sensitivity analysis, a total of 38000 experiments were simulated.

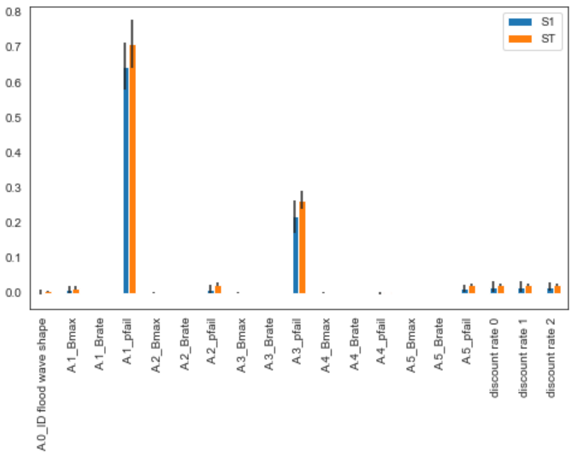


Figure 12: *GSA on uncertain effects on expected annual damage*

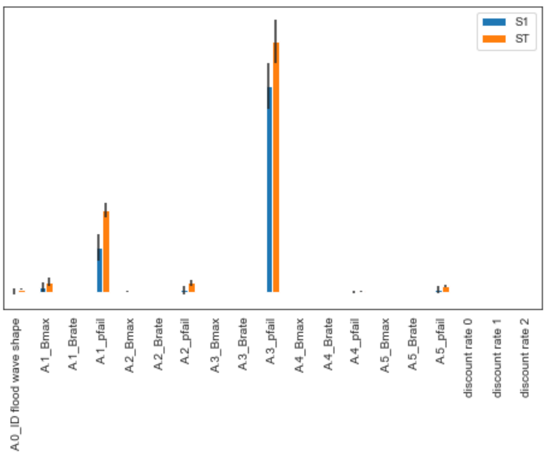


Figure 13: *GSA on uncertain effects on expected annual casualties*

From the results in **Figures 12** and 13, we see that the two uncertainties affecting both estimated damage and casualties are the probability of dike failure for dike rings 1 and 3 (Doesburg and Zutphen respectively).

3.1.4 Feature Scoring

In addition to the effects of the uncertainties on the model outputs, the effects of variance in policy levers were also investigated. This was done by creating SOBOL samples over the lever space. This was done under a reference scenario where all uncertainties were set to be the mean value of their overall ranges. In **Figure 14**, the feature scoring based on these results are shown, with higher correlation of variance shown by higher numbers. For the sake of brevity, only policy levers at time step 0 were included (as further time steps often had similar results). A complete version of table can be found in Appendix A in **Figure 25**.

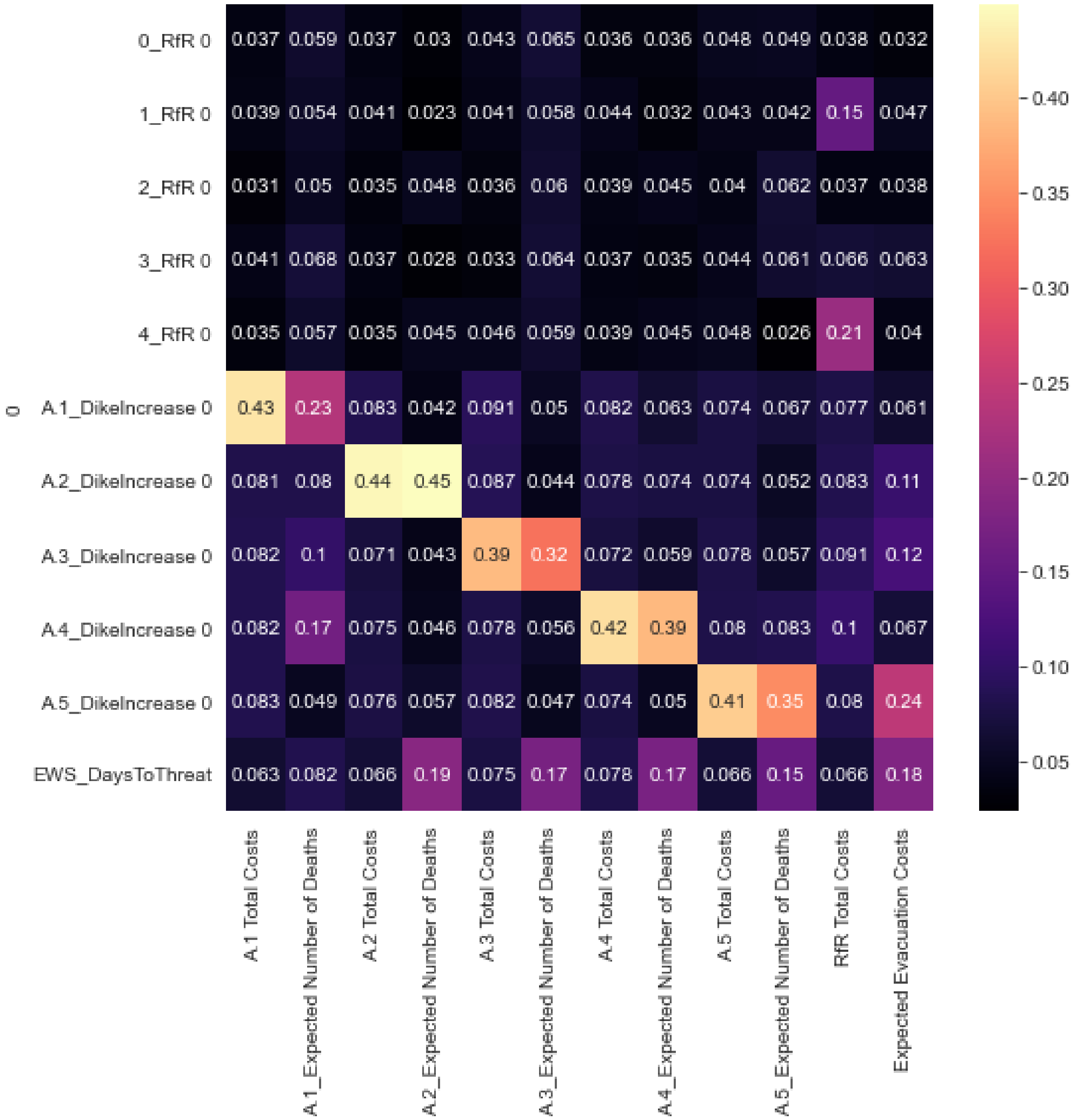


Figure 14: *Feature scoring based on GSA of levers*

From this figure we see that, predictably, dike heightening actions mostly only affect the expected cost and the estimated number of fatalities at that dike ring. Interestingly, we initially see no clear relation between implementing room for the river and the estimated damages and fatalities anywhere. This is potentially due to the reference scenario that was chosen to analyse levers, as the dike failure probabilities were not necessarily selected to be closest to reality. What is clear is that implementing room for the river has the most significant investment cost implications at dike rings 2 and 5.

3.2 Directed search

Following open exploration, which allowed for the discovery of different scenarios of interest, variations in the policy space need to be explored to understand which combinations would have provide greatest vector of impact on Gelderland's outcomes of interest. Directed search uses the fundamental concept of robust decision making (RDM). RDM is a workflow that assumes that developing testing policy combinations across a small set of scenarios does not allow for an effective policy set (Lamichhane et al., 2022). Thus, this DMDU strategy creates a mass number of permutations of policies and scenarios to identify key policies and adaptive options for future policy reshaping (Lempert, 2019). Directed search can be utilized for a plethora of different operations, ranging from worst scenario discovery to developing feasibility ranges for possible solutions. Therefore, directed search is divided into two separate processes:

1. **Policy discovery**, characterised by using a wide range of policies with a reference scenario to optimise outcome results based on pre-specified instructions. This portion will be expanded upon in this section.
2. **Robustness testing and vulnerability analysis**, analogous to a validation step, where a set of policies of interest (extracted from the larger viable policy space) are tested along pre-specified scenarios. Limitations and methodology will be discussed in the following subsection.

3.2.1 Policy discovery

Policy discovery followed a similar logical structure to scenario discovery. The search for candidate policy solutions occurred with the use of a *multi-objective evolutionary algorithm* (MEOA), a critical component of the MORDM workflow. One of the critical aspects of multi-objective decision making are identifying the trade-offs between different outcomes and how they fare with alterations within the model. This is one of the advantages of MOEAs, in that they have been routinely used in water resource management arenas to discover complex tradeoffs of high granularity (Zatarain Salazar et al., 2016). MOEAs also allow promote the aforementioned shift towards a posteriori decision support, meaning that policymakers are provided with a set of outcomes and then must assess preference (A., Lamont, and A., 2007). This reduces inherent bias in initial model specifications, and also promotes a collaboratory review of potential policies or scenarios from all stakeholders.
Because of the stochastic nature of MOEAs, a reference scenario was created and used for the policy discovery process. This reference scenario is with the following uncertainty values:
Once the scenario had been set, the MOEA ran an optimisation. It is important to note here, fr the MOEA, that one of the critical elements of the optimization is the *number of functional evaluations* (or the nfe). Due to the mathematical nature of evolutionary algorithm optimisation, a very high number functional evaluations would be necessary to ensure that all potentially viable policy solutions have entered the aggregated policy set (Kwakkel, 2022; Kwakkel,

Table 2: *Reference scenario uncertainty values*

B_{max}	175
B_{rate}	1.5
p_{fail}	0.5
Discount Rate	3.5
Flood Wave Shape	4

2017). Epsilon progress is a method that could have measured the convergence of the number of policy solutions in this optimizaton, and recommendations were made to use an nfe value of one hundred thousand. However, due to the choice of problem formulation and Gelderland's objective aggregation level, a significantly higher nfe would have been required. Combined with a lack of adequate computational resources, we were forced to accept the trade-off between breadth and depth of analysis. Thus, the subsequent policy recommendations in this report are based on a nfe value of forty thousand; an extended optimization run would be a necessary improvement to this analysis.

Pair coordinate graphs, such as that in **Figures 15** and **16**, were generated to analyse the overall trend of outcomes across dike rings. Pair coordinate graphs for dike rings 1 and 3 to provide a comparison between urban and rural settings, respectively. For dike rings 2, 4 and 5, these can be found in Appendix D (**Figures 36, 37 and 38**).

