Room for the River as adaptive flood risk management in the Netherlands

Applying the notions of decision-making under (deep) uncertainty in the IJssel Delta

EPA1361 - Model-based Decision-making

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Summary

This report analyses, explores and recommends a suitable policy for flood risk mitigation in the IJssel river delta, while taking into account important factors such as economic damage, investment costs and expected fatalities on both a local and aggregated level. The analysis is written from the perspective of the Delta Commission and serves as an interpretation of their mandate in the multi-actor decision arena concerning flood risk. The Delta Commission has as its main objective to form a long term flood risk mitigation plan and to fulfill a brokerage role. Based on a model of flood risks and other effects, an exploration of the decision and uncertainty space was carried out. This provides the Delta Commission with a starting point and a definition of the uncertainty, decision and outcome arena. Furthermore, based on these findings, policies have been searched for that align with the goals of the Delta Commission. These policies have been found by using an optimisation technique called Multi Objective Robust Decision Making and its outcomes have been tested for robustness under different scenarios.

As flood risk mitigation is a multi-actor problem, the perspectives of other actors such as Rijkswaterstaat, transport companies and environmental NGO's have also been considered as well as the perspectives of dyke rings that have a local interest to uphold.

With this in mind, a policy has been recommended that is based on a combination of large scale Room for the River projects near the city of Zutphen as well as the implementation of flood early warning system and the increase of dike height such that the flood risk can be dealt with accordingly for the next 200 years.

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1 Introduction

Water suits the Netherlands, just like tulips and clogs. The Netherlands has developed by taking on the challenges of water. From land reclamation to drainage to diverting water flows. These are challenges not only from the past, but also of the future. In the future, water will remain a critical policy task for the Dutch. Due to climate change, the Dutch Ministry of Infrastructure and Water Management (I&W) is emphatically working on circularity and climate adaptation, including in the field of water and sustainable transport (Heijnen, 2022). Climate change causes sea levels to rise and more ice from glaciers to melt in the Alps. Meanwhile, floodplains in the Dutch rivers are shrinking, and their water level is rising because of heavier rainfall (Rijkswaterstaat, 2017). This therewith also gradually raises the water level of the major rivers in the Netherlands, increasing the risk of flooding in densely populated areas (Edelenbos et al., 2017). In a low-lying country like the Netherlands, flood management has been on the agenda for centuries, but water resilience strategies remain necessary for adequate flood risk mitigation in the future.

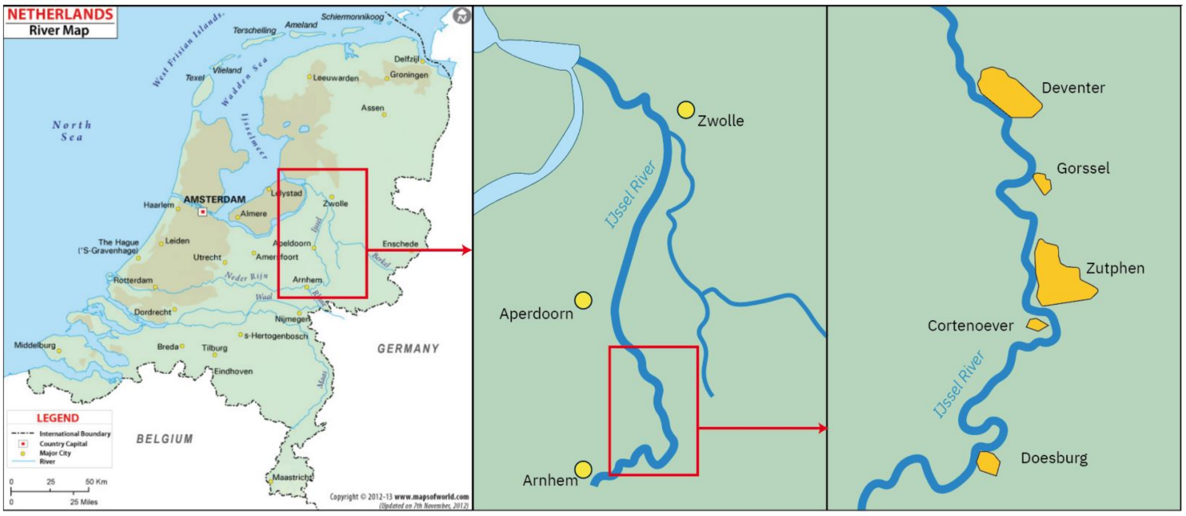


Figure 1.1: Map of the IJssel Delta (Netherlands River Map, 2011)

1.1. The case of the IJssel Delta

Four major rivers intersect the Netherlands: the Rhine, Meuse, Scheldt, and Ems. A distributary of the Rhine river, the IJssel is an important river in the Netherlands as well. As vital Dutch river, measures must be taken in the IJssel Delta to efficiently mitigate flood risk. Meanwhile, one also needs to take into account the socio-economic and ecological challenges in the IJssel Delta related to and affected by water policies.

The IJssel river flows through densely populated areas in the provinces of Gelderland and Overijssel. While the province of Gelderland is located upstream, Overijssel lies downstream. Both provinces again consist of another government layer: several dyke rings (*i.e.,* Doesburg, Cortenoever, Zutphen, Gorssel, and Deventer) focusing on (re)shaping dykes to protect the underlying land. A geographic map of the IJssel Delta has been depicted in Figure 1.1. Since these different levels of government (national, provincial, and regional) are all involved plus several NGOs, all having their own goals and interests, the decision-making process could be regarded as complex. Moreover, this implies that no single solution exists. Discrete modelling under deep uncertainty (DMDU) could help to achieve resilient water policies in the dynamic stakeholder arena of the IJssel Delta, as it recognises that (changing) perceptions of stakeholders contributes to uncertainty in the performance (Kwakkel et al., 2016). Designing resilient policies that are robust to these uncertainties are required. The Delta Commission has an important role in this, for which this report aims to formulate policy recommendations.

1.1.1. The Delta Commission

Ever since its foundation in 1953, the key objective of the Delta Commission (DC) has been long-term water safety and security in the Netherlands. Being an advisory organ of the Ministry of I&W —and therewith to the Directorate-General for Public Works and Water Management (*in Dutch:* Rijkswaterstaat) —its role is to develop policy advice that safeguards water safety and security in the Netherlands (Verduijn et al., 2012). In drafting resilient water policies, the DC traditionally focuses on the very long term. Hence, the DC has been reinstalled by the Dutch government in 2008 for more than a century (Van Twist et al., 2013; Verduijn et al., 2012).

The DC, however, does formally not have any legal power. It is mainly tasked with advising the Ministry of I&W on factors that will determine water safety in the long term. Long-term, adaptive, and resilient policies are key in water management. After all, it takes some time before new water works are built, which requires early anticipation of yet unknown future development of water flows and levels (Edelenbos et al., 2017; Maas et al., 2007). In this way, the DC acts as a critical advisor to the Ministry of I&W, which is often run by politicians with a short-term view. The DC is advising the Ministry not just on water-technical factors, but also on socio-economic, spatial, and ecological concerns related to flood risk management (Verduijn et al., 2012). The general goals of the DC have been summarised in Figure 1.2. The DC therefore often acts —while politically and administratively being accountable to the ministry —as a 'neutral broker' in water strategy processes, since it takes all interests into account while focusing on long-term flood prevention.

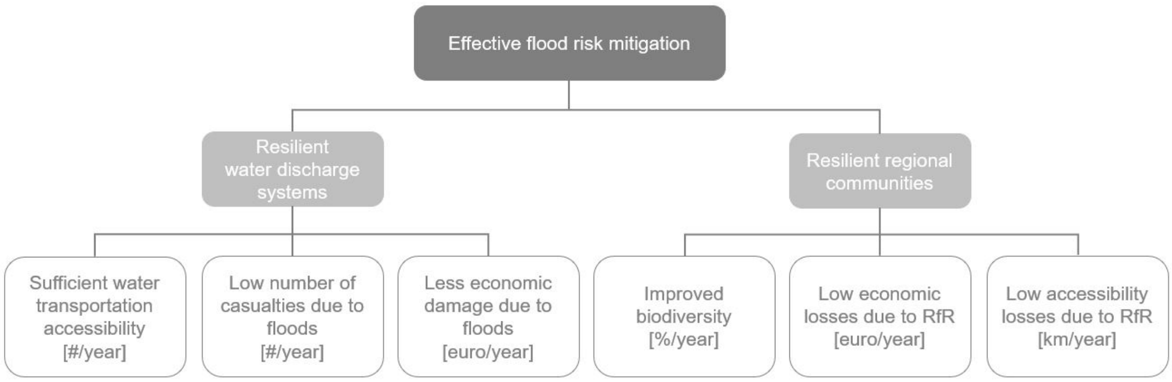


Figure 1.2: Goal tree of the Delta Commission (based on Edelenbos et al., 2017; Maas et al., 2007; Verduijn et al., 2012)

Formally, the DC has thus little power in the political decision-making process. This legal power rests with the Ministry of I&W. Nonetheless, the DC recommends strategies for long-term flood prevention the government should adopt (Verduijn et al., 2012). In practice, these 'recommendations' carry a heavy weight in the decision-making process. In the past, the DC's recommendations have repeatedly directly been endorsed by the government on several occasions (Verduijn et al., 2012). In reality, the DC thus actually has significant yet informal power in water management, even though it will always remain dependent on the Ministry of I&W to adopt long-term resilient water management policies.

1.1.2. Common water policy levers

Various possible policy solutions to the rising water levels in the Dutch rivers have been proposed. Four common policy levers can be distinguished. Firstly, the policy *status quo* in the Netherlands is proactively heightening dykes. For a long time, raising dykes has been able to prevent flooding, which is why this was seen as an effective policy (Pollmann, 2006). Currently, this is still the predominant measure proposed to prevent the four major Dutch rivers from overflowing due to rising water levels. However, it is estimated by the government that only raising dykes is not a sustainable solution to mitigate the effects of the increasing water levels on the long-term (De Bruijn et al., 2015; Rijkswaterstaat, 2017). This puts the question to which extent maintaining this policy lever as the dominant measure in one's water management policy is sustainable, both socially and economically: Why implementing this policy in particular if it is insufficiently effective? And yet, dykes still can be raised in places as part of a broader resilient water policy.

Secondly, reactive policies could be implemented. As soon as there is (possibly) a flood, an early warning system (EWS) could send out an alarm. This gives local residents the opportunity to leave the area in an early stage of the flood. Such an EWS consequently eases evacuation procedures in the flooding area, which should lead to fewer casualties (Rai et al., 2020; Verduijn et al., 2012). However, an EWS cannot adequately prevent material damage. The economic damage to a region of a flood is in principle not much lower if an EWS is in place, despite the fact that it saves human lives (Rai et al., 2020). In addition, an EWS costs a significant amount of money to install and apply.

Thirdly, investing in resilient water systems could prevent rivers from overflowing. Like Room for the River (RfR). In RfR, the national government, together with the provinces, water boards, local communities (*e.g.,* municipalities and dyke rings), the (agri)business community, environmental NGOs, and water transport companies, are looking at what measures can be taken to mitigate flood risks (Rijkswaterstaat, 2017). This collaboration is needed. After all, more room for the river means a balance between the interests of these various actors involved. In some areas, lowering dykes and floodplains to allow water in when necessary restricts food production on this fertile land. Wider rivers pose a threat to local farmers and growers (Edelenbos et al., 2017; Maas et al., 2007). In other regions, dykes, infrastructure, and other public water works might be moved or bypasses might be implemented so that the water has more space (Edelenbos et al., 2017; Maas et al., 2007). This results in less navigability and accessibility, which shipping companies and local communities do not prefer. RfR accordingly provides more space for water, sometimes permanently, but also temporarily if necessary. To summarise, the main objective of RfR is to distribute the water over the low-lying areas of the Netherlands by giving the IJssel river more space rather than just strengthening and raising dykes, while keeping an eye on the economy, accessibility, cultural heritage, and biodiversity (Rijkswaterstaat, 2017). Potential measures under RfR have been compiled in Figure 1.3.

Fourthly, a combination of the three measures could be applied regionally. Indeed, raising dykes as well as introducing an EWS could become an additional part of a broadly supported RfR.

