Limiting Flood Risk of the River IJssel

Advice for the Province of Gelderland on robust strategies to cope with the uncertainties concerning the flood risk of the river IJssel through model based analysis

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http://footage.framepool.com/en/shot/673538564-ijssel-meander-horizon-over-land-netherlands

Executive Summary

This report provides an analysis of protection against flood risk of the river IJssel under deep uncertainty, to provide a robust candidate policy. Deep uncertainty implies there is a wide range of future scenarios and there is no preference in ranking the futures based on probabilities. The method that is being used in this analysis is Exploratory Modeling and Analysis. Using this technique, consecutively, an open exploration, sensitivity analysis, scenario discovery and robust optimization have been executed on a predefined model of flood risk for the IJssel. This way, uncertainties and policy levers that influence the outcomes are identified, after which the best policies under different future scenarios are found. Optimal policies are identified for the most important stakeholders in the case, to minimize risk of opposition.

From the Exploratory Modeling and Analysis, it appears for the Province of Gelderland, the optimal solution would be a combination of a 4 dm dike heightening at Deventer in Overijssel, with four out of five 'Room for the River' measures and an Early Warning System of three days. The reason why dike heightening in Deventer comes forward as a favorable solution for Gelderland, is due to the assumption the costs for this dike heightening will not be carried by Gelderland. Therefore it is no surprise that Overijssel prefers heightening dikes at the locations in Gelderland over the dike at Deventer. Furthermore, Overijssel shares the desire for implementation of 'Room for the River' measures, whereas Rijkswaterstaat is reserved towards 'Room for the River', as they will carry the costs for this expensive measure. However, there is a possibility for the provinces to financially contribute to a certain measure, if the budget of Rijkswaterstaat does not allow a certain implementation.

Furthermore, from the Dynamic Adaptive Policy Pathway (DAPP) approach, where the influence of other external factors is taken into account, it is concluded that dike raising is a measure that creates lock-in situations, and therefore should only be introduced when this is unavoidable. Hence, 'Room for the River' scenarios are to be favored over dike heightening. Moreover, the presented preferred policy is not a fixed solution over time. The dynamic character of water and changing external factors such as climate change, ask for adaptations to the environment to keep areas near the IJssel safe from floods. To create these actions that have to be taken as a reaction towards the changing environment, triggers with consequential actions should be determined and monitoring should be performed with accuracy. In order to follow the predetermined policy pathways and strategies, a new level of cooperation and coordination among all involved actors is essential to ultimately create the best possible flood risk management.

Lastly, these results come from analyses with a static model that does not include all outcomes of interest and will probably not align to future states of society. Therefore it is important to keep in mind that these analyses just give a grip on the candidate solutions, but are not a completely transparent and realistic reflection of reality, since a simulation model, as used for the analyses, is a simplistic reproduction of the reality and is based on many assumptions.

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1. Introduction

The water levels in the IJssel river are rising. The higher amount of rainfall is an important cause of this issue (Rijkswaterstaat, 2018). It is expected that this process will continue the following decades because of climate change (MIRT overzicht, 2018; Minnen et al., 2012). The IJssel enters the Netherlands in the province of Gelderland, and emerges in the IJsselmeer in the province of Overijssel. The river begins in Switzerland and flows via France and Germany to The Netherlands (Figure 1). Mainly The Netherlands have to deal with the higher amount of water in the IJssel and thus rising water levels. For instance, if Germany decides to not make more room for the higher amount of water in the IJssel, this causes a rise of the discharge (m^3/s) of the IJssel in Germany. Subsequently, the water level in The Netherlands will rise, since there is in general less room for the river flowing from Germany to The Netherlands.

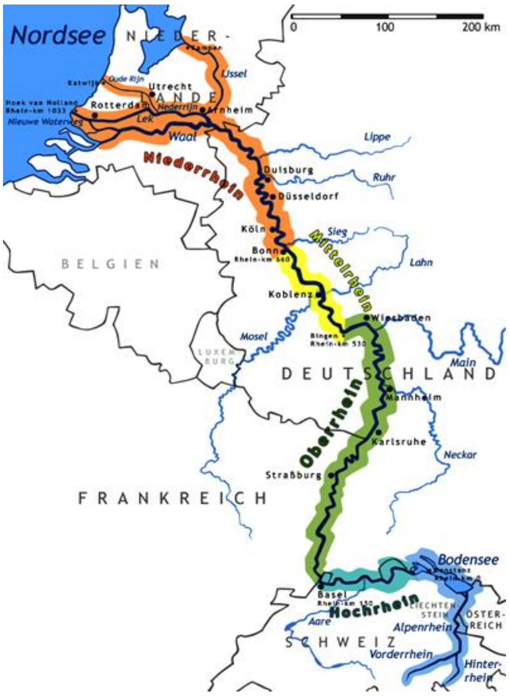

Figure 1: The river Rijn[1]

In the Netherlands, the IJssel flows through rural and urban areas. The actions of upstream parts can influence the water level of the IJssel in downstream parts: the higher the upstream discharge (m3/s), the higher the (eventual) downstream damage (Ciullo, 2018). The fact that upstream parts of the river influence flood risk in downstream parts of the river, makes the problem of the rising water level of the IJssel more complex.

Furthermore, there is uncertainty about multiple futures. The main uncertainties are related to climate change, water distribution over the various branches of the Rhine and land use (Kwakkel, 2018). When there is a range of possible future scenarios and there is no preference in ranking the possibilities in terms of likelihood, it is called *deep uncertainty* (Maier et al., 2016). This case can therefore be seen as deep uncertain.

Because of the complex nature of the project, finding robust policies that work for different actors in different scenarios is a challenge. In the search of these policies, the 'Room for the River' project has come up with various measures that create more space for the river, causing flood risk to decrease (Rijke, 2012).

Measures that have been designed during the 'Room for the River' project in combination with measures more focused on dike elevation and warning systems and their relation to actors involved in the flood risk problem are central to this research. The aim of this report is to give an advice on how to cope with the flood risk in the areas around the IJssel river given the wide range of possible futures.

The different stakeholders and the problem owner

For this research, only The Netherlands will be taken into account. Upstream discharge (in Switzerland, France and Germany) will be considered given. Concerning flood risk management, multiple actors in the Netherlands are involved. First of all Rijkswaterstaat, who has to come up with a final policy that convinces the Minister of Infrastructure and

Water Management (MIRT overzicht, 2018). Of course, Rijkswaterstaat is also involved with the interest of other actors; like the Delta Commissioner, environmental interest groups, transport companies and the Provincial Governments of Gelderland and Overijssel. Furthermore, Rijkswaterstaat and the provincial governments represent the interests of the rural and urban areas where the river flows through. An overview of the actors is given in Appendix A.

Provincial government of Gelderland

The analysis in this report is executed in order to obtain advices and strategies for the Provincial government of Gelderland to have a strong position in negotiations about the policy proposed by Rijkswaterstaat. For the provincial government of Gelderland it is important to represent the interests of the urban and rural areas in their province that are in risk of flooding. An advice on how the Province of Gelderland can show robust results to the decision makers will give Gelderland a stronger negotiation position.

Research question for the problem owner

"What are the most robust strategies the Provincial Government of Gelderland can use in its own interest to convince the other stakeholders to adapt a policy that has a positive effect on Gelderland (given the uncertain future)?"

Structure of this report

In section 2, the methodology chosen in this project for decision-making under deep uncertainty is presented. Firstly, the exploratory modeling techniques that are used will be presented. Exploratory modeling will be used to explore the consequences of a wide range of uncertainties for making decisions in the IJssel river case. Afterwards, the theory behind adaptive planning is introduced. Furthermore, the decision support is discussed, which includes the trade-offs that have to be made between the preferences of the different stakeholders. In section 3 an operationalization of the IJssel flood protection case will be presented. Here, the different uncertainties and outcomes of interest are explained. Furthermore, a range of problem formulations is presented where multiple outcomes of interest are combined for different actors. Lastly, the different policy levers are described and combined in different policies. After that, in section 4, the analysis and results of the exploratory modeling are presented. Followed by section 5, where the adaptive planning and decision support are discussed. Thereafter, conclusions and advices are given in section 6. Also the strategies the problem owner can use during negotiating with the other stakeholders are mentioned. Lastly, the future scope of the project is discussed in section 7.

2. Methodology

The paradigm shown in the paper by Kwakkel & Haasnoot (2018) to support ‘decision-making under deep uncertainty’ can be used as a theoretical framework for this analysis and focuses on three key ideas that will be explained in the following sections: exploratory modeling (2.1), adaptive planning and decision support (2.2).

2.1 Exploratory Modeling

Model-based support is needed to cope with a problem of deep uncertainty, for which in this project Exploratory Modeling and Analysis (EMA) is used. Using the EMA methodology it is possible to figure out complex and uncertain systems (Kwakkel & Pruyt, 2013). The EMA workbench, developed by J.H. Kwakkel, is used to execute the EMA methodology. Different exploratory techniques are explained in the following sections; open exploration (2.1.1), sensitivity analysis (2.1.2), scenario discovery (2.1.3) and robust optimization (2.1.4).

2.1.1 Open Exploration

Open exploration is used to present the uncertainty space and the decision space to the outcome space (Kwakkel, 2017a). A point in the uncertainty space is called a scenario and a point in the decision space is a policy. The full uncertainty space is combined with the full decision space to see what points in the space of the different outcomes of interest are possible. Every combination of a scenario and a policy is called an experiment (Kwakkel, 2017b). The more experiments, the more complete the possible outcome space is. Since the model is already specified within the workbench, experiments can be performed by using evaluators. As a default setting the Latin Hypercube sampling method (which gives a better distribution over the entire space in comparison to the Monte Carlo sampling method) is used in the workbench for sampling over uncertainties and sampling over levers (Kwakkel, 2017a). On the other hand, an advantage of the Monte Carlo sampling method could have been that it generates completely independent experiments (Chrisman, 2014), which makes it possible to combine the results of multiple experiments. Open exploration can also be used to find correlations between the outcomes of interest, which can be useful to find out if all outcomes of interest are interesting to select for further analysis.

2.1.2 Sensitivity Analysis

Sensitivity analysis is used to find out what uncertainties and policy levers have the most influence on the outcomes of interest and is part of the vulnerability analysis. The sensitivity analysis investigates how sensitive the outcomes of interest are for the input variables (Kwakkel, 2017a). The method of Sobol (2001) is a popular method for non-linear models and is used for global sensitivity analysis where the inputs are sampled at the same time, instead of checking each input separately. Not using a global sensitivity analysis gives a loss of information in the non-linear part of the model (Cariboni et al., 2007), because it neglects the possibility of interaction between variables. The Sobol analysis can be conducted in Python using the sampling tool SALib, developed primarily by Herman and Usher (2017). This analysis is useful to get an idea which uncertainties and policy levers are important for the model behavior. When a policy is implemented using a sensitive policy lever, it will influence the outcomes of interest more. A simple alternative for the global sensitivity analysis is feature scoring, which gives visual insight into the relative influence of uncertainties on the model outcomes (Kwakkel, 2017d).

2.1.3 Scenario Discovery

Scenario discovery is an important type of vulnerability analysis and forms the core of robust-decision making. This analysis is performed using the Patient Rule Induction Method (Friedman & Fisher, 1999). This algorithm aims at finding combinations of values for uncertain input parameters that lead to similar outcomes of interest. It will help to identify the restrictions on uncertainties that result in possible output spaces. PRIM seeks for hyper rectangular boxes of the uncertainty space where the value of a single outcome of interest is notably different from the average value over the whole field. These rectangular boxes are obtained by slicing away small amounts of data until a subspace is obtained with a balanced trade-off between coverage and number of restrictions. Coverage is the percentage of results that is in the subspace, whereas density is the percentage of cases within the box that is an outcome of interest (Bryant & Lempert, 2010). The input for the PRIM analyses are computational experiments given a single policy. Through PRIM these experiments are classified as experiments of interest, or not (Kwakkel, Haasnoot & Walker, 2016).

