

# Gelderland Province



Analysis Overview  
Group-20

# Problem Formulation

We're using two problem formulations:

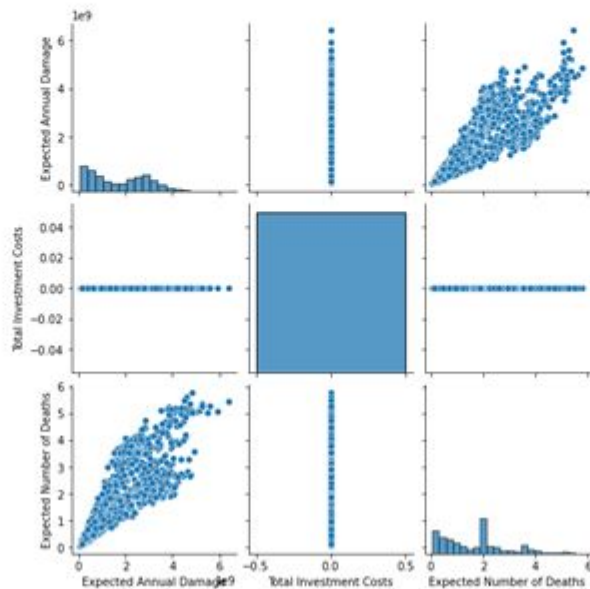
1. PF3 for global sensitivity analysis all regions
  - a. Areas 1 - 5
  - b. Aggregated Total Costs = Dike investment + expected damage
  
2. PF7 for optimization focusing on Gelderland only
  - a. Areas 1 - 3
  - b. Disaggregated Costs = Separate Dike investment + Annual Damage