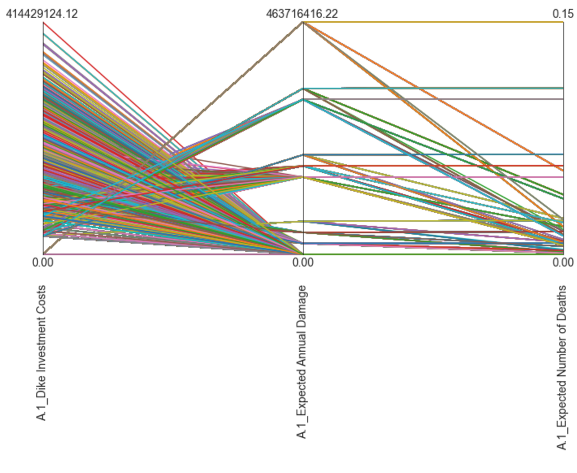


Figure 15: *A pair coordinate plot, running multiple policies against a reference scenario for the rural dike ring 1.*

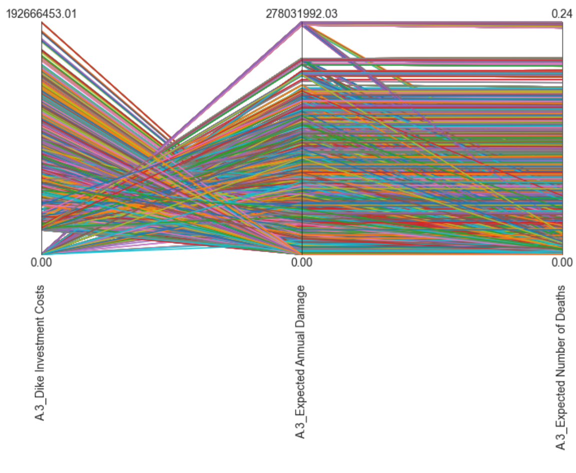


Figure 16: *A pair coordinate plot, running multiple policies against a reference scenario for the urban dike ring 3.*

Overall trends for all three dike rings showed that higher dike investment costs led to a significantly low expected annual damage and casualty rate, with the inverse also being true. This logically makes sense; historically, heightening of dikes (a proxy of dike investment costs) have led to the fortification of flood prevention systems. Furthermore, the more moderate levels of dike investment costs, which could be assumed to also include some development of

RfR projects, had a much less dramatic yet efficient reduction in damage and deaths. Interestingly, there is also a strong correlation between the expected annual damage and the number of deaths in all dike rings. This instills more confidence in the rank order of Gelderland's objectives. Rural dike rings, as a whole, also tend to show much less variation in the damage and casualties as compared urban settings. Moreover, dike rings 2 through 5 show a much wider range of variation, meaning that viable policy recommendations may have to focus investment into these locations.

From this analysis, approximately four thousand potential policy solutions were determined. To find feasible solutions, a telescope-like method was used to greatly reduce the number of policies to a reasonable set, which will be analysed further for robustness and vulnerability. To do this, a normal distribution of the different outcomes was generated (Bell, Fairbrother, and Jones, 2018). In rank order of the objectives of interest, the initial policy solution set was reduced by taking the top 10 percent of each updated solution set. The logic behind this is to ensure the policies that provide desirable outcomes are retained. After three rounds (attributing to three outcomes of interest), nine potential policy solutions were identified.

3.2.2 Robustness

This subsection considers the subsequent analysis of the extracted candidate policies under deep uncertainty. Deep uncertainty in this case refers to iterative simulation over each of the 121 discovered scenarios of interest.

Robustness Metrics

To facilitate analysis of simulation results, two robustness metrics were chosen. At first SnS ratio was chosen, which unveils the relationship between the expected value and the standard deviation. Mathematically, it is either the quotient of expected value and standard deviation for maximizable outcomes or the product of expected value and standard deviation for minimizable outcomes. (McPhail et al., 2018) For minimizable outcomes, a low SnS value is desired. This is, because low expected values and low standard deviations, meaning low volatility over scenarios and thus higher robustness, are preferred. If for instance, the SnS ratio of deaths is high in a particular dike ring, this indicates that deaths are either high on average, or highly volatile, or both. The SnS ratio therefore not only indicates whether a policy is robust, but also integrates the policies performance.

Second, regret was chosen as a robustness metric. Regret as a metric metric compares between different policies and indicates how high the regret is if a policy is chosen over its competitors for the considered outcome (McPhail et al., 2018). In our analysis we take the absolute of the difference between the best policies outcome and each policies outcome to facilitate comparison. Subsequently, the regret values were normalised.

Robustness Analysis: SnS

Figure 17 displays the normalised signal-to-noise (SnS) ratio per outcome for dike ring 1. The different lines represent the respective policies as highlighted in the legend on the right. As explained in the preceding subsection (*Robustness Metrics*), for minimizable outcomes, which is the case for each outcome, low values are desirable. For dike ring 1, it becomes apparent that policies 741 and 823 display the most undesirable extent of SnS for expected deaths. Additionally, policy 823 also has the most undesirable extent for damages, followed by policy 249. While SnS for damages and deaths for policy 118 provide very desirable values, it has more than double the value for investment compared to every other policy. This trade-off is not as prevalent for other policies. The SnS value for dike investments can also be considered as related more closely to the actual dike investment value, as deviation is proportional to the investment value for each scenario. This is due to the investment being defined by policy, and standard deviation only being influenced by variations in discount rate, which is influenced by the scenarios.

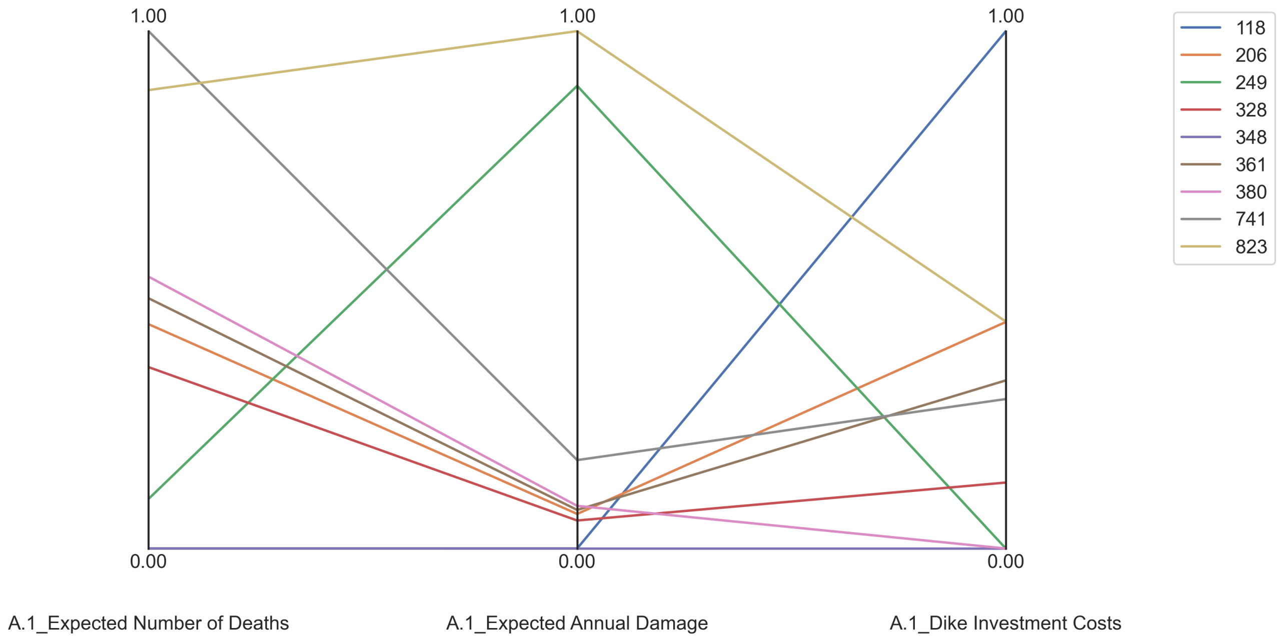


Figure 17: *SnS ratios per policy per outcome for dike ring 1*

Figure 18 functions analogously to Figure 17 but displays the SnS ratios for dike ring 2. According to Figure 18 the most detrimental policies to dike ring 2 in terms of deaths and damages are policies 328 and 118. Policy 348 also scores comparatively undesirable on deaths-related SnS ratio. While scoring well in security-related SnS, policies 249 and 361 show a high trade-off between security and dike investment costs similar to policy 118 in dike ring 1.

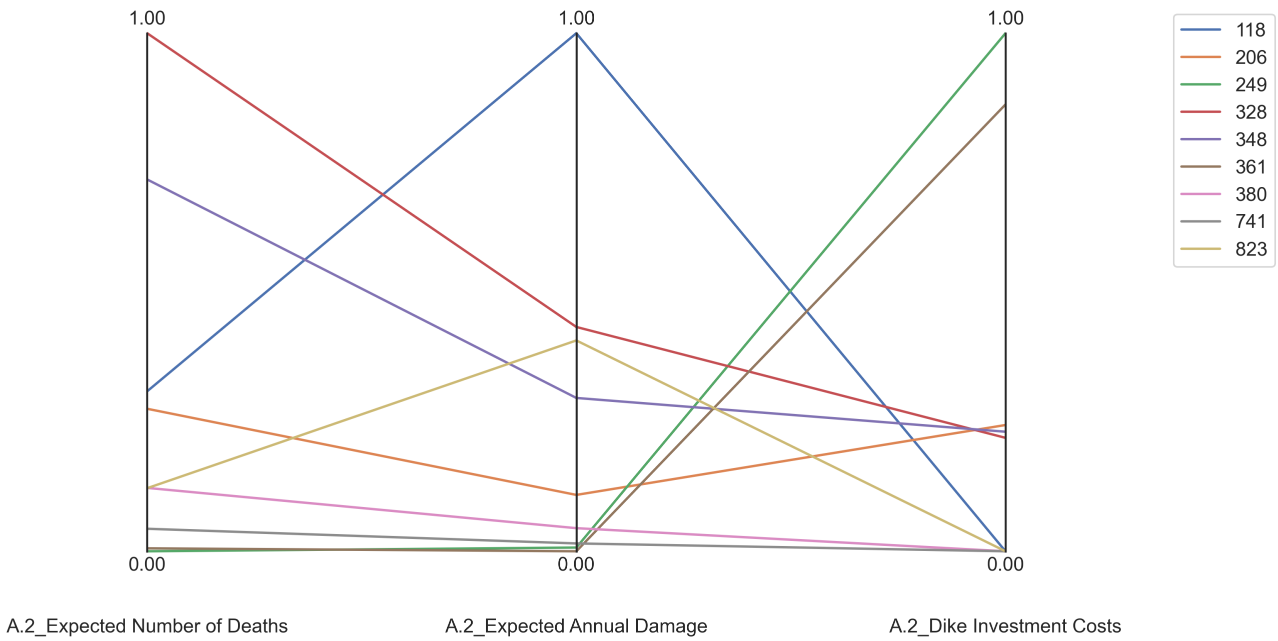


Figure 18: *SnS ratios per policy per outcome for dike ring 2*

Figure 19 also functions analogously to Figure 17. For policy 823, there is a clear trade-off to be seen between dike investment SnS and security SnS. The same trade-off can be observed for policies 380 and 328, which score very well on security, which comes along with high investment in dikes.

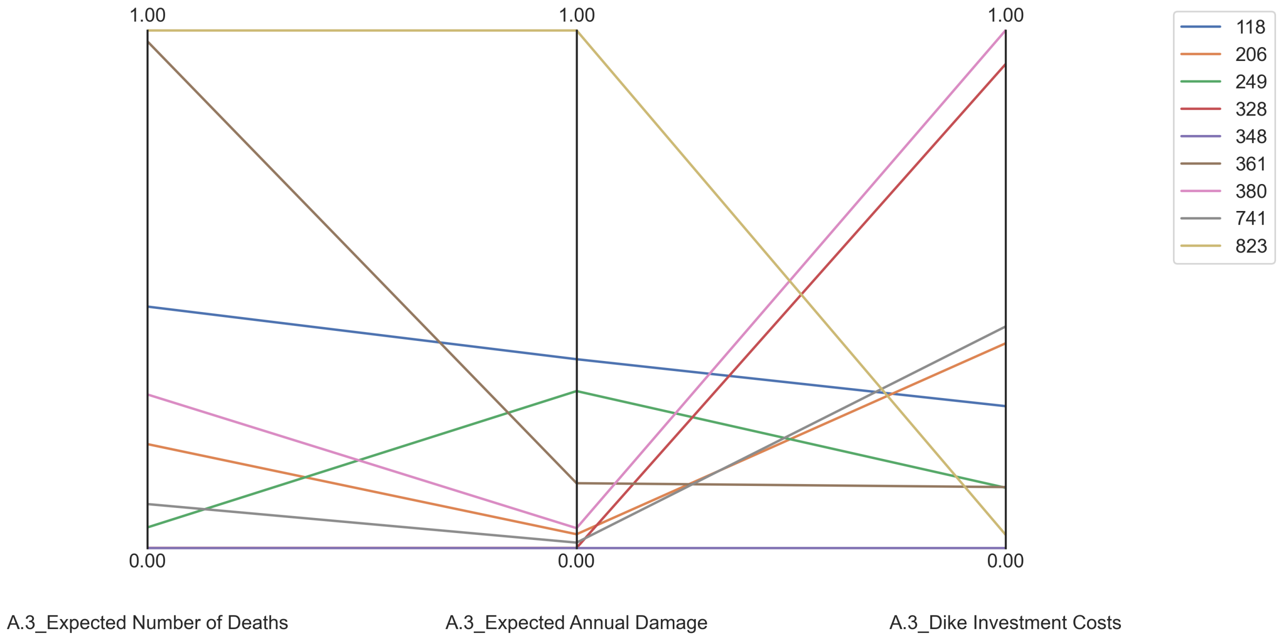


Figure 19: *SnS ratios per policy per outcome for dike ring 3*

With the consideration of individual dike rings in mind, policies 823, 118, 328 and 741 seem to be either detrimental highly volatile to one or multiple dike rings. Other policies, such as 380 or 206 seem to be well-performing and robust consistently over all dike rings of the province of Gelderland.