2.1.4 Robust Optimization

Robust optimization methods are necessary for Robust Decision-making (RDM) and can be used to find those points in the decision space that result in desired points in the outcome space, which are not too sensitive to the uncertainties. There are different methods that can be used during the robust optimization. The framework 'Many Objective Robust Decision-Making' (MORDM) of Kasprzyk et al. (2013) tests possible solutions under possible future states of the world (SOW), in other words the framework tests whether policies are pareto satisficing in alternative SOW. Multiple outcomes of interest are considered and this can cause trade-offs in the decision-making. Besides different possible futures, the candidate solutions can also be tested for multiple outcome-of-interest sets, to check whether the candidate policies are on the Pareto front for multiple objectives. First, candidate solutions are searched through a direct search, using one specific scenario. The direct search can be executed with a reference, worst and/or best case scenario and the results can be compared afterwards. After that, robust search is used to test the candidate solutions for multiple scenarios. Furthermore, optimization can be used to do worst case discovery (Kwakkel, 2017c). The MORDM framework is not the only framework that can be used for robust optimization, but will be used for this project, because of its time efficiency.

2.2 Adaptive Planning and Decision Support

Adaptive planning is part of the policy architecture and is important to make the decision-making more robust (Kwakkel & Haasnoot, 2018), since the plan for limiting flood risk on the river IJssel should be adapted over time to react on the uncertain future. According to Walker et al. (2001) policies should be adaptive; only an action should be taken when it is non-regret, time-urgent and when it decreases the urgency of other actions. A new action should be taken when a certain trigger value is reached. Since the retrieved simulation model for this project is a static model, it is hard to test for adaptive planning. It is still possible to do a qualitative analysis on the adaptive planning by taking the uncertain futures into account. Besides adaptive planning, decision support contributes to putting the analysis outcomes in context and perspective. Decision support includes the trade-offs that have to be made between the preferences of the different stakeholders. Decision support should aim for *a posteriori* exploration of weighing different objectives of varying parties and looking at the robustness of the results over the deep uncertain future (Kwakkel & Haasnoot, 2018).

3. Case Operationalization

The EMA Workbench is designed using three key ideas (Kwakkel, 2017d):

1. The XLRM framework (Figure 2) is used to structure the relevant information (Lempert et al., 2003),
2. The simulation model is run as if it is a function and
3. The EMA Workbench is a taxonomy of robustness frameworks (Herman et al. (2015), which is also explained in the previous section.

For this project a simulation model on the flood risk of the IJssel river is given in Python, called ‘Dike model function’. Besides this file, another Python file is given, containing the specified uncertainties, policy levers and outcomes of interest (in different problem formulations), called ‘Problem Formulations’. This file will also be used for the analysis. The model is predefined by these two and other Python files. Also, available Excel files containing data, are used to specify the model. An explanatory specification of this model is provided in Appendix B.

This chapter focuses on explaining the different attributes of the XLRM framework as presented in Figure 2; the external factors (referred to as uncertainties) are defined in 3.1, the performance metrics (referred to as outcomes of interest), which are formed into actor specific problem formulations in 3.2, and the policy levers, the possible solutions for the problem, that will be formed into policies in 3.3.

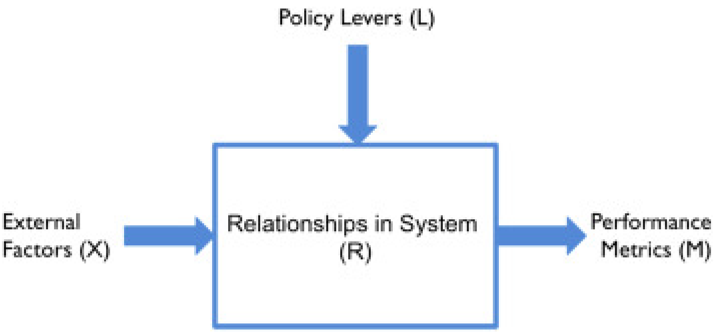

Figure 2. XLMR Framework (Lempert et al., 2003).

3.1 Uncertainties

All uncertainties in exploratory modeling are handled as external factors (Kwakkel, 2017d). An uncertainty can be one of three types of parameters: real, integer or categorical (Kwakkel, 2017b). The uncertainties in this case are predefined in the given simulation model and are the following:

(1) ‘Bmax’: maximum breach in meters (real and location specific)
(2) ‘pfail’: probability of failure (real and location specific)
(3) ‘Brate’: breach growing rate in meters per day (categorical and location specific)
(4) ‘discount rate’: discount rate to calculate the expected annual damage (categorical)
(5) 'A.0_ID flood wave shape': the type of flood wave shape upstream (integer)

For further analysis it is sometimes necessary to use a ‘reference scenario’, when the uncertainties need to be held constant. The following values are used for the ‘reference scenario’: {'Bmax': 175, 'Brate': 1.5, 'pfail': 0.5, 'discount rate': 3.5, 'ID flood wave shape': 4}. These values are not extreme values, but can be seen as an average scenario.

3.2 Outcomes of Interest and Problem Formulations

The outcomes of interest can be compared with the Performance Metrics (M) from the XLRM framework (Lempert et al., 2003). The outcomes are the output of the model and with the output, the solutions and policies presented in the next section can be measured. The outcomes of interest might differ per actor. First, the outcomes that are included in the predefined model are given and subsequently, different problem formulations are formed. This means that outcomes of interest are put together as a set of outcomes where a certain actor has interest in.

The following outcomes of interest are included in the retrieved simulation model and are preferred to be minimized:

(1) Expected annual damage per location
(2) Dike investment costs per location
(3) Expected number of deaths per location
(4) 'Room for the River' costs (total)
(5) Expected evacuation costs (total)

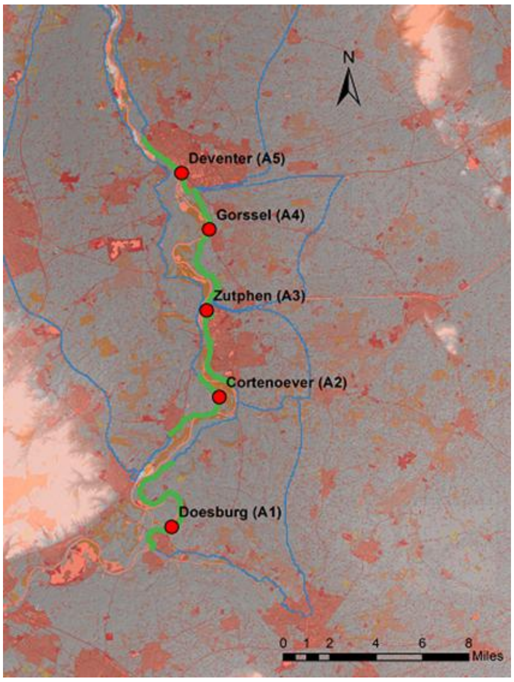

Figure 3. Project locations along the IJssel river.

The first three outcomes of interest are location specific. The following locations are taken into account: Doesburg (A1), Cortenoever (A2), Zutphen (A3), Gorssel (A4), Deventer (A5) (see Figure 3). The IJssel flows through these five locations and the solutions, as presented in the next section, have to be implemented in and around these cities. The last two objectives are measured for The Netherlands as a whole and so, they do not differ per location. As mentioned before, the outcomes of interest can be specified in different problem formulations. Some general problem formulations were pre-specified in the given 'Problem Formulations' Python file, though it is interesting to form actor specific problem formulations.

Reasoning from the Province of Gelderland it is interesting to look at the first three outcomes of interest for the four locations in the Province of Gelderland, which are

Doesburg, Cortenoever, Zutphen and Gorssel. In Table 1 the problem formulation with three outcomes of interest for the Province of Gelderland is given. As shown, the problem formulation is threefold: the expected annual damage (1), the expected number of deaths (annual) (2) and the dike investment costs (3) for project locations A1-4. A strategic choice could be to include the dike investment costs for project location 5 as well. This would contribute to the negotiation process as the second province could be more willing to cooperate when goodwill is noticed from the other party. Nevertheless, since Gelderland lies upstream of Overijssel, it is not sensible to take these costs into account from the start, but they can be used as a strategy later on in the negotiation. The ‘Room for the River’ costs are not taken into account in the problem formulations specific for Gelderland and Overijssel, since these are measured per project and not per location. Moreover, the costs will be carried by Rijkswaterstaat. However, Gelderland can decide to partially contribute to the ‘Room for the River’ project if this turns out to be beneficial for the province.

Table 1. Problem formulation for the Province of Gelderland.

Problem Formulation for the Province of Gelderland	
Doesburg (A1) Cortenoever (A2) Zutphen (A3) Gorssel (A4)	(1) Expected annual damage in A1-4 (2) Expected number of deaths in A1-4 (annual) (3) Dike investment costs in A1-4

To check whether the same policies work for the outcomes of interest for both provinces, a problem formulation is specified for the Province of Overijssel as well (Table 2). This problem formulation has three specific outcomes of interest for the city Deventer (A5) that is located in Overijssel. For Overijssel, it could be strategic to include the dike investment costs for locations 1-4, because Overijssel lies downstream of Gelderland, hence the measures upstream will affect the water flow downstream in Overijssel. Therefore, if Overijssel reaches out to Gelderland by offering to contribute to the costs upstream, it might be possible to realize a more beneficial outcome. This tactical consideration is elaborated upon in chapter 5.

Table 2. Problem formulation for the Province of Overijssel.

Problem Formulation for the Province of Overijssel	
Deventer (A5)	(1) Expected annual damage in A5 (2) Expected number of deaths in A5 (annual) (3) Dike investment costs in A5

Furthermore, Rijkswaterstaat and the Delta Commissioner are expected to have similar outcomes of interest, which is explained in the actor scan in Appendix A. Therefore, in the further analysis Rijkswaterstaat and the Delta Commissioner will be considered as one actor under the name of Rijkswaterstaat. For both these actors the total expected annual damage, the total investment costs and the total expected number of deaths for all locations together is important. The ‘Room for the River’ costs and the evacuation costs are measured for the total project. Since Rijkswaterstaat will pay for the whole project, these outcomes are of interest for Rijkswaterstaat. Rijkswaterstaat cares about the outcomes of the whole project, rather than location specific outcomes. This results in a problem formulation with three outcomes of interest and is shown in Table 3.

Table 3. Problem formulation for Rijkswaterstaat.

Problem Formulation for Rijkswaterstaat
(1) Total expected annual damage
(2) Total expected number of deaths (annual)
(3) Total investment costs = Total dike investment costs + Total 'Room for the River' costs + Total expected evacuation costs

For the environmental interest groups no problem formulation is formed, since there are no outcomes of interest specified in this model regarding the environment. The same counts for the transport companies, there are no outcomes of interest specified in their field. However, in chapter 5 will be explained how the objectives of these parties can still be taken into account in the decision making process.

3.3 Policy Levers and Policies

The main aim is to reduce flood risk of the IJssel river. Five different measures are designed to contribute to this goal and are included in the given simulation model. The extent of each measure has to be decided upon as well. The measures can be divided into two categories: protection and mitigation solutions. The different measures are as follows (Ciullo, 2018):

Protection

(1) Build or raise dikes
(2) Increasing capacity of the river bed ('Room for the River')

Mitigation

(3) Apply early warning systems
(4) Elevate buildings
(5) Raise awareness

A policy is a compound of policy levers in the EMA Workbench. A policy lever can be a range of real values, a range of integers or a set of categories, which are unordered (Kwakkel, 2017b). Not all the measures are defined in the retrieved simulation model. The policy levers that are included are as follows:

Policy Levers

(1) Increasing dikes per location (DikeIncrease from 0 to 10 dm)
(2) 'Room for the River' measures per strategy (RfR, 0 or 1 per strategy)
(3) EWS_daysToThreat (DaysToThreat from 0 to 4 days)

One of the measures is location specific and can be carried out independently: ‘DikeIncrease’. The ‘Room for the River’ measures are project specific, concerning the following projects:

Project 0: Olburgen (influences A1)
Project 1: Havikervaard (influences A1)
Project 2: Tichelbeekse (influences A2 and A3)
Project 3: Welsummer (influences A2, A3, A4 and A5)
Project 4: Obstakelverwijdering (influences A3 and A4)

By increasing or building dikes, flood occurrence is prevented since the resistance against the river has increased. RfR stands for ‘Room for the River’, which means the capacity of the river bed will be increased by for instance deepening the river (different strategies are presented in greater depth in chapter 5). EWS stands for Early Warning System; by warning people earlier for a potential flood, more people can be evacuated. However, too early evacuations can lead to a waste of money when in the end there is no flood at all.

