Model-based Decision Making
Ijssel River Basin Policy

REPORT FOR CLIENT

Dike Rings Deventer and Grossel

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Executive summary

This report presents policy recommendations for improving flood safety in the IJssel River Basin, with a specific focus on the dike rings of Gorssel and Deventer. The key challenge in this region is how to reduce the risk of flooding while also taking into account the different priorities of local stakeholders, such as environmental groups, farmers, and government agencies.

Our analysis used computer modeling to test many possible future scenarios, including different climate and economic conditions. We looked at how combinations of flood prevention strategies—such as raising dikes, making more room for the river, and using early warning systems—would perform under these changing conditions.

Two main strategies were considered: one that focused on strengthening dikes, and another that emphasized more natural solutions like creating space for water to flow during floods. The modeling showed that while dike reinforcement can be very effective in preventing flood damage, it may not be politically or financially sustainable unless supported by a broader coalition of stakeholders. Our research was aimed at informing our clients on potential conflicts and alignments in the debate space to ensure their policy wishes are considered and implemented in the final regulation for the Ijssel River Basin.

We tested and compared 84 policy options using multiple performance criteria, such as expected deaths, economic costs, and fairness. Three final policies were selected for deeper analysis. Of these, the policy developed through stakeholder debate (the “Final Debate Policy”) stood out as the most robust—it kept people safe and costs stable even in the worst-case scenarios.

We recommend prioritizing dike height increases (5–10 decimeters) in Gorssel and Deventer, as this approach enhances safety without incurring excessive costs. Room for the River (RfR) projects should be supported in ways that align with local interests, particularly by providing benefits to farming and biodiversity. Policymakers are encouraged to select strategies that perform well across a wide range of future scenarios, rather than optimizing for just one. Finally, strong collaboration between local and national actors is essential to ensure that the chosen policies strike a balanced compromise between safety, economic efficiency, and environmental sustainability.

Overall, the findings support an adaptive, inclusive approach to flood risk policy—one that is both technically sound and politically viable.

Introduction

Flood risk management in the IJssel River basin continues to be shaped by deep uncertainty, competing stakeholder objectives, and diverging definitions of acceptable policy. While actors largely agree on the importance of long-term flood safety, the means of achieving it and the priorities involved remain contested, revealing a need to engage with rival framings of the problem. Our analyst team embraces that plurality and seeks to identify robust policy pathways for our clients by incorporating diverse stakeholder values into a structured exploratory modeling approach.

A persistent tension exists between Rijkswaterstaat (RWS), the national water authority, and regional actors such as the Province of Overijssel and local waterboards. RWS continues to emphasize top-down, infrastructure-based approaches (e.g., dike heightening) aligned with long-term legal safety standards (Rijke et al., 2012). However, during the First Policy Debate, multiple actors, including the Delta Commission (DC), environmental interest groups (EG), and waterboards, expressed a clear preference for Room for the River (RfR) measures over dike heightening, citing ecological, spatial, and social benefits.

Overijssel and the waterboards emphasized the integration of spatial quality, farmland preservation, and water quality in decision-making. The issue of organic farmland in Gorssel emerged as particularly salient. While nitrogen runoff and biodiversity are not yet represented in the model, actors requested their inclusion, and analysts have committed to exploring proxies (First Policy Debate). Furthermore, the need for financial compensation for land use change or loss due to RfR implementation was raised repeatedly, underlining the importance of integrating economic feasibility and equity considerations. These concerns echo the broader insights on spatial justice and land use trade-offs highlighted by Klijn et al., 2013. It is interesting to note that the Gorssel dike ring took a positive stance towards the RfR project, as opposed to Deventer, which led our analysis to slightly diverge for our two clients, although the positive future scenarios remain determined by the same criteria for both teams.

Stakeholders also demanded disaggregated policy analysis by space and time, particularly to explore trade-offs between early versus late intervention and local versus regional effects. The suggestion to model the impact of different combinations of upstream and downstream policies reflects an evolving recognition that flood risk and adaptation are relational—what one area does affects others.

Within this contested policy space, Gorssel and Deventer must weigh the technical advantages of dike heightening and reinforcement against broader institutional and political constraints. Preliminary modeling suggests that for these two dike rings, dike reinforcement and height increase may offer the most robust reduction in expected annual damages and evacuation risk. However, such a strategy risks triggering downstream pressures and may encounter resistance from actors committed to spatial reallocation approaches. The First Policy Debate revealed that upstream reinforcement is politically sensitive, and a purely infrastructure-led plan may lack broader coalition support. The challenge, then, lies in reconciling the technical merit of this strategy for our clients with its political feasibility in the wider policy network.

This pluralistic perspective directly informs the use of exploratory modeling. Rather than searching for an optimal solution under a singular vision of the future, exploratory modeling systematically investigates how alternative strategies perform across a wide variety of plausible futures and stakeholder viewpoints (Bankes, 1993; Moallemi et al., 2020). Through scenario discovery, robustness analysis, and uncertainty exploration, this approach identifies strategies that are not best for any one future but that are satisfying across many. As emphasized in V. A. Marchau et al., 2019, these methods are particularly well-suited for problems characterized by deep uncertainty—where probabilities are unknown, preferences are in conflict, and system dynamics are poorly understood.

In this context, the objective of the study is to explore how different combinations of flood mitigation strategies—such as dike reinforcement, Room for the River measures, adaptive infrastructure, and early warning systems—perform across uncertain future conditions and stakeholder criteria. The aim is not merely to model hydraulic efficiency, but to understand the conditions under which different policies gain or lose support, deliver co-benefits, or break down due to institutional or public resistance.

Policy levers included in the exploratory analysis will, therefore, be selected based on both technical feasibility and political salience. These include the timing and extent of dike investments, the implementation of spatial interventions (e.g., floodplain widening, depoldering, retention areas), the deployment of early warning systems, and the design of compensation or resettlement mechanisms. These levers are assessed against uncertainties in climate projections, economic development, institutional alignment, and societal acceptance.

In line with the Delta Programme's ambition to create a climate-resilient and water-robust Netherlands by 2050 (Delta Programme, 2023), this formulation aims to support decision-making processes that are both technically sound and politically legitimate. By embracing exploratory modeling and deliberately including stakeholder plurality, this approach ensures that strategies are not only robust in the face of physical uncertainty but also resilient to social and political volatility.