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

```
['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)

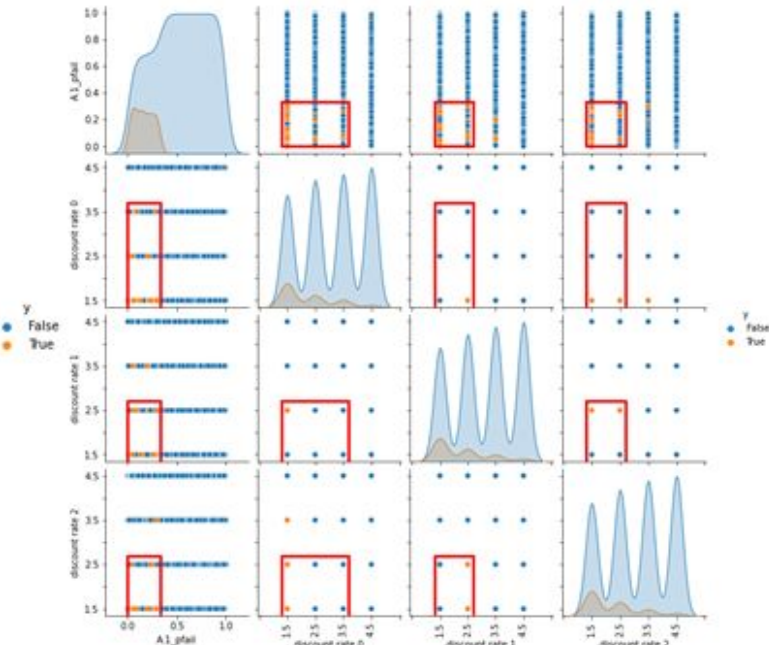
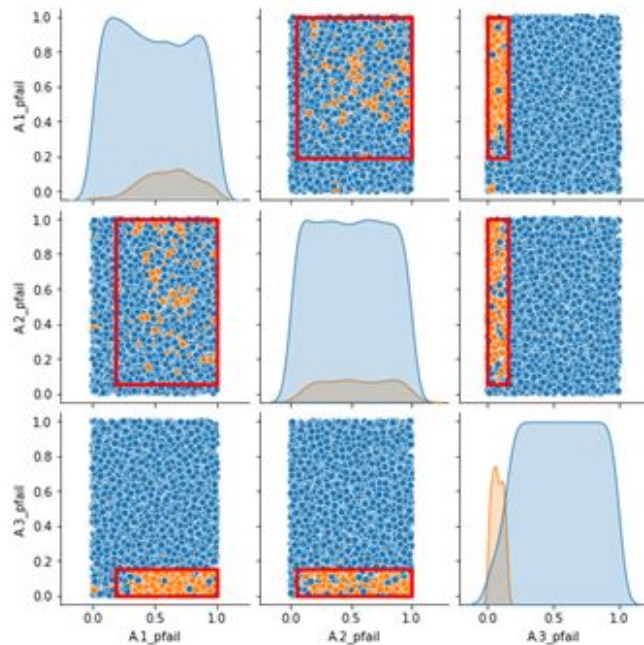
## Aggregated view of outcomes



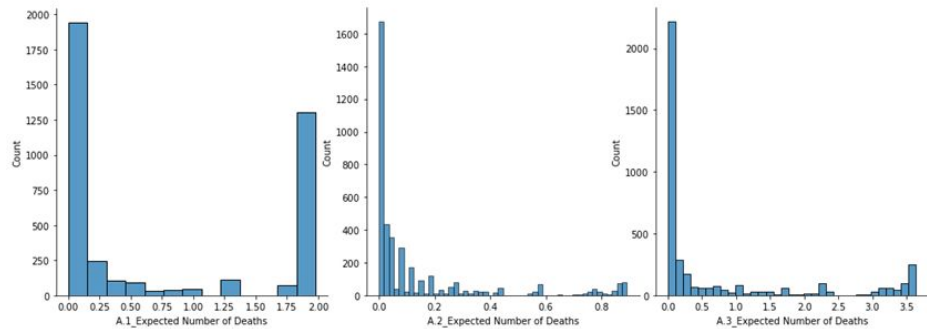
# What are the most important factor?

**Left:** Highest number of deaths occur at low A3\_pfail (Weak dike Zuthpen) and high