Gelderland Province

Analysis Overview
Group-20

Problem Formulation

We're using two problem formulations:

1. PF3 for global sensitivity analysis all regions
    a. Areas 1 - 5
    b. Aggregated Total Costs = Dike investment + expected damage

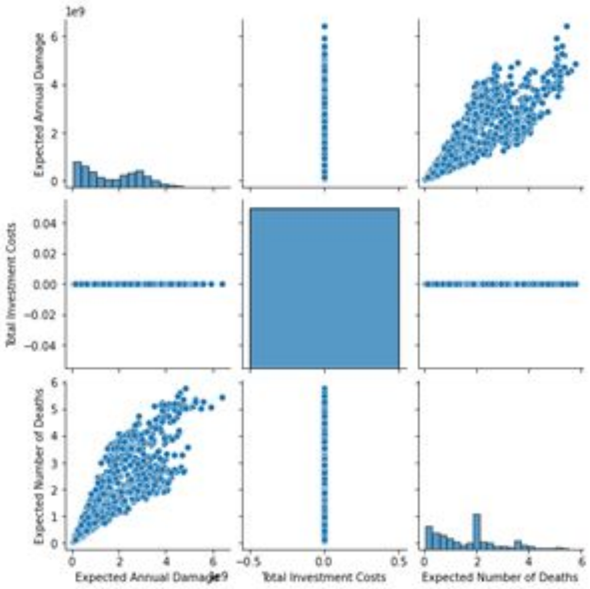
```
A.1 Total Costs
A.1_Expected Number of Deaths
A.2 Total Costs
A.2_Expected Number of Deaths
A.3 Total Costs
A.3_Expected Number of Deaths
A.4 Total Costs
A.4_Expected Number of Deaths
A.5 Total Costs
A.5_Expected Number of Deaths
RfR Total Costs
Expected Evacuation Costs
```

2. PF7 for optimization focusing on Gelderland only
    a. Areas 1 - 3
    b. Disaggregated Costs = Separate Dike investment + Annual Damage

```
['A.1_Expected Number of Deaths',
 'A.1_Expected Annual Damage',
 'A.1_Dike Investment Costs',
 'A.2_Expected Number of Deaths',
 'A.2_Expected Annual Damage',
 'A.2_Dike Investment Costs',
 'A.3_Expected Number of Deaths',
 'A.3_Expected Annual Damage',
 'A.3_Dike Investment Costs',
 'RfR Total Costs',
 'Expected Evacuation Costs']
```

Open Exploration (No policies)

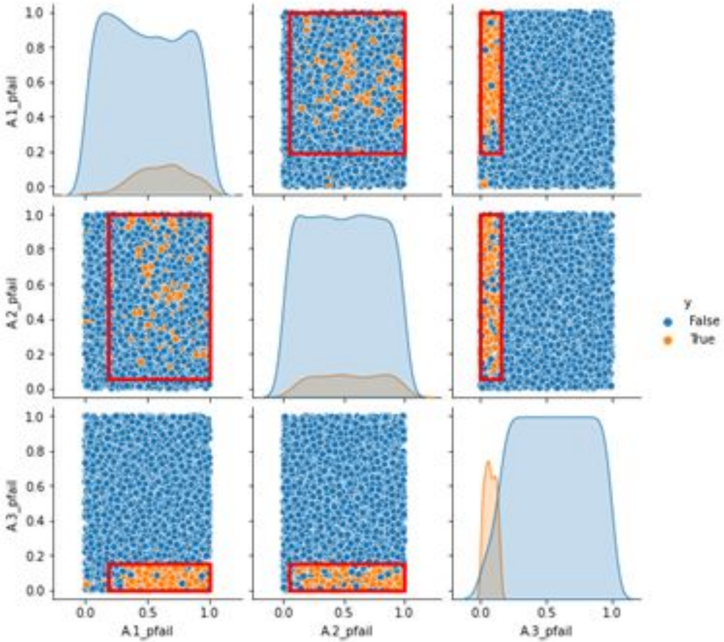
Aggregated view of outcomes

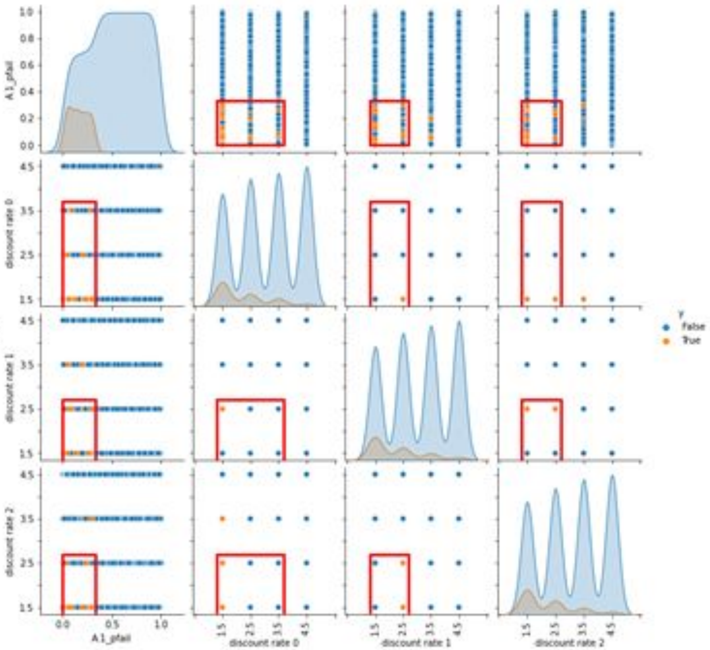


What are the most important factor?