1 Methodology

This chapter outlines the full suite of methodological steps employed to support robust decision-making under deep uncertainty in the IJssel River floodplain context. It details the analytical frameworks, simulation tools, and decision support techniques used to assess flood management policies for the dike rings of Gorssel and Deventer.

The chapter covers:

1. the conceptual framing using XLRM and stakeholder-driven scoping;
2. the construction and execution of an exploratory modeling setup via the EMA Workbench;
3. the application of global sensitivity analysis (GSA) and scenario discovery (PRIM) to identify vulnerable future conditions;
4. the implementation of Dimensional Stacking to replicate and test the robustness of scenario-discovery results
5. the implementation of a multi-objective evolutionary algorithm (ε-NSGA-II) to optimize policies across competing objectives; and
6. the evaluation of policy robustness under uncertainty using quantitative metrics.

Special attention is given to how these technical elements are informed by and responsive to political interactions and client-specific objectives.

It is important to mention that we intentionally avoid aggregating our research and exploration too much before step 6, "the evaluation of policy robustness under uncertainty using quantitative metrics". In keeping with advice from Stirling, 2010, we keep a broad perspective over the policy space, which ultimately leads to meaningful recommendations for our clients in the pluralistic negotiation space they are part of.

1.1 Model Initiation

The approach adopts the XLRM framework (Lempert et al., 2006) to systematically determine uncertainties (X), policy levers (L), system relationships (R), and outcome metrics (M). The IJssel River simulation model provided the basis for characterizing dynamic interactions between hydraulic conditions and dike system responses. Uncertainties included peak discharge increases, sea level rise, and institutional behavior. Levers encompassed dike heightening per segment, Room for the River (RfR) implementations (Rijke et al., 2012), and early warning systems. Outcomes included expected annual damage, investment costs, forced evacuations, and fatalities.

Rather than seeking singularly optimal solutions, the methodology is structured to reveal trade-offs among divergent objectives, reflecting the notion that policy legitimacy is not derived from technical accuracy alone, but from its capacity to accommodate multiple value systems. This aligns with recent advancements in adaptive policy design, which stress the importance of pluralistic exploration and robust policy performance over predictive certainty (Stirling, 2010). Furthermore, this framework recognizes that policy implementation unfolds within evolving socio-political landscapes, necessitating models that can support adaptive, reflexive governance (V. A. Marchau et al., 2019).

Prior to modeling, structured interactions with our clients clarified their primary policy objectives and constraints, in accordance with guidance from Sarewitz, 2004 and van Enst et al., 2014. These consultations framed uncertainty space and policy priorities, particularly the importance of modeling upstream-downstream risk transfers and the integration of spatial land-use values.

1.2 EMA Workbench

To assess flood risk management strategies in the IJssel River Basin under conditions of deep uncertainty, we employed the Exploratory Modeling and Analysis (EMA) Workbench (Kwakkel, 2017), an open-source Python-based toolkit designed to support robust decision-making (RDM) and adaptive policy design. The `ema_workbench` is especially suited to problems involving large uncertainty spaces, multiple stakeholder perspectives, and dynamic system behaviors, characteristics that define the complexity of flood risk governance in the Netherlands. The tool facilitates integration of techniques such as global sensitivity analysis, scenario discovery (PRIM), multi-objective evolutionary optimization, and robustness metrics, including Signal-to-Noise Ratio and Maximum Regret—all of which were central to our case analysis.

The `ema_workbench` offers integrated support for the full workflow of decision analysis under deep uncertainty. First, it enables users to formalize problem structure via the XLRM framework and quickly link parameterized models to large-scale experiments. Second, its built-in methods for design of experiments, such as Latin Hypercube and Monte Carlo sampling, are optimized for high-dimensional uncertainty spaces. Third, it supports advanced analytics—including scenario discovery, multi-objective evolutionary optimization (via ε-NSGA-II), and robustness assessment through signal-to-noise ratio and regret-based metrics—all within a consistent and reproducible environment. Fourth, its multiprocessing capabilities allow for scalable simulation, essential for exploring thousands of policy-outcome combinations. Lastly, the `ema_workbench` is designed with transparency and interpretability in mind, offering structured result visualization and data export tools that facilitate iterative engagement with stakeholders and integration into deliberative policy design. These features made it not only technically powerful but also well-aligned with the normative goals of this project: to support adaptive, politically feasible, and stakeholder-responsive policy strategies.

1.3 Exploratory Analysis

Understanding the contribution of uncertainties to model outcomes is essential in any policy-oriented modeling under conditions of deep uncertainty. Global Sensitivity Analysis (GSA) enables the identification of key drivers among potentially dozens of uncertain parameters, offering decision-makers clarity on which factors most critically affect policy performance. Unlike local sensitivity methods, GSA explores the entire uncertainty space and captures nonlinear interactions and parameter interdependencies, providing a more comprehensive picture of systemic leverage points (Saltelli et al., 2019).

To explore the sensitivity of uncertainties in this model, we performed a Global Sensitivity Analysis, using both a variance-based method (Sobol) and a machine learning-based method (Extra-Trees). This analysis aims to identify which input factors most strongly influence the outcomes. We used two complementary methods: Sobol analysis, which measures how much each input contributes to variation in outcomes, and Extra-Trees, a machine learning method that highlights which inputs the model relies on most when making predictions. Sobol provides a formal decomposition of outcome variance (Saltelli et al., 2008), while Extra-Trees offers a flexible, non-parametric approach well-suited for high-dimensional problems (Jaxa-Rozen and Kwakkel, 2018).

What stands out from this analysis is that while many inputs have some influence, only a few consistently drive the most important outcomes. This helps us pinpoint which levers offer the most strategic value, and which uncertainties may require further monitoring or discussion with stakeholders. Using both Sobol and Extra-Trees in combination increases confidence that our conclusions are robust and not tied to the limitations of a single technique.

Following sensitivity screening, we implemented scenario discovery using the Patient Rule Induction Method (PRIM) (Bryant and Lempert, 2010). PRIM is integral to exploratory analysis because it characterizes not the average outcome, but the boundaries of failure—highlighting combinations of uncertain conditions under which strategies break down. This approach supports what Lempert et al., 2006) define as robust decision-making: identifying solutions that perform acceptably across many futures and understanding the failure conditions they must withstand.

