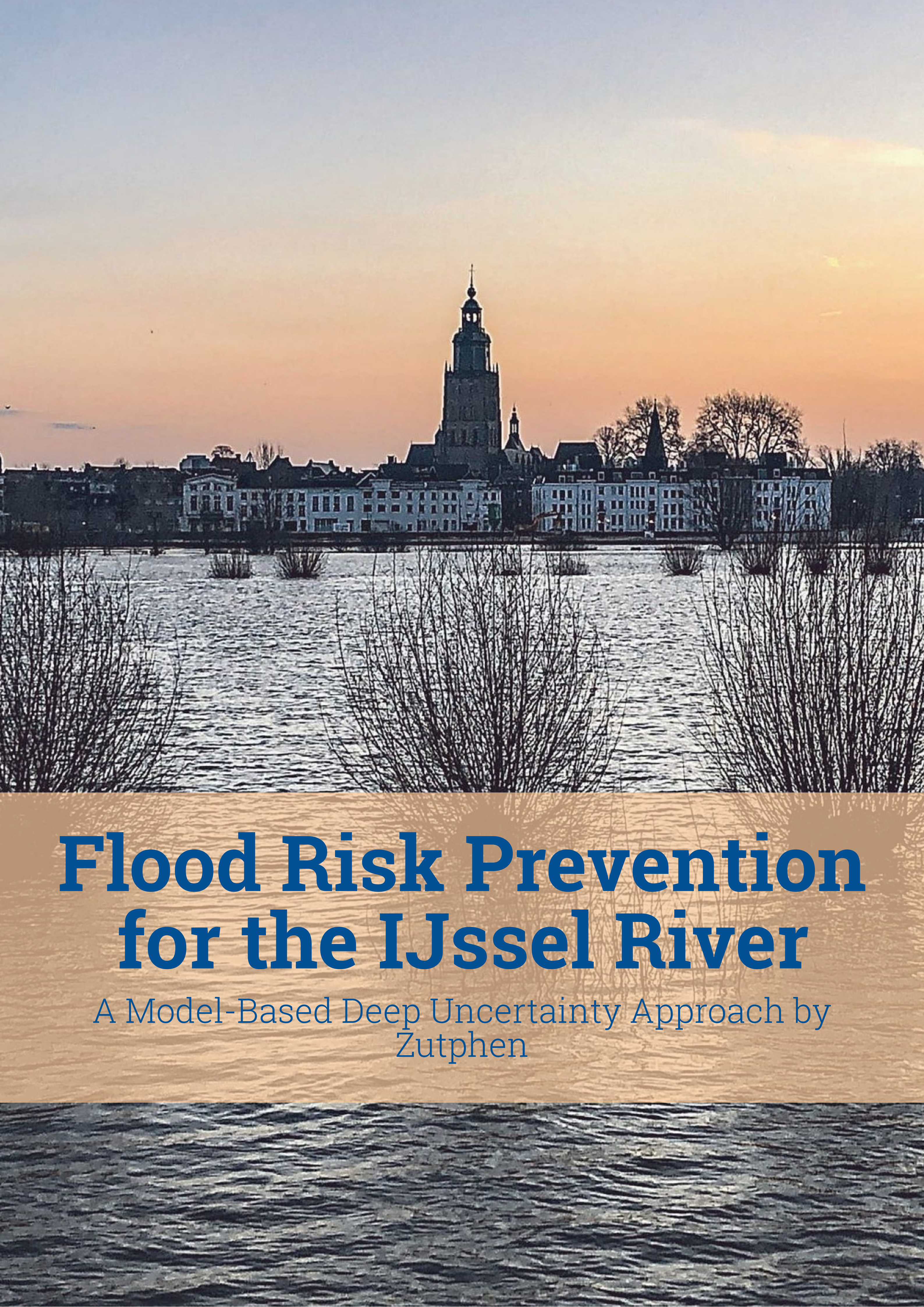

Flood Risk Prevention for the IJssel River

A Model-Based Deep Uncertainty Approach by Zutphen

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by

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Executive Summary

Managing flood risks in a world of changing climate patterns is a complex task, fraught with deep uncertainties. This report delves extensively into the management of flood risks for the Upper Ijssel River, specifically concentrating on Zutphen, a municipality situated in Gelderland, to aid their decision-making processes.

Advanced modeling and analysis methods were utilized in our research to investigate various strategies to address potential flood events. The goal was to identify policies that can sufficiently safeguard Zutphen from potential future flooding, bearing in mind the numerous stakeholders and the deep uncertainties involved.

Based on the findings of our analysis, our primary suggestion is to prioritize increasing the dike heights in the Dike Ring 3 which is located in Zutphen. The reasons for this are as follows:

- *Robustness:* The results of our analysis indicate that this strategy performs well across a broad spectrum of potential future scenarios. This robustness means that even if future conditions diverge significantly from what we expect, raising the dikes provides consistent protection against flood risks.
- *Risk-Aversion:* Our analysis took into account the risk-averse nature of decision-making in the context of flooding. The raising of dikes is a policy that minimizes potential regrets — that is, it reduces the likelihood of future scenarios where alternative policies could have performed better.
- *Stakeholder Consideration:* This strategy respects the interests and concerns of a broad range of stakeholders, including local communities, environmental groups, and policymakers. The raising of dikes provides a clear, concrete plan of action that can be more easily agreed upon than more abstract or contentious strategies.

It is crucial to note that while the advice given here is grounded in a robust analysis, no model can perfectly predict the future, particularly in the face of climate change. As such, this recommendation should be understood as part of an iterative, ongoing process. As new information emerges and circumstances change, it will be necessary to re-evaluate and update our strategies.

We are confident that this report provides a solid foundation for future decision-making. By focusing on robust, risk-averse policies that respect the needs of multiple stakeholders, we can move towards a future where Zutphen, and indeed all of Gelderland, is better protected from the risk of flooding. We highly appreciate the cooperative nature of the decision-making process, which we believe will continue to enable the progression toward a shared, comprehensive solution to this complex problem.

Contents

1. Introduction and Problem Framing

1.1. Problem Summary

The Netherlands, a country in which one-third of its land area is situated below sea level, has faced ongoing challenges related to water management. Over time, the nation has successfully tackled these issues primarily through constructing and reinforcing its famous dikes (Bruijn et al., 2015). Nonetheless, the onset of climate change as well as land subsidence, has presented new obstacles for the nation (Erkens, 2021). Heightened water levels have amplified flood risks and posed threats to various urban and rural regions, emphasizing the necessity of a shift towards a new paradigm in water management. In response to water management challenges, one of the innovative approaches pursued is the Room for the River (RfR) project, which substantially redefines the Netherlands' water management by providing more space for water flow (Bruijn et al., 2015).

The upper stretch of the IJssel River, traversing both Gelderland and Overijssel provinces, is also increasingly susceptible to flooding, necessitating the development of enhanced flood risk management strategies. These strategies should take into account damage, cost, and potential threat to people while striving for balance among these factors. To this end, a mix of the Room for the River (RfR) and traditional methods, such as dike construction and early warning systems, can be deployed. However, the presence of numerous stakeholders with diverse interests adds further complexity to the decision-making process, turning it into a multifaceted challenge.