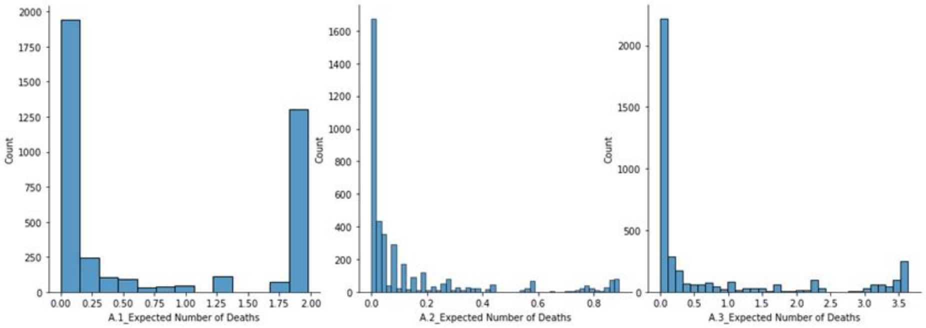
Left: Highest number of **deaths** occur at **low A3_pfail** (Weak dike Zuthpen) and **high A1 & A2 pfail** (strong dikes upstream) values

Right: expected annual damage is highest with low A1_pfail and low discount rates

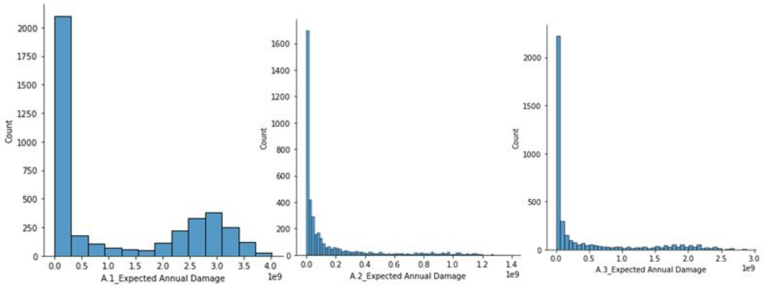




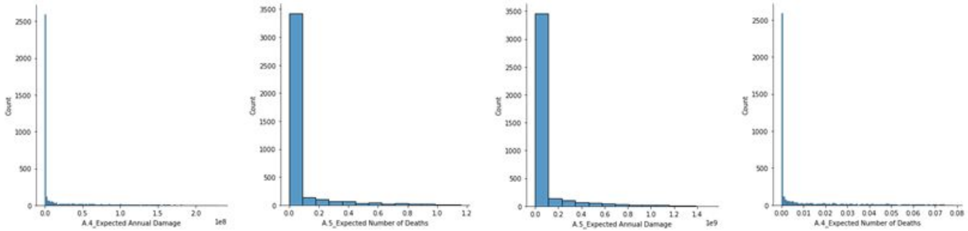
No policy, deaths



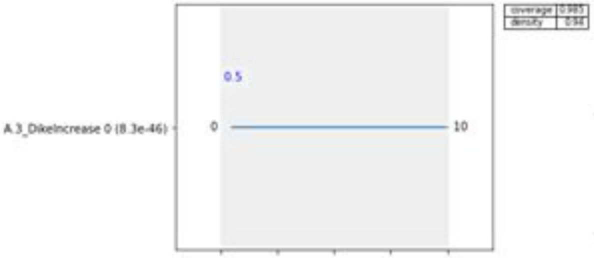
No policy, damage

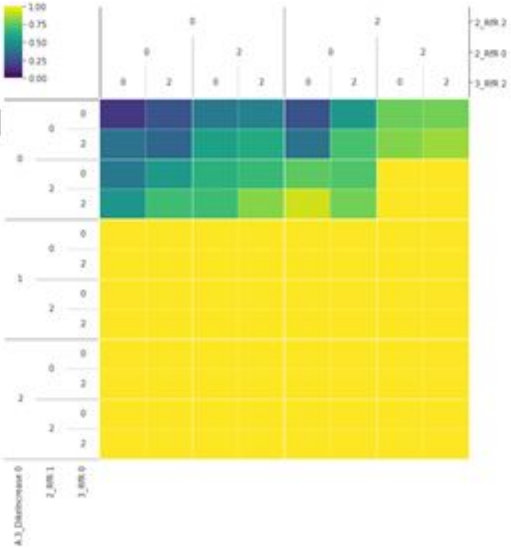


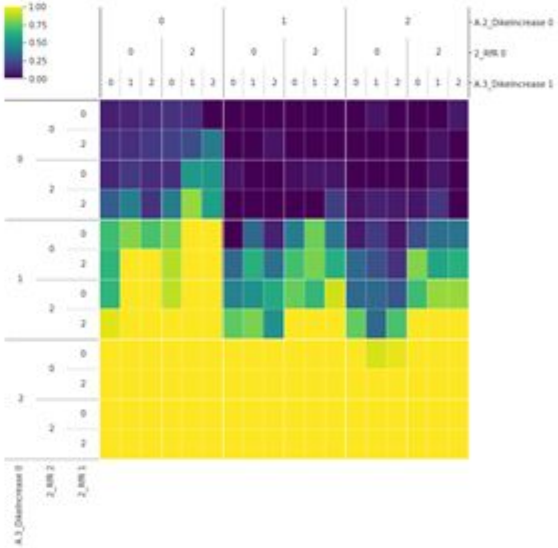
A4 and A5



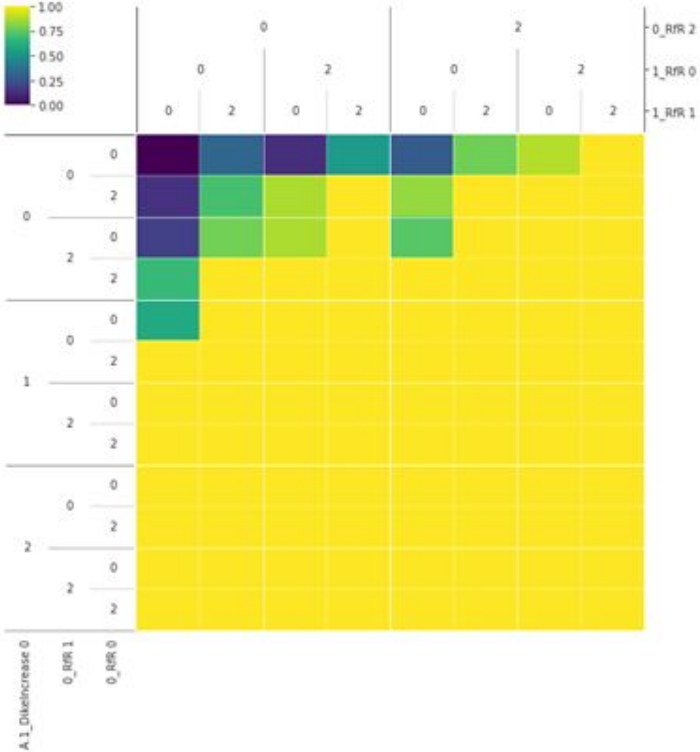
A3, measures of ref scenario (left) and low pfail scenario