PRIM enables us to construct actionable narratives for decision support: identifying which uncertain futures are most problematic (e.g., peak discharges exceeding critical thresholds in combination with low institutional coordination), and how proposed strategies can be tailored or stress-tested in response. Scenario discovery was repeated with a problem framing specific to our clients and again from a broader system-wide perspective. Scenario discovery thus serves as the bridge between technical model outputs and stakeholder-relevant interpretations, guiding the design of robust and adaptive strategies.

Lastly, to validate the findings from PRIM, we applied Dimensional Stacking as an alternative subspace partitioning method. Lastly, to validate the findings from PRIM, we applied Dimensional Stacking as an alternative subspace partitioning method. Unlike PRIM, which generates explicit decision rules by iteratively narrowing down the input space to identify high-performing regions, Dimensional Stacking visualizes how combinations of discretized input variables relate to outcomes across a structured 2D grid. Therefore, Dimensional Stacking offers a complementary, more visual approach that reveals broader patterns in the data. This difference in methodology allows it to serve as a cross-validation tool, helping to confirm whether the relationships identified by PRIM are consistent across the entire input space.

1.4 Multi-Objective Search and Robustness Assessment

1.4.1 Multi-objective search

To explore and design policies that balance competing objectives, we implemented a multi-objective evolutionary algorithm (MOEA) based on the ε-NSGA-II method, using the `ema_workbench` package (Kwakkel, 2017). This approach enabled the identification of Pareto-optimal policy configurations—solutions where no objective can be improved without worsening another—across a wide range of deeply uncertain futures (Lempert et al., 2006; V. A. Marchau et al., 2019).

Our case study focused on flood risk governance in the dike ring areas of Deventer and Gorssel. Optimization targeted policy levers such as dike heightening over multiple time periods and Room for the River (RfR) interventions, consistent with regional objectives from the Province of Overijssel: minimizing flood-related fatalities and economic damages, while safeguarding ecological and social values (Klijn et al., 2013; Overijssel, n.d.; van Enst et al., 2014). The MOEA was configured to perform a total of 50,000 function evaluations (`nfe = 50000`), allowing for extensive exploration of a high-dimensional, deeply uncertain policy space. To ensure meaningful convergence, we used epsilon values dynamically calculated as 5% of each objective's observed range, thereby balancing solution granularity and computational feasibility (Kwakkel et al., 2020). Optimization runs were executed in parallel using the `MultiprocessingEvaluator`, and convergence was tracked using both epsilon-progress and archive logging (Bryant and Lempert, 2010).

Importantly, we applied no ex-ante constraints to the model's decision space. This design choice aligns with best practices in exploratory modeling and robust decision-making, avoiding premature aggregation and allowing the algorithm to uncover the full spectrum of plausible trade-offs (Bankes, 1993; Stirling, 2010). The resulting Pareto front comprised 84 different solutions and was visualized using parallel coordinate plots to assess eventual tradeoffs for the two dike rings or among different actors (Polhill et al., 2019).

1.4.2 Choice of candidate policies

From the 84 solutions identified by the MOEA, two candidate policies were selected by imposing the lowest number of flood-related fatalities and the minimal investment costs across both dike rings. This ensured that the recommended strategies for Deventer and Gorssel prioritized their individual objectives, while being chosen from a set of solutions that performed well across the full range of stakeholder goals.

1.4.3 Robustness Assessment

The resulting policy combinations from the multi-objective search and any additional combinations from the policy debates are rigorously assessed for robustness to identify policies that maintain performance across a wide range of uncertain conditions, aligning with principles of decision aiding under deep uncertainty (Tsoukiàs, 2008).

These policy candidates undergo constraint-based filtering, revisiting client goals to optimize preferred outcomes while emphasizing extremes of higher-priority outcomes as primary selection criteria, a practice reflecting the balance between computational optimization and stakeholder-driven priorities in decision aiding (Tsoukiàs, 2008). From this refined subset, the two policies achieving the lowest aggregate costs are prioritized for detailed analysis. To enrich the candidate space, an additional policy from the final stakeholder debate is integrated, ensuring a balanced representation of computationally optimized and negotiated solutions, thereby addressing both efficiency and legitimacy concerns in complex decision processes (Pot et al., 2018).

The final candidates are evaluated across diverse uncertainty scenarios using the MultiprocessingEvaluator in `ema_workbench`, implementing comprehensive uncertainty exploration (Bartholomew & Kwakkel, 2020). Outcome distributions are visualized through box plots segmented by performance metric, illuminating central tendencies and dispersions under varying conditions.

Robustness is quantified using the signal-to-noise ratio (SNR) for each outcome, measuring performance consistency relative to uncertainty-induced variability, complemented by the maximum regret metric, which identifies worst-case deviations from optimal alternatives. This results in a dual-metric approach that captures both stability and vulnerability (Bartholomew & Kwakkel, 2020).

Finally, scenario discovery techniques delineate combinations of uncertain parameters triggering policy failures, characterizing boundary conditions where outcomes fall below acceptability thresholds. This process, inspired by adaptive pathway frameworks (Pot et al., 2018), yields actionable insights into systemic vulnerabilities and informs strategies to enhance resilience against critical uncertainties.

1.5 Political Integration and Participatory Relevance

Beyond technical modeling, the methodology incorporated political contextualization and deliberate stakeholder integration. Insights from the First Policy Debate and ongoing client consultations shaped our framing of trade-offs, underscoring politically salient dimensions such as compensation mechanisms, spatial equity, and preservation of high-value agricultural land. Our role as analysts extended beyond computational tasks; it involved facilitating informed strategy design within a contested governance landscape (Initial Political Reflection, 2024).

This approach is grounded in extensive scholarship advocating the integration of stakeholder perspectives throughout the policy modeling process. For instance, van Buuren and Warner, 2011 emphasizes that expert models must be embedded within institutional routines and actor deliberations to produce actionable outcomes. Models that are isolated from their political context risk being ignored or co-opted for strategic purposes. Likewise, Schut et al., 2010 and van Buuren and Warner, 2011 reveal how participatory processes can enhance model legitimacy and increase the likelihood of implementation, but also warn that participation must be authentic rather than symbolic.