A1 & A2 pfail (strong dikes upstream) values

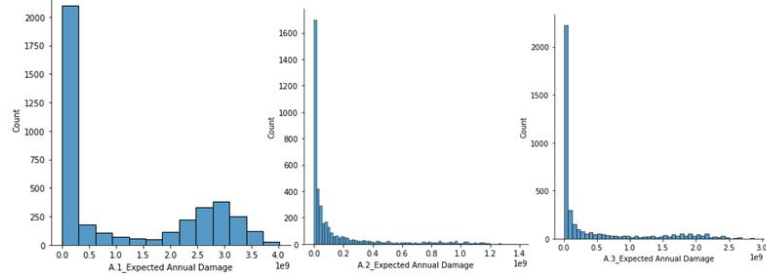
**Right:** expected annual damage is highest with low A1\_pfail and low discount rates



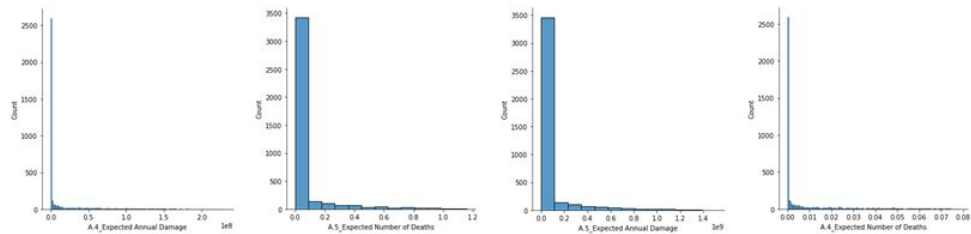
## No policy, deaths



## No policy, damage

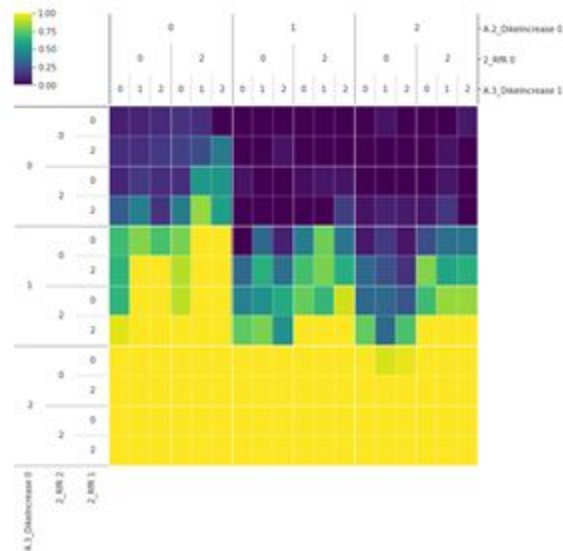
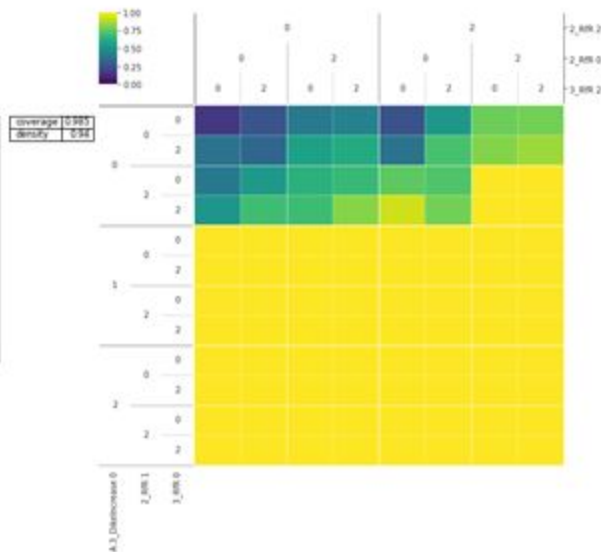


## A4 and A5

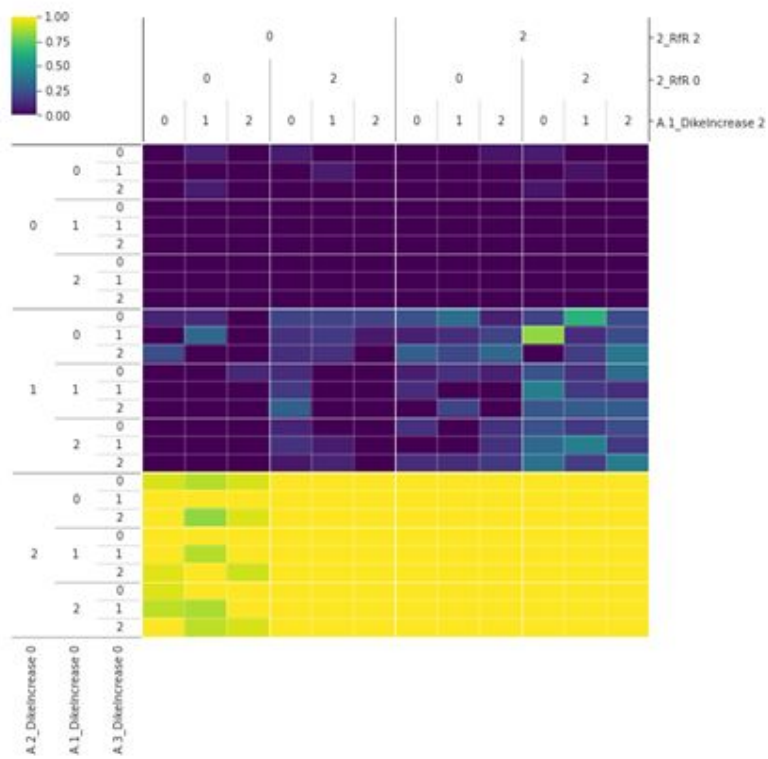