1.1.3. Resilient policies as objective

The DC's main task is to formulate resilient water policies in the Netherlands (Van Twist et al., 2013), as has been proposed with RfR. To deal with the uncertainties and challenges of the future, according to the DC, a policy should be designed around resilience. The term 'resilience' has many (contested) definitions and is applied in various contexts (Manyena, 2006). Concerning disaster management, resilience is often seen as the opposite of 'vulnerability'. In general, a resilient system is adaptive and quickly returns to its normal state after a disruption. It can therefore be described as a system's capacity to resist disruptions and uncertainty (De Bruijne et al., 2010). Nonetheless, the definition of 'stability' is scientific ambiguous. Much as some argue that the speed at which a system can 'bounce' back to its natural state matters most (Holling, 1973), others demonstrate that the magnitude of the disruption the system could handle is determining (Gunderson, 2003). The latter definition seems more applicable in resilient water management when it comes to flood prevention. Resilience strategies, in general, do not aim at controlling flood hazard rather than minimising its consequences (Vis et al., 2003). Not only in terms of water, but also socio-economically, accessibility and ecologically. This is also the type of strategies the DC with RfR aims for.

Such flexible policies are necessary as the precise consequences and development of climate change —in the Netherlands and abroad —are currently very uncertain. Also, because as a downstream country, the Dutch are dependent on other European countries around the Alps regarding wa-

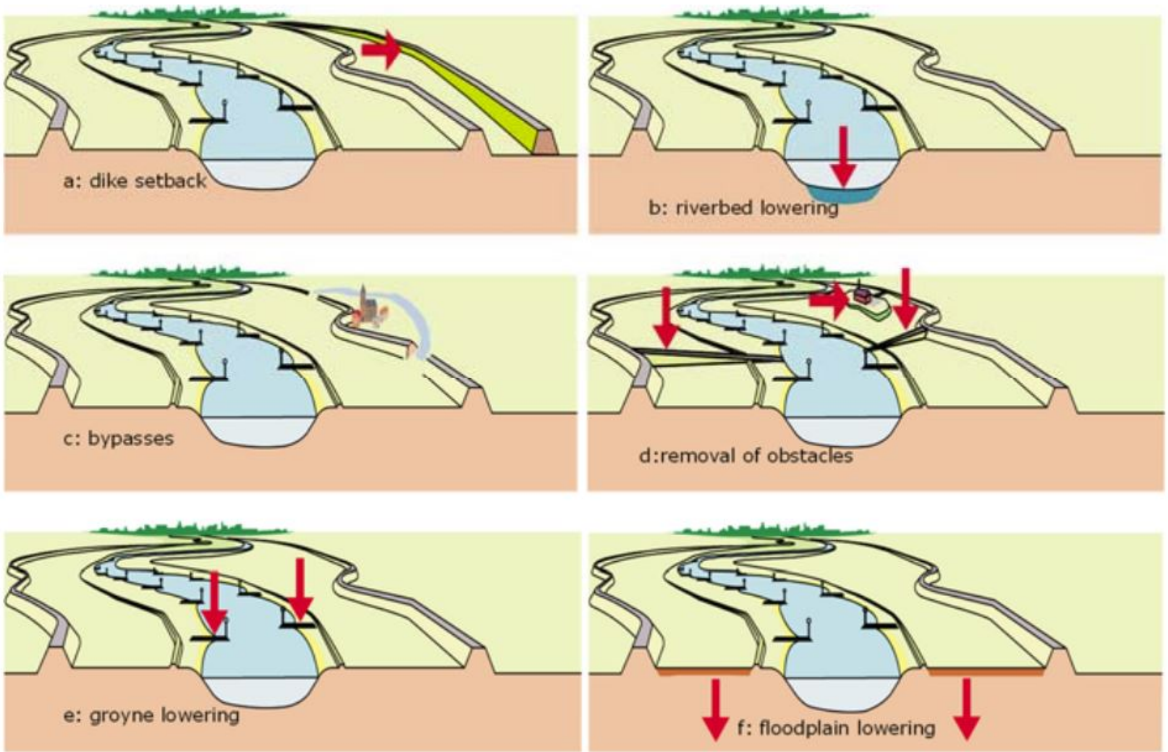


Figure 1.3: Potential measures in RfR summarised: (a) moving dykes to widen floodplains, (b) lower riverbeds, (c) introducing bypasses for water flows, (d and e) removal of obstacles, and (f) lowering floodplains (Havinga, 2020)

ter management and therefore cannot influence everything. That creates even more uncertainty. The need for adaptive and proactive measures has therefore been emphasised by past policies. Previous interventions by the Dutch government around the Rhine have already shown that increasing the storage capacity of the river and removing obstacles leads to a lower peak load —reducing flood risks. Furthermore, historical water policies focusing on increasing discharging measures in the Rhine proved to be of limited effectiveness, given the limited height change of the river in the Netherlands (Silva et al., 2004). There are many uncertainties when predicting flood levels due to climate change and international politics. The (societal) costs of doing nothing are likely to be high. According to the DC, it is thus irresponsible to first look at how floods might develop before taking any adaptive mitigation measures. Ergo, given the lessons learned from previous policies, it is necessary to improve the resilience of the Dutch river system through adaptive and proactive policy instantly (Silva et al., 2004).

Technical implications of resilience

Technical implications of resilience reflect the physical choices that will have to be made when designing resilient policies in RfR (De Bruijn et al., 2015). Preventing hydrological bottlenecks in the rivers is central to this (Silva et al., 2004). In order to enhance the resilience of the river system and its capacity, it is being examined which technical and physical measures can be taken. The technical implication of resilience poses questions such as: Where are dykes being (re)moved or raised? Where can flood plains be flooded? Which infrastructural barriers can be removed? (Edelenbos et al., 2017). The main technical question can be condensed as follows: Which activities are possible where? For example, the floodplains are now frequently used for agriculture. If we allow these to flood, food production is no longer always possible there. The same applies to road transport or shipping that can function less efficiently due to RfR. More room for the river could, for instance, imply that bridges or roads disappear, or that the depth of the river is insufficient to allow ship passage. That limits navigability. Higher dykes have an impact on housing. On the other hand, RfR can offer more space for ecology and the environment, since this land is no longer used for economic activities (Edelenbos et al., 2017). So, the technical implications of resilient water management policies have a major impact on the physical, socio-economic, and environmental characteristics of the RfR delta (De Bruijn et al., 2015). This will also become apparent in the policy process of the design and implementation of RfR as this policy affects land-use. To conclude, resilience also has a strong political dimension.

Political implications of resilience
Flood risk management directly affects land-use. And economic activities of regions. A trade-off must be made between the interests of different actors. Particularly, if actors upstream have to adjust their spatial planning (*i.e.,* bearing the costs) for the benefit of actors downstream (*i.e.,* being protected), while not directly benefiting from RfR themselves, these uncertainties provide a source of conflict and politicisation (De Bruijn et al., 2015). Resilient rivers in the Netherlands are of national interest, nonetheless, the adaptive and proactive measures mainly have a local aspect. This shifts the burden of the water mitigation measures from a national to a local level. This creates a win-lose situation which can lead to political conflicts. 'Losers' will try to counter the decision. Particularly actors in municipalities who will mainly bear the costs for RfR. Because of interdependencies with important actors, they often have ample opportunity to exercise their power - potentially to block decision-making (De Bruijn et al., 2015). These actors will try to contest information and knowledge, so as neutral broker, it is the DC's task to emphasise the facts and focus on a fair trade-off in the negotiations.

Objective of the DC in the IJssel Delta
In short, based on Figure 1.2 and Section 1.1.3, the following mandates of the DC should be complied with in designing water policies in the IJssel Delta:

- A resilient, proactive, and adaptive water policy targeted at reducing flood risks, while considering the socio-economic and ecological concerns of other actors in the IJssel Delta.
- The water management policy should focus on the long-term aspect and requires evaluation for the long-term as well. A policy with just short-term solutions is unacceptable.
- The approved policy should be as specific as possible. Specific interventions are preferred over agreement on goals, priorities, and future developments.
- Broad support for the adopted policy among actors is preferred.

1.2. Challenges for the Delta Commission

The political implications of flood risk management are significant. Different actors have different interests, but certainly also divergent power positions. Three different administrative layers can be identified in the IJssel Delta. First, the national government, consisting of Rijkswaterstaat —on behalf of the Ministry of I&W —and the DC, is involved. It is of national priority that adequate flood risk management strategies are drawn up. What happens upstream has a major impact on the consequences downstream. The DC and Rijkswaterstaat are thence the driving forces behind the writing of this policy plan. *In casu,* the DC particularly has a dominant role in this. The DC and Rijkswaterstaat have the competence to veto policy if they do not consider it resilient and adaptive enough. The informal role of the DC, as discussed earlier in Section 1.1.1, is therefore considerably more powerful and formal in the planning process of the IJssel Delta, giving it a primary position in the political decision-making process. Along these lines, Rijkswaterstaat can be said to depend to a certain extent on the DC when designing policy. That is also the reason why more power has been assigned to the DC compared to Rijkswaterstaat in the PI grid in Figure 1.5.

At provincial level, the provinces of Gelderland and Overijssel are involved. The IJssel river flows through both provinces, each with both rural and urban areas along the river. Gelderland is located upstream, while Overijssel is downstream. The province of Overijssel is mainly looking at Gelderland to take preventive measures upstream, so that it does not have to use its fertile agricultural areas downstream for RfR and to take fewer measures near the city of Deventer. Overijssel aims at tackling flood risk mitigation upstream as much as possible with preventive upstream policies in Gelderland. Subsequently, dyke heightening should be effective to manage flood risks in Overijssel. On the other hand, Gelderland believes that the burden of flood risk management should be shared evenly, with as little RfR as possible in Gelderland. Its economy is located upstream and would be disproportionately affected by RfR. Yet, it experiences fewer water problems than Overijssel and thus would not benefit from RfR. Hence, Gelderland searches for water management policies in both provinces that minimise impacts on (the harbour of) Zutphen. The DC will have to facilitate discussions with both provinces in order to draw up adaptive flood risk management. In an adaptive policy, it is impossible to pass on all consequences on Overijssel, meanwhile the economic interests of upstream Gelderland will also have to be accounted for. As upstream province, Gelderland has more influence in deciding on the outlook of flood risk mitigation, while Overijssel as downstream province has more interest in the matter.