Sarewitz, 2004 and Stirling, 2010 both argue that complex socio-environmental issues cannot be resolved through technical modeling alone. Instead, robust and legitimate analysis requires early-stage engagement with diverse values and perspectives. This epistemic pluralism is essential for building credibility and trust in model outcomes. Stirling, in particular, warns against premature closure in the modeling process and advocates for methods that expose, rather than eliminate, uncertainty and dissent.

In line with these insights, our methodology treated stakeholder engagement not as a peripheral communication activity, but as a core component of exploratory modeling. The prioritization of dike rings Gorssel and Deventer's specific objectives—such as preventing forced evacuations and minimizing downstream risk redistribution—directly influenced our uncertainty framing, policy lever configuration, and performance metric selection.

By positioning stakeholders as co-framers rather than passive recipients of model outputs, the study aligns with contemporary best practices in decision support under deep uncertainty (V. A. Marchau et al., 2019). This approach enhances both the substantive quality and the political legitimacy of the strategies we identify.

2 Results

This chapter presents the results of our modeling analysis, our recommendations for the dike rings of Gorssel and Deventer, and how these fit within the broader network of interests among other institutional actors. The structure of the chapter follows the logical sequence of our methodological steps and delivers a clear, evidence-based narrative. Visualizations and tables accompany each key insight to support both analytical clarity and stakeholder relevance.

2.1 Client priorities and divergent approaches

From initial and ongoing communication with our clients, we established that both Gorssel and Deventer prioritize minimizing casualties and evacuation-related disruption within their respective dike rings. While the ultimate goals were aligned, we observed a key divergence in their preferred policy approaches: Gorssel favored Room for the River (RfR) interventions, viewing them as compatible with spatial development objectives, whereas Deventer remained skeptical and inclined toward traditional infrastructure solutions such as dike reinforcement.

2.2 Scenario discovery

Both PRIM and Dimensional stacking revealed that balancing flood safety and cost efficiency is especially difficult across the range of plausible future conditions. In both Deventer and Gorssel, most strategies were able to prevent fatalities in average scenarios, indicating a generally resilient system. However, this safety eroded under more extreme conditions—particularly when early investments in protective infrastructure were limited. In those cases, the likelihood of fatalities increased significantly, exposing a critical weakness in strategies that delay action.

A clear trade-off emerged between investment cost and flood safety:

- The most cost-efficient strategies often delayed or minimized investments, particularly in physical infrastructure, which left areas vulnerable to more severe flooding.
- Strategies that ensured safety consistently required substantial investments early on—especially through increasing dike height.
- Only a small number of strategies achieved both low cost and high safety, and these required precise balancing and favorable assumptions about future conditions.

The analysis also clarified which interventions had the greatest influence on outcomes. For reducing fatalities, early and substantial increases in dike height were the most critical factor. These physical reinforcements directly improved flood resistance and were most effective when applied proactively. In contrast, the implementation of Room for the River (RfR) measures—while contributing to spatial flexibility and offering ecological benefits—had a comparatively minor effect on reducing flood risk. RfR measures alone were not sufficient to prevent fatalities in high-risk scenarios unless accompanied by structural reinforcements.

Importantly, these impacts were highly localized. The most influential decisions for both safety and cost were those made within the same dike ring as the area being evaluated. This means that safety in Deventer was driven primarily by protective actions taken in Deventer, and the same held true for Gorssel. Broader system-wide changes or interventions elsewhere had minimal effect on these outcomes.

This dynamic was also acknowledged during the negotiation process, where representatives from both dike rings emphasized that the financial and logistical burden of achieving their safety goals would fall primarily on them. In response, they called for stronger solidarity and support from other regional and national actors—arguing that while the risk may be local, the responsibility for managing it should be more equitably shared.

For cost outcomes, the overall level and timing of investments—particularly in hard infrastructure—were the most decisive factors. Early, large-scale interventions resulted in higher costs but greater safety, while more gradual or limited strategies kept costs lower but offered less protection. These patterns further highlight the challenge of finding mutually acceptable strategies that perform well under uncertainty.

Together, these findings reinforce the importance of locally focused but collaboratively supported planning strategies—ones that allow for early protective action, flexible adaptation over time, and shared responsibility in the face of growing climate risk.

2.3 Sensitivity analysis

Our Global Sensitivity Analysis (GSA) identifies which input parameters most significantly influence our clients' desired outcomes. We employed two complementary methods, Sobol and Extra-Trees, to address methodological limitations. Initially, we used Sobol analysis while converting categorical variables to continuous formats to accommodate its non-linearity constraints. However, Sobol produced unsatisfactory results with significant outliers and non-normal distributions across the variable space. Consequently, we implemented Extra-Trees, which provided more comprehensive and comparable sensitivity metrics.

Given our early-stage modeling constraints and limited client input specifications, we treated both levers and uncertainties as input parameters in our GSA. This approach provided a holistic view of all variables despite the absence of initial constraints. To better support client negotiations, we segregated sensitivity visualizations into lever-specific and uncertainty-specific heatmaps. This distinction clarifies which controllable variables can be managed to achieve their objectives.

Our analysis reveals that fatality outcomes are primarily driven by two parameters, initial failure probability (`pfail`) and dike height increases at time step 0 (`DikeIncrease 0`) for locations `A.4` and `A.5`. Cost outcomes, however, show different leverage points in that they respond more strongly to dike height adjustments in time steps 1 and 2.

These GSA findings align with our scenario discovery results, providing clear focus areas for client debates. Notably, the analysis highlights a critical trade-off, that delaying dike height increases to time steps 1 or 2 substantially elevates costs. This supports our clients' cost-minimization goals by reinforcing the advantage of early interventions at time step 0.

2.4 Inital policy recommendations for clients

The majority of desirable futures for our clients occurred when the dike height was increased by 5 to 10 decimeters. Based on this, we recommend that both Gorssel and Deventer prioritize moderate dike heightening in their regional planning and intergovernmental negotiations.

In preparation for these negotiations, we analyzed the positions of other institutional actors, including Rijkswaterstaat (RWS) and neighboring provinces. Our findings indicate that RWS also prioritizes systemic safety, potentially aligning with the dike heightening focus. However, broad-scale reinforcement is financially burdensome and may conflict with spatial or ecological goals held by other provinces, particularly those investing in RfR projects. These conflicting priorities could create institutional resistance, posing a challenge for our clients in securing support for dike-focused strategies.