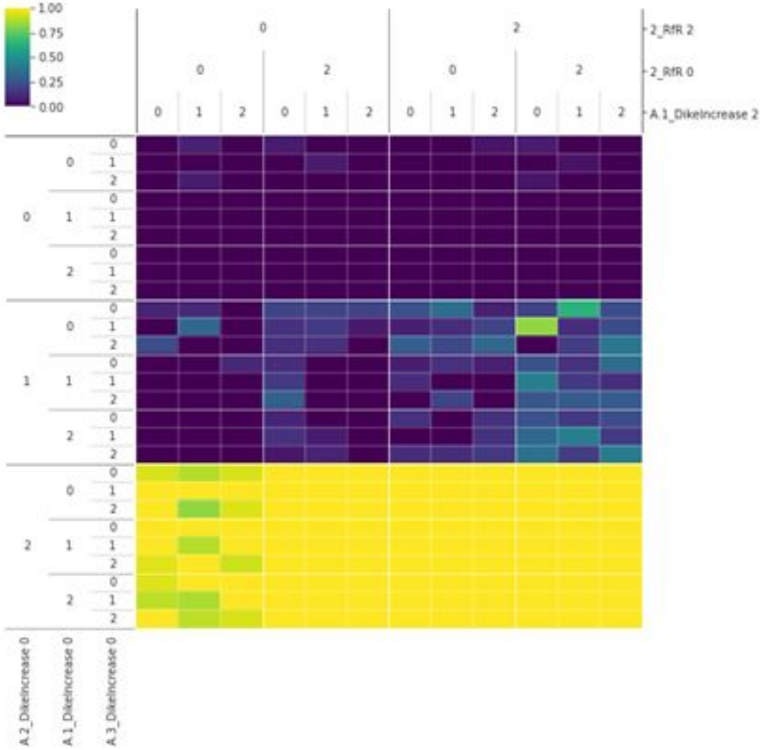


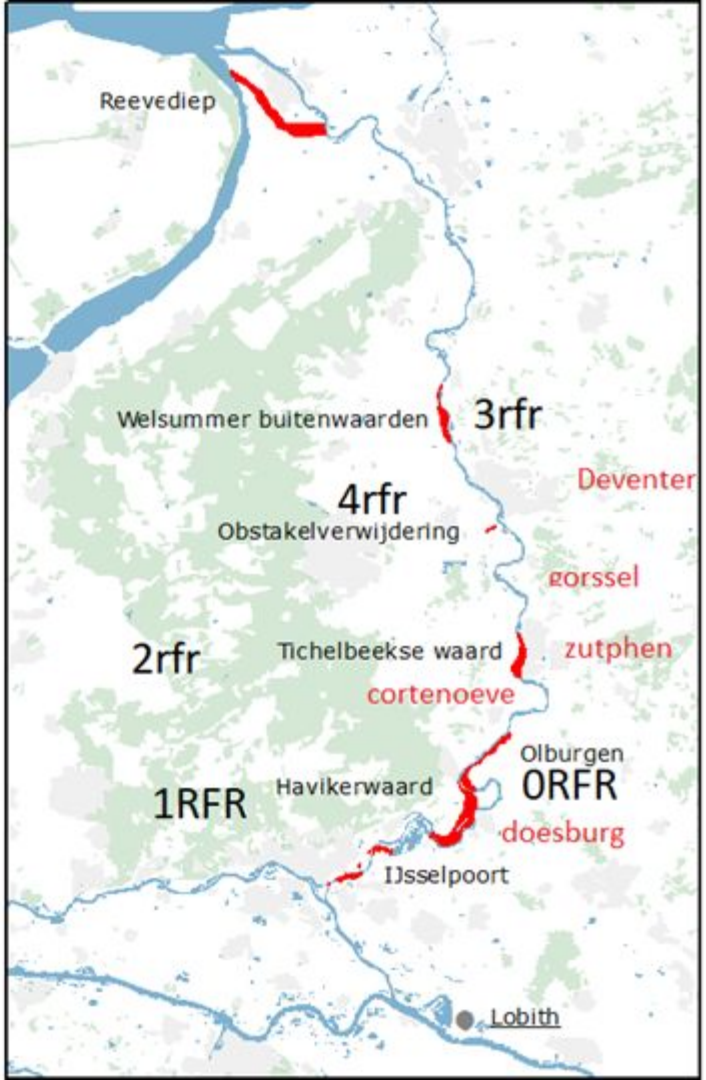




Deaths in A1 and A2







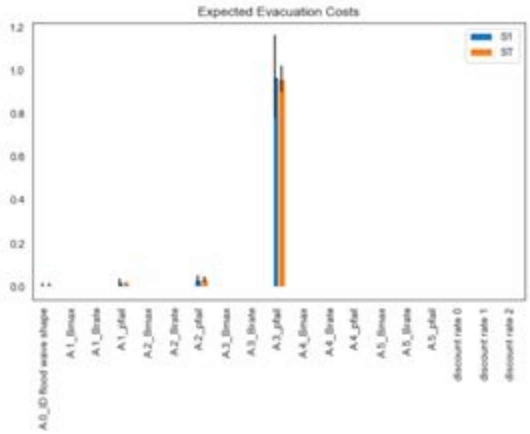
Reevediep
Welsummer buitenwaarden
3rfr
Deventer
4rfr
Obstakelverwijdering
gorssel
2rfr
Tichelbeekse waard
zutphen
cortenoeve
Olburgen
Havikerwaard
0RFR
1RFR
doesburg
IJsselpoort
Lobith

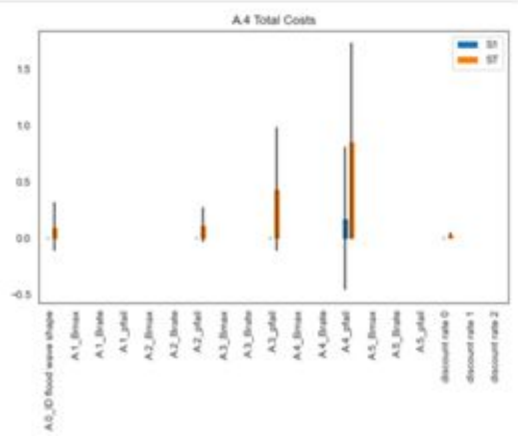
Sensitivity analysis for uncertainties

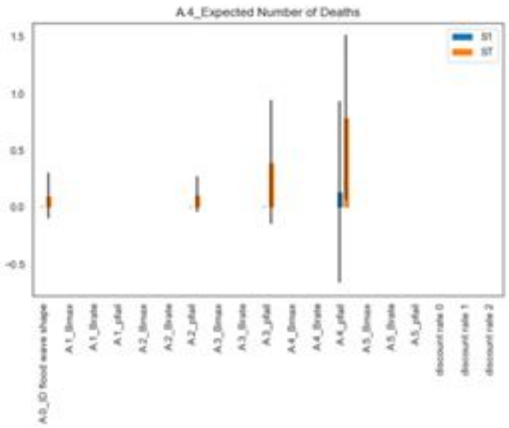