In this report, we will investigate a flood risk management plan for the city of Zutphen, located in Gelderland, with a focus on a specific dike ring within our town to ensure the safety of our citizens. By employing cutting-edge modeling techniques, we will evaluate the potential consequences of diverse strategies, thereby establishing a scientific basis to guide decision-making within the political context.

1.2. Deep Uncertainty

Addressing flood risk management for the upper segment of the IJssel River entails grappling with deep uncertainty, a concept described by Lempert et al. (2003) as a scenario in which decision-makers face difficulty in reaching a consensus on the suitable models for a system's variables, the probability distributions for key parameters, or the valuation of alternative outcomes. This deep uncertainty is partly due to the presence of numerous stakeholders, each possessing diverse and occasionally conflicting interests in flood risk management. These stakeholders consequently assign different values to potential outcomes.

In addition to the differing interests of stakeholders, climate change presents another layer of complexity to flood risk management. Factors such as the unpredictable nature of human activities and the incomplete understanding of climate change dynamics contribute to uncertainty in both the magnitude and consequences of it (Kasprzyk et al., 2013; Marchau et al., 2013). Accordingly, it creates uncertainty in the model parameters while altering the dynamics of the flood risk model. Considering the deep uncertainties inherent in the problem, when formulating a flood management plan for Zutphen, our goal is not to pinpoint an optimal solution that only works in specific circumstances; rather, our aim is to devise a robust strategy that ensures favorable outcomes across a variety of potential future scenarios (Walker et al., 2013).

1.3. Political Arena

The complexity of the issue not only stems from an incomplete understanding of the system and natural phenomena but also from the interactions within the multi-stakeholder arena, where diverse and conflicting interests of these actors come into play. To comprehend the dynamics at work in the flood risk management plan for the upper branch of the Ijssel River, it is crucial to examine the participants engaged in the decision-making process.

The RfR project brings a novel governance approach that requires active collaboration among government agencies in various disciplines at national, regional, and local levels (Rijke et al., 2012). In the upper Ijssel River case, national-level participants include Rijkwaterstaat and the Delta Commission, while the regional-level actors consist of the provinces of Gelderland and Overijssel. Within these provinces, there are five dike rings representing the local level, as illustrated in figure 1.1. Additionally, there are two special interest groups: the Environmental interest group and the transport company. These interest groups, along with provinces, hold voting rights in the decision-making process. On the other hand, Delta Commission and Rijkwaterstaat possess veto powers. Dike rings do not have as much power as other actors in decision-making, as the provinces represent them. A comprehensive overview of each participant as well as their resources is provided in Appendix B.

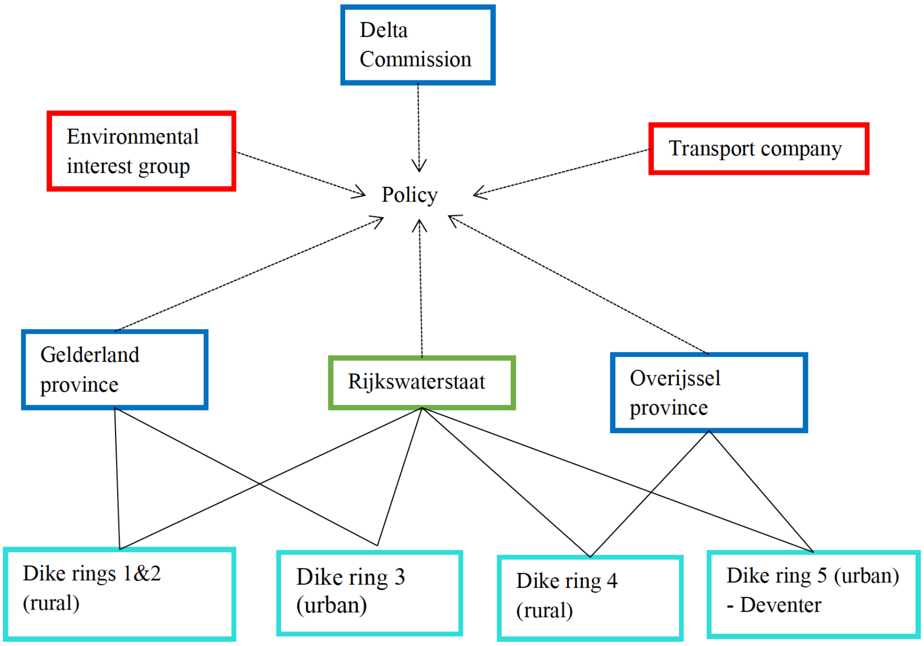

Figure 1.1: Overview of actors in the political arena. *Source:* J. Kwakkel, 2023

As Dike Ring 3, we fall under Gelderland's representation, and as a result, we expect to form a coalition with them. However, they must also take into account two other dikes, which could lead to varying end goals between us. During our meetings, they suggested separate evaluations for each dike. Their preference aligned with our initial plan, opting for dike construction rather than RfR in our region. Nevertheless, a limited budget exists, and Gelderland's choices may not be favorable to everyone. Although they are also focused on reducing flood risk, they need to take into account additional factors, such as economic concerns. Potential conflicts could arise between Overijssel and Gelderland due to their upstream-downstream positions, or Gelderland may not receive the substantial amount of compensation they are hoping for. In summary, all parties involved, including ourselves, strive to reduce flooding by concentrating on their individual interests while endeavoring to broaden the agenda to accomplish their desired outcomes.

1.4. Problem Formulation

As discussed in Section 1.3, flood risk management involves numerous actors with diverse power and interests in the decision-making arena. Each participant views the problem through their subjective lens, resulting in different policy options based on individual problem formulations. Hence, it is crucial to consider the perspectives of other key actors to gain a deeper understanding of political dynamics and anticipate potential challenges that may arise during the implementation of the chosen policy. The analysis will commence by presenting the problem from Zutphen's perspective and then proceed to assess alternative viewpoints.

1.4.1. Zutphen's Perception

As the administration of Zutphen, our top priority in developing a flood risk management plan for the upper stretch of the Ijssel River is ensuring the long-term safety of our residents. While we also seek to reduce flood risks for the entire upper Ijssel region, our primary focus remains on safeguarding our inhabitants from potential flooding. Due to the close proximity of our town's dike ring to a densely populated area, we prioritize mitigating flood risks in Zutphen over rural regions with fewer inhabitants. Moreover, if any policy implementation, mainly RfR, calls for the relocation of our citizens, which we would rather avoid, we insist on providing them with adequate compensation. In tandem with prioritizing the safety of our residents, we strive to minimize the economic impacts of potential flooding on our town and uphold a high level of satisfaction among our residents. While being aware of the diverse stakeholder arena and budget constraints, we are committed to finding a policy that maximizes the safety of our residents. Therefore, our problem statement is:

Which upper Ijssel River flood management strategy best meets Zutphen's goals of ensuring residents' safety and minimizing the displacement of citizens while remaining robust under deep uncertainty and acceptable in a multi-stakeholder context?

1.4.2. Alternative Perceptions

As mentioned in Section 1.3, Zutphen is politically represented by Gelderland. Consequently, it is vital for us to comprehend the issue from Gelderland's viewpoint in order to effectively convey our interests. Moreover, the policies will be implemented in either Overijssel or Gelderland within a limited budget. Hence, considering our policy is particularly reliant on the interplay between the provinces, it is essential to scrutinize the issue from a wider viewpoint that disaggregates over the provinces. The two problem formulations created for these alternative perspectives are:

- **Geldarland:**
  What strategies can Gelderland employ to create a flood risk management plan that ensures the safety of its citizens and minimizes economic damage while also being sustainable and resilient?
- **Disaggregated over the provinces:**
  Considering the constraints of limited budget and potential conflicts, how can an effective flood risk management policy be developed for Gelderland and Overijssel that is approved by the concerned parties, minimizes economic damage, and ensures the increased safety of residents?