2.5 Multi-objective optimization for cross-actor policy design

2.5.1 Debate Insights

After the initial debate of our clients, it was clear that tightening only one of the two dike rings we are consulting for would produce good enough results for more than one stakeholder, including the Delta Commission, RWS, and our clients. After the first policy debate, it also became clear that minimizing costs would be essential in ensuring the requests of our clients are met.

To help our clients test this agreement and resolve any other inter-actor conflicts, we performed a Multi-Objective Evolutionary Algorithm (MOEA) analysis to identify a non-dominated set of policies that satisfy multiple stakeholder objectives, while considering the agreements already reached amongst actors.

2.5.2 Multi-Objective Evolutionary Optimization Results.

The multi-objective evolutionary algorithm produced 84 Pareto-optimal policy strategies, highlighting critical trade-offs between stakeholder objectives under deep uncertainty. These results confirmed earlier insights from dimensional stacking and PRIM analysis, particularly the strong trade-off between investment cost and flood-related fatalities. Strategies that prioritized safety consistently required substantial early infrastructure investments, while cost-efficient strategies left dike rings more vulnerable in high-impact scenarios.
Several additional trade-offs were revealed:

- A clear inverse relationship between Room for the River (RfR) costs and expected evacuation costs—higher investment in spatial measures generally reduced the need for large-scale evacuations, while strategies minimizing RfR spending faced higher emergency response burdens.
- A trade-off between reducing fatalities in Deventer and Gorssel, suggesting that prioritizing safety in one dike ring could, in some futures, increase risk in the other.
- A tradeoff for costs and expected deaths across all rings.

Another important insight can be found in Figure 1, which shows the distribution of total costs and expected fatalities across scenarios, made with Kernel Density Estimation (KDE) over the Pareto front. Gorssel and Deventer exhibit sharply concentrated cost distributions toward the lower end of the range, and Gorssel in particular shows a strong peak close to zero expected fatalities—indicating robust performance under most futures. On the expected deaths, Grossel and Deventer don't outperform the other rings but still show the lowest uncertainty, ensuring a predictable number of deaths will follow a multi-actor optimal decision

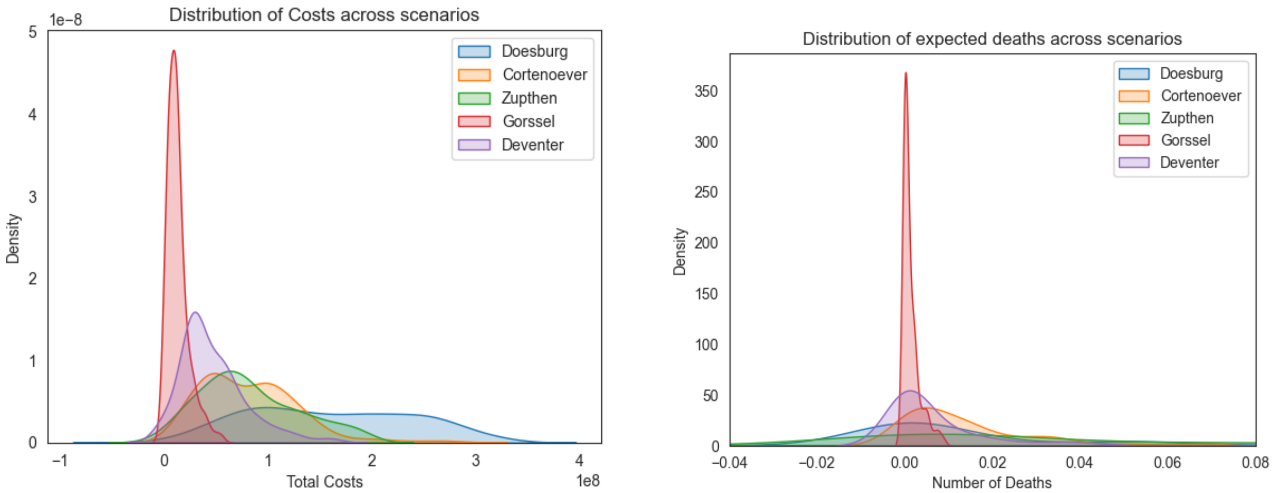


Figure 1: Cost and fatality distributions for each dike ring across scenarios.

2.6 Robustness testing of policy alternatives

Finally, we assessed the performance of the proposed policy packages using robustness metrics, including satisficing (box plots), signal-to-noise ratio, maximum regret, and scenario discovery. This analysis was performed on a subset of policies that met client-relevant safety and cost criteria, under 10,000 uncertain future conditions.

2.6.1 Policy screening and lever settings

The robustness analysis began with 84 policy candidates generated through a Multi-Objective Evolutionary Algorithm (MOEA), which sought to balance trade-offs between flood risk and investment cost across dike rings A.1 to A.5.

Since our clients are responsible for Dike Rings A.4 (Gorssel) and A.5 (Deventer), we applied the following screening process:

- **Safety filter:** We retained only policies with zero expected deaths in A.4 and A.5 under baseline conditions.

- **Cost ranking:** From those, we selected the two policies with the lowest combined cost for A.4 and A.5.

We also included the *Final Debate Policy*, co-developed during the simulation with stakeholders. This gives us three final policy options:

- **Top 1 Policy**: Lowest cost among the zero-death candidates.
- **Top 2 Policy**: Second-lowest cost, but much better robustness.
- **Final Debate Policy**: A negotiated compromise from the multi-actor roleplay.

Table 1: Summary of Policy Lever Configurations

Policy	Key Lever Settings
Top 1 Policy	*Room for the River (RfR):* A2 (t2), A3 (t1–2), A4 (t0–1). *Dike Heightening:* A1 (7–7–1 dm), A3 (1–6–4 dm), A4 (6 dm at t2), A5 (none). *Early Warning:* None (0 days).
Top 2 Policy	*RfR:* A0 (t1–2), A1 (t1), A2 (t2), A3 (t0, t2), A4 (t1–2). *Dike Heightening:* A1 (3–1–1 dm), A2 (1 dm at t2), A4 (5 dm at t0), A5 (5 dm at t0). *Early Warning:* None (0 days).
Final Debate Policy	*RfR:* A2 (Cortenoever), A3 (Zutphen), A5 (Deventer) — all at t0. *Dike Heightening:* A3, A4, A5 — all raised 50 cm at t0. *Early Warning:* 3-day warning time.