Sensitivity Analysis (also called vulnerability analysis) was performed for the 19 uncertainties using SOBOL. Results can be used for factor prioritization.

Results show Area Dike Fails (‘A[1:5]_pfail’) as the most influential factors for respective area outcomes.

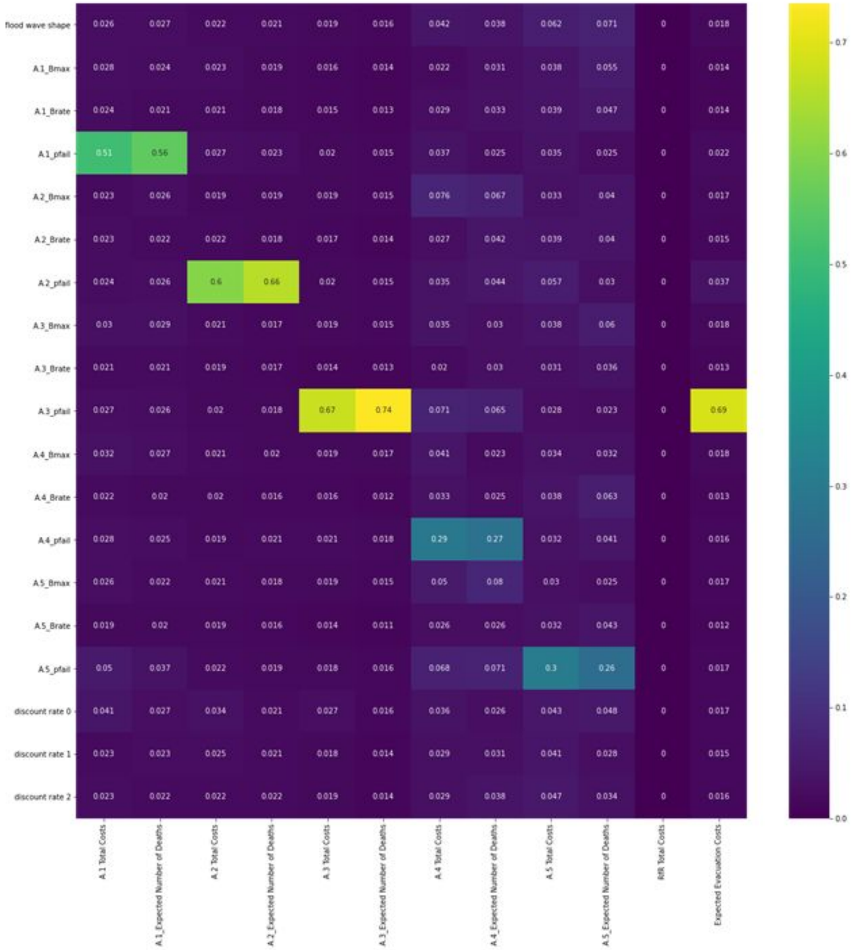
Except in the below figures - Evacuation costs are influenced extensively by A3_pfail, and the costs and deaths for A4 are influenced by flood_wave_shape, A1, A2 and A3 (since A4 is downstream)