Figure 20 functions analogously to the previous SnS graphs, but refers to aggregate values for the province of Gelderland. Comparable to the insights of the individual dike ring-based graphs, Figure 20 demonstrates undesirable values for policies 118 and 823 for damage SnS and for policy 328 on death SnS for the province of Gelderland.

Additionally, while policy 206 scores moderate for death SnS, it performs well for damages and especially dike investment cost for the province of Gelderland. Policy 249 performs best in death SnS and moderate for damages and investment cost SnS on the aggregate level. It is also relevant to note that policy 348 on an aggregate level is dominated by policy 206.

In conclusion, the policies 823, 741, 118, and 328 are excluded from further analysis as they either impose high volatility or bad performance on individual dike rings and the whole province of Gelderland. Compared to policy 348, which on aggregate is dominated, policies 206, 249, 361, and 380 form a Pareto set in the aggregated outcomes, and perform comparatively well for the individual dike rings. This makes these policies the candidate policies which are further excerpted in the following analysis of robustness.

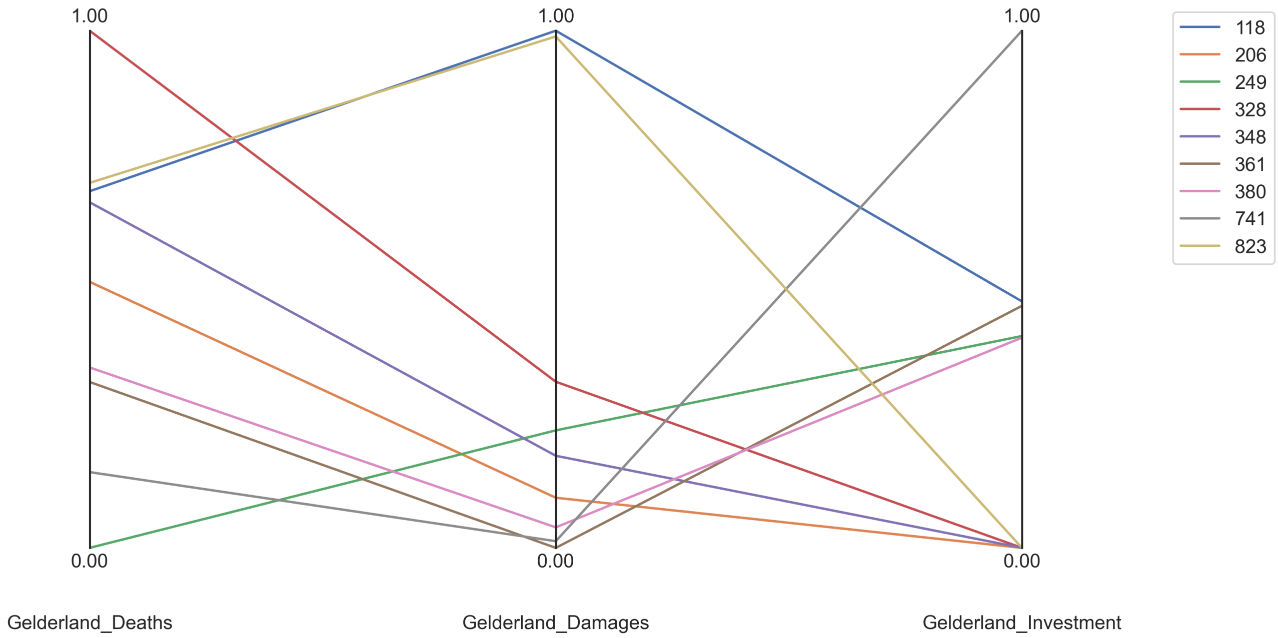


Figure 20: *SnS ratios per policy per outcome for Gelderland*

Robustness Analysis: Regret

Figure 21 shows regret heatmaps for dike ring 1 and 2 on the top left and right, and dike ring 3 on the bottom left as well as the province of Gelderland on the bottom right. The y-axes of the respective heat maps are the individual remaining policies of interest, the x-axes represent the outcomes per dike ring or in aggregation on the bottom right. The individual fields contain the regret values per outcome per policy, where 1 identifies the most regretful policy per outcome, and 0 the least regretful.

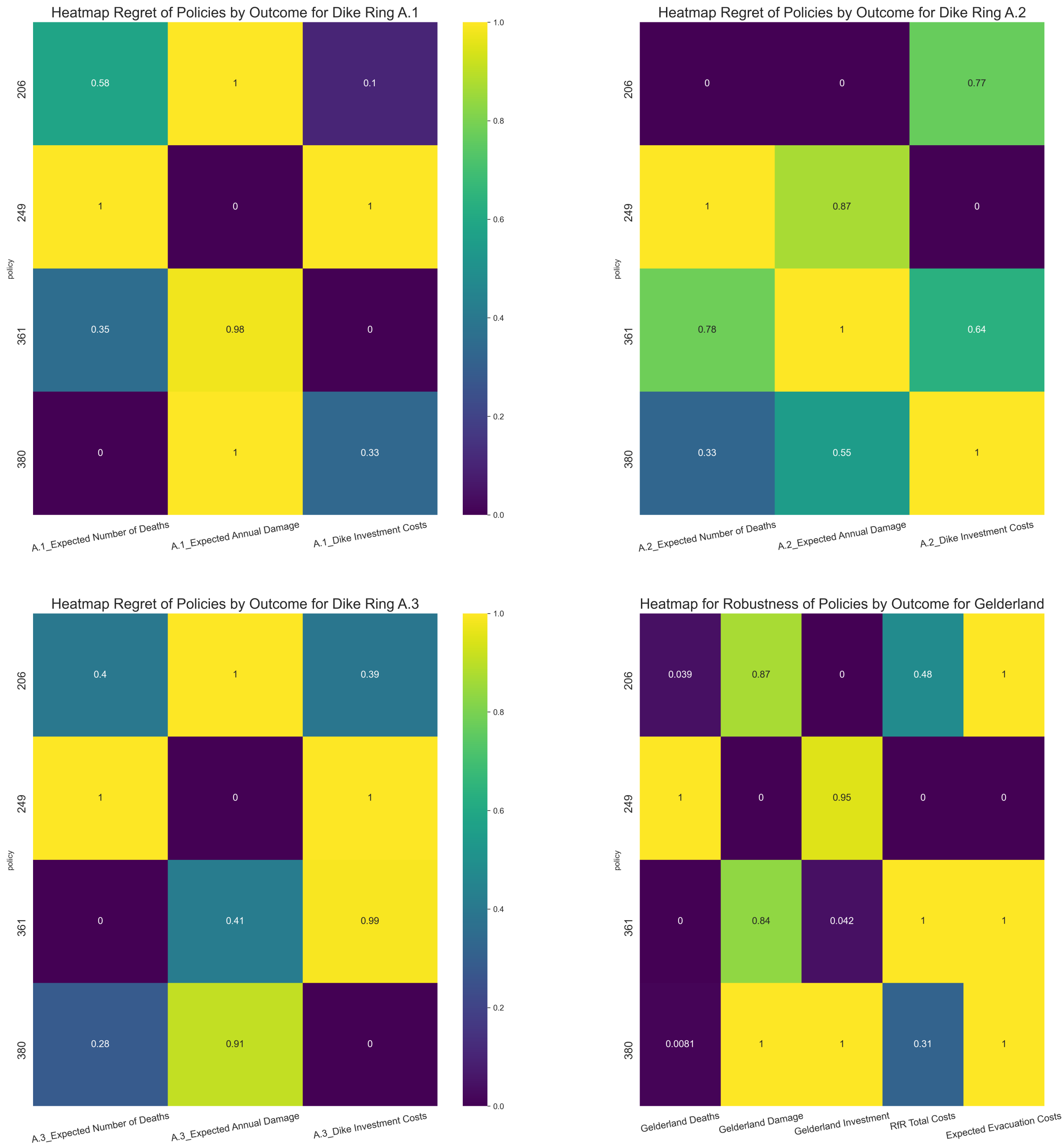


Figure 21: *Regret heatmaps for all Gelderland dike rings and the province of Gelderland*

Considering regret in expected deaths, independent of dike ring or aggregation level, policy 249 is the most regretful. As can be seen in the bottom right subgraph of Figure 21, the other policies in comparison to 249 have remarkably low regret values, indicating a high difference in regret despite normalisation. However, policy 249 is the least regretful for flood damages in dike ring 1 and 3, and in aggregation. The remaining policies overall appear to be similarly regretful for damages.

For investment, policy 206 generally has low regret values for the individual dike rings, which is reflected in the aggregated regret value of 0. Similarly, policy 361 has a low aggregate regret for investment, in spite of a high value in dike ring 3. The highest regret is to be found with policies 249 and 380.

Given our initial prioritisation, which aims to reduce deaths over damages over costs, policy 249 is excluded further due to its high disparity in death regret and the high similarity of the remaining policies in damage regret. The remaining set of candidate policies thus consists of policies 206, 361 and 380.

Final candidate policies

Policy 206

Policy 361

Policy 380

4 Discussion and Analysis

4.1 Policy identification

Given the three policies identified in the previous subsection, we now have to understand how to identify a single policy capable of being effectively integrated into the decision-making arena.
To achieve this, we can start by recalling both the power-interest (**Figure 2**) and position-salience matrix (**Figure 3**) created in the first stakeholder dynamics subsection. From these diagrams, we can derive three major considerations:

- Only five actors (namely Gelderland, Overijssel, Rijkwaterstaat, Delta Commission and transport companies) have sufficient power to be considered players.
- While transport companies are sufficiently aligned with Gelderland's objectives, the province of Overijssel can be expected to obstacle Gelderland's decision-making (if the chosen policy undermines their interests).
- Rijwaterstaat and Delta Commission can almost be classified as *neutral*. Nevertheless, this neutrality is strictly dependent on the policy that will eventually be proposed by Gelderland.

Keeping these considerations in mind, it is now possible to define what an optimal strategy would be for Gelderland for the given decision-making arena.

Optimal policy definition

A policy can be deemed as optimal for a specific player if it satisfies two main characteristics. First, it should be reflective of the player's values, objectives and perspectives for the problem at hand. Second, it should be capable of impacting the decision-making arena in such a way to move contestant relevant players to a supportive position.