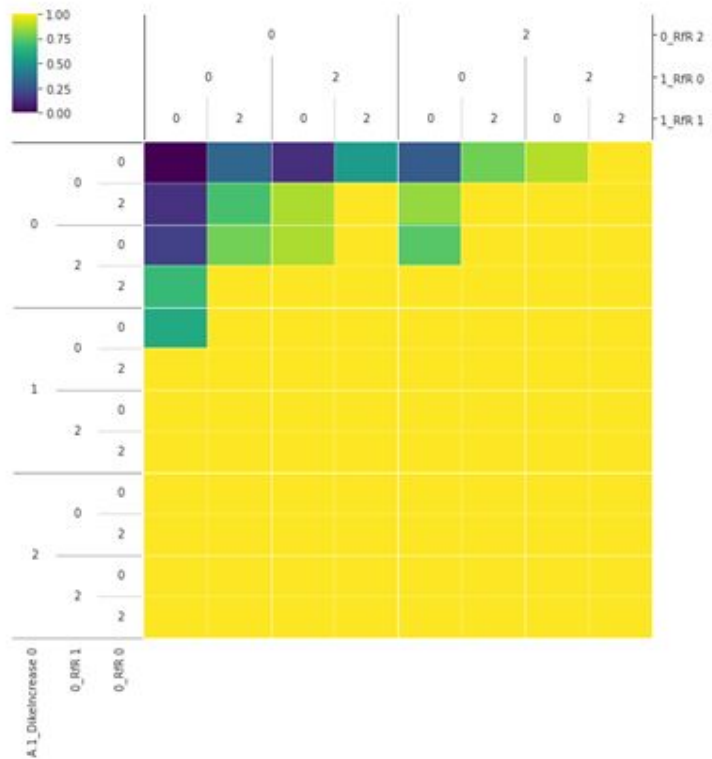


# A3, measures of ref scenario (left) and low pfail scenario

A3\_DikeIncrease 0 (8.3e-46)



# Deaths in A1 and A2







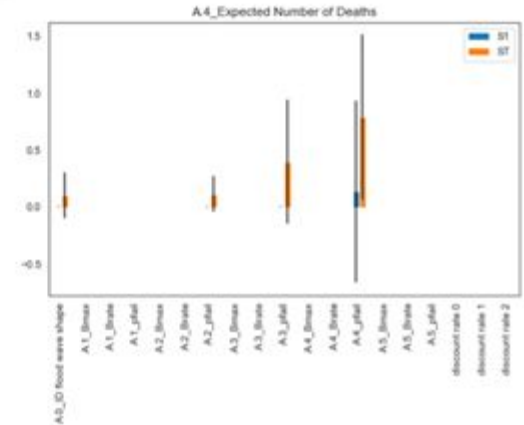
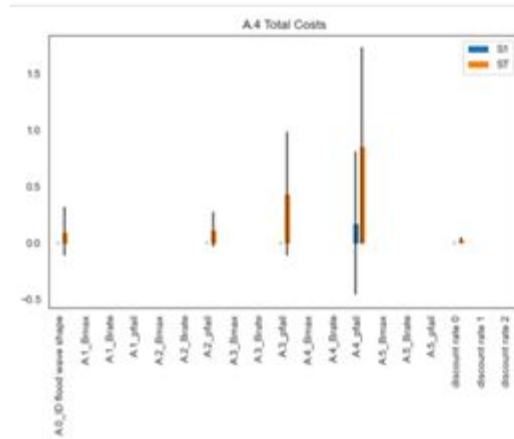
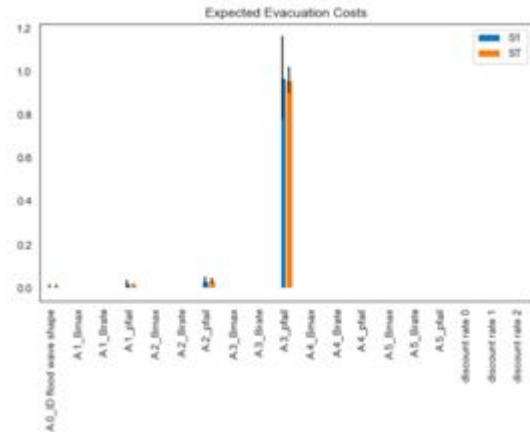


# Sensitivity analysis for uncertainties

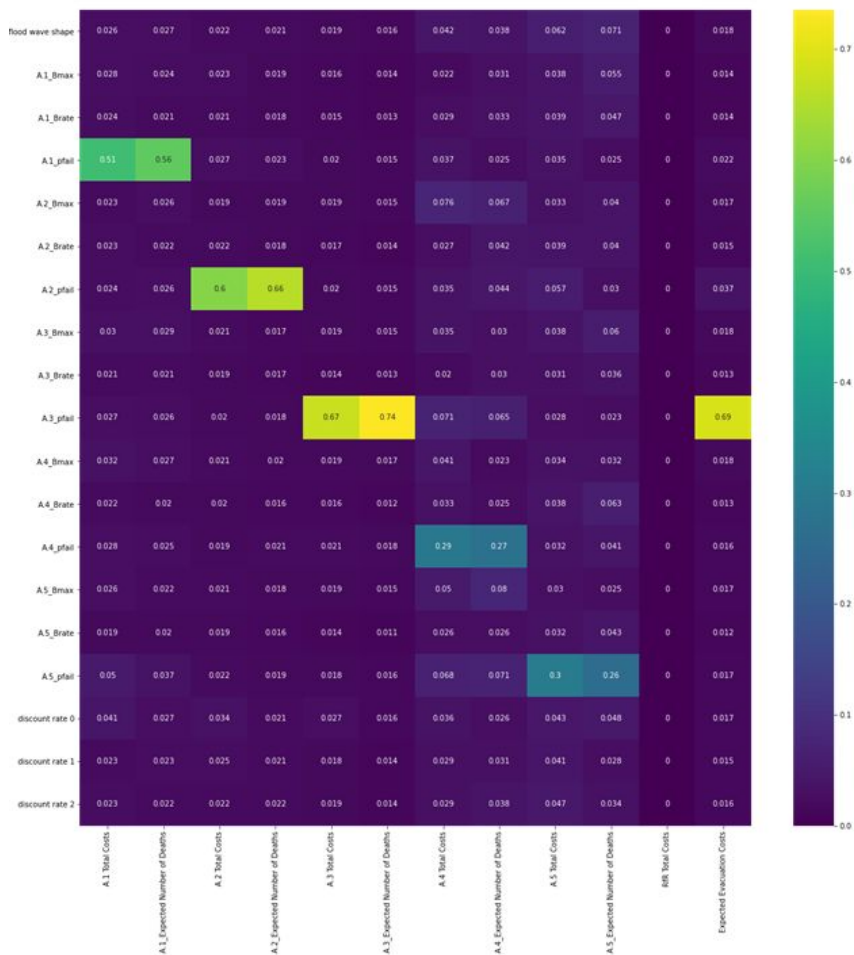
Sensitivity Analysis (also called vulnerability analysis) was