The policy levers mentioned above will together be combined into policies. An example of a possible policy is the ‘Zero Policy’, in which for all locations the DikeIncrease, RfR and DaysToThreat all equal zero.

4. Analysis and Results of the Exploratory Modeling

In this section the analysis and results of the exploratory modeling are presented. The exploratory modeling is divided into four parts, as explained in the methodology section; open exploration (4.1), sensitivity analysis (4.2), scenario analysis (4.3) and robust optimization (4.4). The Python scripts and data used for all the analyses can be found in the folder “Scripts and Data” in the zip file, containing the name of the subsection and the analysis. Placing the documents from this folder in the latest updated ‘final assignment’ folder from ‘https://github.com/quaquel/epa1361_open’, makes it possible to reproduce the analyses.

4.1 Open Exploration

Firstly, an open exploration is executed for the retrieved simulation model[1]. There is chosen to compute 400.000 experiments, in which there is variated with 8.000 scenarios for 50 policies[2]. Even more experiments could be conducted, but due to time limits and computational power no bigger amount of experiments is run. The number of scenarios is much larger than the number of policies, because there are more possible combinations of uncertainties that form the scenarios than possible combinations of policy levers that form the policies. The uncertainty variables are mostly real parameters, while all of the policy lever variables are integer parameters. The chosen problem formulation for the open exploration contains all two outcomes of interest: ‘All Costs’, which is a combination of the twelve objectives of interest that have to do with costs for all locations together and ‘Expected Number of Deaths’, which is a combination of the expected amount of deaths over all the locations. This variable gives the expected *annual* number of deaths. There is chosen to take the combined outcome of interest for ‘All Costs’, since it is easier to interpret the high amount of experiments when not all the costs are taken into account separately. When coming to the optimization for specific actors, actor specific problem formulations are taken into account. The results of the experiments are saved[3] and are afterwards loaded in for visualization, interpretation and further analysis.

In Figure 4, the possible behavior of the dike model for the two outcomes of interest ‘All Costs’ and ‘Expected Number of Deaths’ is shown, using the results from the 400.000 runs explained above. The model shows in some cases that when the amount of deaths is relatively high, the total costs are also relatively high. But in most cases the number of deaths remains low when the total costs increase. These cases might refer to a situation where is invested in the dikes, ‘Room for the River’ and an Early Warning System, hence no flood occurred.

[1] See script: ‘*4.1 Open Exploration.ipynb’.*

[2] The experiments can be found in the file: *‘8000 scenarios 50 policies.tar.gz’.*

[3] The results can be found in the file: *‘8000 scenarios 50 policies.tar.gz’.*

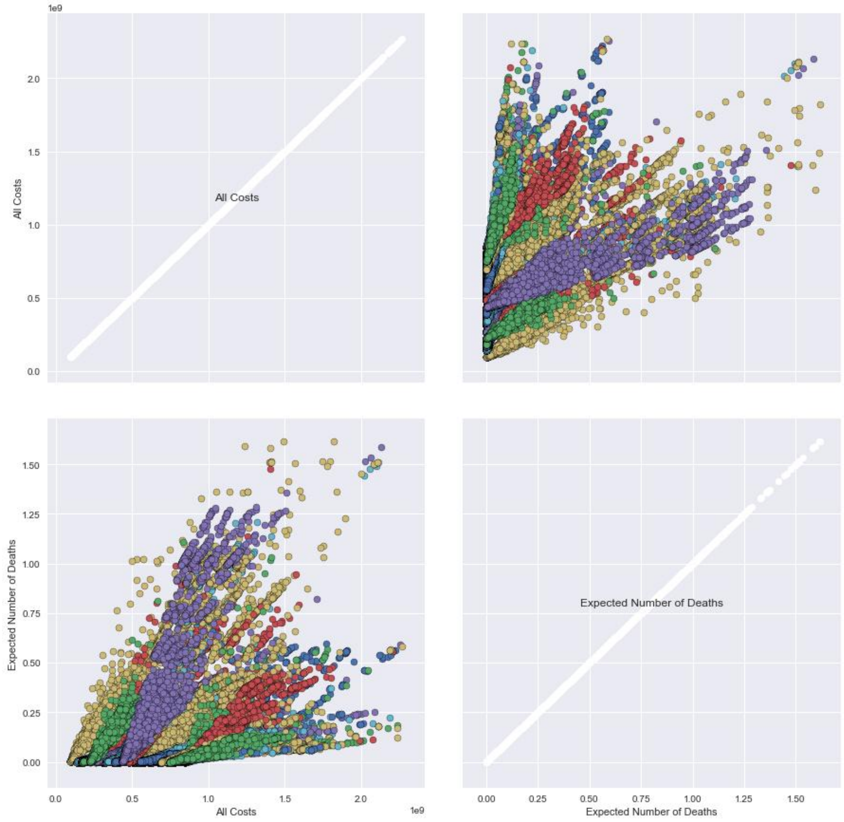

Figure 4. Expected costs and number of deaths for 8000 scenarios for 50 policies

The mean, maximum and minimum of the outcomes of interest are shown in Table 4. As appears from the open exploration, the maximum expected number of deaths does not exceed the national threshold (See Appendix C). However, the closer the number is to zero, the better. The total budget for the ‘Room for the River’ project is €2.300,9 million (see Appendix C), but since it is not entirely clear which part of the budget is meant to be spent on the IJssel, this will rather be seen as something that should be kept in mind than a constraint. For ‘All Costs’ it becomes evident that the total costs are distributed more equally over the experiments.

Table 4. Mean, maximum and minimum results for objectives

	All Costs (in millions euro)	Expected Number of Deaths
Mean	597	0.02
Maximum	961	1.62
Minimum	227	0.00

Besides this, also 100.000 experiments, existing of 4.000 scenarios and 25 policies are computed for the problem formulation that includes all 17 outcomes of interest[4]. This is done to check whether there are highly correlated outcomes of interest. When this is the case, it is possible to leave out one or more outcomes of interest for further analysis.

[4] The experiments can be found in the file: *‘4000 scenarios 25 policies 17 objectives.tar.gz’.*

High correlations (0,59 and higher) are found for the ‘Expected Number of Deaths’ and the ‘Expected Annual Damage’ per location[5]. This also explains why the high total costs in the exploration analysis often correspond to a high number of deaths, probably indicating that a flood has occurred which damages the buildings in the flooded area and also causes more deaths. For further analysis, it is possible to include only one of the two outcomes of interest per location, since it can be expected that the annual damage will be high, when the number of deaths are also high. Nevertheless, it is very important to ensure that the threshold for the ‘Total Expected Number of Deaths’ will not be exceeded while making these derivations, since the two outcomes of interest do not correlate fully. The total costs (‘All Costs’) include the ‘Expected Annual Damage’ costs and the ‘Total Investment Costs’. These are taken together in this analysis since this analysis just gives an indication of the magnitude of the costs that are involved in this case, and whether the costs are related to the ‘Expected Number of Deaths’. However, ‘All Costs’ is the sum of the ‘Total Investment Costs’ (in raising dikes and ‘Room for the River’ measures), which are only once, and the ‘Expected Annual Damage’ costs, which are calculated yearly. These costs thus have a different meaning. Therefore, for further analysis these costs will be split up. This has also been done in order to prevent confusion over the correlation of the ‘Expected Number of Deaths’ and the ‘Expected Annual Damage’ as explained before in this paragraph.

4.2 Sensitivity Analysis

As a start for the sensitivity analysis, a simple feature scoring is executed[6]. This is a relatively simple, hence computationally quick analysis, which gives a visual overview of the uncertainties and policy levers that have a large influence on the selected outcomes of interest. In this case the 200.000 experiments, existing of 4.000 scenarios and 50 policies over the three outcomes of interest; ‘Expected Annual Damage’, ‘Total Investment Costs’ and ‘Expected Number of Deaths’ is used[7]. In Figure 5 the feature scoring for these experiments is shown.

A few results stand out in the figure. Firstly, it becomes clear that the total investment costs are strongly influenced by policy strategy four of ‘Room for the River’, which influences the water level at location A3 and A4. This follows logically from this lever, since it includes the removal of obstacles, which raises the costs in comparison to applying ‘Room for the River’ in other locations (this can be seen in the data table ‘rfr.strategies’ also retrieved with the simulation model). Furthermore, the ‘Expected Number of Deaths’ is mainly influenced by the uncertainty ‘A.3_pfail’, which implies the probability of the dike to fail near Zutphen (A3). This can be explained since Zutphen has more inhabitants, compared to the other three locations, and the largest amount of people living close to the waterside (approximately 15.000 people live in districts close to the waterside; Enneman-Klein Bronsvoort, 2017). The ‘Expected Annual Damage’ is mostly influenced by the uncertainty ‘A.1_pfail’, which implies the probability of the dike to fail near Doesburg (A1). These high costs can be linked to the fact that Doesburg is an old fortified city with many monumental medieval buildings (Bezoek Doesburg, n.d.). It is important to note that the outcomes of interest are most sensible for the failures of dike A.1 and dike A.3, which are both located in Gelderland.

[5] The complete correlation table is derived using the Python script *‘4.1 Open Exploration.ipynb’.*
[6] To be found in the Python script *‘4.2 Feature Scoring.ipynb’.*
[7] The experiments can be found in the file: *‘3 obj 4000 scenarios 50 policies.tar.gz’.*

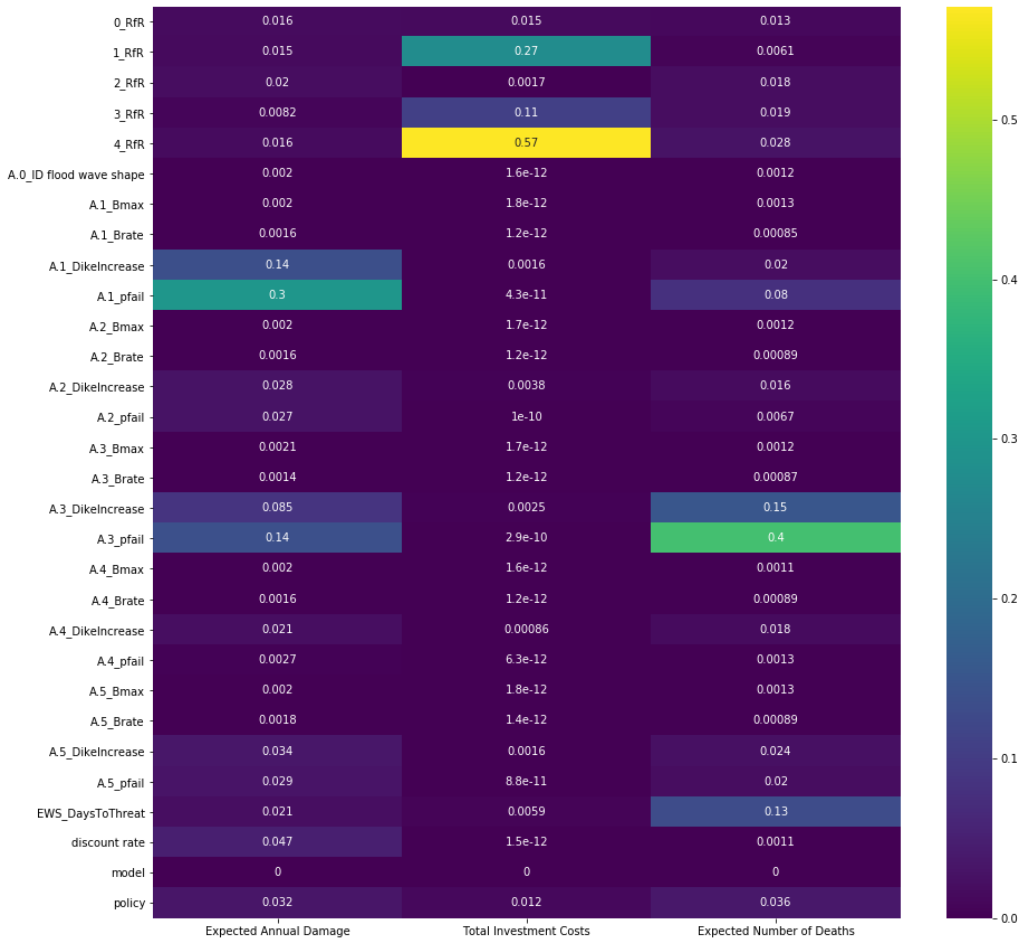

Figure 5. Results of Feature scoring analysis, showing sensitivity of fluctuating input on 3 objectives.