[Click here to view the code and figures]



- A3_pfail most influential on outcomes A3_TotalCosts, A3_ExpectedDeaths AND Expected Evacuation Costs.

- Following this, A1_pfail and A2_pfail are critical.

Sensitivity analysis for levers

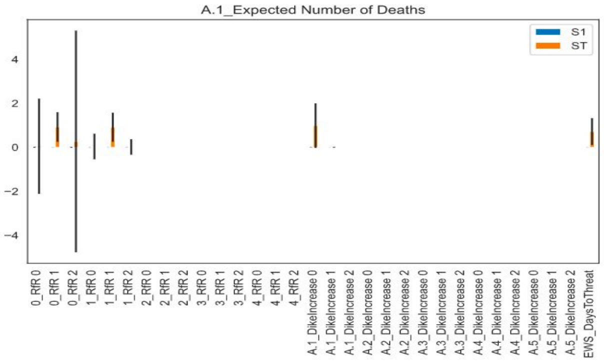
In previous analysis we identified uncertainties having most influence on the outcomes from 16 uncertainties.

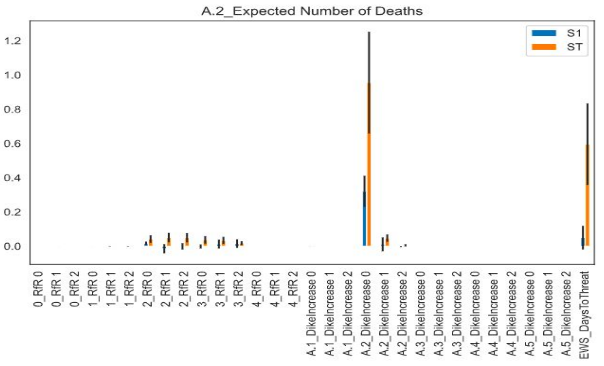
Similarly, we performed another sensitivity analysis with levers to identify the policy levers influencing the outcomes the most amongst 31 levers.

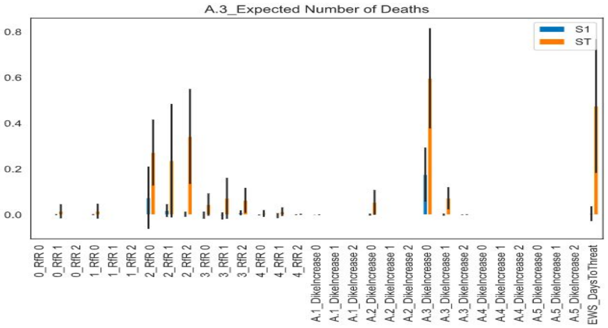
From the graphs in previous slide we know that

(1) Number of deaths are directly influenced by dike hightninh policy lever (Salib Index First order)
(2) RFR is effective in reducing number of deaths in combination with other policies (Third Order)
(3) High outliers signifies that we haven’t run the analysis for sufficient runs because of limited time.