performed for the 19 uncertainties using SOBOL. Results can be used for factor prioritization.

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

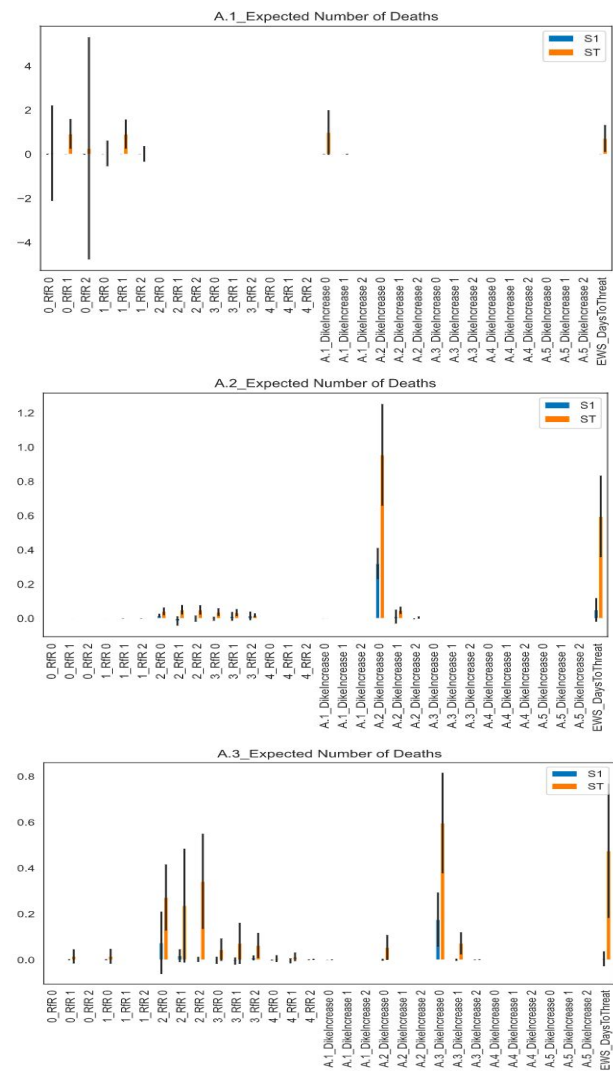
In previous analysis we identified uncertainties having most influence on the outcomes from 16 uncertainties.

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 heightninh 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.