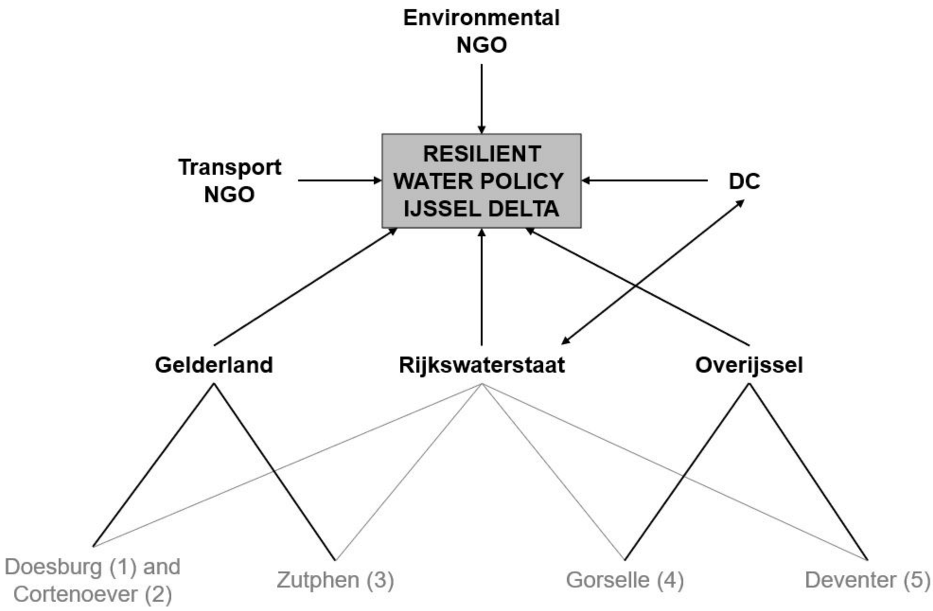


Figure 1.4: Actor dependencies in the political decision-making process. Rijkswaterstaat, the DC, Gelderland, Overijssel, the transport and environmental NGO have voting rights, in line with is administrative relationship with Rijkswaterstaat, the DC is the single actor having a veto right. The five dyke rings are dependent on their provinces and Rijkswaterstaat (based on the debates and Edelenbos et al. (2017))

Regionally, five dyke rings are responsible to protect their hinterland en citizens from flooding. However, there is a big difference between the dyke rings in how they view flood risk management. Rural dyke rings, such as Doesburg (DR1), Cortenoever (DR2), and Gorssel (DR4) do not want to sacrifice fertile agricultural land RfR, which would harm their regional economy and livelihood, and consequently prefer to raise the dykes. So, their problem framing is rival to that of the DC. Urban dyke rings, including Zutphen (DR3) and Deventer (DR5), on the contrary, do not want a dyke raising because this inhibits their (harbour) economy. Instead, they propose RfR in rural dyke rings to conserve their own economic welfare. All dyke rings are dependent on their province in the political decision-making process, as they are not allowed to vote themselves. These conflicting interests between the dyke rings within the provinces also make it difficult for the provincial government to adopt a firm position. Every dyke ring will try to convince its province of the value of its interests. To establish broad support among dyke rings, the DC must pay extra attention to ensure that the impact on the dyke rings is distributed evenly, taking an egalitarian approach (Krütlti et al., 2015). Although the dyke rings do not formally have voting rights, the DC shall include them actively in the decision-making in order to draw up broadly supported policy in Gelderland and Overijssel. The dependencies of the dyke rings on the provinces and Rijkswaterstaat have been visualised in Figure 1.4. That dependency is also reflected in the PI grid in Figure 1.5.

Finally, two major non-governmental organisations (NGOs) are crucial in the IJssel Delta. The transport NGO is interested in the development of the IJssel Delta, considering that RfR might reduce the navigability of the IJssel river, affecting their sector financially. At the same time, the environmental NGO is targeted at conserving and improving biodiversity along the (water areas of the) IJssel river. Although both NGOs have voting rights, the rival interest of the transport NGO is regarded relatively lower than the environmental NGO in Figure 1.5, because the transport sector could be satisfied relatively easy if navigability is guaranteed regardless of measure selected. The environmental NGO, nevertheless, has a specific preference for RfR because it provides more biodiversity than raised dykes.

A complete actor analysis, in which the power, interests, and position of the actors is further elaborated, is presented in Annex A.

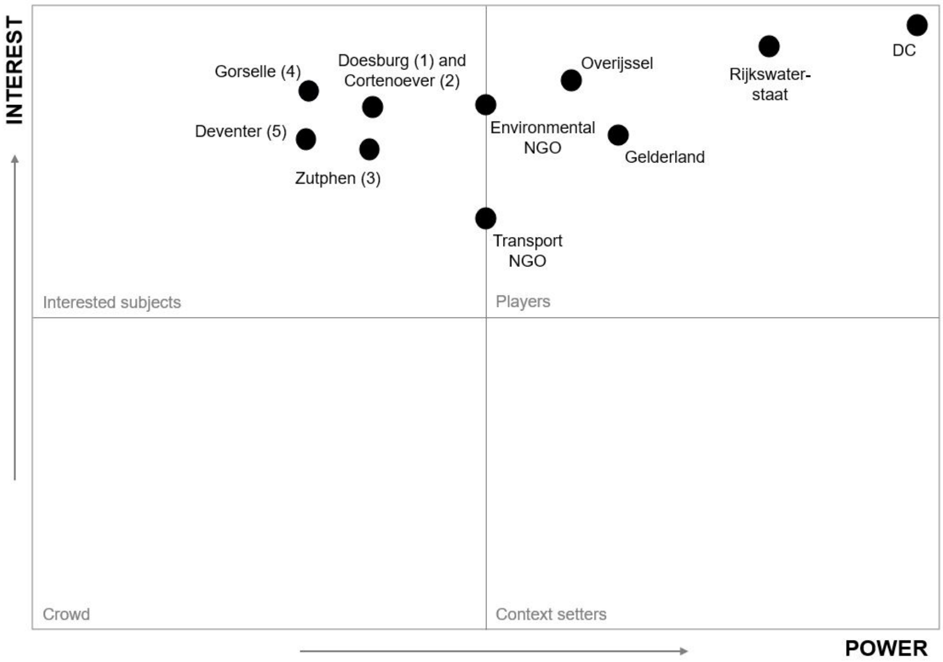


Figure 1.5: Power-interest grid of the IJssel Delta (based on the debates and Edelenbos et al. (2017))

1.3. Research question

This report focuses on developing a flood risk management plan for the river IJssel, as an important branch of the Rhine. The aim of the report is to support the DC in designing resilient water policies in the decision-making process by means of a simulation model by assessing the economic damage and the number of casualties along the IJssel river. Herewith, the following research question has been posed:

How could the Delta Commission develop an adaptive, resilient, and long-term flood risk management plan in the IJssel Delta to minimise casualties, while maintaining the regional economy and improve biodiversity?

This report considers decision-making under deep uncertainty. In principle, this means that a broad range of policies are tested in various scenario contexts so that adaptive long-term water policy can be developed. Considering the rival problem frames of other actors in the IJssel Delta, the analysis shall focus on robust multi-objective decision-making (Kwakkel, 2017). The following are sub-research questions are formulated to facilitate the analysis:

1. Which uncertainties primarily impact the DC's interests in RfR in the IJssel Delta?
2. What policies could potentially address the developed scenarios?
3. What are the effects of developed water policies in the given circumstances?
4. How do other actors in the political arena perceive the DC's proposed policy?

1.4. Structure of the report

To this end, Chapter 2 will first outline the simulation model approach. This chapter elaborately explains which deep uncertainty methods were used and how the analysis was performed. The results of this analysis will be presented in Chapter 3. Finally, conclusions and discussion follow in Chapters 4 and 5 respectively, in which policy recommendations are formulated and discussed for the DC.

2

Research approach and methodology

The case of the IJssel Delta is highly complex and requires state-of-the-art research methods in order to draft fundamental policy recommendations for the DC. The modelling approach focuses on responsible modelling (Saltelli et al., 2010; Saltelli et al., 2020) based on discrete modelling under deep uncertainty (DMDU) (Saltelli et al., 2019). After the goals of the DC have been quantified, exploratory modelling follows. During this phase, the model is gradually discovered, studying the relationship between input and output and the behaviour of the model. Subsequently, an open exploration has been carried out. Herewith, a better insight is gained into the uncertainties of the model by analysing its trends. Potential policies can be distinguished with direct search methods, which are then subjected to a robustness evaluation. This enables investigating how these different policies develop in different scenarios, including the worst-case and less-than-ideal scenario. Following this research approach, more and more policies are dropped due to their limited robustness. Policy recommendations are drawn up taking into account the positions and interests of the other actors in the political arena, as previously discussed in Section 1.2.

Before diving into actual modelling, the research approach shall be substantiated scientifically. First, Section 2.1 shall elaborate on DMDU and multi-objective robust decision-making (MORDM) as methodology. Thereafter, Section 2.2 discusses the operationalisation of the model developed.

2.1. Decision-making under deep uncertainty

From the multitude and diversity of actors involved, the uncertain development and impacts of climate change, socio-economic responsibilities, and the wide range of policy options, it can be concluded that flood risk management in the IJssel Delta is rooted in uncertainty and complexity. So, it is difficult to determine with certainty what the exact impact of flooding in the IJssel Delta will be, as well as the effect of RfR on this region and flood risk mitigation (Walker et al., 2012).

Taking the definition of Rittel and Webber (1973), this problem can be categorised as 'wicked'. Several implications are known to be inherent to wicked problems, which are clearly reflected in the IJssel case. Firstly, wicked problems have no independence between problem formulation and solutions (Kwakkel et al., 2016), which means that the way the problem is defined always influences the designed solutions. Reiterating Section 1.2, distinctive problem formulations have been identified in the political arena. For instance, for the transport NGO, the navigability of the IJssel is much more important than for the environmental NGO. This example already illustrates how different problem formulations lead to different proposed solutions. Secondly, the amount and diversity of actors adds several uncertainties to an already long list of irreducible uncertainties (Kwakkel and Haasnoot, 2019). When different actors do not understand know how the system function or cannot agree on a system definition, a situation occurs that has been characterised as 'deep uncertainty' (Lempert et al., 2003).

However, in order to better understand the uncertainties of flood mitigation in the IJssel Delta and to give more fundamental policy advice to the Ministry of I&W as DC, it is essential that the limitations and value of the outcomes are established (Walker et al., 2012). This is paramount to the DC, since it aims at resilient and adaptive policy, while also acknowledging the socio-economic effects of RfR in Overijssel and Gelderland and its ecological effects. DMDU could support the DC in this aspect.

Through exploratory modelling, insights about the model can be gained by examining simulations of various uncertainties and potential policy options (Kwakkel, 2017; Kwakkel and Haasnoot, 2019). In good practice, the modellers have to invest in clear and sincere communication about uncertainties, assumptions, and (political) framing (Saltelli et al., 2020). Models generate information and insights, but contain uncertainties, assumptions, and biases. These unquantified factors are weighted in DMDU.

2.1.1. Open exploration

Open exploration is a combination of several methods. The aim is to create more understanding of the relationships between factors in the model and the impact of uncertainty. Open exploration can be divided into scenario discovery and global sensitivity analysis (GSA). Scenario discovery is conducted to define a subspace of possible futures that represent vulnerabilities of proposed policies (Bryant and Lempert, 2010). This is done by generating scenarios based on combinations of uncertain external factors, which leads to a set of all futures possible within the set model range. The next step is to distinguish a set of scenarios that will be used to evaluate the effects of policy. In the scenario discovery, a distinction has been made on the expected number of deaths (END), evacuation costs, and the expected annual damage (EAD). These three factors were adopted for scenario evaluation because they were found to be most in line with the DC's goals established in Figure 1.2.

Differently, sensitivity analysis is exploited to study how uncertainty in the model output can be apportioned to different sources of uncertainty in the model input factors. This can either be done locally (*i.e.,* changing variables one at a time) or globally (GSA; *i.e.,* all variables are changed simultaneously and sensitivity is assessed over the entire range per input factor) (Saltelli et al., 2010). GSA is nowadays the preferred method in DMDU, as it can account for non-linearity and interaction effects (Saltelli et al., 2019). The SOBOL method has been used in GSA, as it extensively analyses how various model input influence its output (Saltelli et al., 2010).

2.1.2. Multi-objective robust decision-making

In multi-objective robust decision-making (MORDM), many conflicting objectives of actors involved have been quantified. It would not be the first time that a multi-objective MORDM has been conducted regarding a water strategy. In fact, the Harvard Water Programme (HWP) can be seen as the initiator of multi-objective MORDM because it was the first to stress the importance of both technical and economic objectives simultaneously (Banzhaf, 2009). MORDM offers decision-makers, *in casu* the DC, the opportunity to manage a wide range of actors' (conflicting) perspectives in a 'wicked' political arena (Bartholomew and Kwakkel, 2020; Kasprzyk et al., 2013). In wicked public issues, like climate and land-use change, the system and conditions develop constantly without any consensus among actors how to address the concern (Kasprzyk et al., 2013). Evolved from robust decision-making (RDM), MORDM therefore offers the opportunity to find trade-offs in complex situations —such as the IJssel Delta. Under MORDM, alternatives are generated that present the best possible trade-offs based on the objectives of the actors in the IJssel Delta by conducting optimisation search *ex ante* to scenario discovery (Kasprzyk et al., 2013). This allows for optimisation of the solution space with candidate policies, as MORDM employs multi-objective evolutionary algorithms (MOEAs) addressing conflicting interests by developing Pareto-optimal trade-off sets (Bartholomew and Kwakkel, 2020). Each solution is tested in extreme situations, so that the robustness of the various alternatives is examined (Kasprzyk et al., 2013). Ultimately, this supports decision-makers to opt for resilient policy measures that are quite robust to uncertainties. For the DC, MORDM is thus a useful method for assessing possible policy options in the IJssel Delta, including RfR, for its effects on the interests of other actors. The MORDM work scheme, which has been followed by the authors while programming and analysing, has been shown in Figure 2.1.