1.5. Report Structure

This chapter provides an overview of the report and presents key findings and suggestions for further action. It serves as a quick reference point, summarizing the core issues, methodology, and conclusions.

- **Introduction and Problem Framing**
  This section presents the problem in context and frames it within the broader environment. It introduces key aspects like the nature of the problem, deep uncertainties, political dynamics, and different perceptions.
- **Modelling Approach**
  This chapter outlines the methodology adopted for the study. It discusses the Multi Scenario Multi-Objective Robust Decision Making (MORDM) approach in detail, including steps such as model specification, open exploration, uncertainty analysis, scenario discovery, and domain criterion costs.
- **Modelling Analysis and Results**
  This section presents the results of the application of the Multi Scenario MORDM. It includes an open exploration phase and a detailed analysis of the results under different scenarios.
- **Assumptions and Discussion**
  This chapter elaborates on the assumptions made during the model formulation and discussion around the implications of those assumptions. It further discusses the limitations of the model and the overall approach taken for the study.
- **Conclusions and Recommendations**
  The final chapter synthesizes the findings from the study and provides recommendations based on those findings. It offers a look ahead into the future implications of the findings and potential areas of further research.

2. Modelling Approach

As laid out in Section 1.2., the problem of flood mitigation for the upper IJssel River is characterized by deep uncertainty, rendering traditional decision-analysis techniques ill-suited for effectively tackling the issue (J. Kwakkel & Pruyt, 2013). In order to support Zutphen's decision-making process under these circumstances, a robust decision-making approach is adopted. The analysis employs the EMA workbench, a Python library containing all essential tools for seamless execution within a single Python repository (J. H. Kwakkel, 2017).

2.1. Multi Scenario Multi-Objective Robust Decision Making

Various robust decision-making (RDM) methods have been developed to assist decision-making processes for complex issues, which are marked by deep uncertainties and conflicting priorities within multi-arena (Bartholomew & Kwakkel, 2020). Simply, RDM runs models multiple times to assess the viability of proposed decisions across a broad spectrum of plausible futures in contrast to the traditional "predict and act" approach (Lempert et al., 2013). The variations of RDM are mainly Multi-Objective RDM (MORDM), Multi Scenario MORDM (MS-MORDM), and Many Objective Robust Optimization (MORO), which is the newest contribution to the RDM family (Bartholomew & Kwakkel, 2020). Among these alternatives, MS-MORDM is chosen as the method for the analysis due to its comparative advantages compared to other available approaches.

Firstly, the upper IJssel River issue demands the evaluation of multiple objectives, such as RfR investment cost, dike investment cost, and expected annual damage, which are partly conflicting and limited by the available budget. Additionally, the presence of multiple stakeholders within the decision-making environment adds further complexity to the objectives (see Section 1.4). Under these conditions, single-objective RDM would fail to provide accurate results as it necessitates the identification of promising policy options at the onset (Kasprzyk et al., 2013). MORDM offers a valuable extension by addressing this challenge through the identification of policy alternatives using many-objective evolutionary algorithms (MOEA) (Kasprzyk et al., 2013).

Secondly, despite MORDM's advancements compared to RDM, there exists a potential for further improvement in developing more robust policies, primarily due to the reliance on a singular reference scenario (Watson & Kasprzyk, 2017). The MS-MORDM, on the other hand, removes this limitation by performing a "search for multiple scenarios which are selected because they represent conditions under which solutions found for the first reference scenario performs poorly" (Bartholomew & Kwakkel, 2020, p. 2).

Lastly, although MORO integrates robustness into the search phase and yields better results, the MS-MORDM is chosen over MORO due to its relative runtime efficiency. (Bartholomew & Kwakkel, 2020).

2.2. Multi Scenario MORDM Steps

As a first step, the problem/model specification is performed based on the XLRM framework introduced by Lempert et al. 2003. Then, open exploratory analysis is conducted to effectively understand the model and the uncertainties inherent and to obtain the reference scenario for the MS-MORDM. The worst-case scenario, based on the outcomes determined, is chosen as the reference scenario.

After performing an open exploratory analysis, the first iteration of a directed policy search is carried out, which helps to determine the best-performed policies for the selected reference scenario. A constrained subset of these policies, defined by desired outcomes, is then subjected to uncertainty analysis. Following this, scenario discovery is performed to obtain additional relevant scenarios. Newly discovered scenarios are fed as input back into the policy search. Then, these steps are repeated one more time. The detailed version of the steps pursued in the analysis is presented in Figure 2.1. In the subsequent sections, further elaboration of these steps is provided.

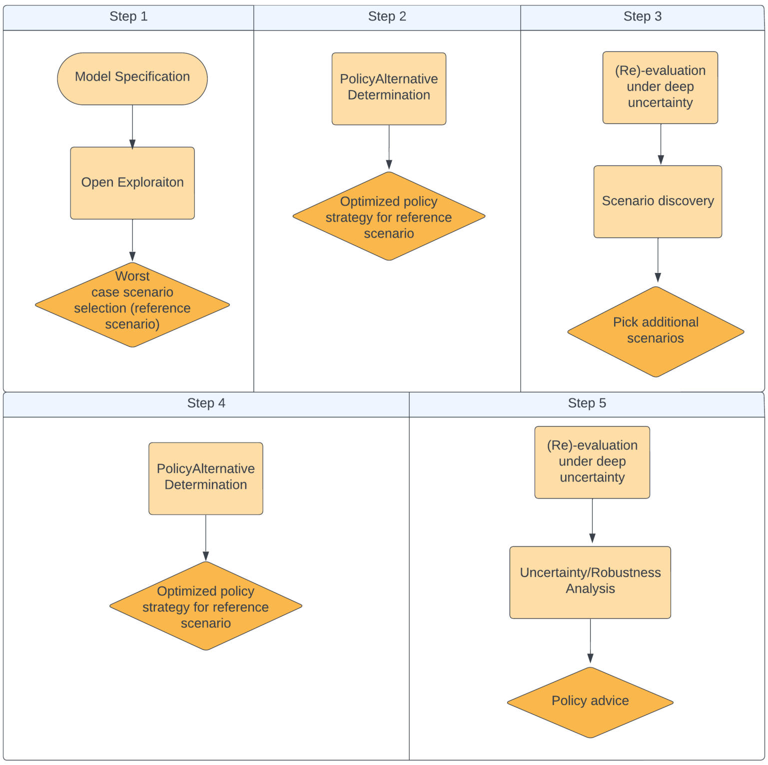

Figure 2.1: Multi Scenario MORDM steps used in the upper Ijssel River case

2.2.1. Model Specification

The conceptual model in this study employs the XLRM framework, which categorizes the analysis elements into four key components: exogenous uncertainties (X), policy levers (L), performance metrics (M), and system relationships (R) (Lempert et al., 2003). By applying the XLRM framework to the case of the upper IJssel River, the study establishes a structured decision framing for understanding the interplay of uncertainties, policies, metrics, and system dynamics in flood risk management. The XLRM framework developed for the upper IJssel River case study is depicted in Figure 2.2. This framework presents the system's uncertainties, available policy options, outcomes of interest, and the flood management model created by Ciullo et al. (2019), providing a clear foundation for the analysis. A detailed explanation of uncertainties and levers can be found in Appendix C.