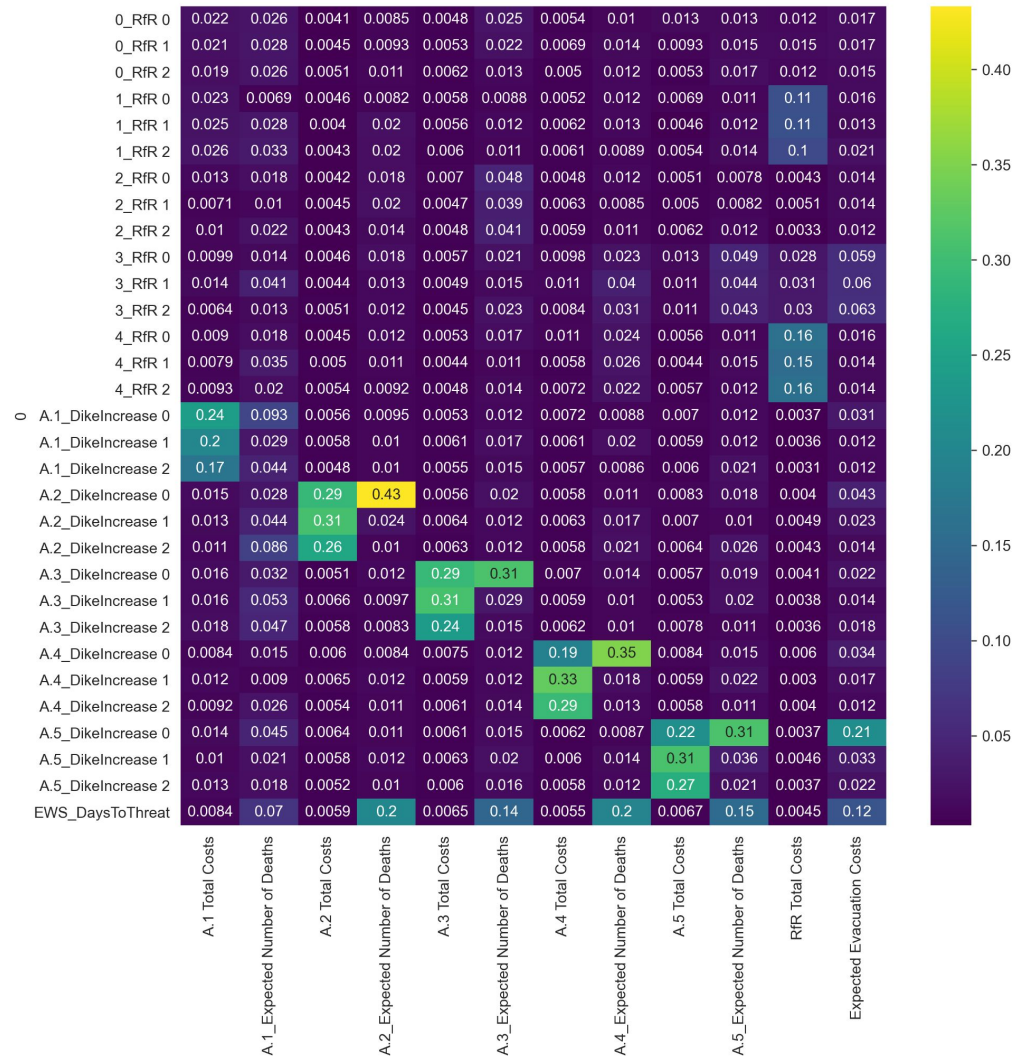
[Click here to view the code and figures](#)



# Sensitivity analysis for levers

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

1. Dike heightening 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.**

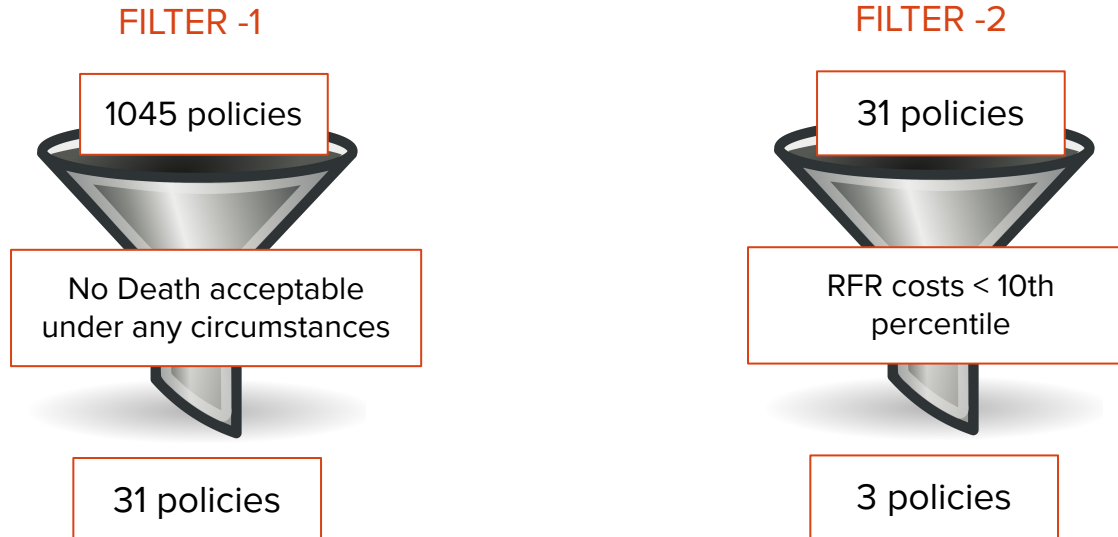
	0_RfR 0	0_RfR 1	0_RfR 2	1_RfR 0	1_RfR 1	1_RfR 2	2_RfR 0	2_RfR 1	2_RfR 2	3_RfR 0	...	A.2_DikeIncrease 2	A.3_DikeIncrease 0	A.3_DikeIncrease 1	A.3_DikeIncrease 2	A.4_
0	0	1	0	0	0	0	1	1	1	0	...	0	0	1	1	
1	0	0	0	0	0	0	0	0	0	0	...	4	1	0	0	
2	0	0	0	0	0	0	1	1	1	0	...	0	0	0	0	