2.1.3. Multi-scenario multi-objective robust decision-making

Multi-scenario MORDM elaborates on one of the key weaknesses of MORDM. The disadvantage of MORDM is that it assumes only one reference scenario (Bartholomew and Kwakkel, 2020; Watson and Kasprzyk, 2017). In other words, if appropriate policy alternatives are sought, only one scenario is used for the deep uncertainty factors. This means that the outcome of this analysis can lead to the generation of policy alternatives that do not function properly when —paradoxically, due to uncertainty —the reference scenario does not apply in the future (Watson and Kasprzyk, 2017). These policy alternatives might only perform well in the reference scenario, but not beyond that scenario. Multi-scenario

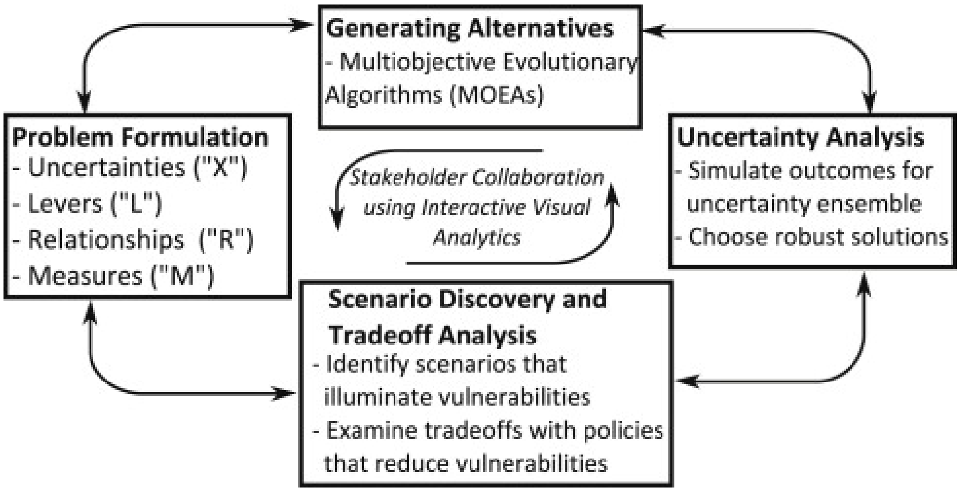


Figure 2.1: MORDM workflow: An interactive process from problem formulation to generating alternatives, to uncertainty analysis, to scenario discovery and trade-off analysis (Kasprzyk et al., 2013)

MORDM takes this into account because it assumes different future scenarios (Watson and Kasprzyk, 2017). These future scenarios reflect challenges that the policy alternatives found are difficult to address in the reference scenario in MORDM (Bartholomew and Kwakkel, 2020). Given the uncertainty of how climate change will develop (Heijnen, 2022; Rijkswaterstaat, 2017) and the wickedness of water management (Banzhaf, 2009; Rittel and Webber, 1973), multi-scenario MORDM is of added value for the DC to arrive at long-term resilient water policies in the IJssel Delta.

2.1.4. Operationalisation of DMDU

The Exploratory Modelling and Analysis (EMA) Workbench of Kwakkel (2022) has been used to perform DMDU. The EMA Workbench provides for a computational approach to conduct analysis on deep uncertainty in complex systems by supporting robustness and vulnerability analyses (Kwakkel, 2017). The model developed by the authors has been connected to the EMA Workbench for further research on (multi-scenario) MORDM in the IJssel Delta.

2.2. Model

The model for the IJssel Delta has primarily been developed by Ciullo et al. (2019). The functioning of the model can be explained by the XLRM process flow diagram in Figure 2.2, reflecting the model's components (Kwakkel, 2017; Lempert et al., 2003).

Basically, the model simulates tidal waves that splash against the dykes of the river IJssel in Gelderland and Overijssel. This tidal wave is simulated on the basis of a combination of water movements (in floodplains) and the probability of dyke failure. These external factors create a degree of uncertainty, as policymakers such as the DC cannot control them. However, through different combinations of policy levers, the model can be used to simulate and validate, under different scenarios, the impact of this policy. The output of the model can be assessed on the basis of the metrics for performance.

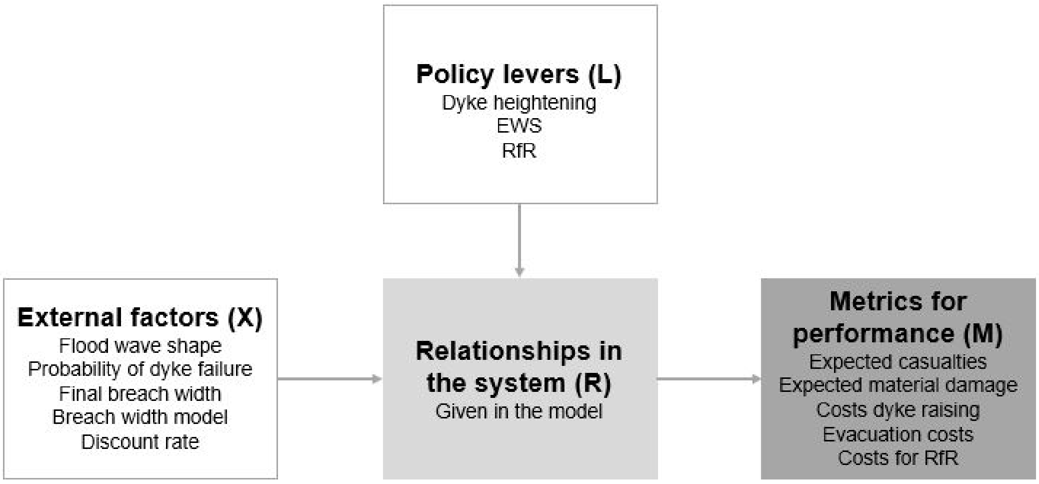


Figure 2.2: XLRM modelling process applied on the IJssel Delta case with its external factors (X) and policy levers (L) as input, the system (R) and metrics for performance (M) to assess the output (adapted from Kwakkel (2017) and Lempert et al. (2003))

2.2.1. Input: external factors
External factors are defined as variables that are beyond any control and inherently contain uncertainty (Ciullo et al., 2019). Because these factors cannot be changed nor controlled directly by the DC, independent scenarios are developed for this. Nevertheless, a combination of policy levers can influence the impact of these external factors, as stated in the MORDM framework in Figure 2.1. These external factors concerning flood risk management in the IJssel Delta are listed in Table 2.1.

Table 2.1: External factors

Factor	Description	Range	Units
Flood wave shape	Describes the temporal discharge at the most upstream location along the IJssel river (*i.e.,* Doesburg (DR1))) by 140 unique yet random shapes following a normal distribution.	0-140	-
Dyke failure probability (per location)	Probability that the dyke fails at one location by a flood wave. The higher the value, the stronger the dyke.	0-1	-
Final breach width (per location)	Total volume of water that enters flood plain through a dyke breach. The higher the value, the more water has entered the flood plain.	30-350	m
Breach width model	Sub-model calculating the growth rate of the dyke breach over days.	1, 1.5, 10	1/day
Discount rate	Rate used to calculate net present value of costs. A lower discount rate implies that future damages are valued higher.	1.5, 2.5, 3.5, 4.5	-

Scenarios are created by compiling a set of values for external factors. A scenario is thus a combination of certain values for every external factor. The exact methodology for scenario discovery is described in Section 2.1.1.

2.2.2. Input: policy levers
Policy levers are policy alternatives that influence the outcomes of the model (Ciullo et al., 2019). All policy levers are thus directly controlled by one or more actors in the political arena. The final policy

strategy will be a combination of several policy levers targeted at flood risk management in the IJssel Delta. The possibilities are outlined in Table 2.2.

Table 2.2: Policy levers

Lever	Description	Range	Units
RfR	An aggregation of projects that wides the river bed by flooding floodplains, reposition dykes, and removes other infrastructural barriers. Five projects exist that can be implemented (1) or not (0).	0, 1	-
Dyke heightening	Dyke heightening in decimetres per location. Raising dykes prevents the (both agricultural or densely populated) hinterland from flooding.	0-10	dm
EWS	System that warns against floods in order to start timely evacuation. The system warns a certain number of days before the potential flood, the number of days can be selected.	0-4	days

A policy thus constitutes a set of values for the policy levers. One goal of this research is to identify potential policies that match the formulated goals, which requires experimentation with different policy lever combinations in different scenarios. Based on the outcomes, the effectiveness of the policies can be evaluated.

2.2.3. Output: metrics for performance

When a set of external values and a policy are entered in the model as input, as shown in Figure 2.2, the model generates a set of outcomes. In multi-scenario MORDM, the performance metrics are critical to assess the impact of the measures, as well as its robustness and vulnerability (Bartholomew and Kwakkel, 2020). The model's metrics for performance are presented in Table 2.3.

Table 2.3: Outcomes

Outcome	Description	Units
Expected annual damage	Value of flood damage over the planning period per location.	euros
Expected number of deaths	Number of casualties expected due to flood per location.	persons
Dyke investment costs	Investment required to raise dykes.	euros
Evacuation costs	Total cost of evacuation due to floods, based on the amount of evacuees and length (in days) of the evacuation period.	euros
RfR costs	Total investment required for RfR projects along the IJssel river.	euros

2.2.4. Operationalisation of problem formulation

Problem formulation in the model indicates how different performance metrics are connected. Working with multiple problem formulations makes it easier to understand the model. Figure 2.3 shows the different problem formulations of the model, as provided by Kwakkel (2022). For well-founded analysis of combinations of policy levers, problem formulation 2 was used as exploratory formulation. An optimisation takes place starting from problem formulation 3, which take into account specific costs and safety requirements, distributed over time (problem formulations 4 and 5) and location (problem formulations 3 and 5).

Problem Formulation 0 *Aggregated 2 outcomes (time and location)*	**All costs =** Dyke investment costs + expected annual damage + costs for RfR + expected evacuation costs **Total Deaths**
Problem Formulation 1 *Aggregated 3 outcomes (time and location)*	**Total investment costs =** Dyke investment costs + costs for RfR + and expected evacuation costs **Expected annual damage** **Total Deaths**
Problem Formulation 2 *Aggregated 5 outcomes (time and location)*	**Total investment costs =** Dyke investment costs **Costs for RfR Expected evacuation costs** **Expected annual damage** **Total Deaths**
Problem Formulation 3 *Disaggregated per location*	**Total investment costs** **Costs for RfR** (total) **Expected evacuation costs** (total) **Expected annual damage** **Total Deaths**
Problem Formulation 4 *Disaggregated over time*	**Total investment costs** **Costs for RfR** **Expected evacuation costs** **Expected annual damage** **Total Deaths**
Problem Formulation 5 *Fully disaggregated (time and location)*	**Total investment costs** **Costs for RfR** **Expected evacuation costs** **Expected annual damage** **Total Deaths**

Figure 2.3: Operationalisation of problem formulations

3

Analysis and results

The research approach and methodology, substantiated in Chapter 2, is implemented in this chapter. First, Section 3.1 will discuss open exploration to get a better understanding of the model. This consists of scenario discovery in Section 3.1.1 and GSA in Section 3.1.2. Then Section 3.2 elaborates on directed search. Directed search *in casu* is constituted by policy discovery in Section 3.2.1 and robustness analysis in Section 3.2.2. Performing an analysis first helps the DC better understand the relationships between the factors in the model, as presented in Figure 2.2. In the following step, the problem formulations from Figure 2.3 can be put in the model. The results provide insight into the consequences and resilience of the outcomes. This supports the DC in selecting the most optimal solution, considering the distinctive objectives in the IJssel Delta. Accordingly, the interpretation of these results forms the basis for the policy recommendations to the DC in the conclusions in Chapter 4.