After the feature scoring analysis, a more extended global sensitivity analysis is performed[8] , using the method 'Sobol', as is explained in section 2.1.2. First, the sensitivity analysis is executed for the uncertainties, given one policy (the 'zero policy', as explained in section 3.3). 2.000 scenarios are run, which gets multiplied by 36 in the analysis (since there are 17 uncertainties and in this way all the interaction effects are taken into account) and this results in 72.000 experiments[9].

Subsequently, the same is done for the policy levers, given one scenario (the 'reference scenario, as explained in section 3.3). For this analysis 2.000 policies are run, which is multiplied by 24 in the analysis (since there are 11 policy levers and in this way all the interaction effects are taken into account) and results in 48.000 experiments[10]. In Table 5 the results of the sensitivity analysis varying the uncertainties for the outcome of interest 'Expected Number of Deaths' can be seen. Table 6 contains the results of the sensitivity analysis varying the uncertainties for the outcome of interest 'Expected Annual Damage'. Since the zero policy is applied, while varying the uncertainties, no influences on the 'Total Investment Costs' are present. For this, the results of the sensitivity analysis varying the policy levers for the outcome of interest 'Total Investment Costs' are interesting and are

[8] The sensitivity analysis can be found in the Python script: *'4.2 Sensitivity Analysis.ipynb'.*

[9] The experiments can be found in the file: *'sobol_uncertainties 3 obj 2000 scenarios.tar.gz'.*

[10] The experiments can be found in the file: *'sobol_levers 3 obj 2000 policies.tar.gz'.*

shown in Table 7. Likewise, the sensitivity to the policy levers for the other outcomes of interests is derived[11].

The index S1 represents the direct influence of the input variable on the outcome of interest, while the index ST stands for the influence of that input variable containing the direct and the indirect influence (of other input variables). For this analysis, the uncertainties and policy levers with a high S1 score are most interesting, since these variables should be prioritized during further analysis and formulation of strategies. Low ST scores indicate that an input variable has a negligible effect, hence these effects can be omitted.

Table 5. Sensitivity of uncertainties on expected number of deaths.

	ST	ST_conf	S1	S1_conf
A.3_pfail	0.650177	0.0368148	0.647257	0.0474043
A.1_pfail	0.285921	0.0162747	0.285597	0.0288324
A.5_pfail	0.0307837	0.00238254	0.0291654	0.0108496
A.2_pfail	0.0268751	0.00227038	0.0280738	0.00983735
A.0_ID flood wave shape	0.0109525	0.00144308	0.0135628	0.00726068
A.4_pfail	0.000230307	1.42996e-05	0.000259016	0.00107395

Table 6. Sensitivity of uncertainties on annual damage.

	ST	ST_conf	S1	S1_conf
A.1_pfail	0.625995	0.0412242	0.597647	0.0417649
A.3_pfail	0.216472	0.015355	0.203931	0.0301046
discount rate	0.139482	0.0133343	0.098049	0.0220572
A.2_pfail	0.0349961	0.00347577	0.0348592	0.0114293
A.5_pfail	0.0390776	0.00319389	0.0348385	0.0116097
A.0_ID flood wave shape	0.00790318	0.000890912	0.0094194	0.00607032
A.4_pfail	0.00116315	0.000104639	0.00106464	0.00230372

Looking at the S1 scores in the above tables, given the zero policy, the 'Expected Number of Deaths' and the 'Expected Annual Damage' are most sensitive to the probability that the dikes fail, especially the dike at location A3 and A1. This corresponds to the results from the feature scoring analysis. The uncertainties not given in the tables above ('Brate' and 'Bmax'), showed no influence on the outcomes of interest (this corresponds to the feature scoring results in Figure 5) and are therefore not relevant to discuss. When the breach is bigger, more water can flow out of the river to the land, but apparently this does not have a significant impact on the amount of deaths nor the annual damage. The 'flood wave shape' appears to have only a slight influence on the outcomes of interest as well. The 'pfail' for the different dikes has a relatively high impact on the outcomes of interest. The 'discount rate' has some influence on the 'Expected Annual Damage', because the discount rate has a direct impact on how the losses are discounted to annual damage.

[11] The results of the sensitivity analysis varying the policy levers for the other outcomes of interest can be found in the folder 'Visuals' within the handed-in zip file.

Table 7: Sensitivity of levers on investment costs.

	ST	ST_conf	S1	S1_conf
4_RfR	0.470062	0.0291605	0.465066	0.0366526
1_RfR	0.339979	0.0211237	0.340137	0.0285562
3_RfR	0.105278	0.00562923	0.10795	0.0176653
0_RfR	0.0504745	0.00285049	0.0513798	0.0140001
A.2_DikeIncrease	0.00970917	0.000783492	0.00979466	0.00585584
A.1_DikeIncrease	0.00905998	0.000679403	0.00805754	0.0058322
2_RfR	0.0067007	0.000391712	0.00683063	0.00540836
A.5_DikeIncrease	0.00327702	0.000267136	0.00405856	0.00406069
A.3_DikeIncrease	0.00185352	0.000157061	0.0018355	0.00243286
A.4_DikeIncrease	0.00042442	3.23967e-05	0.000524074	0.00110536
EWS_DaysToThreat	7.46095e-12	1.07248e-12	-7.13011e-08	1.35026e-07

Looking at the S1 scores in Table 7, given the reference scenario, the outcome 'Total Investment Costs' is most sensitive to the costs for the 'Room for the River' projects, especially project 4 (which came forward in the feature scoring as well). The negative value for the policy lever 'EWS_DaysToThreat' should not be a negative value and is the result of a limited sample size. Due to time limit there is decided not to execute the analysis again with a bigger sample size, also since the negative values are expected to have very low, almost zero, indices. Besides, it is expected that many more samples are needed before the negative values will be solved. The S1 scores for the outcomes of interest 'Expected Number of Deaths' and 'Expected Annual Damage'[12], given the reference scenario, indicate that both are sensitive to an increase of dike A3 and A5. Furthermore, the 'Expected Number of Deaths' is sensitive to Early Warning Systems, but the 'Expected Annual Damage' not, which is a logical result.

4.3 Scenario Discovery

Scenario discovery is executed by using PRIM[13]. For this analysis, five thousand experiments over three outcomes of interest, given the zero policy are used[14]. First of all, is decided what would be the threshold to 'accept' certain outcomes of interest, since there are only a few cases in which the aforementioned threshold is exceeded for the number of deaths per year (Appendix C) and for the annual damage it is difficult to specify a threshold since there are no hard constraints given by Rijkswaterstaat. Therefore is chosen to accept the 30% approximately highest scoring outcomes. The 'Total Investment Costs' are not included in this analysis since the uncertainties have a negligible influence on the 'Total Investment Costs', as is concluded already from the feature scoring shown in Figure 5.

[12] These S1 scores can be found in the folder 'Visuals' within the handed-in zip file.
[13] The PRIM analysis can be found in the Python script: *'4.3 Scenario Discovery.ipynb'.*
[14] These experiments can be found in the file: *'5000 scenarios policy0.tar.gz'.*

After that, for both the outcomes of interest the PRIM analysis is executed, with a threshold equal to 0.8, which stands for the desired coverage (Kwakkel, 2015). When looking at the 20th box for the analysis for both the 'Expected Number of Deaths' and the 'Expected Annual Damage' (this box has a coverage and density larger than 80%) the following conclusions can be extracted:
For both the outcomes of interest the probability of failure of dike A1 ('A.1_pfail') is found to be significantly more influencing on the results than other uncertainties. Furthermore, the failure of dike A3 ('A.3_pfail') is found to have a significant impact as well, but only for the 'Expected Number of Deaths'[15].

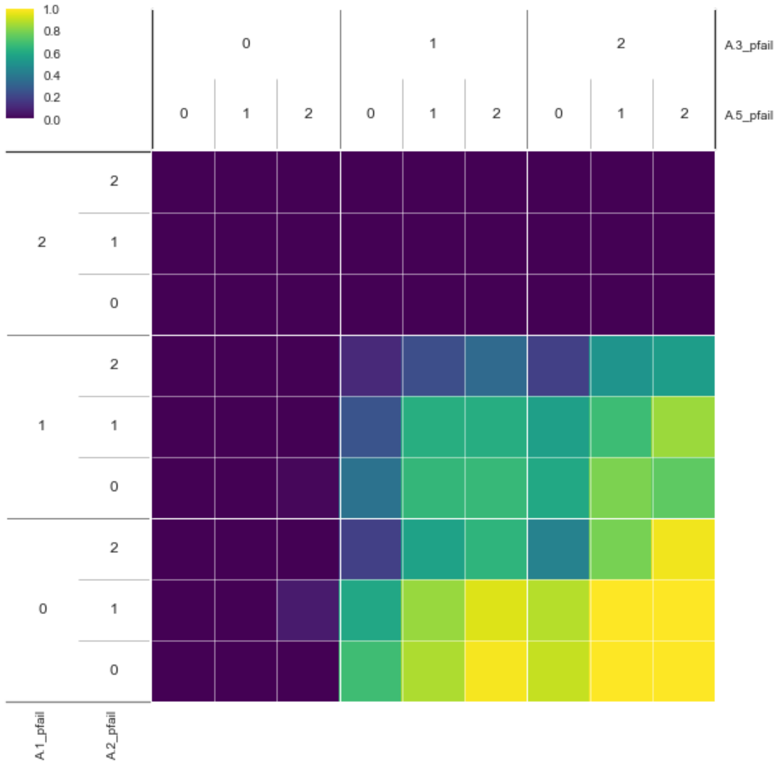

Figure 6. Dimensional Stacking for the outcome of interest 'Expected Number of Deaths', given the zero policy.

The results of the PRIM analysis are also used to visualize the impacts differently, using dimensional stacking. Dimensional stacking shows the combinations of uncertainties that drive results. Since similar results come forward for both the outcomes of interest, only the results are shown for 'Expected Number of Deaths' in Figure 6[16]. It can be concluded that a high probability of failure for dike A1 in combination with a high probability of failure for dike A3 (values equal to two) are no drivers for the 30% highest scoring results. This implies they do not have a desired effect on the 'Expected Number of Deaths' and 'Expected Annual Damage'. Furthermore, when the probability of failure for dike A1 is low, a high probability of dike A3 can still give desired outcomes of interest. This means, that it is not always necessary to have low failure probabilities for all dikes, in order to get desired outcomes.