Therefore, considering this simplified definition, we can understand that an optimal policy for our particular problem would create a change in the decision-making arena like the one displayed in the following salience-position matrix.

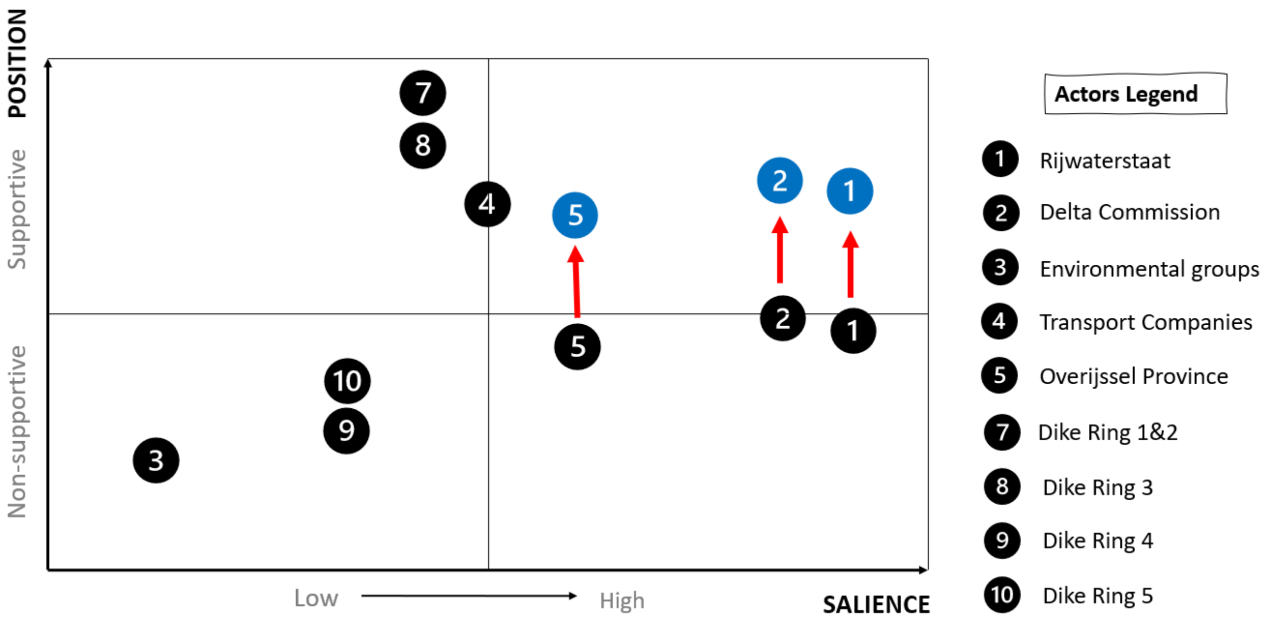


Figure 22: *Salience-position matrix modified by the implementation of an optimal policy. The policy would be aimed at modifying the position of Overijssel, Rijwaterstaat and Delta Commission (new position identified in blue).*

In the case of our problem, drawing both from the objectives of these different actors (collected in Table X Appendix X) and the insights gained throughout meetings with their representatives (collected in Appendix X), we can try to infer the optimal policy following these subsequent steps:

1. Identify the time-frame of interest for the analysed actors.
2. Identify the preferred spatial aggregation level for the considered actor.
3. Create new qualitative tables for policy evaluation.
4. Formulate explicit interests that could be impacted by the proposed policies.
5. Evaluate the proposed policies based on actor's perspectives and interests.

The practical implementation of this qualitative framework for , as presented in Figure 7, lead to the identification of one optimal policy together with two backup solutions.

Final policy recommendation

Optimal policy: Policy 206

First backup option: Policy 361

Second backup option: Policy 380

4.2 Limitations and extensions

Throughout the modelling and policy preparing process, many limitations in the selected process became visible. This, in addition to inherent model limitations, are presented in this section to provide an opportunity to reflect on potential extensions and expansions of both the model, and the model-based decision making process in general.

4.2.1 Limitations of the model

When attempting to capture a complex socio-technical system is a challenging endeavour, complicated even further attempting to capture natural processes. Practically, this means that any attempt to capture such a model naturally results in limitations and constraints:

- The model is **limited in terms of scope**: socio-economic factors such as demographic composition, economic growth and potential costs of productive land are not taken into account by the model. This limits the depth at which conclusions and policy effects can be evaluated on.
- **Policy lever options are not implemented in depth**: Room for the river, as a policy, consists of many separate measures, such as river deepening, polder making, and so on (). These measures can be implemented in varying combinations and to varying degrees, leading to different costs and land requirements. The effects of these potential variations in room for the river policy are not investigated, and instead captured by the model as a binary switch.

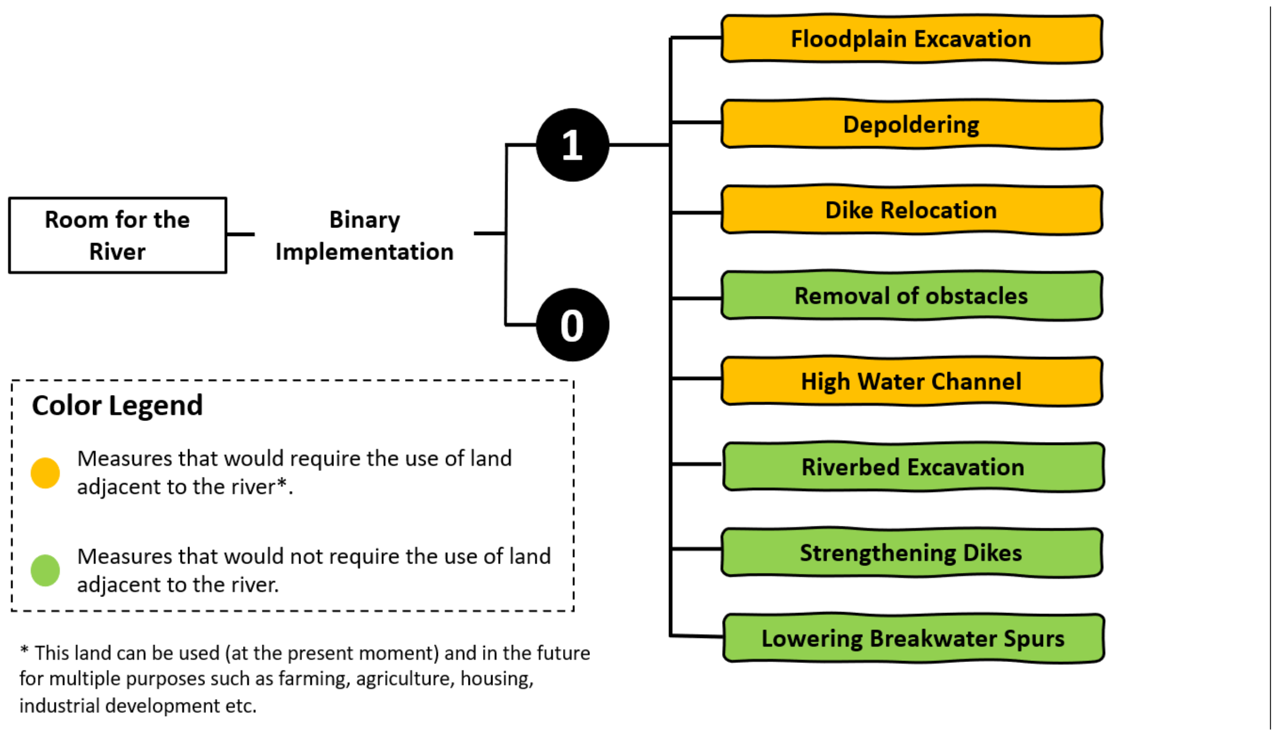


Figure 23: *Different RfR interventions as listed in*

- **Climate change is not taken into account** by this model, which is potentially a significant shortcoming, given the model's time horizon, global climate trajectories, and the percentage of the Netherlands that lies below sea-level.

- Certain **time-dependent processes are assumed to be constant** throughout the modelling time horizon. Some uncertainties, such as the probability of dike failure, might also have value-ranges that change with time. This might lead to unrealistic forecasts and potentially dangerous overestimations.
- Policy **robustness is only broadly defined**: During policy robustness evaluation, policies are evaluated based on a set of robustness requirements, which are independently defined from the model.
- For some outcomes, such as estimated damages or fatalities, measurements were aggregated over all dike rings. This represents an important **underlying utilitarian approach** taken by this model. Since the contributions of each of the dike rings to these outcomes are hidden, it only becomes possible to optimise overall outcomes - without considering individual dike rings. This was mitigated in the policy optimisation stage by optimising over geographically disaggregated outcomes - but lead to less ideal optimisation convergence. This represents a trade-off between detail and computational limits.
- In this approach, **no vulnerability analysis was attempted.** Vulnerability analysis shows the scenarios under which certain policies fail, in an attempt to show the ranges of operation that can reasonably be expected from the candidate policies. Accordingly, we cannot with complete certainty know the limits to which our policies will be valid.

4.2.2 Limitations of the decision-making approach

Apart from limitations specific to how the preferred policy is generated and of the policy itself, the general approach followed to generate decision-making support from computational models is subject to notable shortcomings, limitations, and potential improvements.

- **Adaptive control for policies** is often included to a policy recommendation to address the dynamic real-world setting in which these policies are applied. This report provides no such adaptable advice, partly due to model limitations of time-variable scenarios.
- The recommended policy given here was generated through the modelling workflow and followed by a political reflection on its viability in the political arena. While political coordination was also necessary to determine Gelderland's value and objective prioritization, there was **little real coordination between stakeholder analysis and deep uncertainty**. This means any model-recommended policy was not tested or optimised in the political, multi-stakeholder dimension. This shortcoming can potentially be solved by **iteratively moving between stakeholder analysis and deep uncertainty modelling** - to adequately both technical and political factors in the final policy optimisation and recommendation.
- Related to the previously mentioned point, this policy advice is created based on Gelderland's perspective of the problem arena from a single, monolithic point of view. **Gelderland's role in the decision-making network is**

not taken into account. This excludes potentially useful and viable alternate policy pathways based on political network characteristics. A practical way to address this shortcoming would be to **integrate a social network analysis** (SNA) to the decision-making workflow. Additionally, the creation of **salience matrices** for all the policies in the initially recommended policy set can serve to provide valuable input towards the reception of said policy in the political environment.

4.2.3 Limitations of the policy

The recommended policy is limited in many ways by limitations to the model and the decision-making approach that were discussed above. In addition to these limitations, however, the specific recommended policy is also limited:

- The recommended policy, even though providing a longer-term plan for flood management, **is not dynamic**. This policy recommendation does not make any provision for changes in stakeholder relations and different scenarios. One way to address this would be to construct an adaptive policy framework with different decision points distributed over time.
- This policy recommends **implementing room for the river across four of the five dike rings**. This is potentially in direct contrast with the objectives of many of the dike rings, risking the loss of their cooperation and support.
- **The recommended strategy is incremental in nature.** Since no big initial changes are recommended, the burden of change is shifted more towards future generations. In addition, some actors such as the Rijkswaterstaat and Delta Commission might still be unhappy with such a relatively slow reaction.

5 Conclusion

When dealing with complex socio-technical issues, such as flood prevention in the IJssel river area, special care must be taken when devising solutions. This is rendered even more important in light of increasing rates of climate change and dangers to human life. While it may be tempting to search the technical domain for easy solutions to such issues, these issues neglect important dimensions in the problem space. Regardless of any technical uncertainties, which already complicate potential solutions, socio-political factors such as stakeholder dynamics and political structures have to be taken into account if any candidate solution is desired to be effective.