3	0	0	0	0	0	0	1	1	1	0	...	0	1	0	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

# 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:

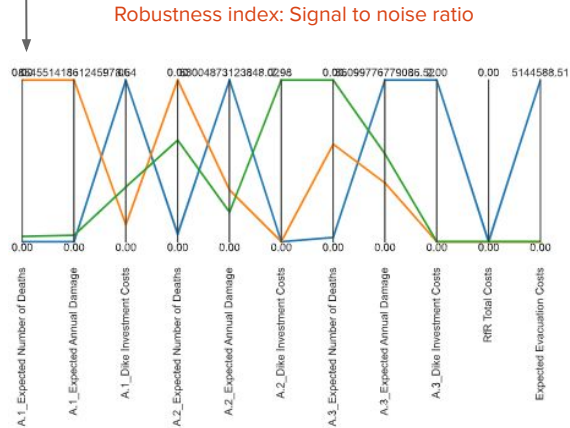




We are using two robustness indices to analyze the robustness of filtered policies.

# MORDM: Robustness Analysis

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



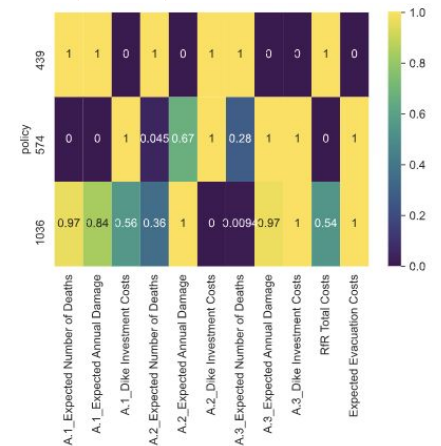
Comparing the shortlisted policies

(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)



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