[15] The results and visualisation can be found in the Python script: *'4.3 Scenario Discovery.ipynb'* and in the folder 'Visuals' within the handed-in zip file.
[16] The other visualisation can be found in the same Python script and folder.

From the sensitivity analysis and scenario discovery, it can be concluded that mostly the probability of the dike failures (especially A1 and A3) and the discount rate for the 'Expected Annual Damage' influence the outcomes of interest and should be taken into account when designing scenarios for the optimization.

4.4 Robust Optimization

The framework MORDM is used for the robust optimization and for this framework it is necessary to start with defining a problem formulation that contains the desired outcomes of interest. Till now, the predefined problem formulations from the dike model have been used for the analysis. For the optimization it is more interesting to use the actor specific problem formulations as explained in section 3.2. In the beginning of the optimization, the problem formulation for the Province of Gelderland will be used. Here it should be noted that the dike investment costs are added as outcome of interest. Without this addition, the most expensive solutions, resulting in zero casualties and zero damage will always come forward as best, whereas they might not be realistic in terms of costs. Later on, when robust candidate solutions for the Province of Gelderland are found, an analysis will be done to check whether these robust candidate solutions are also in favor and on the Pareto front of the Rijkswaterstaat and the Province of Overijssel.

First, the right problem formulation for the Province of Gelderland is loaded into the Python scripts[17], after which the direct search is started. Since the policies will be tested upon one scenario in the direct search, this analysis is performed three times. First, solutions are sought for the worst-case scenario, then for the best-case scenario and finally for the reference scenario as specified in section 3.1 (see Appendix D.1 for further specification of the scenarios). For the direct search an epsilon of 0,05 and a number of function evaluations of 10.000 is used. This results in a nicely converged plot, which indicates that these settings are adequate. These graphs can be found in Appendix D.2.

Gelderland: preferred solutions

Naturally, the worst-case scenario is more demanding than the best-case scenario. This explains why only one or two solutions are found for the first, whereas for the latter more than hundred solutions appear to be appropriate. The reference scenario follows in between, with little more than twenty-five solutions. The solutions for the worst-case scenario show the trade-off between the three outcomes of interests nicely: high investment costs results in zero expected annual damage and number of deaths, whereas zero investment costs results in high expected annual damage and casualties (see Figure 7).

[17] This concerns the scripts: '*4.4 MORDM Gelderland Best Case Scenario.ipynb*', '*4.4 MORDM Gelderland Worst Case Scenario.ipynb*' and '*4.4 MORDM Gelderland Reference Case Scenario.ipynb*'.

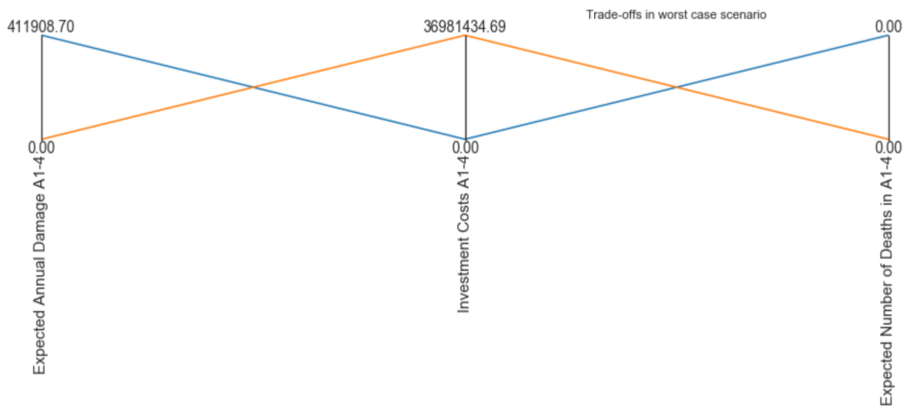

Figure 7. Trade-off between outcomes of interest for Gelderland in worst-case scenario.

Since the two proposed solutions are selected only based upon the worst-case scenario, it is interesting to know whether similar policies come forward as solutions in the best-case and the reference scenario. In order to get a grip on the trend in solutions in the worst-case scenarios for Gelderland, the direct search in this particular scenario is performed three times. These outcomes are presented in Appendix D.2. In general, the solutions show that investment in a two or three day Early Warning System is combined with four out of five ‘Room for the River’ projects, which can be explained by the fact that the costs for the ‘Room for the River’ projects are not included in the problem formulation of Gelderland. When one of these projects does not come forward in the candidate solution, it is always the first or the second. Also, a dike increase in Deventer (A5) comes forward as a good addition, which can be explained since the costs for this dike heightening are not included in the problem formulation of Gelderland.

Robustness throughout other scenarios and objectives

Solutions are robust, when they are also suitable in other scenarios and for other actors. The type of solution, as described above can also be found in the solution set for the reference scenario and the best-case scenario, therefore it is robust throughout extreme scenarios. Secondly, the solutions are tested over 1.000 scenarios, after which the signal-to-noise ratio is calculated. The signal-to-noise ratio is a metric for robustness, since it represents the size of the standard deviation, compared to the mean, taking into account whether this mean should be preferably minimized or maximized[18] (Box, 1988). This shows for example that the uncertainty about the ‘Expected Annual Damage’ is large, since the metric gives a very large number, indicating a large standard deviation (see Figure 8).

[18] When an outcome of interest should be maximized, the signal-to-noise ratio is obtained by dividing the mean over the standard deviation. Conversely, when an outcome of interest is preferably minimized, the signal-to-noise ratio is calculated by multiplying the mean with the standard deviation, resulting in a larger uncertainty-range (Box, 1988).

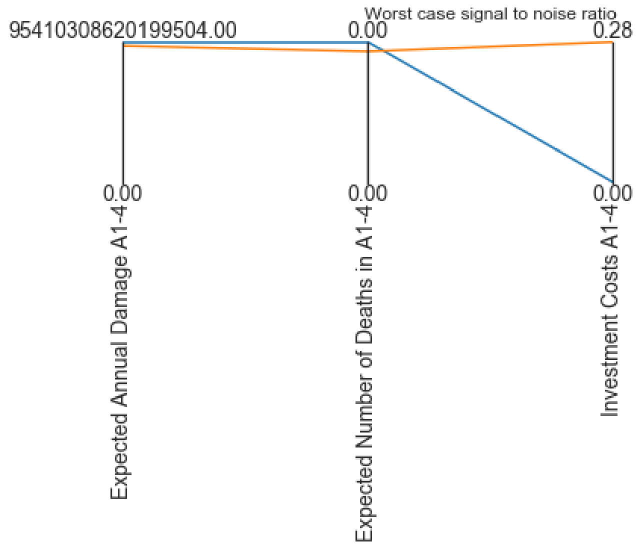

Figure 8. Signal-to-noise ratio representing uncertainty ranges for the outcomes of interest for Gelderland.

Now the robustness through multiple objectives remains. While in the reference and best-case scenario, the Early Warning System is always equal to at least 3 days, this is also chosen for further testing. Two sets of solutions will be tested for robustness in multiple scenarios for Rijkswaterstaat and Overijssel. These are specified as follows:

Solution 1:
- Increasing dike at location A5 with 4 dm
- 'Room for the River' measures 1-4
- Early Warning System, 3 days to threat

Solution 2:
- Increasing dike at location A5 with 4 dm
- 'Room for the River' measures 0 and 2-4
- Early Warning System, 3 days to threat

However, it is expected that Overijssel will prefer a solution where no increase in the dike at location A5 (Deventer) is realized, since this is the only dike they have to pay for (following the assumptions made for the actor specific problem formulations). Therefore, the same solutions are added to the solution set once more, but then leaving out the increase of the dike at location A5 (Deventer).

Figures 9 and 10 show the maximum regret for each of the solutions for Rijkswaterstaat and Overijssel. The maximum regret is obtained by testing the solution throughout 1.000 random scenarios[19], and shows for each outcome of interest on a scale from zero to one how much worse one solution is compared to the best. Indeed, Overijssel experiences higher costs when the dike at location A5 (Deventer) is increased, indicated by a higher regret for these two solutions. Otherwise, it would have a clear preference for non-increasing the dikes in terms of expected damage and deaths. For Rijkswaterstaat, the preference is less straightforward. It also recognizes the least expected damage and deaths when the dike at location A5 (Deventer) is increased, and 'Room for the River' measures

[19] The experiments can be found in the files: *'MORDM_reevaluation_OVERIJSSEL.tar.gz'* and *'MORDM_reevaluation_RIJKSWATERSTAAT.tar.gz'*

zero and two to four are realized. However, the costs will be higher compared to the same case solution, but then excluding heightening the dike at location A5 (Deventer). Combining both objectives equally, policy 2 comes forth as best in Figure 9, corresponding to solution 2.

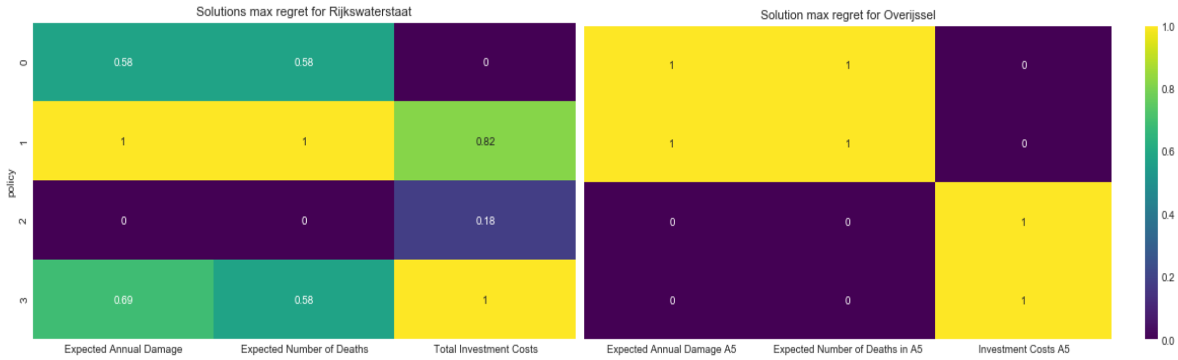

Figure 9 and 10. Maximum regret for each of the solutions for Rijkswaterstaat (left) and Province of Overijssel (right).

Furthermore, a scenario discovery using the PRIM algorithm is executed the same way as in paragraph 3.3, but then for 'policy 2' for the problem formulation of Gelderland, to investigate how this policy will be influenced by the uncertainties[20]. For both the outcomes of interest 'Expected Number of Deaths in A1-4' and 'Expected Annual Damage A1-4' approximately 30% of the best outcomes are driven by probabilities of failures of the dikes at locations A1, A2 and A3. Low probabilities are desired to get the best outcomes, but since the 'Expected Number of Deaths' is already sufficiently low in all cases, it will not exceed the threshold in any case. For the 'Expected Annual Damage A1-4' it is more difficult to say this, since no threshold is known and for the 'Investment Costs A1-4' no PRIM analysis could be conducted, since no investment by the Province of Gelderland is included in this policy[21].

Overijssel and Rijkswaterstaat: preferred solutions in worst-case scenario

Since the proposed solution is developed, based on the preferences of the Province of Gelderland, it is interesting to research whether Rijkswaterstaat and the Province of Overijssel would have found similar solutions if their preferences had been leading from the start. Therefore, a disrect search in a worst-case scenario is also executed for these actors (the resulting solutions are presented in Appendix D.2). These analyses showed that Overijssel also has many 'Room for the River' measures in its Pareto-front, though combined with multiple dike increases. Again, this can be explained by the fact that costs for increasing dikes one until four are not for that province. Rijkswaterstaat conversely seems to prefer no investments in 'Room for the River' projects, accepting more casualties and damage costs on its Pareto-front. This can be explained because of the high costs of the 'Room for the River' projects compared to the dike raising, which already came forward in Figure 5 (Feature Scoring). This does not correspond with the actor scan in Appendix A, where is stated that Rijkswaterstaat prefers the 'Room for the River' projects over increasing dikes. This probably has to do with the fact that in the model the long term benefits of the 'Room for the River' projects are not taken into account. Where the preferences for an Early Warning

[20] The PRIM analysis can be found in the Python script: *'4.4 Scenario Discovery of Best Solution.ipynb'*, the results can be found in the file: *'PRIM_bestsolution.tar.gz'.*

[21] Visual representations of the PRIM analysis can be found in the folder 'Visuals' within the handed-in zip file.