Click here to view the code and figures



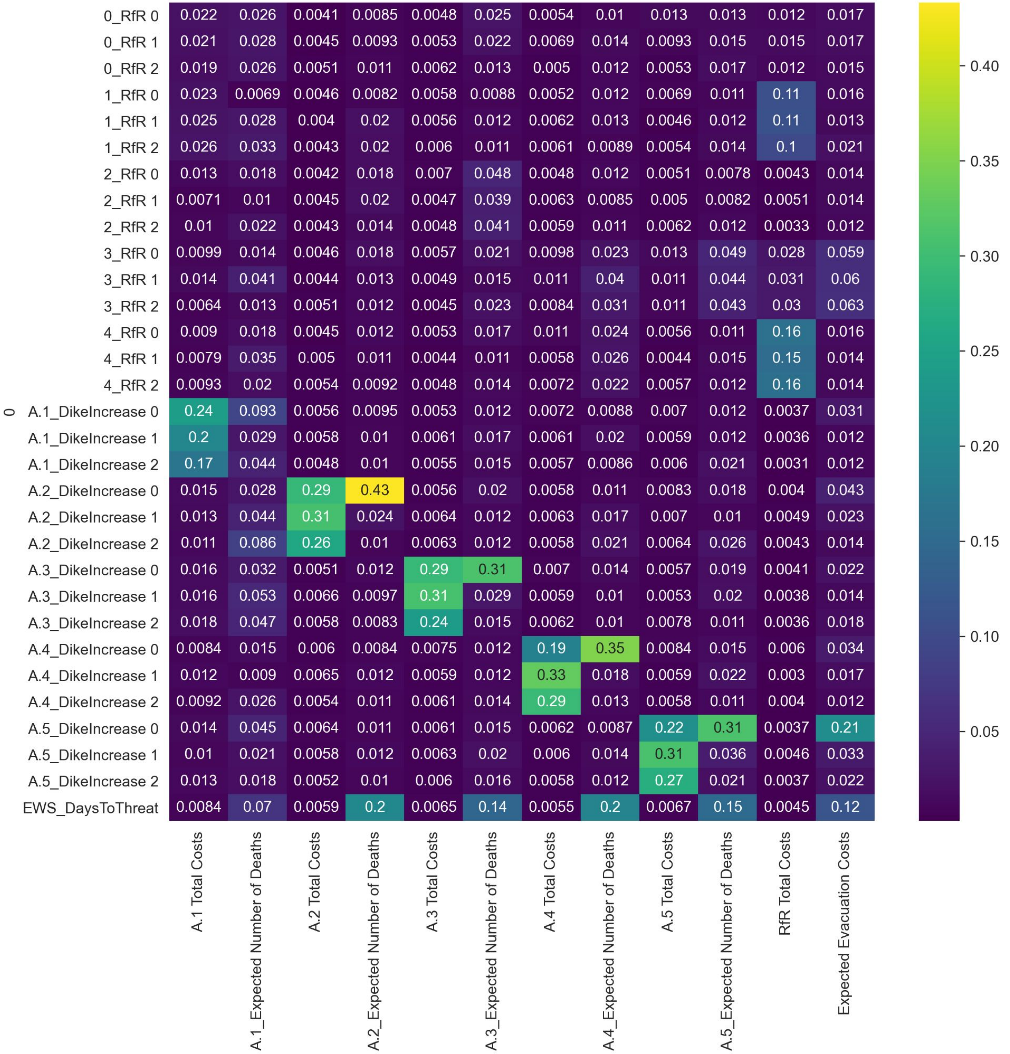




Sensitivity analysis for levers

This feature scoring plot provides an overview of all the policy levers and there effectiveness in influencing the outcomes.

1. Dike heightning is most important for reducing number of deaths in all regions.
2. RFR also has some impact, but we have already seen that it can not be used as a stand alone policy. In addition to that, RFR also conflicts with the political stance of province of safeguarding the interest of farmers and thus should be minimized.



Click here to view the code and figures

Optimization - Search over levers (Pareto set)

Aim: To find optimal policies for the **worst-case scenario**. A worst-case flood scenario would be when all the dikes fail, and the flood wave shape is on the maximum due to climate change, discount rates is low simulating bad economic implications.

To simulate this worst-case scenario, ‘p_fail’ for all areas was retrieved as the 20th quantile from the experiments and flood wave shape was set to the 0.9 quantile, discount rate was set to be 1.5.

This scenario is used as a reference for policy optimization using lever sampling.

```
ref_high_dikefailure_prob = Scenario('ref_high_dikefailure_prob', **{
    'A.0_ID flood wave shape':experiments_loaded['A.0_ID flood wave shape'].quantile(0.9),
    'A.1_Bmax':300,
    'A.1_Brate':10,
    'A.1_pfail':experiments_loaded['A.1_pfail'].quantile(0.2),
    'A.2_Bmax':300,
    'A.2_Brate':10,
    'A.2_pfail':experiments_loaded['A.2_pfail'].quantile(0.2),
    'A.3_Bmax':300,
    'A.3_Brate':10,
    'A.3_pfail':experiments_loaded['A.3_pfail'].quantile(0.2),
    'A.4_Bmax':300,
    'A.4_Brate':10,
    'A.4_pfail':experiments_loaded['A.4_pfail'].quantile(0.2),
    'A.5_Bmax':300,
    'A.5_Brate':10,
    'A.5_pfail':experiments_loaded['A.5_pfail'].quantile(0.2),
    'discount rate 0':1.5,
    'discount rate 1':1.5,
    'discount rate 2':1.5
        })
```

Directed search is used to search over the decision levers in the worst case scenario in order to find good candidate strategies. This is the first step in the Many Objective Robust Decision Making (MORDM) process. **After optimizing, about 1045 policies were found.**

	0_RfR 0	0_RfR 1	0_RfR 2	1_RfR 0	1_RfR 1	1_RfR 2	2_RfR 0	2_RfR 1	2_RfR 2	3_RfR 0	...	A.2_DikeIncrease 2	A.3_DikeIncrease 0	A.3_DikeIncrease 1	A.3_DikeIncrease 2	A.4_
0	0	1	0	0	0	0	1	1	1	0	...	0	0	1	1	
1	0	0	0	0	0	0	0	0	0	0	...	4	1	0	0	
2	0	0	0	0	0	0	1	1	1	0	...	0	0	0	0	
3	0	0	0	0	0	0	1	1	1	0	...	0	1	0	0	
4	0	0	0	0	0	0	0	0	0	0	...	0	1	0	0	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
75	0	0	0	0	0	0	0	0	0	0	...	7	1	0	0	
76	0	0	0	0	0	0	0	0	0	0	...	1	7	0	0	
77	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	
78	0	0	0	0	0	0	0	0	0	0	...	1	0	0	0	
79	0	0	0	0	0	0	1	0	1	1	...	0	0	0	0	