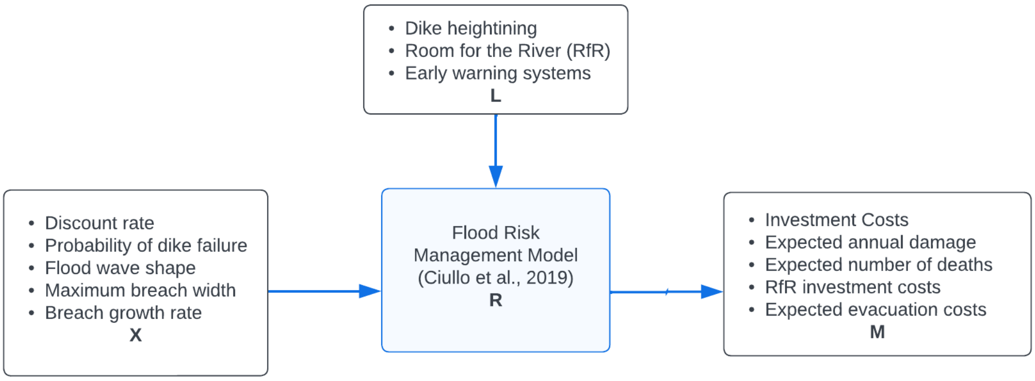

Figure 2.2: The XLRM framework for the , modified from J. H. Kwakkel (2017)

To utilize the problem formulations for Zutphen and Gelderland (see Section 1.4), it is necessary to operationalize them for the modeling process. While their uncertainty and lever space are the same as in Figure 2.2, the outcomes will differ based on the specific problem definition. The operationalized version of the problem formulations can be seen in Figure 2.3.

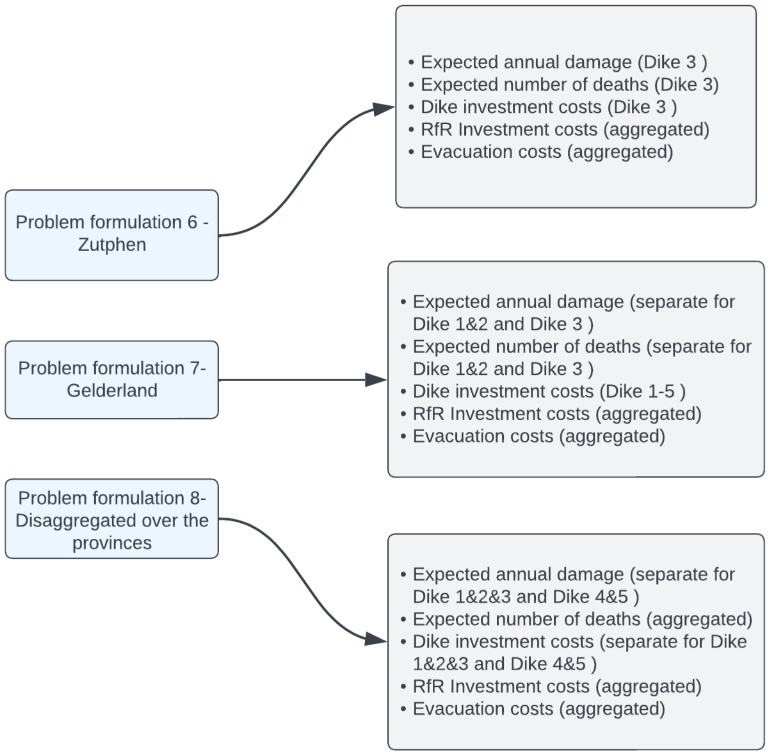

Figure 2.3: Operationalized problem formulations for the Ijjsel River with their associated problem IDs

The provided analysis is built to run on all three of the problem formulations depicted in Figure 2.3. However, we decided to present results only on the problem formulation of Zutphen for one distinct reason. We are presenting a piece of information in a larger mosaic. This report is written to support Gelderland province. Our target audience has to find a trade-off between multiple perspectives that most crucially satisfies the needs for the Dike rings 1,2 and 3. We chose to present our findings in the most disaggregated and targeted manner to avoid death by figures and circumvent the "problem of aggregating technical opinion" (Turner, 2005).

2.2.2. Open Exploration

Initially, we explore both the uncertainty and lever space to gain a preliminary understanding of the problem dynamics and inherent interaction effects before conducting a directed search for potential policies.

Next, we execute 10,000 scenarios without implementing any policies, utilizing Latin Hypercube Sampling - the default sampling method in the EMA workbench. This method enables efficient searching of the policy space and exhibits good space-filling behavior (Sanchez & Wan, 2015). Afterward, we compare the outcomes of scenarios with no policy intervention to the outcomes of the scenarios deploying a random policy to determine if policies positively impact the problem.

Subsequently, the worst-case scenario with no activated policies, based on Zutphen's desired outcomes, is selected as a reference scenario for the first iteration of the MS-MORDM process.

2.2.3. Uncertainty Analysis

The primary objective of the uncertainty analysis is to develop a formulation and a set of solutions that demonstrate performance satisfying Pareto optimality across a broad spectrum of potential scenarios. This robustness of policies is measured by two distinct metrics. Firstly, the Signal-to-Noise ratio quantifies the robustness per policy per variable by dividing the mean performance of a specific policy across all simulated scenarios by its standard deviation (Doumpos et al., 2016). Secondly, the Maximum Regret value is a metric for risk-averse decision-making, comparing each policy's performance against others to identify policies with minimal regret (Savage, 1951; Giuliani and Castelletti, 2016).

2.2.4. Scenario Discovery

The purpose of scenario discovery is to identify the susceptibilities of robust solutions. This is achieved by scrutinizing the performance of policies under uncertain circumstances, particularly those that result in sub-optimal outcomes. From the discovered pool of scenarios in which the robust policies show weaknesses, we selected 5 reference scenarios as new inputs into the MOEA algorithm and conducted the next iteration. The algorithm used for this analysis is the Epsilon-NSGAII algorithm from the existing MOEAs (Kasprzyk et al., 2013).

There are several methods for conducting scenario discovery. In this report, we utilize the Patient Rule Induction Method (PRIM). PRIM is a lenient hill-climbing optimization algorithm that iteratively refines the uncertainty space. Its interactive nature, visualization capabilities, and the option to present multiple scenarios make PRIM particularly valuable for scenario discovery (Bryant and Lempert, 2010).

Furthermore, PRIM allows us to choose various trade-offs among the three primary measures for scenario quality: Coverage, density, and interpretability (Rozenberg et al., 2014). PRIM pinpoints specific candidate boxes that rest on a Pareto optimal surface determined by these measures (Kasprzyk et al., 2013).

2.2.5. Domain Criterion Costs

The Domain Criterion Costs play a crucial role in the evaluation and selection of policies within our problem context. They serve as a critical monetary measure, aiding in the decision-making process for policy implementation.