System by Overijssel are ambiguous, Rijkswaterstaat clearly has no preference for this measure. Again, this could be explained by the short-term vision in the model.

Concluding, when Gelderland gets to propose a set of solutions, Rijkswaterstaat and the Province of Overijssel would agree on their preference within this set. However, if one of them gets to propose a set of solutions, these would be very different. The robustness through multi-objectives is therefore not very big. It would be interesting to see if for example the preferences of Rijkswaterstaat for no 'Room for the River' investments would also sustain when a larger time horizon is considered, since annual damage costs might exceed the investment costs. Also, as stated before, the division of costs in this model is not extensively included. This could impact the trade-offs and therefore also the preferred solutions, this will be discussed more thoroughly in the next chapter. Furthermore, it should be noted that robust optimization is an iterative process, still the solution is sensitive to some uncertainties and the search for a robust solution could be an infinite process of optimization.

5. Adaptive Policy and Decision Support

The solution, that follows from the analysis in favor of the Province of Gelderland, will not align to future states of society. In former times, this solution would be labeled as the best, since it was assumed that the future had been taken into account, and so to say had been predicted (Haasnoot et al., 2013). However, there are certain factors that are not included in the model but which do have an influence on how solutions will withstand in the future. These factors include for instance stakeholders who are not taken into account in the model, but are influenced by the project. Other factors are external factors such as increasing climate change, water distribution over the Rhine and land use that enlarges flood risk. All these external factors are of deep uncertainty, leading to a situation in which no measures can be taken right now to respond to them, but letting these depend on future states. The conditions under which an action to change the current plan has to be made, is called a trigger, and are specified during the creation of an adaptive policy.

To address these deep uncertainties and specify the triggers and corresponding action plans, one needs to design so called dynamic adaptive plans (Haasnoot et al., 2013). To guide future actions, the dynamic adaptive policy pathway approach (DAPP) will be applied. The DAPP will create a strategic vision on the future containing proactive and reactive actions for the river IJssel flood problem (Haasnoot et al., 2013; Ranger et al., 2010).

In paragraph 5.1, the influence of these uncertain future states and the adaptation to these will be explained. In paragraph 5.2, the impacts of the project and the solutions on other stakeholders will be explained, to support the decision that is preferred by Gelderland

5.1 Dynamic adaptive policy

The simulation model as used in this project is static, which makes it difficult to analyze dynamic adaptive planning quantitatively. Nevertheless, the analysis can still provide insight in the adaptive policy architecture that might be necessary for the flood risk management. The steps that should be followed for DAPP, are presented in Figure 11. The main external factors, as mentioned in the introduction, are climate change, land use and water distribution over the various branches of the Rhine. For adaptive planning, it is important to understand under what conditions, which policy levers should be influenced in what way (Hamarat, 2014).

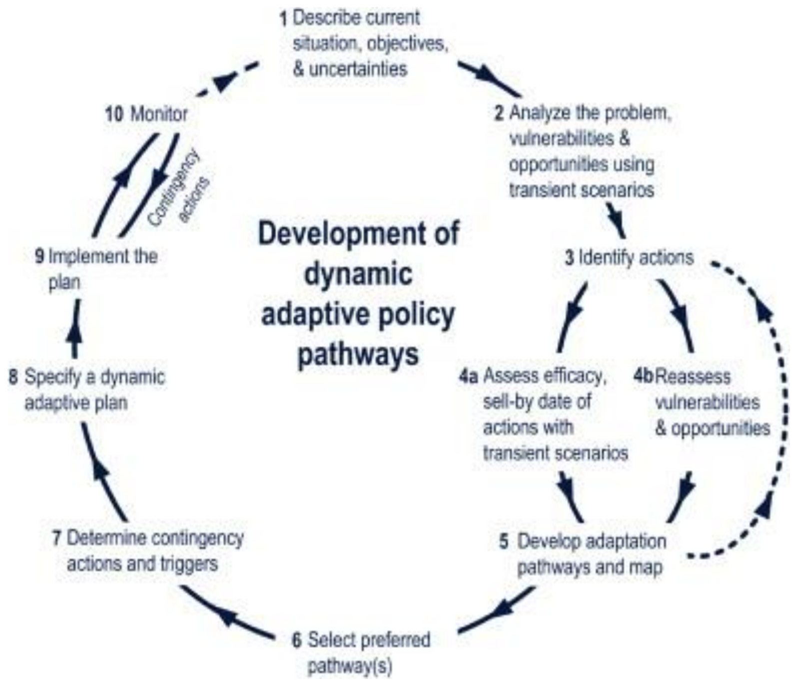

Figure 11. Schematic overview of the design of dynamic adaptive policy pathways (Haasnoot et al., 2013).

Scenarios for external factors and their development over time

Climate change

Climate change has led to an enlargement of risks related to rainfall, temperature, the disruption of ecological systems and runoff patterns (Palmer et al., 2009). The amount of ecological change and the risk on floods will depend on the rate of temperature change, which varies regionally (Palmer et al., 2009). Table 8 presents the different climate change scenarios until 2100.

Table 8: Climate change and sea level rise scenarios for 2100 (Kwadijk et al., 2010).

	Smallest		**Largest**	
	Winter	**Summer**	**Winter**	**Summer**
Temperature change	+1.8	+1.8	+4.6	+5.6
Rainfall charge (%)	+8	+6	+28	-38
Evaporation change (%)	0	+6	0	+30
Sea level rise (cm)	30	30	105	105

Table 8 shows that in the worst case scenario, in 2100 the sea level rise is 105 cm, which has direct influence on the flood risk of the river IJssel. A higher sea level causes higher discharge capacity. Together with an increasing rainfall charge in the winter, this causes a rise in water level of the river IJssel.

Water distribution over the IJssel (branch A) and the other branches of the Rhine

The Rhine has three distributaries; lake Lek, -Waal and -IJssel. With the Rhine as the largest contributor to the water flow of the IJssel, the IJssel has to transport surpluses of the Rhine (Glaser et al., 2003). A rise in the discharge of the Rhine therefore can create a problem for the available capacity of the IJssel. In times of very high discharge volumes, water should be distributed over the branches of the Rhine according to its capacities. Study shows that if climate change takes on drastic forms (Table 8), there is a large chance of the Rhine exceeding its discharge thresholds (18000 m3/s) between 2040 and 2045 (Rijkswaterstaat 2011).

Land use

As previous studies have shown, rapid land use change aggravates the frequency and severity of floods (Tollan, 2002). Land use is going to transition in the following 100 years in the form of urbanization, de-urbanization, sustainable growth and the expansion of nature (Kwakkel et al., 2015). The growth of flood risk is mainly a consequence of deforestation, urbanization and extensive cultivation. Urbanization and deforestation lead to a decrease in vegetation with larger runoff as an effect. The runoff is caused by the absence of vegetation that previously held down the soil during heavy rains where the soil absorbed (most) excess water (Dijk, 2009). Besides the decrease in absorption, the relatively smooth impermeable surface allows floods to take place more easily. At last, besides the effect on flood frequency and -severity, urbanization can also lead to more people being affected by a flood due to a higher population density at the flooded area.

Anticipating on the future

The possible future scenarios as described in the previous section will influence the effectiveness/suitability of all described policy levers. It is important to predefine corrective actions to handle vulnerabilities and/or opportunities that arise from these scenarios.

For example, when climate change will take on these extensive forms, this has an effect on all previously implemented proactive policies. The ‘Room for the River’ measurements have to cope with more water that exceeds the river bank, covering water storage areas and winter beds. A reactive measure for this would be to restore or increase the protection of floodplains.

Furthermore, erosion resulting from land use can be act upon immediately by deploying river restoration projects (Haasnoot et al., 2013). Concerning demographic changes caused by population growth, it is important to keep in mind that current thresholds for the maximum number of people to die from a flooding per year, will be reached more easily since more people will be affected. Therefore, EWS will become of even greater importance (even though the presented solution already has a value of three days); the evacuation of a large amount of people will take more time and therefore the days to threat should be increased.

Lastly, in terms of dynamic adaptive pathways, increasing dikes is a measure that will create a lock-in situation and therefore is not in line with the dynamic adaptive policy approach. Dikes are large investments with a big environmental impact, leading to path-dependency and lock-in situations. This does not mean that dikes are not a good possible solution, but it should be taken into account that the choice of current decision-makers, can limit the possible choices for future decision-makers (Gerrits et al., 2008).

Adaptation pathways with sequence of promising actions

As said before, the model should be made dynamic to examine the behavior of outcomes of interest as an effect of different policies in different scenarios. Once this transition has been made, the adaptive pathways can be determined. A visualization such as presented in Figure 12, will help to choose preferred pathways. Subsequently, when a trigger is reached in a certain scenario, predefined action plans can take effect immediately (Haasnoot et al., 2014).

Examples of constraints where triggers will be formed around:

- The water exceeding a certain level
- The population living around the river exceeding a certain number
- Erosion taking on a certain level
- Rainfall exceeding a certain level
- Number of days the river expands to the winter beds exceeding a certain number
- Discharge of the river exceeding a certain point

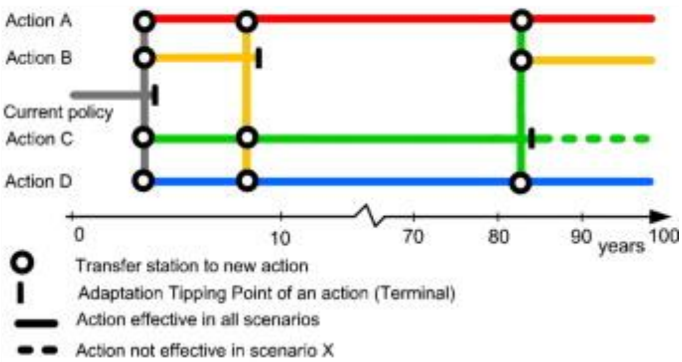

Figure 12. Adaptation pathways map (Haasnoot et al., 2013).

Monitoring the DAPP

Once the dynamic adaptive plans have been formed, there should be a monitoring system to keep notion of triggers and holding on to desired policy pathways (Haasnoot et al., 2013). In order to follow the predetermined policy pathways and strategies, a new level of cooperation and coordination among all involved actors will be essential (Palmer 2009).

5.2 Decision Support

For Gelderland, increasing the dike at location A5 (Deventer) with 4 dm, an Early Warning System with 3 days to threat and 'Room for the River' measures 2, 3 and 4 and variably 0 or 1 is the preferred solution for now. However, for Rijkswaterstaat and Overijssel this is not a solution of first choice. It is important for Gelderland as a province to be aware of the preferred solutions of other involved actors and how the preferred solution for Gelderland can be presented to other actors in the best possible manner. It might also help to propose solutions that show that the interests of the other actors are also taken into account. This will strengthen the position of Gelderland in deliberation with the other actors during the decision-making process. Furthermore, the measures proposed in the solution all have beneficial influences for Gelderland and subsequently 'Room for the River' measure three has a beneficial influence for Overijssel (datatable 'rfr_strategies' retrieved with the dike model), but is expensive for Rijkswaterstaat to implement 'Room for the River' measures.

However, as mentioned already in paragraph 4.4, Rijkswaterstaat has stated to prefer 'Room for the River' over dike increase (Appendix A), so there is a possibility to get them on board. A trade-off that Gelderland and Overijssel can make is to contribute to the investment costs, showing Rijkswaterstaat their willingness to deliberate.