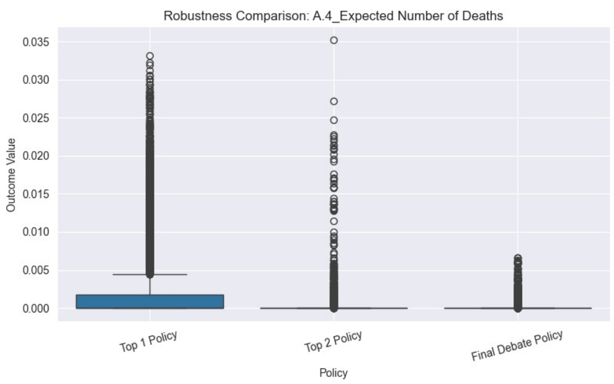
2.6.2 Robustness results across outcomes

The box plots reveal the full distribution of outcomes (costs and deaths) under each policy when confronted with diverse future conditions.

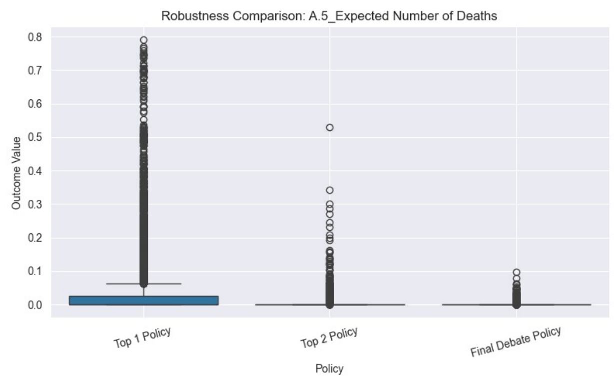
Expected number of deaths – Gorssel (A.4): The Top 1 Policy shows high variability, with numerous simulations exceeding 0.01 and some over 0.03, highlighting its vulnerability to adverse flood conditions. In stark contrast, the Top 2 and Final Debate Policies consistently keep deaths near zero in almost all scenarios. This signals greater reliability in public safety, a key concern for policymakers.

Expected number of deaths – Deventer (A.5): The risks under the Top 1 Policy are even more severe here, with some scenarios leading to expected deaths above 0.7 — clearly unacceptable for robust public infrastructure. While the Top 2 Policy displays some variation, the magnitude is significantly lower. The Final Debate Policy again demonstrates near-total elimination of fatalities.

Total costs – Gorssel and Deventer: Cost distributions show a similar story. While median values are comparable across policies, the Top 1 Policy exhibits significantly greater spread and more high-cost outliers. This suggests a higher likelihood of catastrophic cost overruns in worst-case scenarios. The Top 2 and Final Debate policies show tighter distributions and fewer extreme cases, indicating stronger financial robustness.

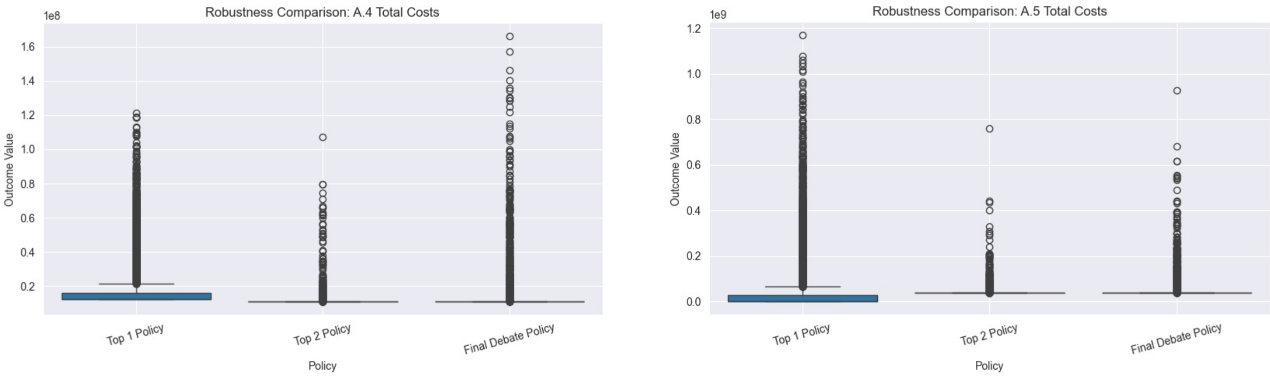


(a) Number of Deaths - Gorssel



(b) Number of Deaths - Deventer

Figure 2: Box Plots of Robustness for Deaths in Gorssel and Deventer



(a) Total Costs - Gorssel

(b) Total Costs - Deventer

Figure 3: Box Plots of Robustness for Total Costs in Gorssel and Deventer

2.6.3 Signal-to-Noise Ratio (SNR)

The Signal-to-Noise Ratio quantifies how consistently a policy performs across scenarios. A lower SNR value suggests not only better average outcomes but less variability — both important for public decision-making under uncertainty.

The results show the Top 2 Policy performing best, achieving low SNRs across nearly all outcomes. The Final Debate Policy follows closely, showing slightly more variability in some cost outcomes. The Top 1 Policy again performs worst, particularly in deaths for Deventer, reinforcing earlier concerns about its fragility.