Under the domain criterion costs, each policy is evaluated based on the total financial outlay required for its execution. These costs, typically comprising the RfR costs and Dike investment costs, are assessed across all simulated scenarios.

In a similar vein to the Signal-to-Noise ratio and Maximum Regret value, the domain criterion costs contribute to the measurement of policy robustness. They provide a quantifiable financial measure against which the performance of a policy can be gauged, providing a comprehensive understanding of the financial implications associated with each policy. This facilitates a cost-benefit analysis, allowing decision-makers to weigh the potential damages and casualties prevented against the financial commitment required.

Furthermore, the domain criterion costs also factor into the scenario discovery process. Scenarios, where robust policies lead to excessive costs, can be identified as areas of potential policy weakness. These situations can then be used as inputs into subsequent iterations of the MOEA algorithm to seek improved policy solutions.

It is essential to note that, unlike other metrics, the unit for the domain criterion cost is monetary, making it a tangible and direct indicator of the policy's financial implications. This underlines the importance of considering domain criterion costs alongside other performance measures in crafting the most effective and economical policy strategy.

3. Modelling Analysis and Results

This section unfolds the findings of our investigation aimed at shaping decision-making processes for the Dike Ring 3 regions of the Gelderland province. The results are structured in the following order:

Section 3.1 illuminates our open exploration results, offering preliminary insights that guided subsequent analyses. In Section 2.3, we delve into the MS-MORDM analysis, showcasing the derived policies from this detailed scrutiny. Following this, Section 3.3 elucidates the global sensitivity analysis, exploring how variations in policy levers impact the outcomes. The insights from this analysis furnish policymakers with comprehensible overviews of interactive effects, enhancing their ability to promptly respond to policy proposals in their negotiations with the province of Gelderland.

Our findings provide crucial decision-making guidance for both the Dike Ring 3 area and the entirety of the Gelderland province, addressing distinct policy scenarios, uncertainties, and sensitivities to optimize the outcomes of their decision-making processes. We aspire, with this transparent and comprehensive approach, to enhance Gelderland's understanding of the situation unique to Dike Ring 3 and ensure that Dike Ring 3's concerns are appropriately considered in Gelderland's future policy deliberations.

3.1. Open Exploration

Our initial step in this exploration was to contrast the consequences of implementing no flood management measures with the impact of a randomly selected policy. To ensure the reliability of our findings, we used a considerable sample size (1000 for each scenario set), and statistical significance was established ($p<.001$ for expected annual damage, $p<.001$ for total investment costs, $p<.001$ for expected number of deaths). These findings provide a strong basis to argue that any active intervention in flood management will have a positive influence on the upper IJssel River.

Given the significant difference that the flood management measures made, it was logical to establish the scenario with no implemented policies as a 'worst-case' reference. This reference serves as a benchmark for the directed policy search, allowing us to evaluate the relative success of different policy initiatives.

With this groundwork laid, we proceeded to conduct a directed policy search. We looked at a variety of potential policies and evaluated their effectiveness against our 'worst-case' scenario, using the comprehensive set of outcome metrics. This approach allowed us to identify the most effective strategies for flood management in the upper IJssel River area, taking into account a wide variety of potential impacts.

It is important to note that while the open exploration phase was primarily quantitative, it helped set the stage for more detailed, nuanced analysis in later stages. The patterns and trends identified in this stage provided a solid foundation for subsequent policy exploration, helping to ensure that our recommendations are robust, well-rounded, and backed by rigorous analysis.

3.2. Multi-Scenario MORDM

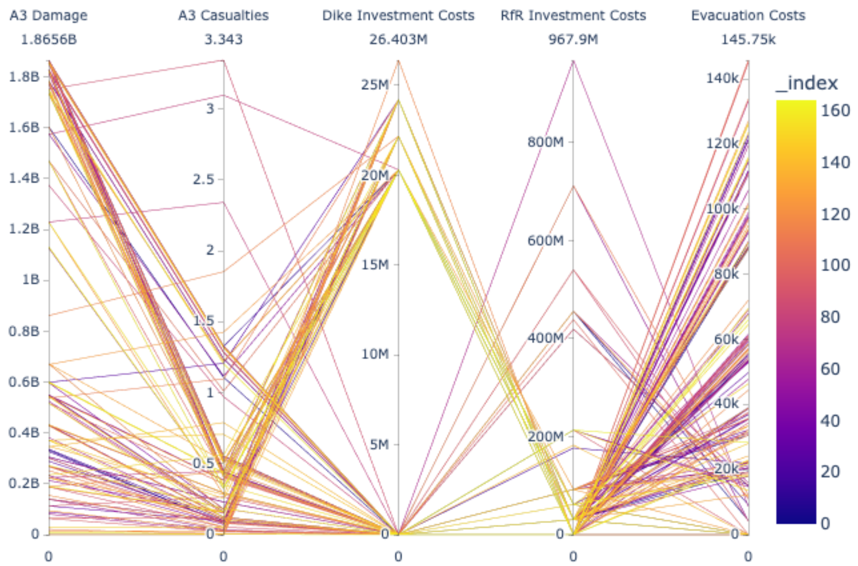

Figure 3.1: Parallel plot after the first iteration

As observed in Figure 3.1, a selection of policies reveals two fundamentally contrasting views on the preferred approach: whether to enhance the height of the Dikes or to invest in RfR projects. Nonetheless, these policies exhibit considerable variation in terms of resultant damages and casualties. This necessitates a subsequent run of the selected policies from this iteration through an extended range of scenarios. This further investigation will provide more definitive insights and facilitate the identification of more robust, future-oriented policies.

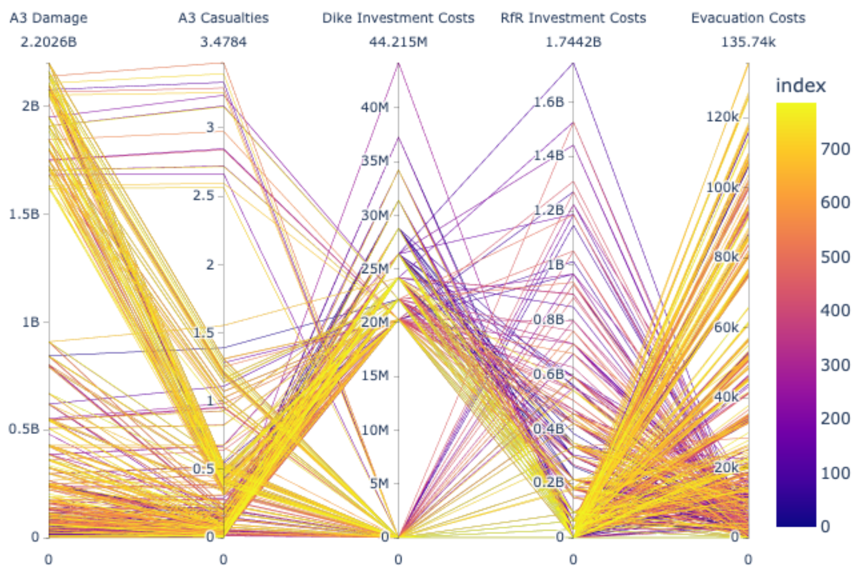

Figure 3.2: Parallel plot after the second iteration

Figure 3.2 illustrates the outcomes of selected policies after the second iteration. These formulated policies curtail the occurrence of casualties. Two prominent clusters of strategies observed earlier also emerge more evidently during the second iteration, discernible by the extent of city damage in Zutphen they induce. The casualty range for both clusters is comparably lower than alternative scenarios.