This has been attempted in this report – providing policy advice from a technical base, but created in cooperation with a critical political lens. Initially, Gelderland's responsibilities and position in the political arena had to be well understood in order to frame and prioritise their objectives in terms of the IJssel river model. Open exploration on the IJssel river model provided insights into how the model reacted to certain inputs and uncertainties, with the failure probability of dike 3 having particularly concerning potential impacts. With policies that were identified through the directed search process (using MORDM), it was made clear that many policies could potentially address flooding concerns. When introducing robustness against previously identified dangerous scenarios (through tools such as regret calculation), however, the range of potentially suitable policies shrank. Eventually, three potential policies were obtained. These policies addressed flooding concerns through varying different policy combinations. A final policy was eventually selected based on the performance of the candidate policies in the stakeholder arena, and how it aligned with the goals of each of the significant stakeholders in the arena (namely the Rijkswaterstaat, Delta Commission, Overijssel and transportation companies). Through an iterative qualitative evaluation, one single policy was selected which involves implementing Room for the River at dike rings 1 to 4 over differing time periods. These differing time horizons of implementation was also found to make the policy more agreeable to some opposing actors. Additionally, dikes are increased at all dike rings at some time during the 200 year time horizon. It was found that investing in the early warning system resulted in reduced casualties in most cases.

Although the approach attempted to explicitly include political and stakeholder considerations in the modelling workflow, it is potentially still not sufficient. The extent to which complex political decision-making concepts, such as framing, compromise and trade-offs, can be incorporated into the simulation model, is limited to two things: the inputs – through prioritising certain objectives over others - and the outputs – through which a set of candidate policies are evaluated in the stakeholder context. Future model-based decision-making approaches should strive to adopt a more iterative approach between modelling and stakeholder framing phases, to ensure that hard-to-capture political factors can be holistically incorporated into the policy recommendation instead of being incorporated retrospectively.

6 Political Reflection

After a thorough analysis, one optimal policy advice has been identified. In a complex decision-making arena, it is imperative to analyse how different actors would perceive the policy advice. This section identifies the key challenges and tensions that Gelderland will likely face in the multi-actor context. The report further delineates the steps taken to tackle these challenges during the analysis and strategies identified for navigating these tensions during decision-making. Lastly, the report reflects on these tensions, the effectiveness and limitations of identified strategies, and additional tensions that may arise.

6.1 Tensions and Challenges

To understand those potential obstacles that our analysis might face in the decision-making arena, we can create a simplified visual representation of the main steps of the policy deliberation process (**Figure 24**).

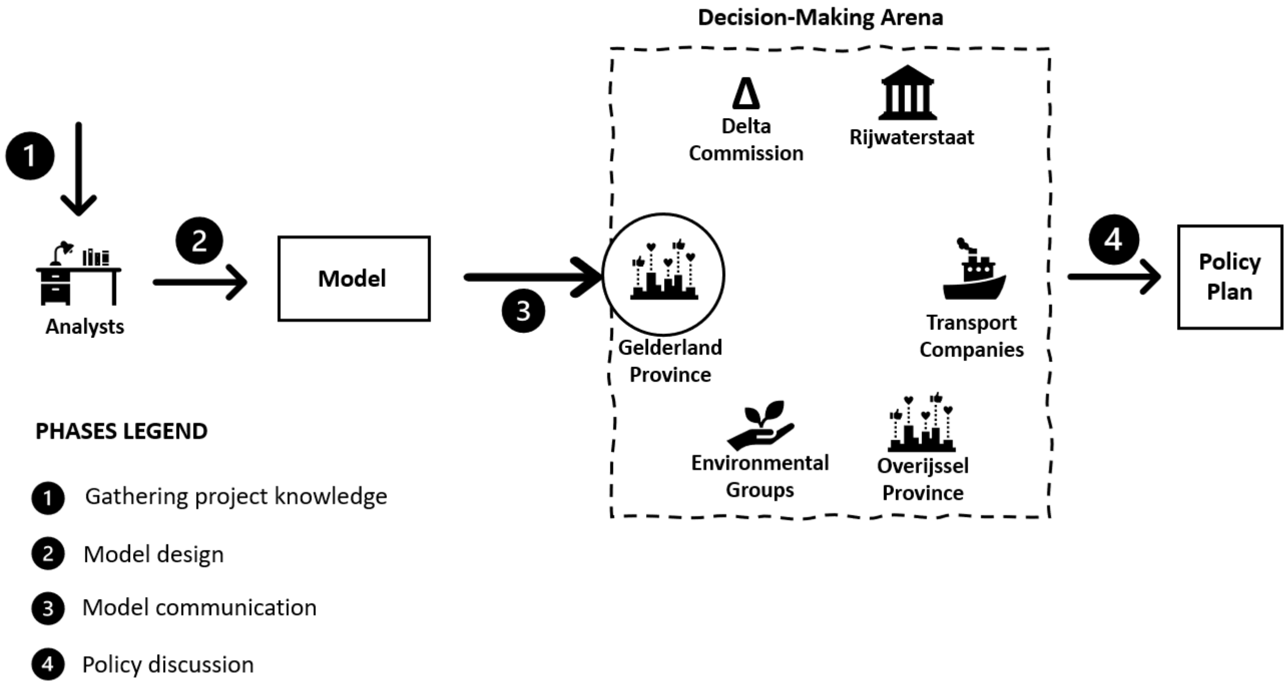


Figure 24: *Simplified visualisation of a policy-making deliberation from the perspective of Gelderland.*

6.1.1 Limits to Knowledge

Scientific knowledge is created at the nexus of science and politics. It is rarely separate from political influences and carries several inherent biases (Jasanoff et al. 1996a). The analysis has identified this policy advice based on scientific insights created from the perspective of Gelderland. The metrics, driven by Gelderland's objectives, are inherently biased and consequently make certain insights opaque. This challenge occurs at the first and second phase of Figure 24. For example, the analysis uses deaths in Gelderland as a metric but does not account for deaths in Overijssel. In other words, the recommended policy advice could be far from the optimal solution for Overijssel in terms of the number of deaths in their province. This would lead to conflict with a potential ally.

Similarly, the transport company might oppose the recommended policy since it might hamper their economic interests. The transport companies are aligned with dike rings 1,2 and 3. As discussed in the first debate, dike rings 1 and 2 produce; transport companies transport the goods and dike ring 3 exports. Implementing an RfR project in dike ring 2 in the first planning stage can hamper their economic interests by reducing the depth of the IJssel river. Similar conflicts exist with other actors since scientific knowledge is created with political interests. While there is awareness of a limit to the scientific insights previously delineated, there is no clarity as to what that entails.

6.1.2 Managing arenas

In "controversial" topics, such as the implementation of RfR in the Netherlands, science can be both used to confirm an interpretation through factual claims but also to disprove it (Rayner, Lefty, and Sarewitz, 2021). Gelderland is in a unique position since it has to navigate both provincial and national arenas. While the timeframes and aggregation levels for the local arena are smaller, it's the opposite for the national arena. This challenge arises at the third phase of Figure 24.

At the provincial level, the dike rings are concerned about their economic interests and the safety of citizens. Dike heightening would be the ideal solution since it protects their land and subsequently economically viable industries while offering flood protection to the citizens. However, this low level of aggregation does not consider the potential detrimental impact it can have on the downstream areas, namely regions in Overijssel. This directly contrasts with how Rijkswaterstaat or the Delta Commission would approach the problem. They would prioritise the overall safety of the citizens in the region, which could potentially undermine one or more of the dike rings. In this analysis, an egalitarian approach has been taken. Any policies that might be desirable from the utilitarian viewpoint but have adverse impacts on one or more dike rings have been removed. This might conflict with the approach taken by Rijkswaterstaat and the Delta Commission, implying that the recommended policy might not be the best in minimising the number of total deaths.

6.1.3 Conflicting timelines

The merit of the policy advice is in its incremental execution. It keeps in mind the short-term safety of citizens in the region and the long-term transition to an environmentally beneficial solution. However, in the context of tumultuous climate trends, delayed implementation of RfR in dike rings 1,3 and 4 might raise concerns with the environmental groups, Delta Commission and Rijkswaterstaat. While there is a likely alignment with Overijssel and Transport companies in terms of timeframe, the same cannot be said for the previously mentioned actors. The three actors mentioned prefer longer timeframes. They would likely prefer long-term, environmentally sustainable solutions from the onset of the project. Investing in incremental dike strengthening might be seen as an inadequate solution that temporarily ameliorates the situation.

The planning stages are a way of enabling a smooth transition, but they also serve as re-evaluation points. In case the climate trends change drastically, more aggressive measures can be taken. These points are desirable for Overijssel, Gelderland and transport companies since they offer an opportunity to renegotiate their positions based on current environmental and economic trends. The environmental group might disagree with this approach since these re-evaluation points might undermine their objective of promoting biodiversity. Further, as discussed in the first debate, Rijkwaterstaat is concerned about the vulnerability of dike rings 1 and 3 and would like to implement RfR in these areas. They might prefer immediate implementation in these regions that is incompatible with the policy advice.

6.2 Mitigating Strategies: Managing different framings

All of these challenges can be traced back to different framings of the problem. While these tensions are difficult to address, a strategy has been devised to address them in a systematic manner. All actors apart from the transport company agree that RfR is a desirable project. Accordingly, if Gelderland is not willing to broaden the agenda and focus on the desire of its dike rings, notably dike ring 3, to build dikes, Gelderland will be framed as the villain. It is framed to effectively block the implementation of RfR and abuse its position as the upstream province. In this scenario, the people living in Overijssel are the victims as they depend on flood protection measures from the upstream province to be implemented. Otherwise, they must deploy considerable investments on dike heightening to provide adequate flood protection. The other actors, apart from the transport company, are framed as the hero due to their attempts to convince Gelderland to implement RfR and, hence, protect the citizens of Overijssel.

To escape the framing of the villain in the victim-villain-hero model, Gelderland needs to reframe this model to present a different perspective of the same situation (Bruijn, 2017). Thus, the following framing is advised to Gelderland to circumvent the opponent's frame and shed a more favourable light on their actions.

Gelderland is fully aware that flood risk will significantly increase in the future due to the threat posed by climate change. With the growing detrimental impact of climate change, mitigating these effects has become a top priority for the Kingdom. However, this entails drastic changes in lifestyle for citizens in the entire country and globally. A significant contributor to climate change is food production (Vermeulen, Campbell, and Ingram, 2012). The Netherlands is the world's second-largest food exporter and is considered to possess the most sustainable and efficient agriculture worldwide (Whiting, 2019). Particularly the provinces Gelderland and Overijssel are major agricultural contributors, with the world-renowned "Food Valley" as a centre of sustainable innovation in the region (Whiting, 2019). Large Floodplains lower the river level in times of flooding but significantly hamper agricultural output by reducing land for livestock and farms.

Protecting the agricultural backbone of the Netherland and the citizens in the region most effectively is Gelderland's number one priority. This protection can be achieved by raising the dikes in the next 66 years to prevent RFR-induced land loss of its and Overijssel's precious agricultural areas. Being true to the tradition of the Netherlands, living with water means building around water. The strengthened dikes protect the agricultural output for the foreseeable future and contribute to providing food for the Netherlands and the world while mitigating the effects of climate change. It would be irresponsible in the current transition period toward a sustainable economy to restrict the world's most significant agricultural producer by taking away farmland for floodplains.

Similarly, it would increase the already heavy burden on farmers imposed by the necessary carbon tax increases. As a significant contributor to the sustainable transition, crops and livestock from Gelderland and Overijssel are not only needed by the Netherlands but by the world. For this reason, raised dikes are needed now to protect the land and the people of Gelderland and Overijssel. After the transition is managed, RfR can be implemented to protect the citizens further.