80 rows × 31 columns

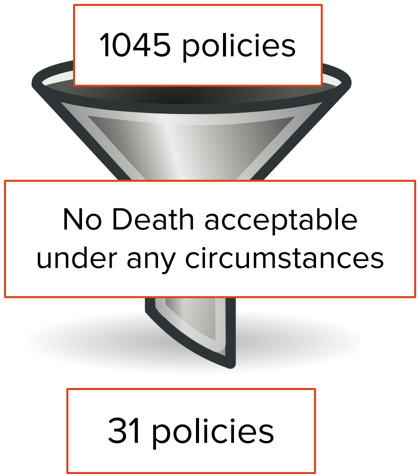
[Click here to view the code and figures](#)

MORDM - Filtering candidate solutions

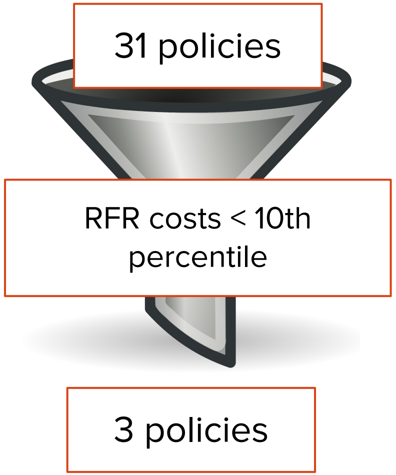
All the optimized policies are pareto optimal, so we had to pick one policy from the set.

We filtered the policies based on following criterias:

FILTER -1



FILTER -2

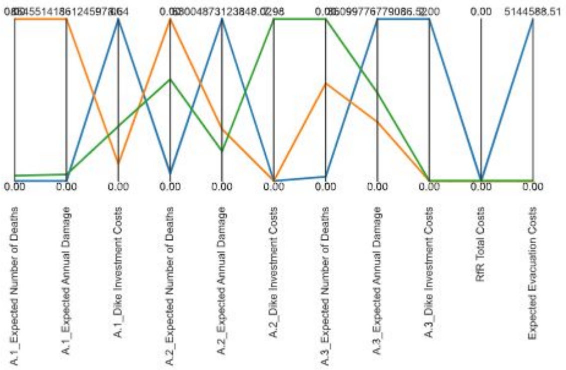


MORDM: Robustness Analysis

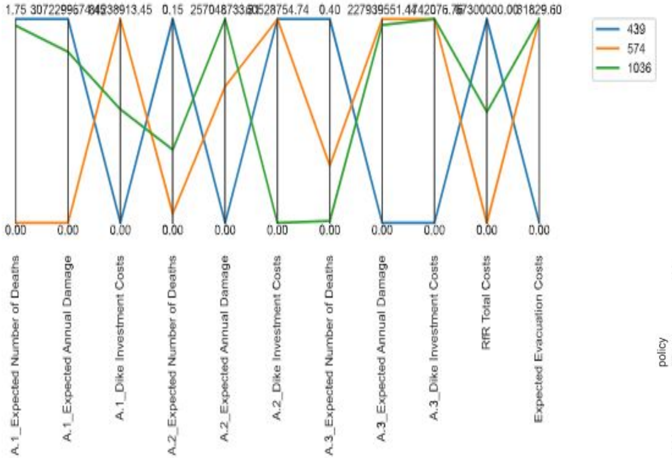
We are using two robustness indices to analyze the robustness of filtered policies.

1. Signal to Noise ratio (higher the better)
2. Maximum Regret (Lower the better)

Robustness index: Signal to noise ratio



Robustness index: Maximum regret (trade offs)



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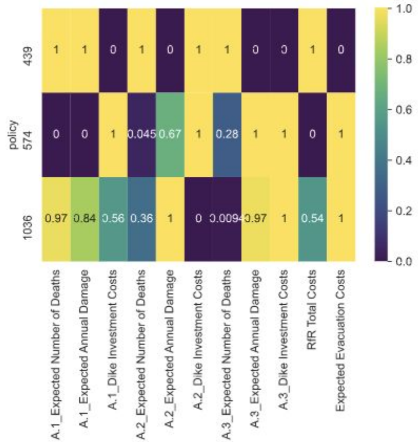
Comparing the shortlisted policies

(Trade Offs)

Policies have tradeoffs between expected number of deaths and dike investments costs.

We cannot accept death under any circumstances, thus selecting policy 574.

Robustness index: Maximum regret (overview)



Selected policy and its limitations

Room for river along with dike strengthening

Also aligns with the lever sensitivity analysis

[Click here to view the code and figures]

Considering the worst case scenario, avoiding room for river is impossible thus it should be seen as an investment. Although, the policy is focused on minimizing the room for river and avoiding casualties under any circumstances.