3.1. Open exploration

As already noted in Section 2.1.1, the simulation model of the IJssel Delta contains a number of uncertainties. Either as a result of external factors (*e.g.,* climate change or flood development), or due to uncertainty in the behaviour of relevant actors. Scenario discovery and GSA assists DC's understanding of the impact of these uncertainties in the model (Saltelli et al., 2019; Saltelli et al., 2010).

3.1.1. Scenario discovery

In scenario discovery, random samples over the range of uncertainties in the model are generated. Following Figure 2.2, the uncertainties in the model consist of probability of dyke failure, breach width model, and final breach width per dyke ring. In case disaggregation per time is perceived in the problem formulation, this adds another uncertainty to the model. Each sample consists of a random set of uncertainties, together these uncertainties form a scenario. In general, scenarios are easier to explain by the public because they represent possible scenarios in the real-life context (Bryant and Lempert, 2010). The generated scenarios are used as input for the model. The output of the model is measured against a threshold for interest clarification.

Exploration of inaction

An important benchmark to establish is the path of inaction, the scenario in which actors fail to act against potential flooding (Workman et al., 2020). To make a fair comparison, this policy path was compared to five other random policies, all for 5,000 different random scenarios. As can be distinguished from Figure 3.1, inaction clearly results in the highest number of expected deaths and annual damage. That is not an unexpected outcome in light of climate change (Workman et al., 2020). However, Figure 3.1 also displays that a policy, like 10001, with a required investment of close to €2 billion, could still result in more substantial damage and deaths than a policy like 10005, which only needs a €1.5 billion investment. This shows that a careful balance between expectations of damage and investment could be reached, which supports the necessity of the analysis that follows in this chapter.

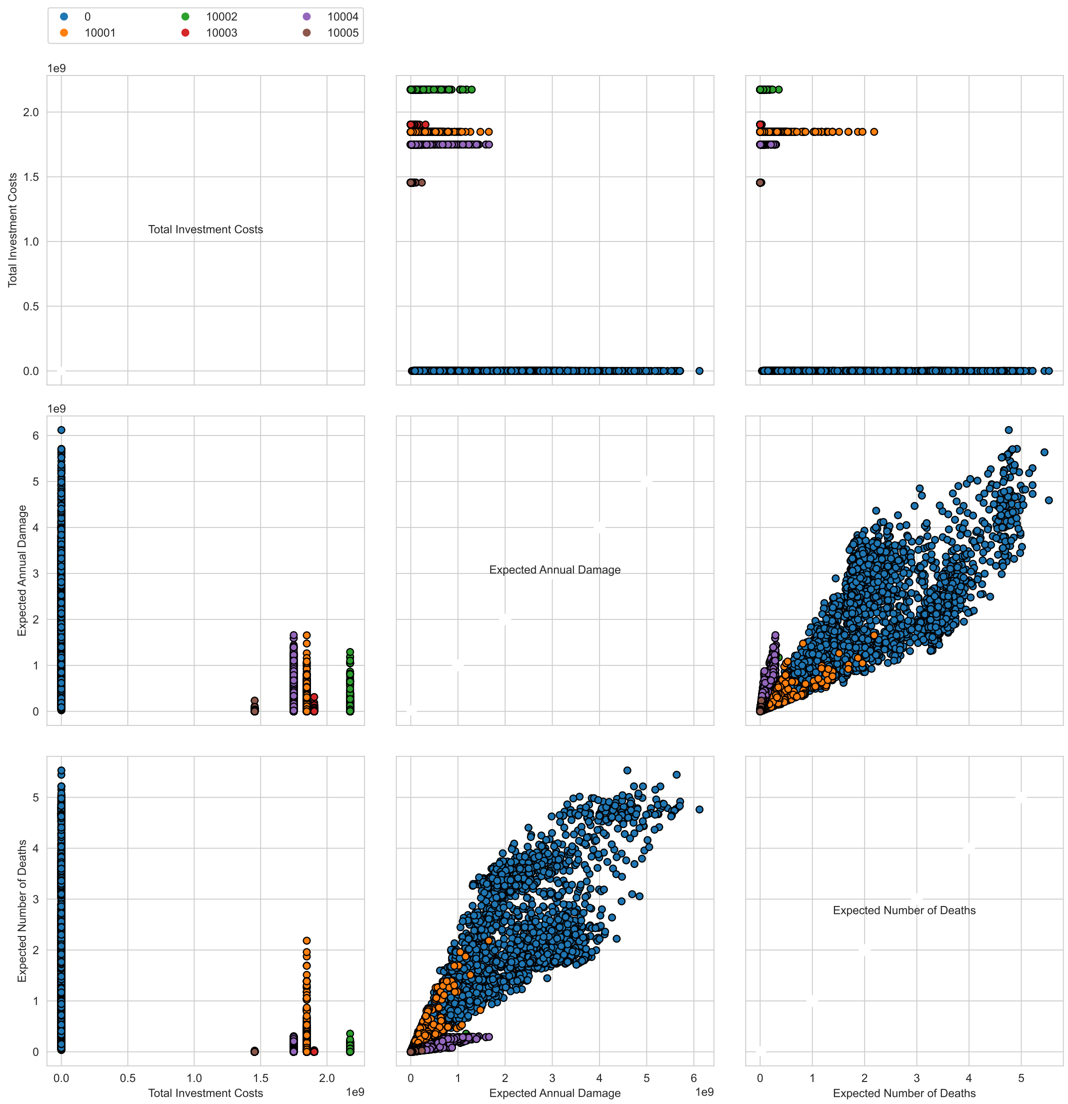


Figure 3.1: A comparison between five random policies and the scenario of 'no action'

Establishing worst-case scenario

Using 10,000 scenarios for the simulation carried out in Section 3.1.1, a worst-case scenario was selected based on the expected number of deaths. In this manner, the inaction scenarios that would result in the worst outcome was selected, which scenario in principle should be avoided. The model uncertainties found in this worst-case scenario have been summarised in Table 3.1. These values will be used in both the GSA and the multi-scenario MORDM analysis.

Table 3.1: Worst-case scenario

External Factor	General	A1	A2	A3	A4	A5
ID flood wave shape	25					
Dyke failure probability		0.109	0.044	0.036	0.354	0.144
Final breach width (m)		46.89	35.80	50.84	36,28	175.72
Breach width model (1/day)		10	1	1	10	1
Discount rate	2.5-4.5-3.5					

Exploring policies of interest
The next step offers the opportunity to investigate the impact of potential policies. This exploration focuses on the impact the different policy levers will have on most of the actors in the political arena. In addition to the policy of inaction, four policies of interest were formulated by the DC to cover the objectives of multiple actors (Kwakkel, 2017):

1. **RfR-only**: At the start of the simulation only RfR was implemented, no dyke heightening introduced.
2. **Dykes-only**: At the start of the simulation only dyke heightening was implemented, no RfR planned.
3. **Combination**: Both dyke heightening and RfR were incorporated at the start of the simulation.
4. **Combination-adaptive**: Both dyke heightening and RfR were enforced at the start of the simulation, but dyke heightening gradually increases throughout the simulation.

Two important additional decisions for accurate comparison were made. Firstly, for each scenario aside from the null-scenario, an EWS was implemented for three days. As the DC is unlikely to accept a plan where people will not be evacuated properly (De Bruijn et al., 2015; Edelenbos et al., 2017; Rijkswaterstaat, 2017, the EWS will not be set any later. Secondly, to decently compare the two 'Combination' policy packages, both consisted of just dyke heightening of 9 decimetres (0.9 metre). However, for the 'Combination-Adaptive' policy plan this adjustment was implemented incrementally at each of the three time instances, while for the 'Combination' package it was all implemented at the start. These five policies were simulated for 5,000 distinctive scenarios, for problem formulation 3, as described in Figure 2.3.

In Figure 3.2 the aggregated results of this experiment are shown. A more complete figure, aggregated by dyke ring, can be seen in the following section.

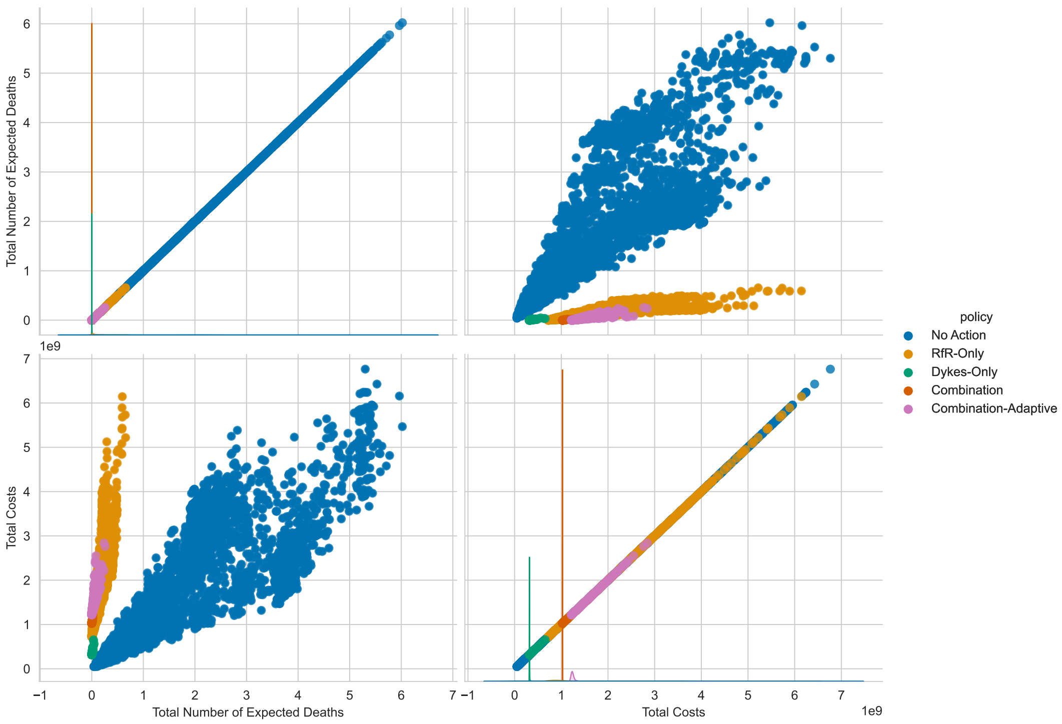


Figure 3.2: A comparison between five random policies and the scenario of taking no action.

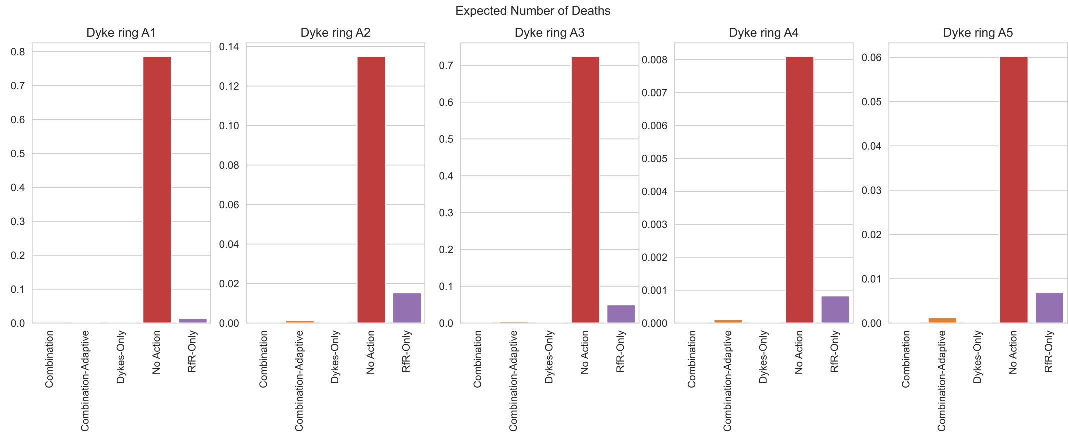
Figure 3.2 provides some interesting insight into the dominance of the policies, which can be briefly summarised by the following order:

$$Noaction < RFR - only < Combination - adaptive < Combination < Dykes - only$$

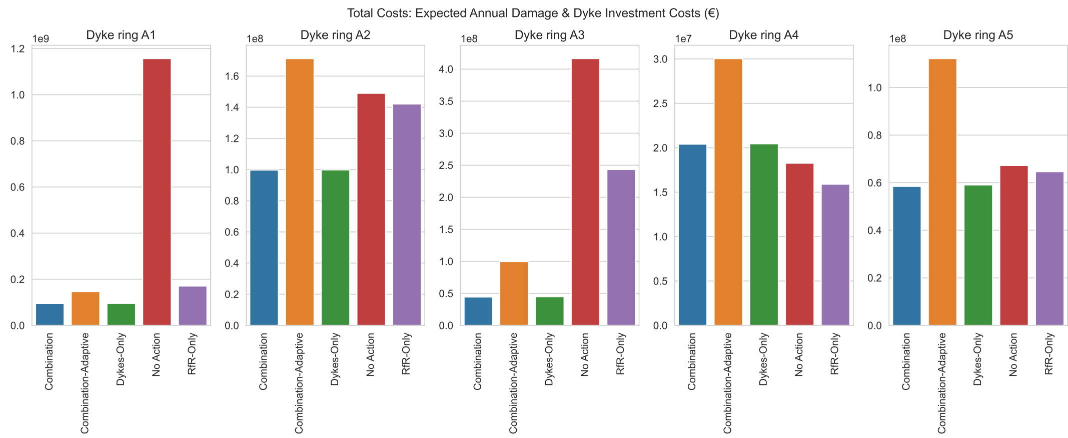
This order is based on the objectives of the DC, as reflected in Figure 1.2, in which both the casualties and economic damage should be kept minimal.