The challenges mentioned above can be tackled with a systematic strategy to address diverging objectives. To deal with this, at the final stage of policy identification, a qualitative approach has been adopted to address the multi-issue nature of the problem. The policies were compared from the point of view of different actors, and a ranking system was devised. All the policies were ranked from 1 to 3 based on the preferences of other actors, and a final optimal policy was identified. This method is explained in detail in Appendix C. There, the analysis draws on their preferences regarding RfR or dike heightening. An attempt was made to break out of the cage of limited knowledge, conflicting timelines and arena expectations.

This method addressed the challenge of limited knowledge by building upon the objectives of other actors, as discerned from the two debates. With this information, the analysis cautiously attempts to estimate the preferences of different actors. However, bearing in mind the bias and limitations in acquiring information about the true objectives of the other actors, described by the concept of bounded rationality, this attempt is doomed to remain precisely that, an attempt (**simon**).

Further, this method addresses the issue of different arenas and conflicting timelines since the analysis allows for different interpretations of timelines and preferences in the last stage of policy identification. The ranking from the point of view of the provincial-level actors has been done with a smaller aggregation level and shorter timeframe in mind. Whereas, for the national-level actors, the analysis is done with a long-term approach. The policy that satisfies all the actors from their framing of the problem has been selected.

6.3 Navigating the decision-making arena:

While steps have been taken to tackle these challenges, they are insufficient. Navigating the decision-making arena with these challenges is crucial to facilitate favourable decision-making. Some of the strategies that can be deployed are as follows.

6.3.1 Model uncertainties

Scientific knowledge is often treated as the objective truth, while in practice, it is more often biased and created to serve a particular purpose. Since Gelderland is expected to make significant compromises to accommodate for RfR, in the case that national-level actors use their models to back their arguments, Gelderland can highlight the model's limitations to question the validity of these results.

The model does not consider climate change, the river's depth or the land's value. The economic loss due to RfR in dike rings 1 and 2 would be higher than in other dike rings due to the productivity of intensive farming practices along the river. Since the model does not consider the value of the land needed for RfR, any insights from the model can be questioned. The same can be done concerning the navigability of rivers in the case of RfR since widening the river can impact its depth. Additionally, climate change trends add another layer of complexity to the problem make any long-term projections uncertain. As this is the case, values can be contested to a point where the question arises: "Why should we account for the model at all?". It needs to be established that models can give directions but not answers.

6.3.2 Missing Stakeholders

The IJssel river is a distributary of the Rhine which flows through Germany before entering the Netherlands. The province of North Rhine-Westphalia is upstream of the Netherlands, and any flood risk mitigation strategies taken in Germany will directly impact both Gelderland and Overijssel. Creating a policy plan without input from the German stakeholders is a misguided effort, and policy proposals should be made contingent on German cooperation. In case there is increased pressure on Gelderland to accommodate RfR projects in planning stage 1, the province can highlight the inherent uncertainty of these measures due to 'missing stakeholders' in the decision-making arena. In this case, having dike strengthening to ensure the safety of citizens in the short term would be preferable.

6.3.3 Broaden the Agenda

Since RfR projects can disrupt the agricultural output of the province and, in turn, the entire country, representation by Agriculture and Finance ministries would strengthen the case of Gelderland. At present, the focus of the decision-making arena is on ensuring safety from flood risk and promoting biodiversity in the region. However, the province of Gelderland is also focused on protecting the economic interests of the citizens. Since Gelderland is a major agricultural hub of the Netherlands, broadening the agenda and including the ministries of Agriculture and Finance could help underscore these objectives. This broadening of the agenda could result in a more favourable position on the decision making table for Gelderland (Bruijn, 2017)

6.4 Addition Tensions and Conclusions

Despite the strategies deployed, there are certain additional challenges that Gelderland will face:

- **The challenges upstream-downstream:** In this problem, upstream measures can significantly impact regions downstream. This implies that Gelderland has a greater responsibility in the arena since Overijssel is downstream along the river. If Gelderland advocates for policy decisions that prioritise their citizens, they risk being framed as the 'bad actor'.
- **Challenges of being a broker:** Since the province acts as a broker between the local and national arena, it is essential to maintain cordial relations with all actors. The policy advises that dike ring 2 must have RfR in the first planning stage. This can lead to them losing faith in the representation provided by Gelderland, and they might try to circumvent their alliance. They could align themselves with the transport company, leading to a weakened position for Gelderland in both the national and provincial arena.
- **Challenges of effective communication:** If Gelderland wants to use the model appropriately in decision-making, effective communication of model structure and outcomes is crucial. If the communication channel and techniques are not strong enough, the client will not be able to adapt their strategy based on the insight presented in the report. This can lead to losing legitimacy in the decision-making arena and ultimately result in a neglected policy because it was not understood by the Rijkswaterstaat and the Delta Commission, irrespective of the "scientific merit" of its findings.

The proposed policy has been created using a multi-actor approach and should partially alleviate these tensions. While the strategies identified in subsection 6.2 and 6.3, address the most imminent political challenges, the approach is very qualitative and speculative in nature. Further, these strategies do not address the lack of alignment in the problem formulation stage. Objectives need to be discussed, negotiated and established in the first stage of the modelling step. Without this alignment, gridlock is imminent in the policy arena. Stakeholders should collaborate on establishing relevant metrics that represent the interests of all actors and then derive insights from the model.

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7 Appendices

Appendix A: Open exploration

Table 3: *Model uncertainty factors and accepted ranges*

Uncertainty factor	Symbol	Accepted Range
Final breach width	B_{max}	[30, 350]
Breach width model	B_{rate}	{1, 1.5, 10}
Dike failure probability	p_{fail}	[0, 1]
Discount rate		{1.5, 2.5, 3.5, 4.5}
Flood wave shape		[0, 132]