The first cluster displays a trend of substantial city damage. Upon further analysis, it is evident that this cluster all but neglects investments in Dike reinforcement and Evacuation measures. Instead, substantial financial resources ranging from 0.2 to 1.77 billion are allocated towards Room for the River (RfR) projects.

In contrast, the second cluster demonstrates a pattern of reduced damage and casualties. This is accompanied by significant funding towards Dike fortification and Evacuation initiatives, with a noticeable absence of RfR investments.

This dichotomy poses an intriguing conundrum: RfR projects incur high setup and damage costs, reaching up to 3 billion in certain instances. Alternatively, investing approximately 45-50 million in Dike heightening and evacuations, when necessary, results in significantly less damage, usually less than a billion. This cost-benefit analysis motivates the decision for Zutphen to actively invest in increasing the height of the Dikes and prepare to evacuate people in case of a disaster rather than invest in RfR projects that may result in property damage that may result in more monetary damage.

More figures and plots for the first iteration can be found in Appendix A.

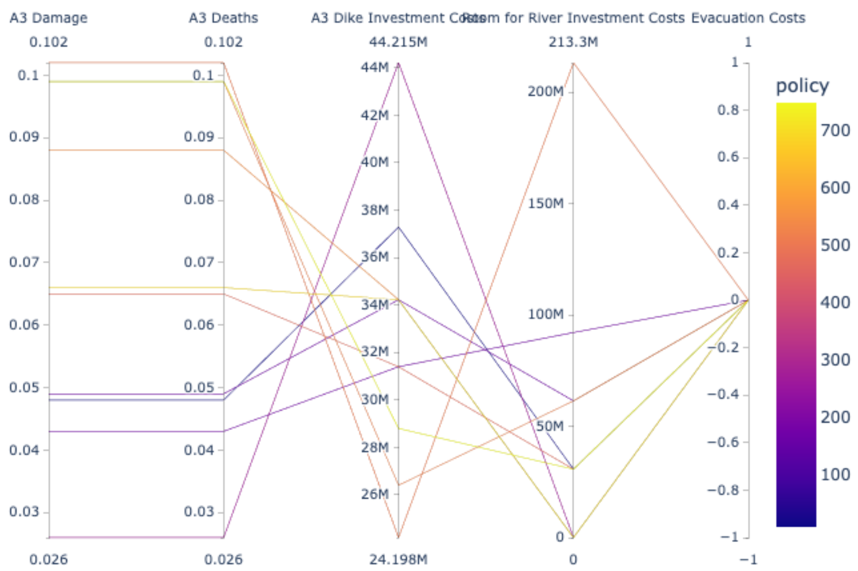

Figure 3.3: Parallel plot for selected policies after the second iteration

Upon the completion of the second iteration, we distinguish the top 10 policies by averaging their outcomes across a plethora of scenarios, under conditions of deep uncertainty. These policies display diversity in terms of investment implications, thus providing the province of Gelderland with the flexibility to select from among these 10 policies, all of which guarantee comparable outcomes regarding damage and deaths.

Nonetheless, we advocate for the policy set of 270, 695, and 547 as the most efficacious, given their superior performance marked by the lowest metrics of death and damage. These recommended policies underscore the strategy of raising the height of the Dikes exclusively.

Remarkably, in all the runs under deep uncertainty, no policy incurs evacuation costs. Our focus is primarily on the trade-offs between damages and deaths, consistent with the primary concerns of the city of Zutphen, as highlighted in section 1.4. Given the domain criterion is a dimensionless metric, we include the total costs (comprising RfR costs and Dike investment costs) in the parallel coordinated plot to exhibit the "price of robustness". It is essential to consider that, unlike the domain criterion metrics which are dimensionless, the unit for total cost is monetary.

The policies were filtered using specific thresholds where each unique policy in the reevaluation data frame was subsetted and evaluated on various criteria: A3 Expected Annual Damage, A3 Aggregated Expected Number of Deaths, A3 Dike Investment Costs, Room for River Investment Costs, and Evacuation Costs. Policies were scored on each criterion, with higher counts in areas such as Damage and Deaths leading to lower scores. The scores across all criteria were then averaged to produce a final score for each policy, which was then ranked. The top 10 policies by this ranking were then selected for further analysis.

4. Assumptions and Discussion

This chapter discusses the potential assumptions that may impact the understanding of our results. We first address the main limitations of the model we used, then critically review our research methodology. It's important to note that our study exists within a broader political decision-making process, which we will further discuss in Chapter 6.

4.1. Model Limitations

Our model has certain limitations that affect how we interpret the results. First, the model outcomes are restricted to a select few pre-defined options. For instance, certain stakeholders, like environmental groups, might emphasize biodiversity. However, since biodiversity is not included in the model's options, it can't be used in model-based arguments. This limitation also applies to the specific choices and details of levers, and the fact that most outcomes don't have units.

In addition, socio-economic factors, which could impact policy implementation, are not considered in the model. These limitations can cause considerable uncertainty in our final policy recommendations. However, as every model is a simplified representation of reality, we understand this issue can't be entirely eliminated.

Another fundamental limitation we encountered is related to computational capacity. Because of constraints in hardware and the time needed for computation, we had to limit the number of iterations when running the EMA Workbench. This may have led to potentially more effective solutions being overlooked due to these computational constraints. We recommend other researchers consider these limitations when attempting to validate and reproduce our findings.

4.2. Approach

The success of any Robust Decision Making (RDM) framework assumes a consensus among stakeholders regarding outcomes of interest and system boundaries. It is thus essential that the model chosen for analysis is universally accepted and not a subject of contention (J. Kwakkel et al., 2016). The agreement of all stakeholders to use the same model alleviates limitations by ensuring that the model itself can't be used to challenge policy proposals.

Our analysis is primarily focused on the dike ring 3 areas. It's important to note that we haven't included problem formulations from all stakeholders. As Van Enst et al. (2014) highlight, researchers can potentially influence their agenda by selectively including or excluding certain information, a concern within the policy-science interaction. Although our report might be seen as promoting a specific agenda by excluding other stakeholders' problem definitions, it's part of the broader scientific evidence base. As Sarewitz (2004) contends, the growth of scientific evidence can often heighten political controversy as more information provides a pool from which varied positions can be drawn. Our report should be viewed as a piece of evidence in the larger knowledge corpus, specifically offering a perspective from the dike ring 3 area. It primarily serves the province of Gelderland, which is tasked with consolidating the interests of dike ring areas 1,2, and 3 into a single policy proposal. Providing a comprehensive insight into all stakeholders' problem framing and solution requirements exceeds this report's scope.

We acknowledge that the choice of modeling framework likely impacts the results. The Multi-Scenario MORDM framework, part of the RDM family, is considered to provide the most robust solutions (Bartholomew and Kwakkel, 2020). Given the serious implications of this work, we are confident that our policy recommendations are robust for future scenarios. Considering climate change, a shorter time horizon than the current 200 years may be a reasonable extension of our analysis. The Dynamic Adaptive Policy Pathways, another decision-making technique under deep uncertainty, could be a valuable addition to our analysis. Climate change is likely to bring unforeseen challenges to the IJssel River system. The likelihood of scenarios outside of our simulated uncertainty space can be assumed to increase over time. This approach acknowledges path dependency and allows for shifts in policy paradigms as situations evolve (Bartholomew and Kwakkel, 2020).