Selected Policy - ‘Policy 574’

2_RfR 0 -------- 1

3_RfR 0 -------- 1

A.1_DikeIncrease 0 -------- 6

A.2_DikeIncrease 0 -------- 7

A.3_DikeIncrease 0 -------- 7

A.3_DikeIncrease 1 -------- 7

A.3_DikeIncrease 2 -------- 7

A.4_DikeIncrease 0 -------- 6

A.4_DikeIncrease 1 -------- 6

A.4_DikeIncrease 2 -------- 7

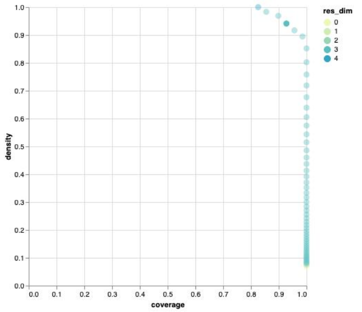
A.5_DikeIncrease 0 -------- 3

A.5_DikeIncrease 1 -------- 1

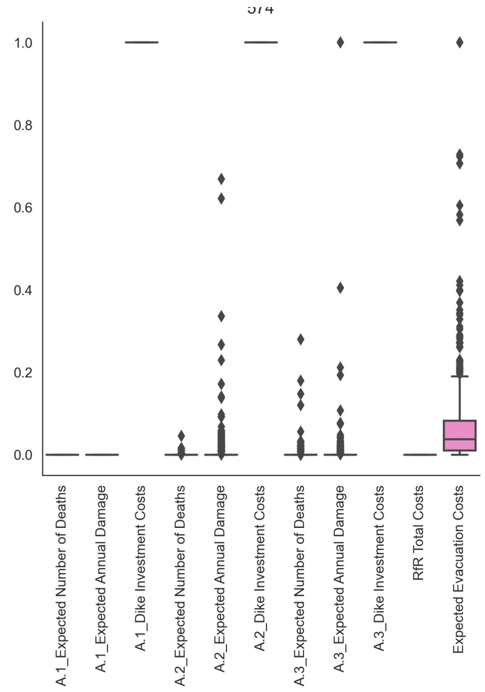
A.5_DikeIncrease 2 -------- 4

We know that this policy might result in high evacuation cost.

So lastly, we did a scenario discovery to know when this policy can result high A2 expected annual damage

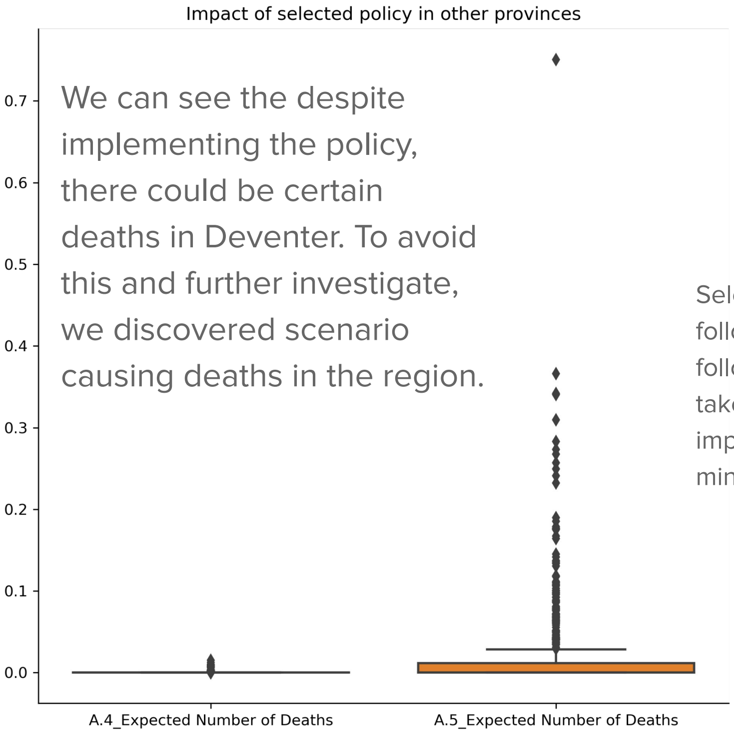



```
                              box 50
                                 min
max
A.2_pfail                   0.000649
0.072211
A.1_pfail                   0.088464
0.999474
A.0_ID flood wave shape     6.500000
```



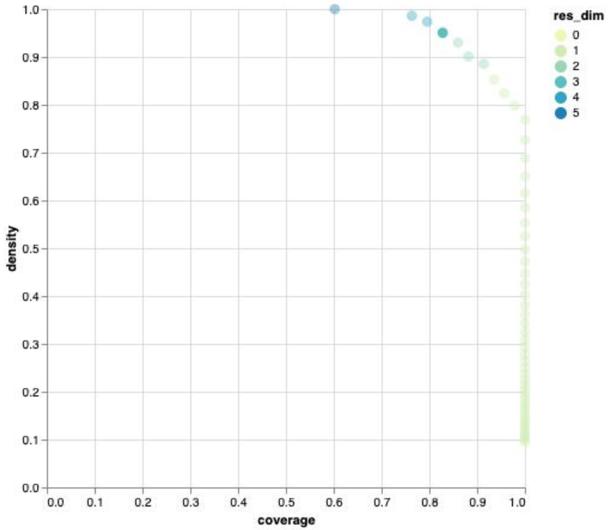
Selected policy might result higher A2 expected annual damage when

Testing impact of policy on other provinces



We can see the despite implementing the policy, there could be certain deaths in Deventer. To avoid this and further investigate, we discovered scenario causing deaths in the region.

Selected policy fails under following scenario thus following limitations should be taken into account while implementing policies and minimizing the damage.



box 47	min	max
A.5_pfail	0.000012	0.090174
A.0_ID flood wave shape	0.000000	126.500000
A.1_pfail	0.045613	0.999638