Inspection of disaggregated results

The results of the experiment presented in Section 3.1.1 for each of the five dyke rings has been displayed in Figures 3.3a and 3.3b.



(a)



(b)

Figure 3.3: (a) For each of the five dyke rings, the expected number of casualties are shown for each of the five chosen policies. (b) Similar to (a), but now for total Costs accrued by the dyke rings.

Several observations can be derived from these figures:

- Figure 3.3a shows the following hypotheses:
    1. Dyke rings A1 & A3 are endangered the most if no action were to be taken against potential flooding.
    2. Meanwhile, the dangers for dyke rings A2, A5, and, particularly, A4 are significantly smaller.
    3. RfR proofs to be successful in battling the danger of flooding, but is even more successful when dyke heightening is included.
    4. Dyke heightening on itself could reduce flood casualties without any additional cover from RfR measures.
- Figure 3.3b presents the following points to reflect on:
    1. The burden of inaction is mostly carried by dyke ring A1. It has a total cost of circa €1.2 billion. Followed by dyke ring A3, with €400 million.

2. At the same time, most of the policy levers seem to be more expensive to dyke ring A4 rather than doing anything. This suggests that dyke ring 4 needs incentives to invest and take flood risk mitigation measures.
3. For A2, A4 & A5, the least preferred option from a financial perspective seems to be to implement all policy levers gradually, as this will cost more than doing nothing.
4. For most dyke rings, rather implementing RfR seems to increase costs mostly, which stresses that RfR probably needs to be supported by additional dyke investments to balance out potential annual damage.

3.1.2. Global sensitivity analysis

A GSA has been conducted as a second approach to evaluate the impact of the input on model behaviour and outcomes. A GSA was chosen as the common method instead of a local sensitivity analysis. By changing all variables simultaneously and assessing its sensitivity over the entire range per input factor, a better understanding of the uncertainties in the model is created (Saltelli et al., 2019). To this end, the SOBOL method has been applied, which examines the relationship between input and output variations. Nevertheless, sample sampled in a SOBOL sequence guarantees that the space parameter is uniform in the created samples (Saltelli et al., 2010).

The GSA of the IJssel model was performed by using SOBOL sampling techniques. This was done by using the worst-case scenario determined earlier in this section. This resulted in a feature scoring diagram, presented in Figure 3.4. In addition to the relationship between external factors and the output of the model, feature scoring also examines the effect of variance in policy levers. This was done by creating SOBOL samples over lever space. The conduction of this analysis enabled the discovery of correlation between all of the different policy levers and outcomes of the model, which were explained in Section 2.2. Interestingly, one can see that all RfR measures have relatively low impact on all outcomes, aside from their own costs. While for certain dykes the total costs can be high, they correlate strongly with the expected number of deaths in their own region. Notably, every instance of dyke increase, (zero, one, and two) only appears to be correlated with their respective costs and number of deaths. However, this does not hold true for dyke ring A3, where the strongest correlation between the total costs of A3 and its expected number of deaths is found, while this correlation is reduced greatly in the next two instances. This suggests that dyke heightening is only successful if it were to be implemented as quickly as possible, otherwise it does not appear to worth the costs. Meanwhile, a dyke increase in dyke ring A1 seems to have a minor impact on the safety in their own region, they will have to rely on a wider range of measures in other regions as well.

3.2. Directed search

In order to come up with a suitable policy advice, the model was studied with the use of several techniques that show the behaviour of several policies under different scenarios, essentially looking for policy alternatives that fit the multiple objectives present. These policies were sought from the lever space with the help of MOEAs (Bartholomew and Kwakkel, 2020). The search begins by obtaining a worst-case scenario against which to run the model and search for policy levers that would minimise the negative outcomes mentioned before. MORDM was applied here (Banzhaf, 2009; Kasprzyk et al., 2013), taking into account multiple objectives in one scenario to come up with solutions that are close to Pareto optimal. Since the worst-case is only the starting point in searching for policies that would be fit for purpose, the candidate policies were also compared to a 1,000 other random scenarios to test their behaviour and robustness in different situations. As discussed in Section 2.1, this differentiates the method of multi-scenario MORDM from regular MORDM where it is only possible to test the potential policies to a large variety of scenarios and choose a robust solution, as earlier elaborated on in Section 2.1. In short, this DMDU strategy creates a multitude of policy and scenario alterations to unfold policies and adaptive solutions for future policy development (Lempert, 2019).

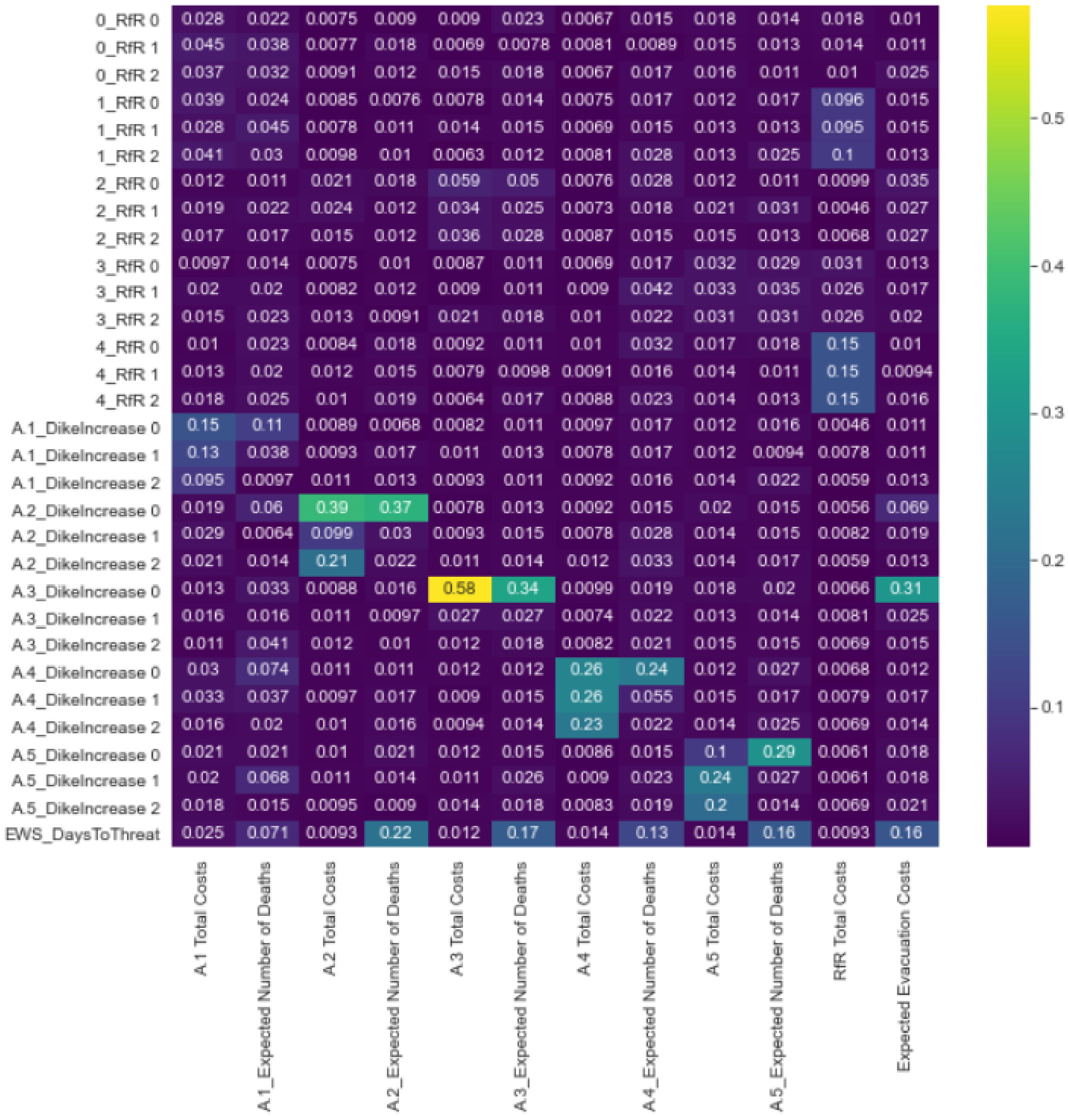


Figure 3.4: Feature scores between policy levers and model outcomes

3.2.1. Policy discovery

MOEAs are a critical component of MORDM (Bartholomew and Kwakkel, 2020). MOEAs are a good method to identify trade-offs in policy options, as well as how they respond to changes (*e.g.,* uncertainties) in the model. Logically speaking, policy discovery therefore resembles scenario discovery, since with MOEAs policymakers, like the DC, are presented with a set of outcomes in which itself must indicate preference. This reduces the inherent bias in the model specifications and offers scope for analysing policy options and scenarios, taking into account the political arena (Bartholomew and Kwakkel, 2020).

Policy discovery in this analysis has been done by running a MOEA with ε-NSGA II over 100,000 function evaluation. Shown in Figure 3.5 is the convergence of epsilon of this run. However, this number of function evaluations (NFE) was chosen due to time constraints. A higher NFE might have flattened the curve, resulting in policy candidates coming closer to the approximate Pareto front. An ε-value of 0.1 was used after trail-and-error showed that a courser grid —*i.e.,* ε equal to 1 —would provide fewer policy candidates.

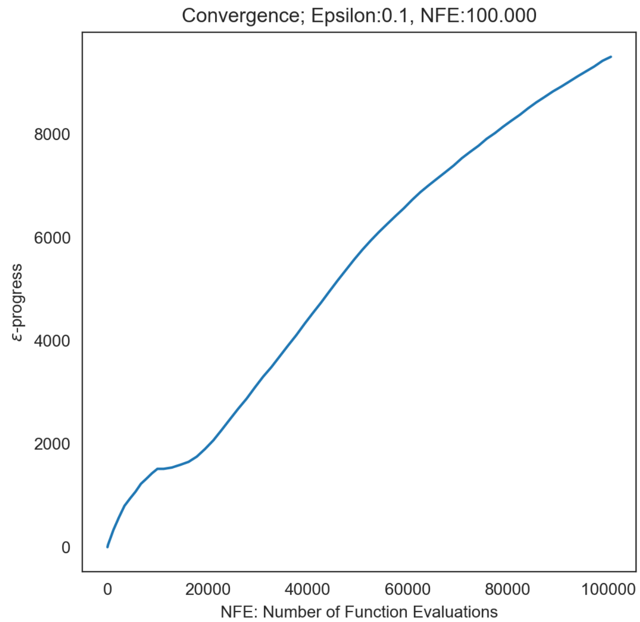


Figure 3.5: Convergence under the worst-case, 100,000 NFE's, ε = 0.1

Figure 3.5 demonstrates that the ε's do not converge, as the line would then be more straight. Notwithstanding, the policy search for the worst-case scenario already provided over 2,000 potential policy candidates. From these candidates, a selection was made by applying the condition that no casualties should be expected. This is in line with the goal of the DC to minimise the number of casualties as much as possible, as set in Figure 1.2. Still, minimising the number of casualties is not the sole objective of the DC, other objectives have been determined as well. Nevertheless, selecting policies that result in zero casualties provides a sufficiently small subsection of six policies. The smaller selection allows for conduction of robustness analysis, in regard to time constraints and computational limitations.