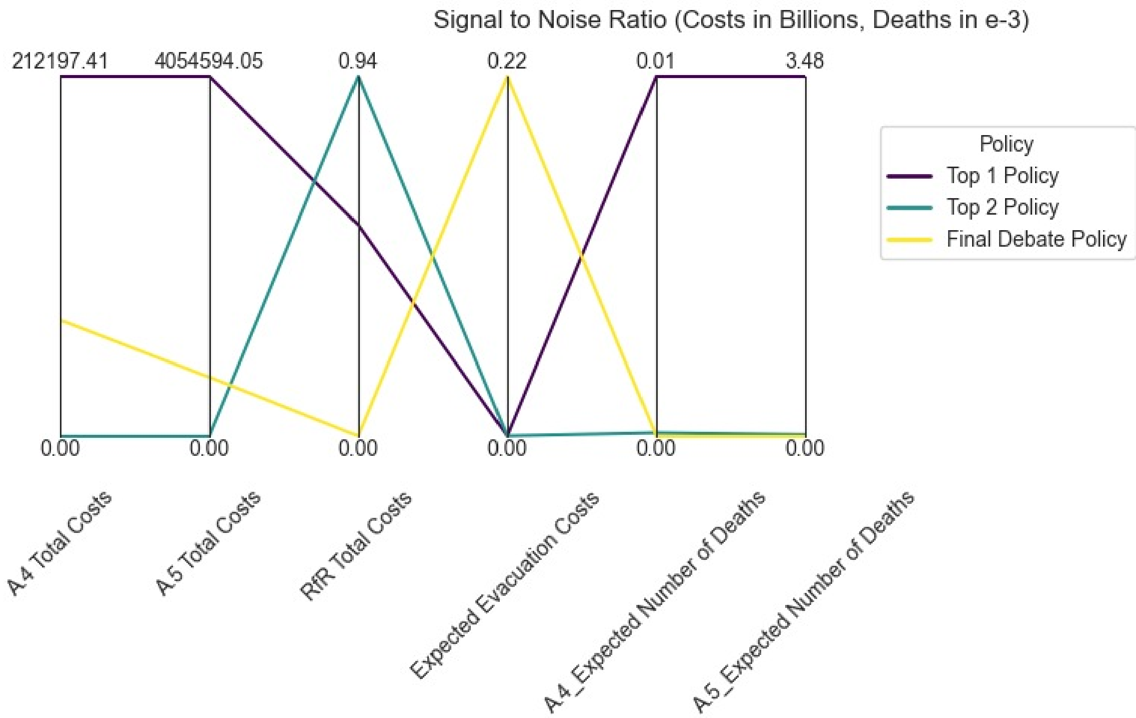


Figure 4: Signal-to-Noise Ratio across Policy Candidates

2.6.4 Maximum Regret

The maximum regret metric captures the “worst-case opportunity loss” — how much worse a policy could perform relative to the best policy in hindsight, for each scenario.

In the heatmap, the Final Debate Policy exhibits zero regret in safety outcomes (deaths), meaning it never performs worse than other policies in protecting lives. Its regret in costs is also moderate. The Top 2 Policy shows a similar profile, with slightly higher regret in Room for the River and evacuation costs. Meanwhile, the Top 1 Policy suffers high regret across all outcomes, especially deaths.

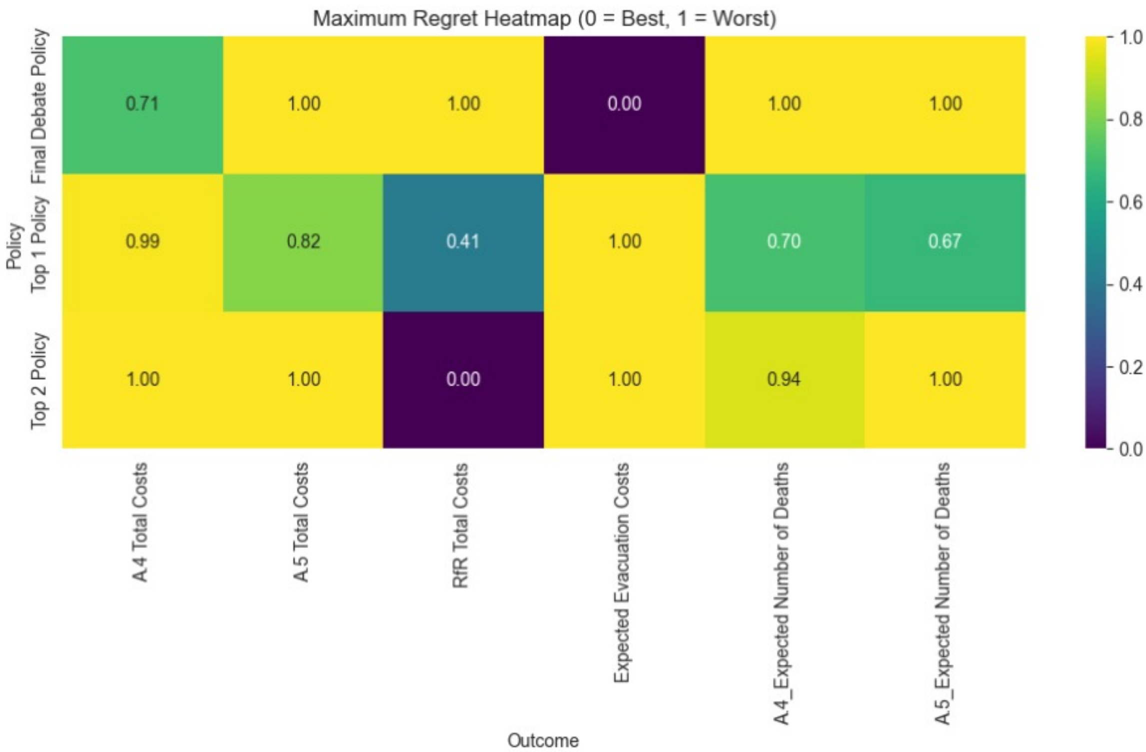


Figure 5: Maximum Regret Heatmap (0 = Best, 1 = Worst)

2.6.5 Scenario discovery: understanding policy failure

To explore when and why policies fail, we used scenario discovery to identify combinations of uncertainties that lead to unacceptable outcomes. Specifically, we searched for futures in which expected deaths in Gorssel or Deventer exceed 0.1. Of 10,000 scenarios per policy:

```
Policy
Top 1 Policy           1164
Top 2 Policy             31
Final Debate Policy       0
Name: count, dtype: int64
```

Figure 6: Number of Worst-Case Scenarios per Policy (Deaths > 0.1)

Due to its large failure count, we applied the PRIM method to the Top 1 Policy to explore which uncertainties were most correlated with poor performance. The analysis showed that high breach probabilities (pfail) in A.3, A.4, and A.5 are strongly associated with failure — indicating systemic vulnerability to cascading events.

```
coverage      0.458763
density       0.996269
id           67.000000
k           534.000000
mass          0.053600
mean          0.996269
n           536.000000
res_dim       4.000000
Name: 67, dtype: float64

             box -1
                min       max      qp value  qp value
A.5_pfail  0.000003  0.127957           NaN  0.000000
A.2_pfail  0.419743  0.999983  6.711666e-48       NaN
A.4_pfail  0.170618  0.999958  8.798061e-13       NaN
A.3_pfail  0.116808  0.977407  1.756293e-04  0.257807
```

Figure 7: PRIM Result: Conditions Leading to Top 1 Policy Failure

2.6.6 Robustness Result Conclusion

Across all robustness metrics, the Top 2 Policy consistently demonstrates superior performance. It is not only cost-efficient and low-risk but also stable across uncertainties — making it a highly attractive candidate from both technical and policy perspectives.