Our results should not be viewed as the final word. Instead, this report explores potential mitigation strategies subject to change due to an uncertain future and the ongoing democratic decision-making process. The results are a starting point in a continuous iterative process, influenced by new scientific insights and evolving political, environmental, and economic contexts. This dynamic environment may require stakeholders to reassess their objectives and engage in model-based policy reiterations. Despite shared interests, stakeholders are likely to have different problem formulations. The emerging political tensions may likely be resolved through compromises and trade-offs over several negotiation iterations. The policies proposed here offer a starting point for these negotiations.

5. Conclusions and Recommendations

In closing, our research findings, while formulated within certain limitations, offer robust recommendations apt for the complex, multi-actor context of the province of Gelderland. The conclusion drawn, and the subsequent advice, are consistent with the comprehensive analysis we undertook, embracing the intricacies of a problem owned by many stakeholders with varying interests.

We acknowledge that any decision based on certain parameters within our model could be attributed equally to the heuristics and meta-expert judgments employed in the process. The use of heuristics or pragmatic justifications forms a crucial part of meta-expertise. It is a necessary element when navigating any complex system fraught with uncertainties.

We found that running the MORDM framework twice seemed superfluous, and further research could help to determine the best approach here.

We must also recognize that every model is intrinsically flawed due to the abstractions required in the modeling process. Reality presents an overwhelming number of parameters that cannot all be accounted for in a simulation. The unpredictable nature of climate change further complicates this, reminding us that even the most robust policies may falter against unforeseen natural events. This humbling reality checks any guarantees of success.

Our report was crafted with the intention of aiding Gelderland's decision-making process. We have selected information carefully to provide accurate, disaggregated insights into the requirements of Dike ring 3. As Gelderland assumes the responsibility of aggregating these technical opinions, we trust in their "meta-expertise."

5.1. Looking Ahead

The collective efforts invested in this report bring forth a rich repository of insights. We are keen to see how these findings shape a diverse and comprehensive, data-driven foundation for future decision-making processes. The research presented in this document aspires to influence policy direction with objective, empirically substantiated information.

Our analysis is designed to advocate for the unique requirements of Dike ring 3, aiming to give it the necessary prominence in the complex negotiation landscape. We firmly believe that the results presented herein will ensure that Dike ring 3 is adequately represented and considered in the next iteration of model-based policy exploration.

The approach we adopted was inherently participatory, recognizing the need for shared understanding and collective action in such decision-making processes. This collaborative method was instrumental in navigating towards a consensus amid a multi-actor context. We deeply value this aspect of the model-based decision-making process, without which, achieving political agreement could have potentially been more challenging.

In conclusion, we remain optimistic about the ongoing negotiation process, and we look forward to witnessing how our research insights are interpreted and integrated into future policy decisions. By maintaining a participatory approach, we trust that this process will continue to advance in a manner that is inclusive, transparent, and responsive to the evolving challenges of flood management.

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A. Appendix

A.1. Model Results

Index	Policy	A3 Damage	A3 Deaths	Evacuation Costs	Total Costs
0	547	0.088	0.088	0.0	3.422156e+07
1	695	0.066	0.066	0.0	3.422156e+07
2	270	0.026	0.026	0.0	4.421502e+07
3	749	0.099	0.099	0.0	5.949840e+07
4	473	0.065	0.065	0.0	6.209880e+07
5	10	0.048	0.048	0.0	6.798504e+07
6	521	0.099	0.099	0.0	8.780338e+07
7	163	0.049	0.049	0.0	9.562156e+07
8	173	0.043	0.043	0.0	1.234988e+08
9	508	0.102	0.102	0.0	2.374980e+08

Table A.1: Ten policies with price of robustness

Index	Policy	A3 Damage	A3 Deaths	Evacuation Costs	A3 Dike Investment Costs	Room for River Investment Costs
0	547	0.088	0.088	0.0	3.422156e+07	0.0
1	695	0.066	0.066	0.0	3.422156e+07	0.0
2	270	0.026	0.026	0.0	4.421502e+07	0.0
3	749	0.099	0.099	0.0	2.879840e+07	30700000.0
4	473	0.065	0.065	0.0	3.139880e+07	30700000.0
5	10	0.048	0.048	0.0	3.728504e+07	30700000.0
6	521	0.099	0.099	0.0	2.640338e+07	61400000.0
7	163	0.049	0.049	0.0	3.422156e+07	61400000.0
8	173	0.043	0.043	0.0	3.139880e+07	92100000.0
9	508	0.102	0.102	0.0	2.419803e+07	213300000.0