# 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.

## Planning cycle 1

RFR - Tichelbeekse waard (Zutphen)

RFR - Welsummer buitenwaarden (Deventer)

Doesburg dike increase 6 dm

Cortenoever dike increase 7 dm

Zutphen dike increase 7 dm

Gorsssel dike increase 6 dm

Deventer dike increase 3 dm

## Planning cycle 2

Zutphen dike increase 7 dm

Gorsssel dike increase 6 dm

Deventer dike increase 1 dm

## Planning cycle 3

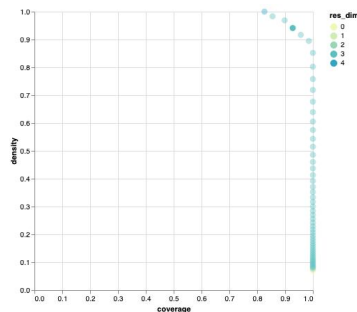
Zutphen dike increase 7 dm

Gorsssel dike increase 7 dm

Deventer dike increase 4 dm

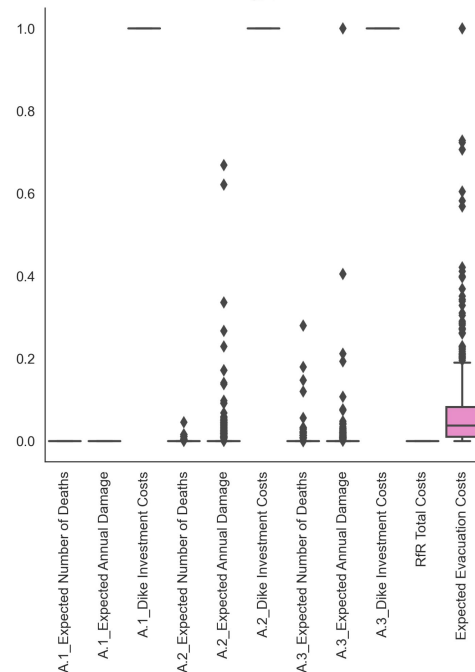
We know that this policy might result in high evacuation cost.

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



```

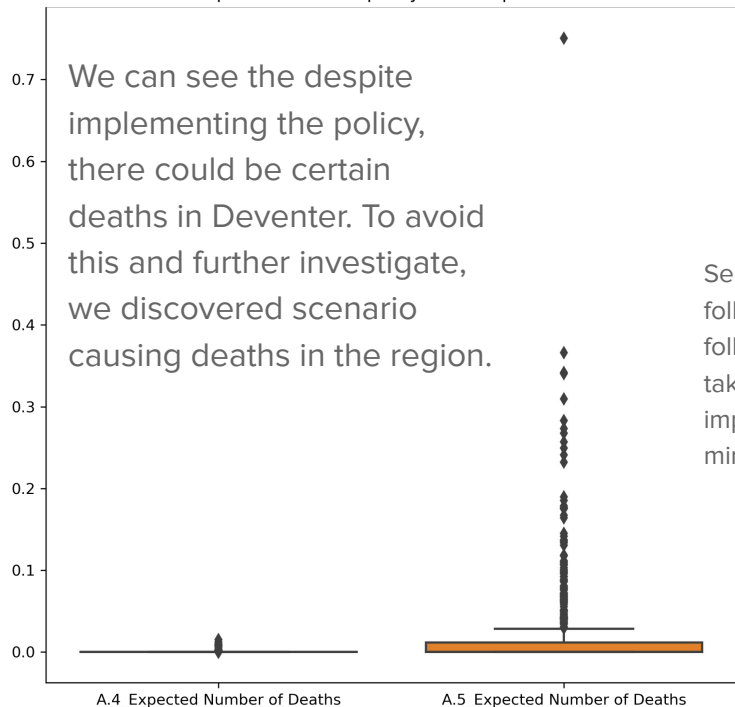
box 50
min
max
A.2_pfail 0.000649
0.072211
A.1_pfail 0.088464
0.999474
A.0_ID_flood_wave_shape 6.500000
    
```



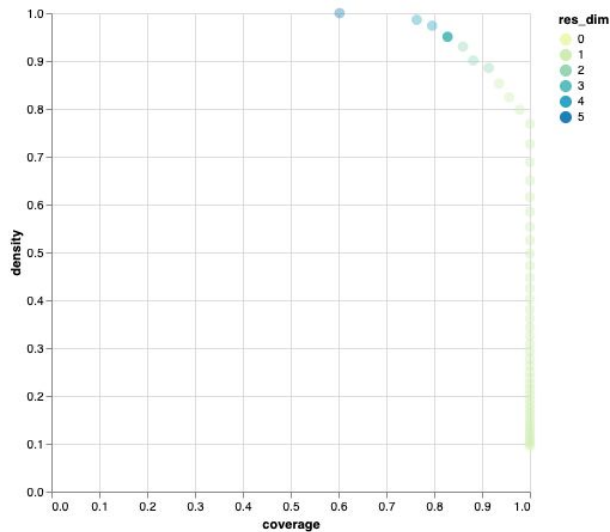
Selected policy might result higher A2 expected annual damage when

# Testing impact of policy on other provinces

Impact of selected policy in other provinces



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



name	A. 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