First of all, dike creation and elevation contributes to lowering the probability of flooding. However, this measure comes with risks as dikes can fail which can lead to floods larger than the original flood (Plate, 2002). Moreover, dikes sometimes are seen as an insult to the landscape, as small villages are blocked from previous direct connection to the waterside (Van Eeten, 1999). Therefore, and because of contradiction with adaptive policy design as described in chapter 5.1, dike increase should be held to a minimum.

Secondly, the 'Room for the River' policy lever focuses on the increase of the river bed capacity. The chance of floods will decrease as room for the river makes higher discharges possible to be conveyed into the river (Rijke, 2012). Figure 13 shows the measures that are represented by the 'Room for the River' policy lever. Because claims on space are embedded in these measures, coordination between provinces will be important. Furthermore, 'Room for the River' can contribute to the attractiveness of an area for both inhabitants and tourists, as it can be combined with enriching the area with recreational possibilities.

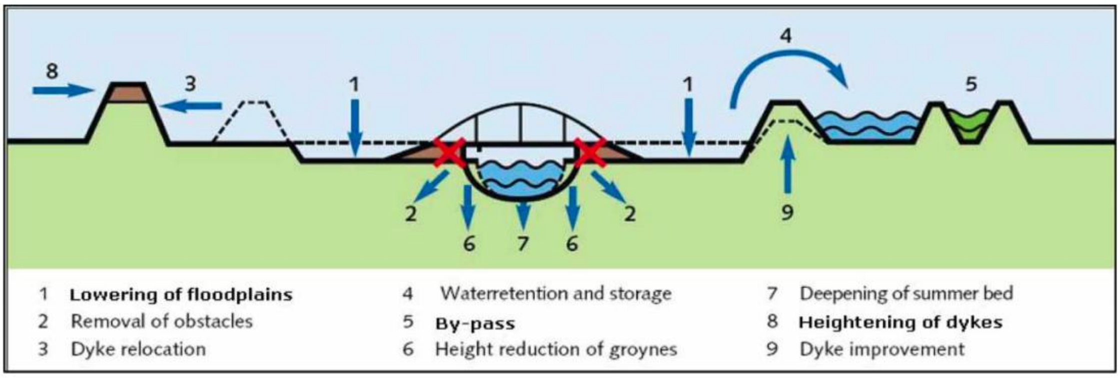

Figure 13: Measures that are applied in Room for the River (Rijke, 2012).

Having effective flood Early Warning Systems (EWS) is an important component to manage flood risk. An EWS focused on people living in an area with flood risk, contains of three key elements: risk knowledge/prediction through monitoring and analysis, communication of warnings and local possibilities to respond to the warnings in a proper manner (Basher, 2006). Only if all these components are in place, EWS will be effective (Comiskey, 2015). Therefore, the optimal three days to threat should be taken seriously and implemented in the EWS, in combination with the right monitoring and communication system.

Lastly should be taken into account that more stakeholders, like environmental groups and transport companies (as already mentioned before), can oppose against the solutions proposed by the Province of Gelderland. While some previous 'Room for the River' projects have created more nature (Beintema, 2016), there still is a challenge in getting one-issue parties on board (Warner & Van Buuren, 2011). Transport companies can oppose the plans if the 'Room for the River' solution creates nature where big transport ships are not allowed to go. Environmental groups might on the other hand propose the 'Room for the River' solutions and try to block future dike raisings. Since in the simulation model the outcomes of interest of these stakeholders are not taken into account it does not mean these stakeholders should be forgotten in the decision-making process.

6. Conclusions and Advices

In this report a model-based approach is used in order to develop an advice for the Province of Gelderland on how to cope with the flood risk in the areas around the IJssel river, given the possible future developments. The research question that has been answered in this report is the following: *“What are the most robust strategies the Provincial Government of Gelderland can use in its own interest to convince the other stakeholders to adapt a policy that has a positive effect on Gelderland (given the uncertain future)?”*

Based on the model outcomes, there are several measures that Gelderland want to be taken to protect their inhabitants against the water to prevent flood damage and deaths. The best possible solution for Gelderland would be to implement ‘Room for the River’ measures 2, 3 and 4 and variably ‘Room for the River’ measure 0 or 1. Besides this, Gelderland prefers to implement a system that sends out warnings three days in advance and to raise the dike in Deventer with 4 dm. However, some remarks have to be made, based on the way the model has been used. First of all, the ‘Room for the River’ solutions and the Early Warning System are the policy levers that, in contrast to dike raisings in Gelderland, the Province of Gelderland does not have to pay for. Therefore it is self-evident that these solutions derive from the model as the preferable policies for Gelderland. Moreover, the assumption in the model that Gelderland does not financially contributes to dike raising in Deventer, leads to dike raising as a dominant solution for Gelderland at that location.

For other involved actors, contradicting criteria are important. The Province of Overijssel preferably does not want to increase the dike in A5, since there is assumed they will have to contribute financially. They do not have to contribute to dike raisings in Gelderland and therefore they prefer dike raisings in A1 until A4, combined with two or three ‘Room for the River’ options to guarantee safety in Deventer.

Rijkswaterstaat is the actor that has to pay for all solutions, although provinces can decide to contribute financially to their preferred solutions. Rijkswaterstaat prefers dike heightening above an Early Warning System and ‘Room for the River’ measures since the latter two are more expensive. However, the Early Warning System could be a valuable contribution to the normativeness of a solution, since it can save many lives in case of a flooding. Moreover, Rijkswaterstaat declared to the Ministry of Infrastructure and Water Management that it prefers ‘Room for the River’ solutions above dike raising (Rijksoverheid, 2018, Appendix A). This is because heightening dikes can create a lock-in: once you start raising dikes, ‘Room for the River’ projects will only get more expensive in the future. This potential lock-in is something that Gelderland can emphasize during the negotiation process to convince Rijkswaterstaat to implement ‘Room for the River’ measures, starting with projects 2, 3 and 4. Adaptivity of solutions is of great importance, since external factors can influence the situation in such ways that policies have to be adjusted significantly. As once written by Giuseppe Tomasi di Lampedusa: ‘*For everything to stay the same, everything must change’.*

A remark has to be made regarding the actors that have been involved in this analysis. In the model, single-issue actors like environmental groups and transport companies that make use of the IJssel river, are not included. Hence, their preferences are not included in this analysis. However, this does not mean they are excluded from the decision making arena. Therefore it is advisable to conduct research to their preferences and resources as well.

7. Future Scope

Because of limited amount of time, computational capacity and scope of the project, not all interesting aspects are researched, therefore a short list with possible further investigations is presented below:

- It could be interesting to take into account the influences of policy decisions in other countries where the IJssel flows through (for example: Germany). It might influence the outcomes of interest for the Dutch stakeholders.
- In the model nothing is defined about the costs of maintenance. All the investment costs are one-time only and do not seem to include any costs of maintenance. Since the model is static, it is understandable that these costs are not taken into account, but when trying to construct robust adaptive policy it could be interesting to take maintenance into account as well.
- For now, no policies or outcomes of interest were added to the dike model. Still it would be interesting to include outcomes of interest for environmental groups and transport companies. Also it would be interesting to split up the costs for 'Room for the River' strategies, since provinces are willing to invest in certain projects. Moreover, it would be interesting to see if contribution to 'Room for the River'-funding by provinces would make this appear amongst the preferred solutions for Rijkswaterstaat.
- In any run, more experiments could have been conducted, or other sampling methods could have been used, such as independent methods like Monte Carlo. Also, the experiments could have been run in different batches, with different random seeds.
- In the Multi-Objective Robust Optimization, three scenarios are identified. The worst-case and best-case scenario have a probability of dike failure equal to 1 and 0 respectively. However, in the dimensional stacking analysis it came forward that the probability of all five dikes failing simultaneously does not necessarily have a higher impact on the outputs of interest. Moreover, it makes sense to argue that for each dike the probability of failing is not exactly equal to 1, hence the probability of all dikes failing simultaneously could not equal 1. Furthermore, it is possible to give the probability of failure a different value per dike within one scenario. In this project this is not included, but it could be interesting to see what is the result of a scenario with only a high probability of failure of the dikes that have the most influence on the outcomes of interest ('pfail_A.1' and pfail_A.3').
- The optimization algorithm should be executed multiple times, since Python deals with a random seed, and therefore the results might differ slightly when the algorithm is run multiple times. Even though the optimization algorithm is executed for a worst, best and reference case it might be possible to have slightly different results when all of the optimizations were executed multiple times.

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Appendices

Appendix A. Actor Scan

In the IJssel river flood risk case, the four most important actors are the Delta Commissioner, Rijkswaterstaat, and the two involved provinces: Gelderland and Overijssel. In this appendix these four actors will be discussed to determine what their position is in the playing field. There will be special focus on why these actors are involved, their view in the problem, and which actor is paying for which solution. Based on this information it will be elaborated what their desired policies are and which actors have the same view as the province of Gelderland and under what conditions. Also their resources will be discussed. This information can be used in the negotiation process with the other stakeholders.

First of all, there is the Delta Commissioner. The Delta Commissioner has been appointed by the Dutch government after the Delta Commission, a temporary commission that existed from 2007 to 2008, advised the government to do so (Deltacommissaris, n.d.). The Delta Commissioner is set up to protect The Netherlands from flooding. Therefore, the Delta Commissioner yearly provides the national government with a report, called 'the Deltaprogramma', on how to protect The Netherlands against the water in the coming years. The Delta Commissioner also implements the 'Deltaprogramma' after the cabinet approved with it. This shows that the Delta Commissioner is very committed to the problems with the IJssel river. They would like to see a good, solid solution that will last for the long term. Therefore they are interested in the total investment costs, total expected annual damage and the total expected number of deaths.

Rijkswaterstaat is an organization that implements the policies that are being established by the Ministry of Infrastructure and Water Management. Being responsible for both the construction and maintenance of the dikes or for 'Room for the River' solutions (Rijksoverheid, n.d.), they are committed to the problem as well. Since they are responsible for the problem they are, just like the Delta Commissioner interested in the total investment costs, total expected annual damage and the total expected number of deaths. So Rijkswaterstaat will pay the investment costs, but will also pay for the damage after a flood (UVA, 2017), which is why the expected annual damage costs will be seen as important for Rijkswaterstaat too. Rijkswaterstaat prefers 'Room for the River' over increasing the dikes; only if it is impossible to make extra room for the river, or if it is too expensive, dikes will be increased instead of creating more room for the river (Rijksoverheid, 2018)

When it comes to main water systems, Rijkswaterstaat and the Delta Commissioner, but also the water boards, work together (Deltaprogramma 2017, 2016). Since they also have similar interests in this case, as mentioned before, the Delta Commissioner and Rijkswaterstaat are assumed to act as one actor in this case. Therefore they are put together in this report under the name Rijkswaterstaat.

The province of Gelderland is, just like other provinces in the Netherlands, responsible for the conversion of the national water policies to regional measures (Rijksoverheid, n.d.), but most of all they are concerned in this problem since they want to minimize the expected number of deaths and annual damage in their province. In Gelderland this includes locations

Doesburg, Cortenoever, Zutphen and Gorssel (respectively A1 to A4). Since dikes are local solutions, provinces can financially contribute to this kind of water management projects (Deltaprogramma 2018, 2017). Therefore Gelderland is also interested in the investment costs in dikes in their province. Since the investment costs officially are paid by Rijkswaterstaat, the damage and deaths are the most important outcomes for the province of Gelderland.

The province of Overijssel is, like Gelderland, concerned with the expected number of deaths and annual damage in their province. The only location included in this analysis is Deventer (A5). Since dikes are local solutions, in contrast to room for river, Overijssel can also financially contribute to this kind of water management projects, moreover, they already do (Rijksoverheid, 2018). Therefore also Overijssel is interested in the investment costs in dikes in their province. Since the investment costs officially are paid by Rijkswaterstaat, the damage and deaths are the most important outcomes for Overijssel.