Table A.2: Ten policies after second iteration

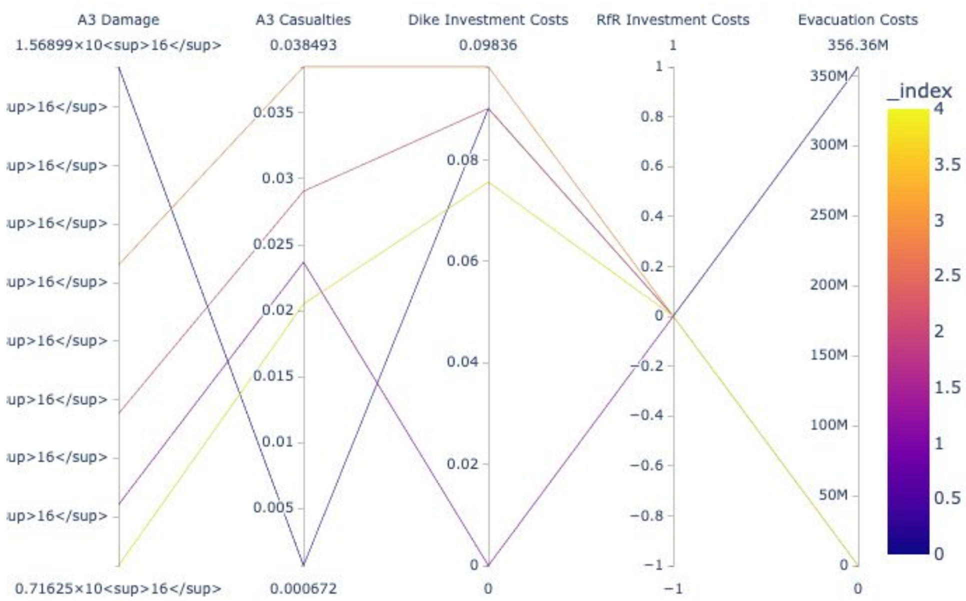

Figure A.1: Performance of selected 5 policies after the first iteration

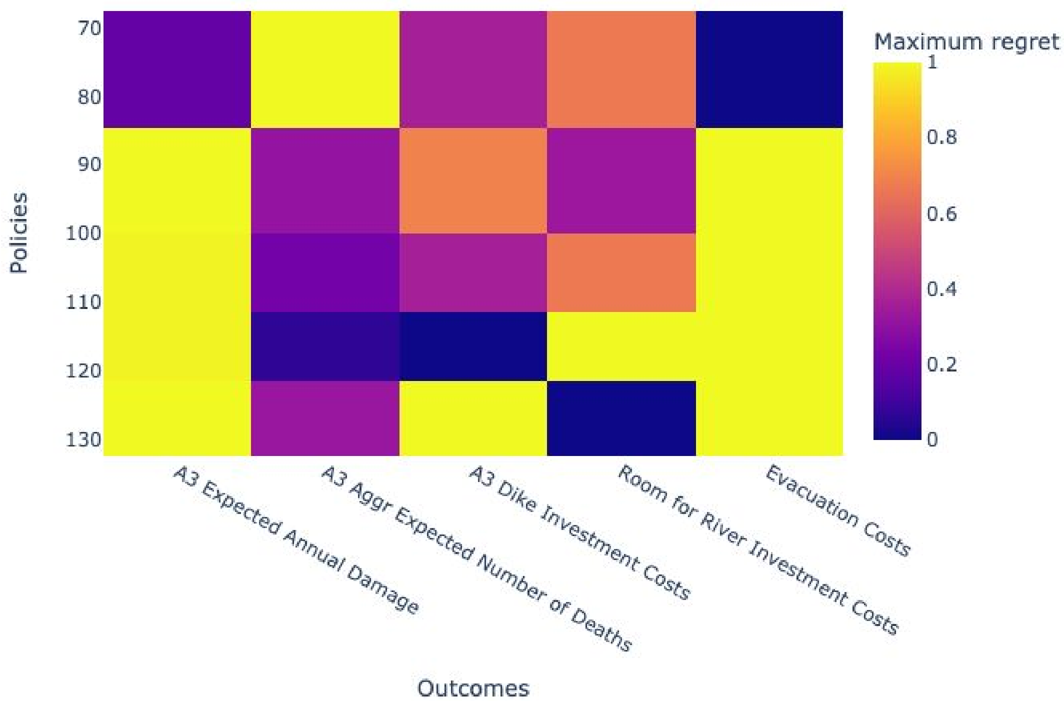

Figure A.2: Maximum Regret for 5 policies after the first iteration

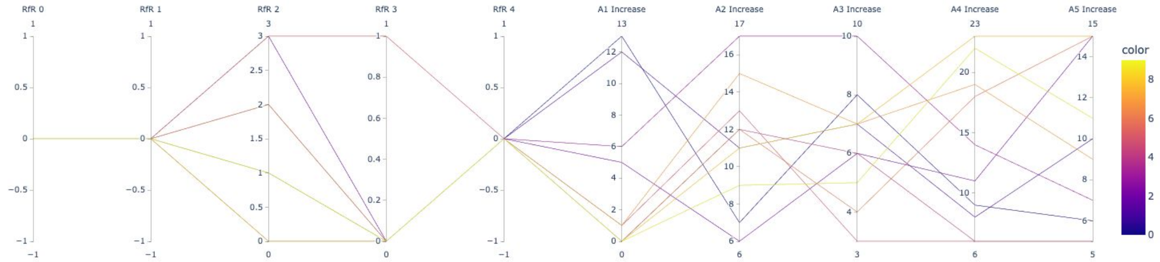

Figure A.3: Specifications of policy implementations for 10 policies after second iteration

B. Appendix

B.1. Objectives

Actor	Strategic objective	Problem-specific objective
Delta Commission	To secure the safety of the Netherlands from flooding in the coming century by implementing robust flood protection measures, sustainable water management strategies, and innovative coastal defense systems (Rijksoverheid, n.d.).	Mitigate floodrisk of the IJssel river with long term and sustainable solutions
Rijkswaterstaat	Ensuring a country that is protected against floods, where there is sufficient greenery, and sufficient clean water (Rijkswaterstaat, n.d.)	Mitigate floodrisk of the IJssel river while maintaining the environment nature
Gelderland	Striving for a sustainable, connected, and economically powerful Gelderland, which encompasses a healthy, safe, clean, and prosperous environment. (Gelderland, n.d.)	Effectively mitigate the flood risk of the IJssel River while ensuring the protection of the economic sector and the environment
Overijssel	To ensure sustainable development, promote economic growth, preserve natural resources, and enhance the quality of life for the residents of Overijssel province (Overijssel, 2022).	Effectively mitigate the flood risk of the IJssel river while ensuring the protection of the economic sector and the environment
Transport companies	fostering a sustainable transport sector that facilitates future growth	Maintaining a sustainable transport sector along the IJsel river despite the flood mitigation measures.
Environmental groups	Advocate for environmental justice, empowering communities and individuals to address environmental challenges and ensure equitable access to a clean and healthy environment	Ensure clean and healthy environment and protection of biodiversity despite the flood mitigation measures

Table B.1: Objectives of key actors

B.2. Resources

Actor	Financial	Technical	Social	Institutional
Delta Commission	Government funding	Engineering expertise, technological tools	Stakeholder involvement, public awareness and participation	Legal and policy mandate, collaboration and partnerships:
Rijkswaterstaat	Government funding	Engineering expertise, technological tools, infrastructure assets	Stakeholder involvement, Education	Legal and regulatory framework, collaboration and partnerships, human resources
Gelderland	Provincial Taxes and Levies, Government Grants	Infrastructure Assets, planning and engineering expertise	Stakeholder involvement, public participation and awareness	Collaboration and partnerships, human resources, policies and regulations
Overijssel	Provincial taxes, Government Grants	Infrastructure Assets, planning and engineering expertise	Stakeholder involvement, public participation and awareness	Collaboration and partnerships, human resources, policies and regulations
Transport companies	Revenue, capital, bank loans, subsidies	Fleet and Equipment, logistics and supply chain expertise	Customer base, workforce	Industry associations and networks, regulatory compliance
Environmental groups	Funding	scientific and environmental expertise	membership and supporter Base, public awareness and education	Advocacy and influence, legal and policy expertise

Table B.1: Resources of key actors

C. Appendix

Uncertainties and levers are explained based on the information provided by J. Kwakkel (2023).

C.1. Uncertainties

Name	Type	Values	Description	Dimesion
Discount rate	Categorical	1.5, 2.5, 3.5, 4.5	Discount rate for calculating present value of damages	dmnl
Flood wave shape	Integer	0-132	A standardized curve that depicts the incoming flood wave's shape over time. There are 132 predefined curves available.	dmnl
Growth rate of breach	Categorical	0, 1.5, 10	How fast the breach grows over time.	1/day
Dike failure probability	Real	0-1	The probability that a dike ring can endure the hydraulic load.	dmnl
Final breach width	Real	30-350	The ultimate width of the breach determines the volume of water that enters the floodplain per unit of time. A larger width results in a greater influx of water.	meters

Table C.1: The uncertainties (X) of the model

C.2. Levers

Name	Type	Values	Description	Dimesion
Room for the River (RfR)	Integer	0-1	The decision to initiate the Room for River (RfR) project at a particular location. It increases the space for the water, by widening the river beds. Once activated, the project will remain ongoing.	dmnl
Early warning systems (EWS)	Integer	0-4	Number of days prior to a threat to give a warning. False warnings can diminish trust in the system. Providing an earlier warning allows more time for evacuation, but it also increases the likelihood of false alarms.	days
Heightening dikes	Integer	0-10	Raising a dike's height can aid in strengthening existing dikes to resist greater hydraulic pressures from flood waves. The extent of dike height increases may vary depending on the dike's location (Dike Ring 1-5).	decimeter

Table C.2: The levers (L) of the model