Multi-scenario MORDM

The six policy candidates have primarily been optimised for a shallow problem frame. Namely, for the single worst-case scenario. In reality, it is not expected that a solitary focus on this scenario will lead to finding a robust policy that functions under more than one scenario. Noting that constraint, an analysis has been conducted for each policy over 1,000 random scenarios. The outcome of this analysis is plotted in Figure 3.6.

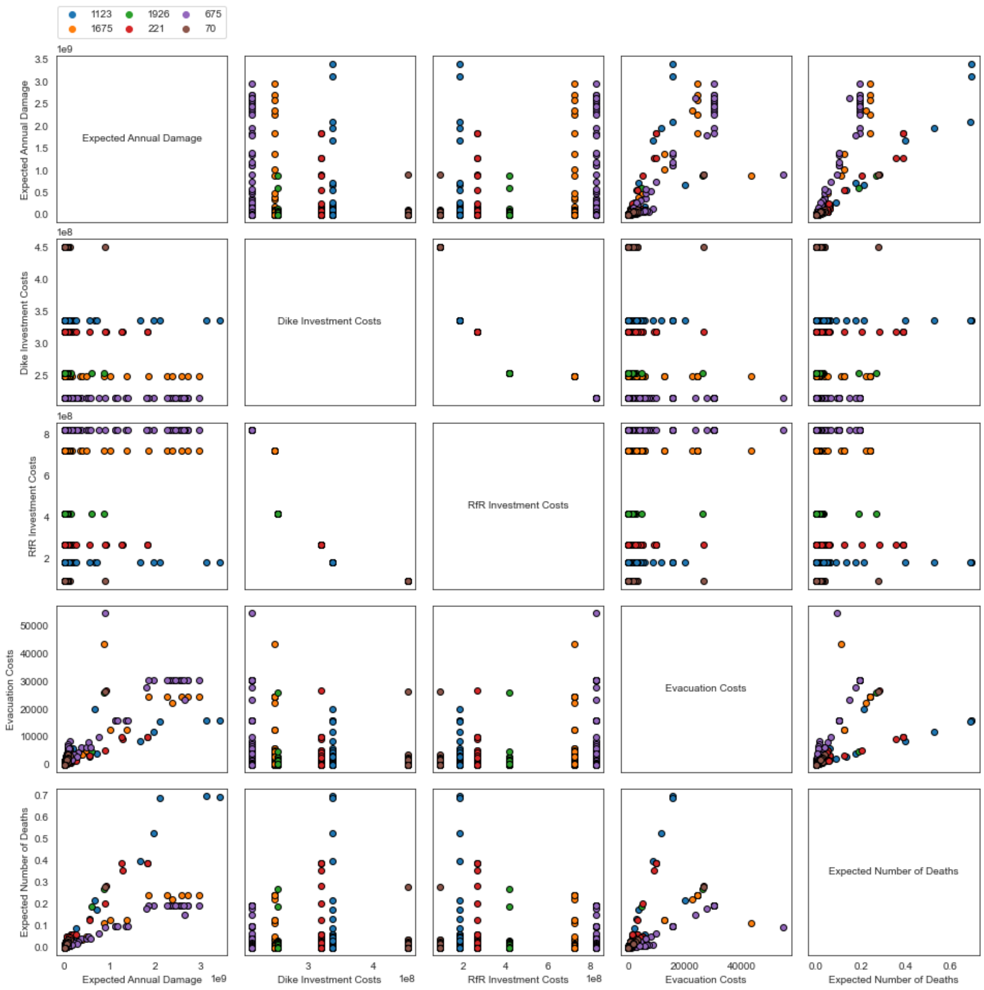


Figure 3.6: Pair plot of six candidate solutions under 1,000 scenarios

3.2.2. Robustness

From the multi-scenario MORDM, it becomes clear that each policy behaves differently under different scenarios. And, that behaviour is far from optimal for some policies. Their fitness for purpose does therefore not directly translate from the worst-case to other scenarios. This section therefore analysis the candidate policies extracted under deep uncertainty. For this analysis, two methods have been applied. First is Signal-to-Noise (SnS) being discussed in Section 3.2.2, after which regret has been employed in Section 3.2.2.

Signal-to-Noise

SnS aims to show the relationship between the mean value and the standard deviation (McPhail et al., 2018). The goal of SnS is to be as small as possible if you want to minimise the negative outcomes. Low expected values and standard deviations lead to low volatility over scenarios and higher robustness (McPhail et al., 2018). SnS, thus, describes for each policy the multiplication between its standard deviation and the mean. Besides robustness, SnS therewith also reflects performance of policies. Figure 3.7 presents SnS for the six candidate policies.

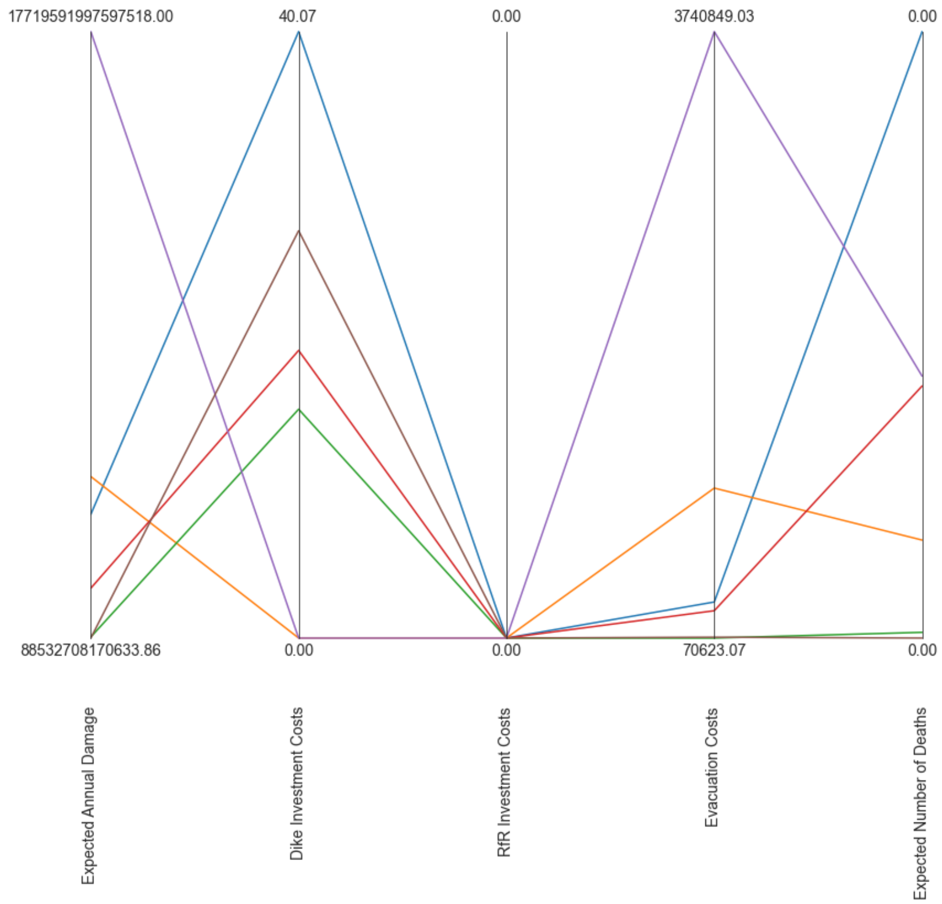


Figure 3.7: Parallel plot of Signal to Noise

The figure shows that in the case of the green policy (1926), signal to noise is often minimized with regard to other scenarios, yet high noise can be seen for it in Dyke Investment Cost. It seems very effective at mitigating deaths as does the brown policy (70).

Regret

Another method of checking the robustness of the candidate policies is to calculate a regret score. The regret score is the difference for each policy between it and the best alternative under the outcome of considerations also considering the scenarios. Put differently, the regret matrices show how high the regret of a particular policy choice is, compared to the outcomes of other policy solutions (McPhail et al., 2018). The difference between the best and worst outcomes of each policy outcome is normalised in the comparison. In Figure 3.8 the regret scores of the policies are plotted in a parcoord plot.

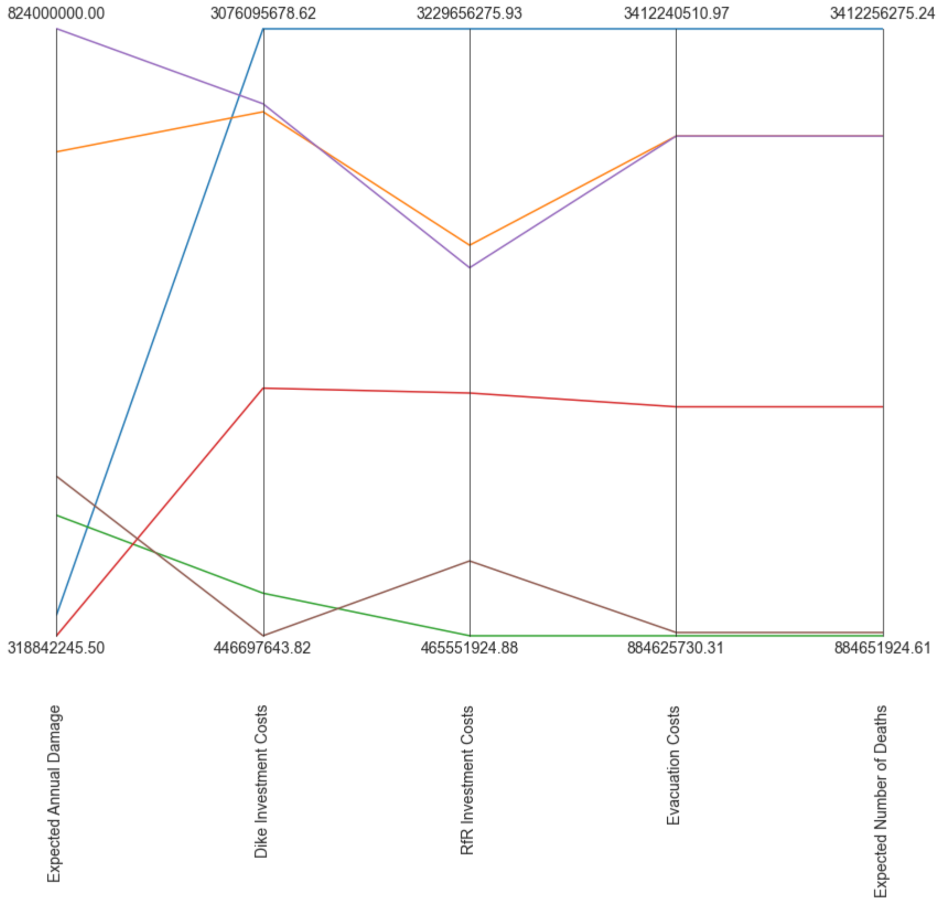


Figure 3.8: Regret score for the six policy alternatives

Naturally, the best policy alternative will have the lowest regret score, indicating that it is closest to the best solution. Since regret is calculated per outcome, there will be no policy that will minimise the regret for all outcomes. We can clearly see that here, once again both the green and brown policy are performing well and have a low regret score. From this we can conclude that given the selected policy candidates, both the green policy (1926) and the brown policy (70) are good performers under the test conditions.

4 Conclusion

In this Chapter the analysis from the previous Chapters will accumulate in a policy that shows the most potential to support the Delta Commission in reaching their objectives, which were set out throughout this report. In Section 4.1 the analysis from the previous Chapter will be summarised and built up towards a single policy to be implemented. Followed by an analysis of the implications of that advise in the multi-actor context in Section 4.2. The limitations of this advise will be further discussed in Chapter 5.