Besides Rijkswaterstaat and the provinces, there are two more actors that are interested in the case. These are transport companies, using the river and its ports for their transport and environmental groups, which prefer solutions that are positive for the nature. The outcomes of interest that are important for these two actors are however not included in the simulation model. Therefore these two actors will not be considered during the analysis using the model, but will be reflected on when the decision support is discussed.

Appendix B. Model Specification

The model used for this report calculates the consequences of different policies that can be executed to protect The Netherlands against the rising water level of the IJssel, under different uncertainties. Here, it will shortly be explained how the different levers, uncertainties and outcomes are specified in the Python model. It will become clear which levers and uncertainties influence which outcomes, and in what way, according to the Python model.

In the model, the chance of the water discharge exceeding the maximum discharge is calculated. This is the chance for a flood.

Levers

- Early Warning System: Days to threat. This lever specifies the number of days before a potential flood that people will be evacuated. The higher this number 'days to threat', the more people can be evacuated.
- Dike increase (location specific). This lever allows the acceptable water level to be higher.
- 'Room for the River' (project specific). This lever causes a decrease in the water level. It depends on which project is executed, in which locations the water level will decrease and by how many meters.

Uncertainties

- Discount rate, used to calculate expected annual damage.
- Maximum breach (the width of the breach in meters), which influences the amount of water flowing out of the river (discharge in the floodplain), when there is a breach. This in turn influences the water height on land.
- Chance of failure, which specifies the chance the water level is above the maximum level.
- Growth of the breach, which influences the amount of water flowing out of the river, when there is a breach. This in turn influences the water height on land.
- Flood wave shape, which influences the chance of a dike failure.

Outcomes

- Expected number of deaths (location specific). This variable calculates the annual expected number of deaths, using the probability of exceedance of the acceptable water level and the amount of deaths per flood (predefined in the location specific losses tables). The lever 'days to threat' influences this variable in such a way that the number of days to threat influences the amount of people that can be evacuated. Those who are evacuated will not die.
- Expected annual damage (location specific). This variable is calculated using the losses (monetary value) when a flood happens and the probability of exceedance. Because the losses are given in a monetary value (here: euros), to get from losses to expected annual damage, the losses need to be discounted over the planning period, set to 50 years, and the (uncertain) discount rate.
- Evacuation costs. This variable is the sum of the evacuation costs per location. Each of these location specific evacuation costs are calculated by taking the amount of people evacuated (depending on 'days to threat') and the costs per evacuated

person (€22,- a day). Besides this, it depends on the gravity of the event (the water level), because the heavier the flood, the more people need to be evacuated.

- Dike investment costs. This variable shows the costs to heighten the dikes, which is location specific and also depends on the amount of decimeters the dike is heightened.
- Total ‘Room for the River’ costs. This variable depends on which of the five optional projects is being executed. The costs for each of these different projects are already specified in the dataset. These costs can be seen as investment costs; they are not yearly but only once.

Appendix C. Range of the Outcomes

Budget

The budget made available for the whole project to reduce flood risk in The Netherlands is €2.300,9 million, which is adjusted on December 31, 2017 (Rijksoverheid, 2018). This budget cannot fully be spent on reducing the flood risk of the IJssel in specific. To give an indication of the part of the project that belongs to the IJssel: 5 out of the 36 already finished projects in the Dutch 'Room for the River' project are being executed on the IJssel (Unesco-IHE, 2013).

Maximum accepted amount of deaths

Dutch legislation about the accepted amount of casualties for different risks in The Netherlands, classifies the risk of a flooding as 'involuntary', which has a limit of 10^{-5}. This is an individual limit, which means the minimum protection level should be 10^{-5}; 1 casualty per 100.000 persons per year is accepted (Planbureau voor de Leefomgeving, 2014). All throughout The Netherlands, this limit should be strictly observed. The limit is determined, based on an utilitarian approach; if a lower risk would be accepted, the costs would simply be too high (Deltaprogramma, 2013).

The accepted amount of casualties for this project can be calculated by taking the total amount of inhabitants of the cities/villages surrounding the IJssel - approximately 200.000[22] (CBS, 2018) - of the area by the flood risk. This results in an accepted maximum of 2 casualties per year for this area. More than 2 casualties is per definition not accepted. Policies that might result in a higher amount of casualties will thus not be taken into account as possible.

[22] This approximation has been made using the CBS data for the amount of inhabitants of the bigger surrounding cities and villages, and by adding 10% to this number for the smaller villages which are not all taken into account in the calculation.

Appendix D. MORDM

D.1. Scenarios for MORDM

For the robust optimization, the actor specific candidate solutions will be found by optimizing over three different scenarios: a worst case scenario, an average case scenario and a best case scenario. These different scenarios will further be specified in this appendix.

As appeared from the sensitivity analysis (chapter 4.2), the uncertainties Bmax, Brate and flood wave shape do not have a significant impact on the outcomes of interest. This is why these uncertainties will be held constant at the value of the reference scenario, while the uncertainties that have a high impact - discount rate and pfail - are varied while finding the optimal candidate solution.

Uncertainty specification

In the worst case scenarios, the two most influential uncertainties will be set to the value which is the less optimal. The exact values of the uncertainties are shown in Table 9. The discount rate is set to 1.5, which is the lowest uncertainty value. The expected annual damage is calculated using the following formula:

$$EAD_d = \sum_{t=1}^{T} \frac{EAD}{(1+r)^t}$$

From this formula, it appears the lower the discount rate, the higher the expected annual damage. The other uncertainty that will be varied in the scenarios is Pfail. If the value for Pfail is set to 1, this makes the failure chance of a certain dike 100%, which is obviously not favorable for the outcomes of interest. In the average case scenario (Table 10), the uncertainty values of the reference scenario are taken (as shown in chapter 3.1). For the best case scenario, the discount rate is set to 4.5 and the Pfail is set to 0, as can be seen in Table 11.

Table 9. Values of uncertainties in worst case scenario.

Uncertainty	Value
Bmax (m)	175
Brate (m/day)	1.5
Discount rate	1.5
pfail	1
Flood wave shape	4

Table 10. Values of uncertainties in average case scenario.

Uncertainty	Value
Bmax (m)	175
Brate (m/day)	1.5
Discount rate	3.5
pfail	0.5
Flood wave shape	4

Table 11. Values of uncertainties in best case scenario.

Uncertainty	Value
Bmax (m)	175
Brate (m/day)	1.5
Discount rate	4.5
pfail	0
Flood wave shape	4

D.2. Results of Direct Search

Province of Gelderland

When performing a direct search analysis, the convergence is plotted, showing the number of function evaluations and epsilons. For the direct search for solutions in the worst-case scenario for Gelderland, this convergence is reached well within the chosen range, as can be seen in Figure 14 below. If the graph does not stabilize, more function evaluations are needed. In this case, the number of experiments is chosen wide enough.

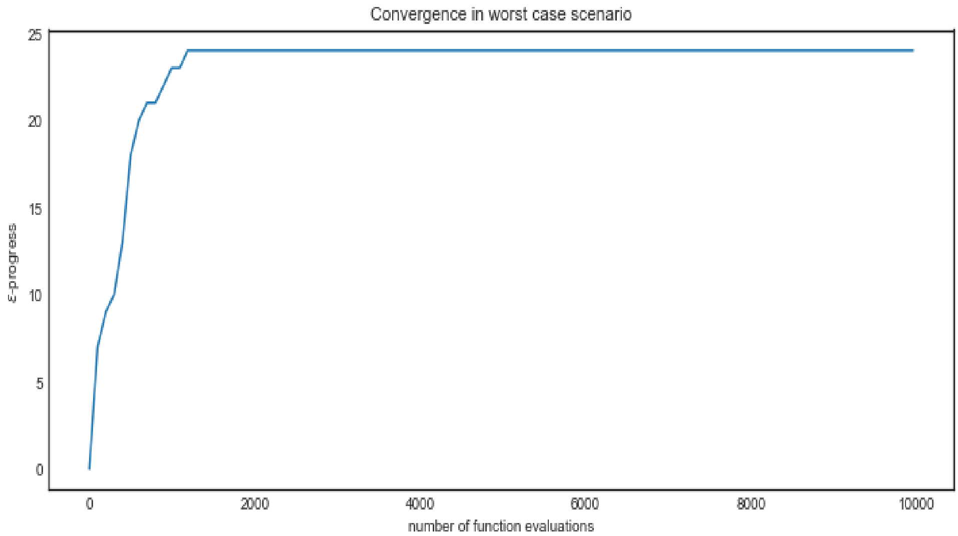

Figure 14. Convergence of evaluations.

The first time the direct search was performed, this resulted in two suitable solutions for Gelderland in the worst-case scenario, as specified in Appendix D.1. In order gain insight in the robustness of these solutions, the directed search was performed two more times. The second search resulted in only one solution, the third search proposed two solutions again. All proposed solutions (as presented in Figures 15, 16 and 17) show similar policies, which are summarized in two options as follows:

Solution 1:

- Increasing dike 5 with 4 dm
- ‘Room for the River’ measures 1-4
- Early Warning System, 3 days to threat

Solution 2:

- Increasing dike 5 with 4 dm
- ‘Room for the River’ measures 0 and 2-4
- Early Warning System, 3 days to threat

	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat
0	0	1	0	0	5	0	1	1	1	1	2
1	0	0	0	0	1	1	0	1	1	1	3

Figure 15. Solutions for Gelderland after first Direct Search analysis.

	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat
0	0	0	0	0	6	1	0	1	1	1	2

Figure 16. Solutions for Gelderland after second Direct Search analysis.

	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat
0	0	0	0	0	1	1	0	1	1	0	3
1	0	1	0	0	2	0	1	1	1	1	3

Figure 17. Solutions for Gelderland after third Direct Search analysis.

Province of Overijssel and Rijkswaterstaat

The Direct Search analysis is also performed for the Province of Overijssel and for Rijkswaterstaat, resulting in the proposed solutions as shown in Figures 18 and 19. The proposed solutions differ from the ones for Gelderland as follows:

Differences for Overijssel:

- Zero or only limited increase of dike five, but a lot of investment in heightening dikes
- Only two or three out of ‘Room for the River’ projects seems enough

Differences for Rijkswaterstaat:

- Clearly no preference for ‘Room for the River’ projects
- Also no preference for an Early Warning System
- Dikes only need to be heightened a little bit.

The differences in preferences can be explained by looking at the distribution of costs of all measures. For example, Gelderland and Overijssel do not have to contribute to the costs of the ‘Room for the River’ project, whereas Rijkswaterstaat has to pay for this entirely. Also the choice of dikes to increase for both the provinces is directly negatively correlated with the ones they have to pay for.

	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat
0	8	6	0	2	1	0	1	1	1	0	0
1	8	0	7	4	0	0	1	0	1	0	4

Figure 18. Solutions for Overijssel after Direct Search analysis.

	A.1_DikeIncrease	A.2_DikeIncrease	A.3_DikeIncrease	A.4_DikeIncrease	A.5_DikeIncrease	0_RfR	1_RfR	2_RfR	3_RfR	4_RfR	EWS_DaysToThreat
0	0	0	2	0	2	0	0	0	0	0	0
1	0	1	2	1	2	0	0	0	0	0	1
2	0	0	1	0	1	0	0	0	0	0	0
3	0	0	2	0	1	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0	0	0	0
5	0	0	2	1	2	0	0	0	0	0	0
6	0	0	2	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	0	0
9	0	0	0	1	2	0	0	0	0	0	0
10	0	0	1	0	2	0	0	0	0	0	0
11	0	0	0	1	0	0	0	0	0	0	0
12	0	1	2	0	2	0	0	0	0	0	0
13	0	0	0	0	2	0	0	0	0	0	0
14	0	0	0	0	1	0	0	1	0	0	0
15	0	0	0	1	2	0	0	1	0	0	0
16	0	0	0	0	2	0	0	1	0	0	0

Figure 19. Solutions for Rijkswaterstaat after Direct Search analysis.