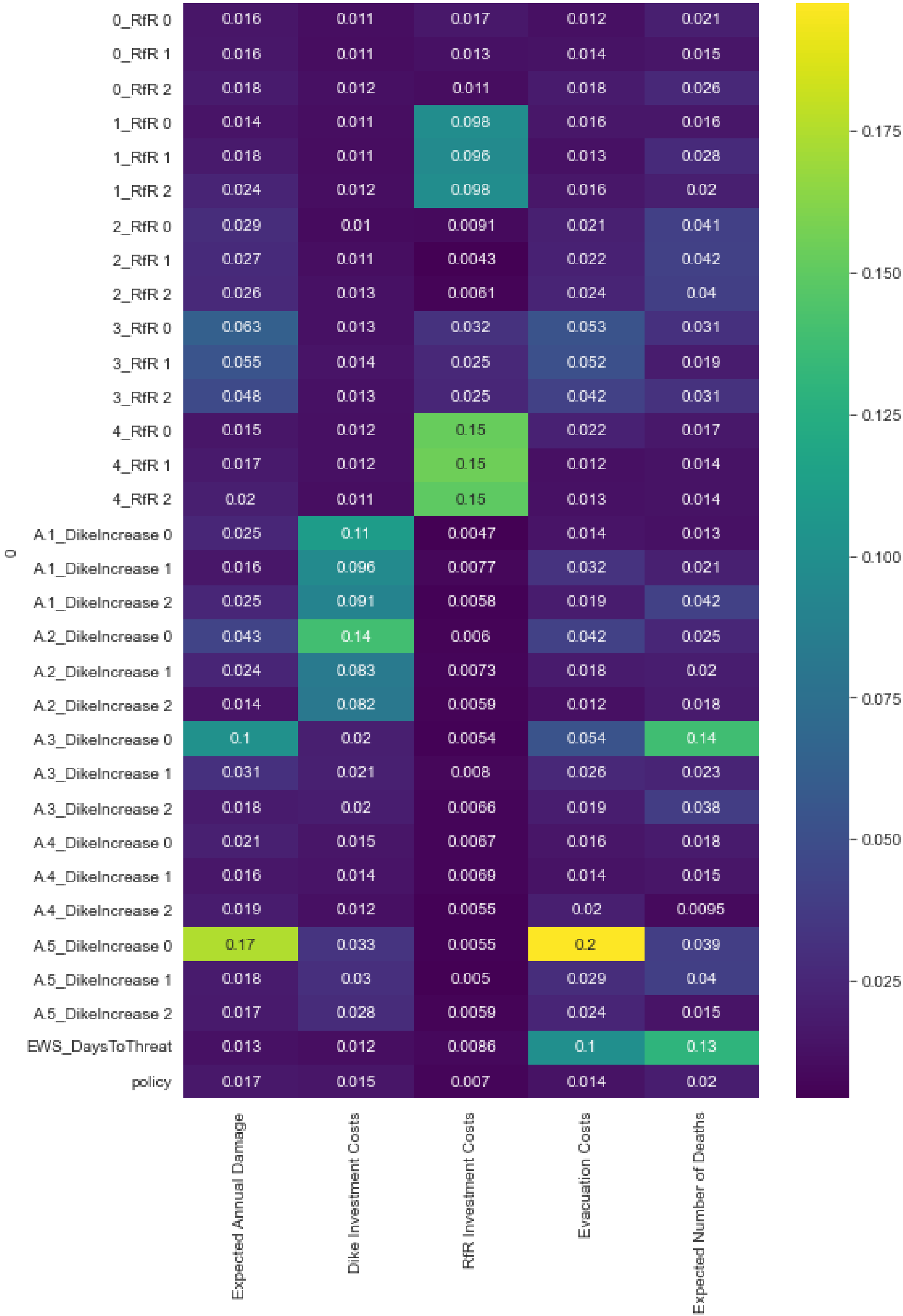

Figure 25: *Feature scoring based on GSA of levers*

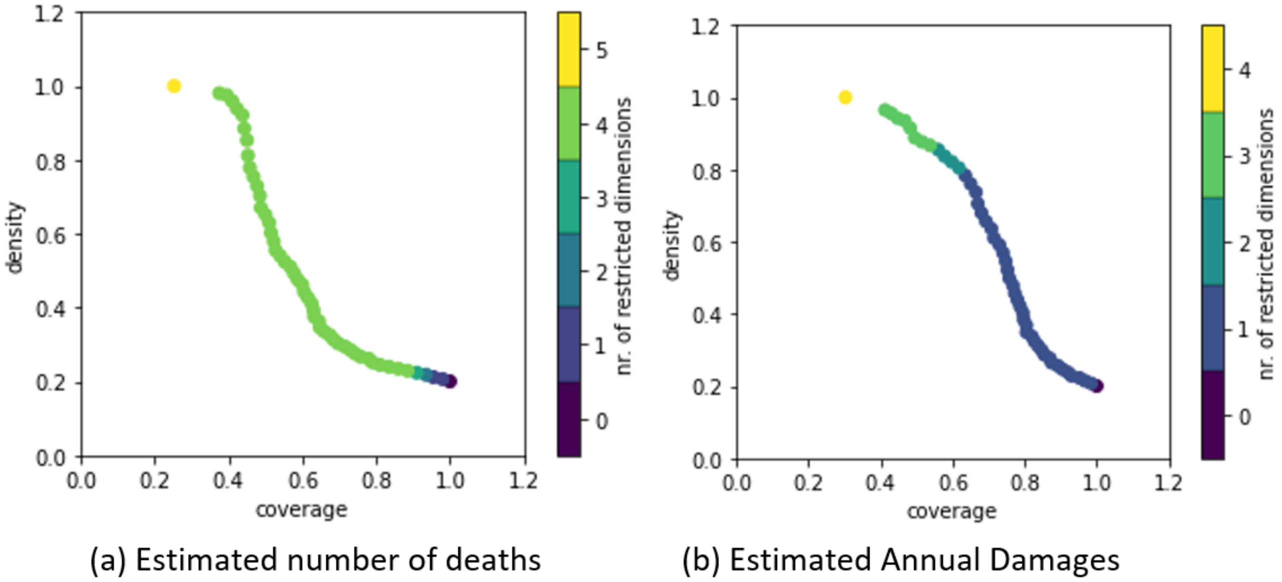

Figure 26: *PRIM peeling graphs for different outcomes of interest for PF 1*

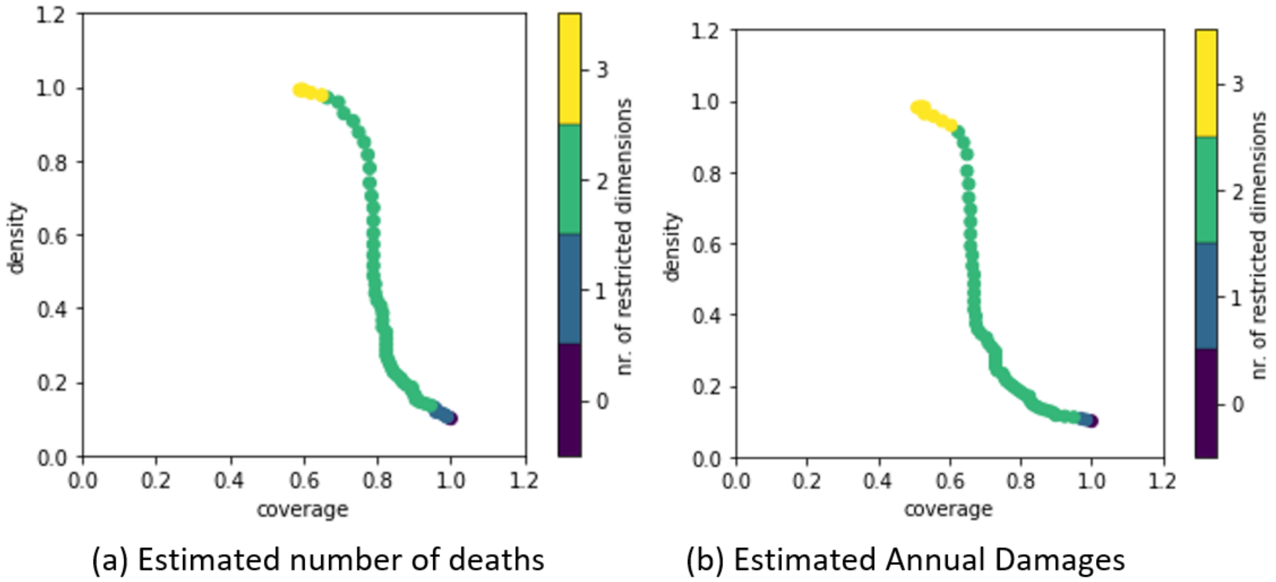

Figure 27: *PRIM peeling graphs for different outcomes of interest for PF 3*

Appendix B: Resources and Objectives

Rijskwaterstaat	Delta Commission	Environmental Groups	Transport Companies	Overijssel	Gelderland
Financial: • money, • financial assets	Financial: • dependent on funding by government, but can leverage that funding for their research and projects	Financial: • dependent on funding (NGOs)	Financial: • money • capital in terms of goods and services (transport, ships)	Financial: • money • financial assets	Financial: • money • financial assets
Institutional: • legal and regulatory framework • official organisational mandates	Institutional: • Their recommendations are relevant, and their word carries weight as the cabinet tasks them with the analysis	Institutional: • legal resources (can go to court, promising given the strict European law concerning the environment)	Institutional: • rights and powers from cultural norms (the Netherlands are dependent on water transport to keep the economy running)	Institutional: • regulatory power in province	Institutional: • regulatory power in their province • legal
Social: • Final decision-making authority • strong position in the network	Social: • Direct input on the cabinet • not restricted by other actors (theoretically)	Social: • access to the public via (social) media • leverage and influence the public opinion • tapping into societal undercurrents such as growing environmental awareness and support for sustainable actions	Social: • strong position in network as they connect Overijssel and Gelderland • public opinion on their side (relevance of logistics)	Social: • access to the public • can leverage the public opinion in province • weakened position in the network (downstream location)	Social: • access to the public and can leverage the public opinion in their province • strong position in the network due to upstream location
Technical: • domain-specific knowledge and expertise (adept due to broad knowledge and experience from dealing with the topic for a long time) • human resources (Ministries) • leadership • mediation skills	Technical: • domain-specific knowledge and expertise (working on flood risk management since 2007 • human resources (Ministries and Rijkswaterstaat) • leadership as leading policy advisors • mediation skills	Technical: • domain-specific knowledge and expertise (research from TU Delft and Wageningen)	Technical: • employment capability	Technical: • human resources (citizens) • capabilities to manufacture (industrial hub)	Technical: • Farmland and intensive farming practices.

Figure 28: *Resources table of the stakeholder in the decision-making arena*

Actor	Strategic Objectives	Problem-specific Objectives
Rijkswaterstaat	Ensure safety, mobility, and quality of life for Dutch citizens.	Mitigate flood risk in the IJssel river area to prevent fatalities without harming the environment
Delta Commission	Protect Netherlands from flood risk and ensure supply of fresh water for everyone	Mitigate flood risk in the IJssel river area by ensuring long term robust and sustainable solutions
Environmental Groups	Advocate for the protection and promotions of biodiversity	Ensure protection of biodiversity in flood risk mitigation projects on the IJssel river
Transport Company	Safeguard the economic interests of the transport companies and facilitate future economic growth	Ensure the navigability of waterways along the IJssel river despite the flood risk mitigation strategies used
Overijssel	Ensure the well-being of Overijssel citizens	Maximise the safety of Overijssel's citizens from flood risk along the IJssel river area without damaging the economic interests of the communities
Gelderland	Ensure the well-being of Gelderland citizens	Maximise the safety of Gelderland's citizens from flood risk along the IJssel river area without damaging the economic interests of the communities

Figure 29: *Objectives table of the stakeholder in the decision-making arena*

Appendix C: Qualitative multi-actor policy analysis

Taking into account the considerations mentioned in Subsection 4.1, we can now practically demonstrate how to implement this qualitative framework for multi-actor evaluation of the proposed policies.

7.0.1 Rijwaterstaat and Delta Commission policy evaluation

While these two actors have different mandates and resources, their objectives and framing of the problem at hand is sufficiently uniform and consistent. Thus, the qualitative analysis will be conducted by considering these players as one entity.
Step 1: Timeframe of interest
They want solutions that look far into the future of the Netherlands. Thus, they would be supportive of incremental and adaptive strategies planned over the next 200 years.
Step 2: Preferred spatial aggregation
They have to protect the interest of all citizens in the Netherlands. Thus, they focus primarily on the aggregated measures taken across all dike rings.
Step 3: Creation of new qualitative tables
Given the identified time-frame and spatial aggregation preferences of these actors, we can modify the initial policies' tables in the following way:

- *Temporal aggregation:* for each policy, the implementation of RfR and dike heightening measures will be aggregated across the three planning stages.
- *Spatial Aggregation:* the proposed interventions can also be aggregated across the different dike rings.

The results of such aggregation methods are reported in the following figures.

RfR Implementation															
	RfR, Dike Ring 1, PS 0	RrR, Dike Ring 1, PS 1	RfR, Dike Ring 1, PS 2	RfR, Dike Ring 2, PS 0	RfR, Dike Ring 2, PS 1	RfR, Dike Ring 2, PS 2	RfR, Dike Ring 3, PS 0	RfR, Dike Ring 3, PS 1	RfR, Dike Ring 3, PS 2	RfR, Dike Ring 4, PS 0	RfR, Dike Ring 4, PS 1	RfR, Dike Ring 4, PS 2	RfR, Dike Ring 5, PS 0	RfR, Dike Ring 5, PS 1	RfR, Dike Ring 5, PS 2
206	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0
361	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0
380	0	0	1	0	1	0	0	0	0	0	0	0	1	1	0

Temporal Aggregation

RfR Implementation					
	RfR, Dike Ring 1	RfR, Dike Ring 2	RfR, Dike Ring 3	RfR, Dike Ring 4	RfR, Dike Ring 5
206	1	2	1	1	0
361	2	0	1	0	0
380	0	0	0	0	1

Spatial Aggregation

RfR Implementation	
	RfR, All Dike Rings
206	5
361	3
380	1

Figure 30: *Effects of spatial-temporal aggregation on RfR policies table for Rijwaterstaat and Delta Commission.*

Dike Increases															
	A1 Dike Increase, PS0 (dm)	A1 Dike Increase, PS1 (dm)	A1 Dike Increase, PS2 (dm)	A2 Dike Increase, PS0 (dm)	A2 Dike Increase, PS1 (dm)	A2 Dike Increase, PS2 (dm)	A3 Dike Increase, PS0 (dm)	A3 Dike Increase, PS1 (dm)	A3 Dike Increase, PS2 (dm)	A4 Dike Increase, PS0 (dm)	A4 Dike Increase, PS1 (dm)	A4 Dike Increase, PS2 (dm)	A5 Dike Increase, PS0 (dm)	A5 Dike Increase, PS1 (dm)	A5 Dike Increase, PS2 (dm)
206	1	3	2	4	3	0	5	2	3	7	4	0	0	0	4
361	2	3	3	7	2	0	3	3	0	3	1	3	3	7	1
380	2	4	0	7	0	0	6	5	5	4	1	1	0	1	6

Temporal Aggregation

Dike Increases					
	A1 Dike Increase (dm)	A2 Dike Increase (dm)	A3 Dike Increase (dm)	A4 Dike Increase, (dm)	A5 Dike Increase, (dm)
206	6	7	10	11	4
361	8	9	6	7	11
380	6	7	16	6	7

Spatial Aggregation

Dike Increases	
	All dike rings Dike Increase (dm)
206	38
361	41
380	42

Figure 31: *Effects of spatial-temporal aggregation on dike heightening policies table for Rijwaterstaat and Delta Commission.*

Step 4: Identification of policies-specific interests

The following interests can be identified:

1. They would support RfR to be implemented as widely as possible across the different dike rings (i.e. implemented in a minimum of two dike rings in the across time).

2. Swift implementation of RfR in the first PS (Planning Stage) is particularly important in at least two dike rings.
3. Minimising dike heightening measures implemented over time is crucial.

Step 5: Qualitative evaluation of proposed policies
We can now also use this additional set of tables to understand how the different policies affect the specific identified objectives of Rijwaterstaat and Delta Commission. We will assign a + sign when the effect of the policy supports one interest, a - sign when it hampers such interests. The results of such procedure can be summarised in the following table.

Policies qualitative evaluation	Interest 1	Interest 2	Interest 3	Aggregated effect
Policy 206	+	+	+	+/+/+
Policy 361	+	-	-	+/-/-
Policy 380	-	-	-	-/-/-

Figure 32: *Qualitative evaluation of policies results for Rijwaterstaat and Delta Commission.*

Given these considerations, we can conclude that, from the perspectives of Rijwaterstaat and Delta Commission, **policy 206** would be the optimal solution (out of the three initially identified policies). Also, it is possible to say that **policy 380** would be the worst option while **policy 361** could be considered as a potential trade-off.

7.0.2 Overijssel

To understand which policy can be ultimately supported by Overijssel province, we can apply the same steps we used above.

Step 1: Time-frame of interest
While accounting for a broader time-frame to secure the well-being of their citizens, Overijssel will particularly focus on a smaller time-frame that should, in turn, be representative of their own limited political and administrative mandate. Therefore, they will have the greatest interest in understanding what actions will be implemented during the first planning stage (from the current moment to 66 years from now).