4.1. Conclusion and policy advice

4.1.1. Scenario discovery & GSA

As the DC is interested in the overall impact that any policy plan might have, an aggregated perspective was taken first. By assessing in which scenario the highest potential for destruction could be found, the situation to be avoided became apparent. After all, the DC wants to advise on how to increase resilience for the region as a whole and not just for a single dyke ring. By further exploring this scenario with several policy options the following observations could be made:

- Dyke rings A1 and A3 stand to lose the most - both financially and in lives. They will be the most eager to invest in safety measures. A3 requires investments in their own area, while A1 is reliant on other areas as well.
- Solely relying on implementations of new Room for the River projects will not work. It will have to be supported by the classical approach of heightening the dykes to be truly prepared for a resilient future.

4.1.2. Policy Candidates

The worst case scenario has been optimized and from the pool of over 2000 potential policies, six policies have been selected that reduced the number of expected deaths under the worst case scenario to zero. These policies have been tested using multi scenario MORDM and two candidates have been selected, the green (1926) and brown (70) policy. The green policy has a more pronounced mix of interventions than the brown policy, which depends more heavily on a single method of flood risk mitigation, namely dike heightening. Both are effective in preventing deaths in the IJssel delta and the final decision will be a political one.

4.1.3. Final policy advice

Considering the position of the Delta Commission as a broker with a long term perspective, it is advised to choose the green policy (1926) that in the current scenario seems to align best with these interests due to its diversity of levers and the balance between benefits and drawbacks it provides to all actors. With a pronounced focus on decreasing safety, the green policy is composed shown in table 4.1

Table 4.1: Policy advise, RfR and Dyke Increase disaggregated over time

Policy Lever	General	A1	A2	A3	A4	A5
EWS	1 day					
RfR		0/1/0	0/0/0	1/1/1	1/1/0	0/0/0
Dyke Increase (dm)		7/0/0	7/0/0	7/0/0	7/3/1	7/0/0

4.2. Implications to multi-actor context

The policy advise presented offers several challenges within the political arena which are outlined below:

- **EWS**: While the simulation might suggest that with sufficient investment in safety measures a 1-day warnings should suffice, this might not hold up in the political landscape. EWS with 2 days warning will garner more support as it has the potential to save 20% more of the population. The possibility for an EWS scale-up should therefore definitely be left on the table.
- **RfR**: The main burden for Room for the River ends up in dyke rings A3 & A4, and a smaller implementation in A1. For Zutphen (3) this builds upon their need to invest in safety, as it was shown in the open exploration in Section 3.1.1 that they stand to lose the most in case of inaction. The same goes for the additional investment in Doesburg (1), but does not hold for Gorssel (4), since dyke ring A4 has very few inhabitants and faces little risk. To take action dyke ring will quite likely need sufficient financial compensation and/or support.
- **Dyke increase**: As was shown earlier, dyke increase is proven to be most effective when it is implemented right away and across the board. From an egalitarian perspective it is quite positive to see that the load is shared equally across the five dyke rings. For the areas around the RfR projects dyke heightening might present additional challenges, as more Room for the River will potentially require dykes to be moved as well. These projects should therefore be set-up in close cooperation with the local authorities to facilitate a designing process that enables this combination. Special attention should be given to quality of the public space to make these large scale changes a success.

5 Discussion

In this Chapter the limitations that might weaken the provided analysis in this report are discussed and potential avenues for improvement are recommended to tackle these challenges.

5.1. Limitations

5.1.1. Modelling limitations

Use of the model built by Ciullo et al., 2019 provides several challenges. As it was developed to study the optimisation of embankment heights, the design of the model heavily leans towards the implementation of that policy lever. It might therefore not be a surprise that heightening dykes proves most effective in affecting the outcomes of this model.

In addition, the model does not give any insight into other implications that the policy levers might have. In the political arena the accessibility of the river for transport is of great interest, just like the ecological impact of measures implemented. Inclusion of these factors might change the policy advise quite a bit, as they will influence the economic assumptions that are set within the model. However, potential addition of factors like these to the model can easily disrupt the balance reached in its calculations.

Finally, the assumptions beneath the model are not very transparent. A simple example - why does an Early Warning System have such a great impact on the percentage of the population that could be saved? The only provided information is the data and not where it was found and how it is supported by prior research. Many of these assumptions provide additional uncertainty, which results in additional difficulties when operating in such a deep-uncertainty situation already.

5.1.2. Political challenges

As discussed in the section above, the lack of transparency about the data and the assumptions behind the calculations will proof difficult in a political arena. This opens up any policy advise the model provides to questions about where the information within the model was found and why certain modelling choices were made.

Since any river delta has close interconnections between the different regions along the river, this model only provides limited insight. As displayed in the introduction of this report, the reason why additional safety measures need to be taken is of an immense international scale. The visibility of the challenges of global warming is limited in this model, while it is one of the driving forces behind the need for action. Additionally, there are many other cities and regions further upstream which may affect the dyke rings in the Dutch region much more than any measures they might implement themselves. International coordination is unfortunately completely missing from this analysis.

The actors defined in this analysis cannot be fully represented within the model used. While it provides an overview to the national and provincial governmental bodies, the local details are missing. There are no mentions of where these dykes are located and how the embankments are used at this moment in time. While heightening a dyke might make sense on a computer screen, it will be more challenging to comprehend from the house built upon that very dyke.

5.2. Recommendations

For future analysis the following changes might be of interest:

- First and foremost, more transparency and insight should be provided about the assumptions behind and the limitations of the model. It is unclear to users of the model why certain values were chosen and why they are given the weight that they have.
- The policy levers for RfR and EWS could be expanded upon. As shown in the introduction there are many different options for RfR projects, by assessing the impact of these variations a more complete policy advise could be provided. Similarly, evacuation includes more steps than just a warning, precautionary measures could be included for example.
- Addition of outcomes such as river depth (accessibility) and biodiversity (ecological impact) might provide additional insight into the impact of implemented measures. This will ease the gathering of political support of any piece of policy advise.

To explore further challenges within this political arena the following areas of study might be of interest:

- The international landscape. As discussed previously, the river does not solely flow through the Netherlands and the changes upon that river are of an international scale. However, the analysis provided in this report already shows that upstream action can be quite effective. This could quite easily translate to measures implemented in Germany as well.
- A study of a locally implemented Room for the River project might provide insight into how a balance can be found between different safety measures and how this impacts the surrounding environment. This will provide more thorough knowledge of the impact of an innovative measure like this one and will support similar analysis, but deeper, to the one in this report.

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A

Actor analysis

In order to determine the position of the various actors in political decision-making in the IJssel Delta, an analysis is needed of their influence, interests and positions regarding flood risk management. To this end, their strategic objective is first examined, as well as their objective in this specific case and how they can exert influence. On the basis of this, the resource dependencies of the actors and a power-interest grid, as presented in Figures 1.4 and 1.5 respectively, can be mapped, so that it is clear to the DC which actors are most relevant for it to arrive at a resilient and adaptive long-term policy in the IJssel Delta.

A.1. Power and interests

Eleven actors can be distinguished in the IJssel Delta. Nine of them are (semi-) government institutions of different levels. At national level, the DC and Rijkswaterstaat —on behalf of the Ministry of I&W —are involved. Gelderland and Overijssel have provincial interests in the development of flood risk management policies in the IJssel Delta. Regionally, the dyke rings of Doesburg, Cortenoever, and Zutphen (all three located in Gelderland) and Gorssel and Deventer (both in Overijssel) have been mandated to protect the hinterland against flooding. However, they do not have the right to vote and are thus dependent on the province they belong to for their advocacy. Finally, the transport and environmental NGOs were included in the political decision-making process to defend their interests. The strategic and case-specific objectives and the power of the actors are summarised in Table A.1.

Table A.1: Power and interests of relevant actors (based on the debates and Edelenbos et al., 2017)

Actor	Strategic objective	IJssel objective	Power
Delta Commission	Resilient water strategies targeted at reducing flood risks while balancing the socio-economic consequences for the region, maintaining local livelihood, and improving the environment	Long-term (>100 years) adaptive water management plan to reduce flood risks in the IJssel Delta	Veto
Rijkswaterstaat	Maintaining and improving mobility, safety, and livelihood of regions in the Netherlands	Mitigating flood risks in the IJssel Delta, while maintaining water accessibility and improving biodiversity	Veto
Gelderland	Ensuring well-being and welfare of its citizens	Protection of citizens (and their materials) against flood risks, without economic damage to the region. Private actors must also contribute. The costs must be shared with Overijssel and interests of the dyke rings should be complied with	Vote
Overijssel	Ensuring well-being and welfare of its citizens	Protection of citizens (and their materials) against flood risks, without economic damage to the region, particularly with regard to their agricultural sector. The costs must be shared with Gelderland and interests of the dyke rings should be complied with	Vote
Transport NGO	Facilitating future growth of the water transport sector by guaranteeing their economic importance (on and around the Dutch rivers)	Preserving navigability of the IJssel river	Vote
Environmental NGO	Protecting and improving biodiversity in the Netherlands	Conserving and improving biodiversity in flood risk management of the IJssel river	Vote
Doesburg (DR1) and Cortenoever (DR2)	Protecting hinterland en citizens from flooding	Ensuring safety of citizens and protecting agriculture as economic driving force for farmers, employment, and the regional economy	None
Zutphen (DR3)	Protecting hinterland en citizens from flooding	Ensuring safety of citizens and economic welfare of the hinterland by reducing flood risks	None
Gorssel (DR4)	Protecting hinterland en citizens from flooding	Ensuring safety of citizens, protecting agriculture, and avoiding that fertile land is being used for water management	None
Deventer (DR5)	Protecting hinterland en citizens from flooding	Ensuring safety of citizens and economic welfare of the hinterland by reducing flood risks	None

A.2. Political arena

Every actor with voting rights has his own demands and position in the political arena of the IJssel Delta. These are shown in Table A.2. It follows immediately that there are conflicting interests and positions. Gelderland, for example, wants as much RfR as possible in Overijssel, while Overijssel wants this the other way around. There is also a dispute between the dyke rings. The rural dykes, such as Doesburg (DR1), Cortenoever (DR3), and Gorssel (DR4), would rather raise dykes to protect their agriculture and certainly not give up fertile land for RfR. On the other hand, the urban dyke rings, Zutphen (DR3) and Deventer (DR5), prefer RfR to be applied in the outlying areas of the other dyke rings, so that they have to take fewer measures themselves in densely populated areas. The approach proposed by the rural dyke rings is supported by the transport NGO, which does not RfR as it negatively affects their navigability, while the environmental NGO is more on the side of Zutphen and Deventer in the context of more rural biodiversity. These different interests lead to conflicts. Notably, both Gelderland and Overijssel represent rural and urban dyke rings, which means that the provinces must first come to an internal compromise on flood risk mitigation strategies before entering the negotiating table with other actors. It is the task of the DC to take them all into account and arrive accordingly at a broad supported and resilient strategy.

Table A.2: Policy positions of voting actors (based on debate and Edelenbos et al. (2017))

Actor	Policy demands	Position
Delta Commission	Long-term, adaptive, and resilient water strategy (>100 years) and minimising casualties	Stimulate RfR and avoid dyke heightening
Rijkswaterstaat	Long-term and broadly supported water policy, minimising casualties and minimal costs	Effective water policy
Gelderland	No RfR in Doesburg (DR1) and Zutphen (DR3), particularly not in DR3 because of its financial damage to the Zutphen harbour. Minimise impacts of water policy on Zutphen as major city in Gelderland	Avoid RfR in Gelderland as much as possible
Overijssel	Lower EWS to reduce evacuation costs, compensate fertile land-use that cannot be used for agriculture any longer, and minimise dyke heightening in Gelderland (*i.e.,* to prevent more RfR in Overijssel)	RfR in Gelderland as much as possible
Transport NGO	Avoid RfR because it reduces navigability, particular around Doesburg (DR1)	Avoid RfR as much as possible and elevate dykes
Environmental NGO	Introduce RfR rather than dyke heightening for improved biodiversity along the IJssel	Maximise RfR

https://github.com/quaquel/EMAworkbench