Step 2: Preferred spatial aggregation
They will be interested in having a more granular view of their own dike rings (Dike Rings 4 and 5). On the other hand other dike rings can be represented with a lower level of spatial granularity.

Step 3: Creation of new qualitative tables
Given the identified time-frame and spatial aggregation preferences of these actors, we can modify the initial policies' tables in the following way:

- *Temporal aggregation:* for each policy, the implementation of RfR and dike heightening measures taking place during planning steps 1 and 2 will be disregarded.

- *Spatial Aggregation:* the proposed interventions can be aggregated across the different upstream dike rings (Dike Rings 1,2 and 3). On the other hand, dike Rings 4 and 5 will be considered as two separate *geo-entities*.

The results of such aggregation methods are reported in the following figures.

RfR Implementation	RfR, Dike Ring 1, PS 0	RrR, Dike Ring 1, PS 1	RfR, Dike Ring 1, PS 2	RfR, Dike Ring 2, PS 0	RfR, Dike Ring 2, PS 1	RfR, Dike Ring 2, PS 2	RfR, Dike Ring 3, PS 0	RfR, Dike Ring 3, PS 1	RfR, Dike Ring 3, PS 2	RfR, Dike Ring 4, PS 0	RfR, Dike Ring 4, PS 1	RfR, Dike Ring 4, PS 2	RfR, Dike Ring 5, PS 0	RfR, Dike Ring 5, PS 1	RfR, Dike Ring 5, PS 2
206	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0
361	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0
380	0	0	1	0	1	0	0	0	0	0	0	0	1	1	0

Temporal Aggregation

RfR Implementation	RfR, Dike Ring 1, PS 0	RfR, Dike Ring 2, PS 0	RfR, Dike Ring 3, PS 0	RfR, Dike Ring 4, PS 0	RfR, Dike Ring 5, PS 0
206	0	1	0	1	0
361	0	0	1	0	0
380	0	0	0	0	1

Spatial Aggregation

RfR Implementation	RfR, Upstream Dike Rings, PS 0	RfR, Dike Ring 4, PS 0	RfR, Dike Ring 5, PS 0
206	1	1	0
361	1	0	0
380	0	0	1

Figure 33: *Effects of spatial-temporal aggregation on RfR policies table for Overijssel.*

Dike Increases	A1 Dike Increase, PS0 (dm)	A1 Dike Increase, PS1 (dm)	A1 Dike Increase, PS2 (dm)	A2 Dike Increase, PS0 (dm)	A2 Dike Increase, PS1 (dm)	A2 Dike Increase, PS2 (dm)	A3 Dike Increase, PS0 (dm)	A3 Dike Increase, PS1 (dm)	A3 Dike Increase, PS2 (dm)	A4 Dike Increase, PS0 (dm)	A4 Dike Increase, PS1 (dm)	A4 Dike Increase, PS2 (dm)	A5 Dike Increase, PS0 (dm)	A5 Dike Increase, PS1 (dm)	A5 Dike Increase, PS2 (dm)
206	1	3	2	4	3	0	5	2	3	7	4	0	0	0	4
361	2	3	3	7	2	0	3	3	0	3	1	3	3	7	1
380	2	4	0	7	0	0	6	5	5	4	1	1	0	1	6

Temporal Aggregation

Dike Increases	A1 Dike Increase, PS0 (dm)	A2 Dike Increase, PS0 (dm)	A3 Dike Increase, PS0 (dm)	A4 Dike Increase, PS0 (dm)	A5 Dike Increase, PS0 (dm)
206	1	4	5	7	0
361	2	7	3	3	3
380	2	7	6	4	0

Spatial Aggregation

Dike Increases	Dike Increase, Upstream Dike Rings, PS0 (dm)	A4 Dike Increase, PS0 (dm)	A5 Dike Increase, PS0 (dm)
206	10	7	0
361	12	3	3
380	15	4	0

Figure 34: *Effects of spatial-temporal aggregation on dike heightening policies table for Overijssel.*

Step 4: Identification of policies-specific interests

The following interests can be identified:

1. Their primary concern lies with the idea that RfR measures should be implemented in upstream dike rings. This would, in their perspective, lower the potential safety risks their province would face in case of flooding events.
2. They strongly oppose dike heightening interventions in upstream dike rings. In their opinion, this would just move, and aggravate, flooding events from Gelderland to their own dike rings.
3. They would argue against the implementation of RfR in Dike Ring 4 since they consider that area to be agriculturally relevant.
4. The implementation of RfR in Dike Ring 5 would hamper the expansionary policies of the urban area.

Step 5: Qualitative evaluation of proposed policies
Following the same strategy that was used for Rijwaterstaat and Delta Commission, we can trace the effect of the proposed policies on Overijssel specific interests as shown in the table below.

Policies qualitative evaluation	Interest 1	Interest 2	Interest 3	Interest 4	Aggregated effect
Policy 206	+	+	-	+	+/+/-/+
Policy 361	+	-	+	+	+/-/+/+
Policy 380	-	-	+	-	-/-/+/-

Figure 35: *Qualitative evaluation of policies results for Overijssel.*

From these qualitative results we can argue that:

- Policy 380 will be the least preferred policy since it negatively impacts three out of four identified interests.
- Policy 361 and 206 qualitatively wield the same effects on the four interests. Nevertheless, policy 361 implies larger dike heightening measures in upstream dike rings. This policy feature, in turn, could result in harsher debates in the decision-making arena. Thus, policy 206 is preferred over policy 361.

Therefore, the ranking of the proposed policies is perfectly coherent with the one implied from the qualitative analysis of Rijwaterstaat and Delta Commission. In other words, **policy 206** will be the best option, with **policy 361** and **380** being the backup solutions (in this precise order).

Appendix D: Directed Search

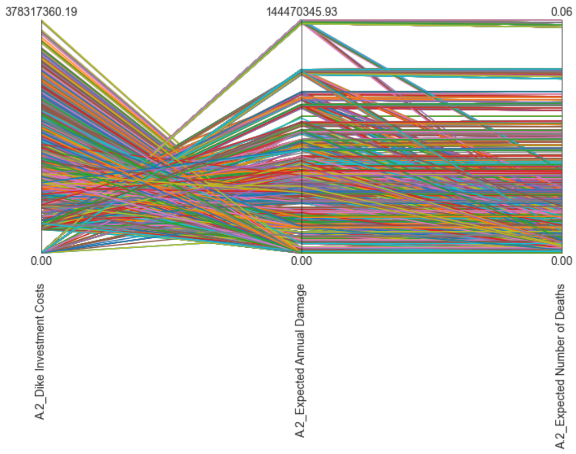

Figure 36: *A pair coordinate plot, running multiple policies against a reference scenario for the rural dike ring 2.*

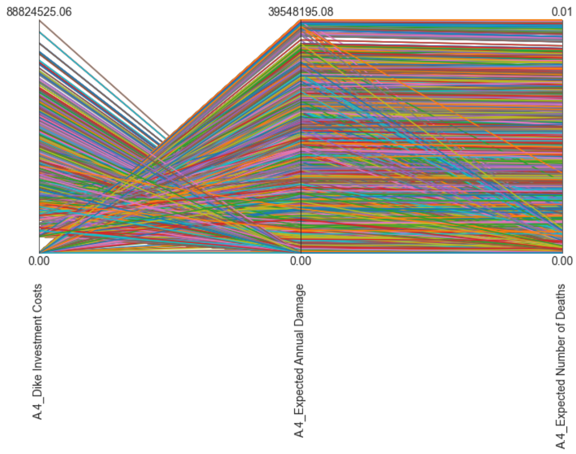

Figure 37: *A pair coordinate plot, running multiple policies against a reference scenario for the urban dike ring 4.*

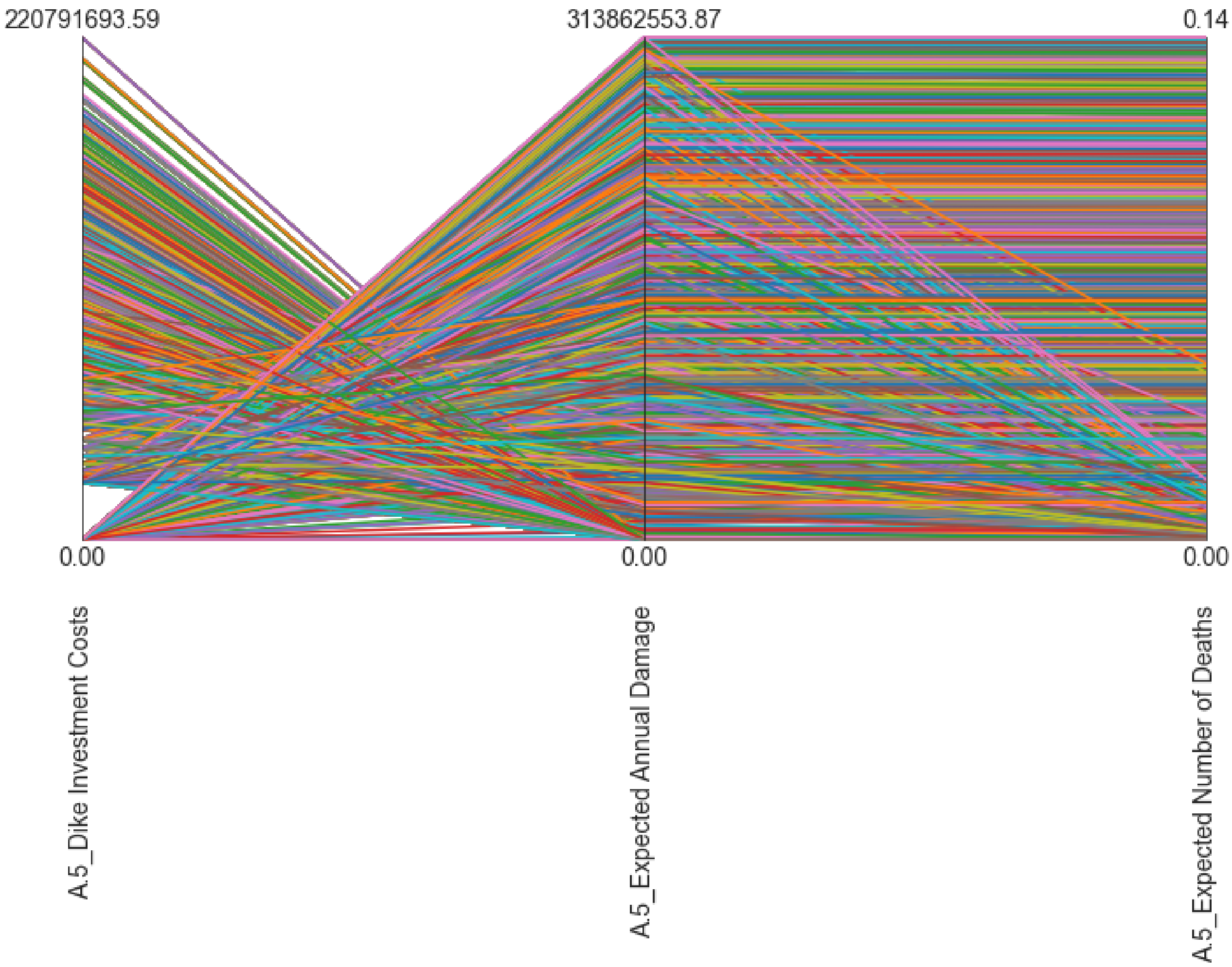

Figure 38: *A pair coordinate plot, running multiple policies against a reference scenario for the urban dike ring 4.*