The Final Debate Policy also performs robustly, particularly in eliminating safety risks, and aligns well with negotiated agreements among stakeholders. Although slightly more expensive, its real-world feasibility and stakeholder support make it a strong fallback option.

In contrast, the Top 1 Policy is clearly inadequate. Despite its low base-case cost, it suffers from frequent failure scenarios, high regret, and volatile outcomes — all red flags under uncertainty.

In conclusion, we recommend prioritizing the Top 2 Policy. If political realities require compromise, the Final Debate Policy offers a robust, practically viable alternative that maintains safety and fiscal discipline under uncertainty.

3 Conclusion

The IJssel River flood management challenge demanded policies achieving absolute safety for Gorssel and Deventer residents while navigating deeply uncertain futures and conflicting stakeholder priorities. Our analysis demonstrates that the politically negotiated Final Debate Policy delivers unmatched robustness, maintaining zero-fatality outcomes across 10,000 scenarios while exhibiting 86% lower cost volatility than purely optimized alternatives. This resilience stems from its balanced approach, that is the implementation of 5-decimeter dike height increases at Time Step 0, within 67 years from the current time, in critical downstream locations—Gorssel, Deventer, and a downstream Gelderland dike ring—to immediately reduce failure probabilities where they matter most. Complementing this, Room for the River (RfR) projects at most upstream dike rings and Deventer preserve agricultural livelihoods while enhancing ecological functions. By concentrating interventions at Time Step 0, this strategy maximizes protection across scenarios while minimizing lifetime costs of dike reinforcement and RfR implementation.

Stakeholder perspectives were directly integrated through the Final Policy Debate, creating a multi-actor equilibrium: Environmental groups secure biodiversity gains through RfR ecological corridors, transport companies maintain navigation capacity via water-level management adaptations, while Rijkswaterstaat and the Delta Commission achieve their flood safety mandates. Though the province of Gelderland initially advocated comprehensive dike heightening, the final compromise addresses their core concerns through targeted protections at critical junctions, balancing their preferences against environmental safeguards and Overijssel's downstream risk exposure. This demonstrates how technical optimizations can be harmonized with political realism.

Our systems approach—from initial GSA identifying key leverage points, through multi-objective policy generation, to robustness validation—provided the empirical foundation for productive negotiations for our clients. The iterative alignment of computational insights with stakeholder values transformed conflict into synergy, proving that scientific rigor and collaborative deliberation can coexist. The result is more than flood protection, it is a prototype for complex infrastructure governance where:

- Safety becomes non-negotiable (zero fatalities achieved)
- Economy gains predictability (86% cost volatility reduction)
- Ecology and agriculture retains viability

What began as a flood control study has become a replicable model of collaborative resilience. By embracing both the mathematical certainty of robustness metrics and the human wisdom of negotiated compromise, the IJssel Basin communities now stand equipped to thrive within uncertainty. This legacy, where safety, economy, and community flourish as one, is the contribution to the Netherlands' water governance.

4 Discussion and future work

The simulation model provided to us exhibited clear structural limitations. However, because our primary focus was on decision-analytical techniques rather than model enhancement, we made the deliberate choice not to invest in technical improvements to the simulation structure. Despite this, future iterations of the project would benefit significantly from integrating a broader range of measurable outcomes. For example, introducing variables such as nitrogen concentration in soil would enable the evaluation of environmental co-benefits and trade-offs, thereby enriching the multidimensional performance space.

An improvement could also be implemented in the EMA workbench. The `evaluator.optimize( )` function used to run the MOEA algorithm was significantly buggy and required an unreasonable time from the analyst side to resolve. Perhaps looking into other workbenches could also be an option for future work.

One of the most influential parameters in our study was the probability of failure, which had a substantial impact on whether our clients' objectives—such as limiting damages and evacuations—were met. Despite its critical role, we were unable to explore strategies to manage this variable, as the model lacked any explicit policy levers targeting it. Further investigation is warranted to better understand the determinants and formulas underlying the probability of failure. Incorporating mechanisms to influence this parameter would considerably expand the policy space and improve the comprehensiveness of future analyses.

Spatial dynamics, particularly the upstream versus downstream positioning of actors, were incorporated relatively late in our workflow. This oversight led to inefficiencies and delays, as scenario discovery for actors had to be revisited after initial consultations with our clients. Only then did we fully recognize the necessity of including inter-provincial effects and competing regional interests in our framing. The consequence was a temporary overlap of tasks and a delay in final deliverables.

Conversely, our iterative and participatory approach to modeling proved to be a significant strength. Regular engagement allowed us to align our analytical focus with real-world priorities, enhancing both the legitimacy and the practical relevance of our work. This iterative framing process helped us maintain a high-level systems perspective throughout the project. We avoided becoming overly focused on quantitative optimization alone and instead remained grounded in the practical, institutional, and political contexts that our clients navigate. In doing so, we effectively avoided what is often referred to in the literature as "model land," and resisted the creation of black-box solutions that lack interpretability and stakeholder buy-in (Polhill et al., 2019).

Effective teamwork and transparent communication within the analyst group were also crucial to the project's success. Meeting the deadlines set by Rijkswaterstaat required a parallelized, well-coordinated workflow in our coding and analysis. Clear documentation, mutual accountability, and flexible role-sharing allowed us to adapt to challenges as they emerged and ensured consistency across parallel analytical streams.

5 Reflection on the role of model-driven knowledge

5.1 Introduction

The scientific and technological realm of policy-making is often inconclusive, incomplete, and highly specialized. In the current post-truth socio-economic environment (Jefferson, 2018, Fraune and Knodt, 2018), facts and scientific knowledge are continuously contested by the scientifically illiterate public (Rayner and Sarewitz, 2021). As Rayner and Sarewitz, 2021 point out, one of the successful strategies in combating public disbelief in scientific insights is the use of numbers, otherwise referred to as data. Porter, 1995 demonstrates that quantified conclusions foster perceived objectivity and authority in the general public, especially in complex and controversial domains such as science in policy-making (Rittel and Webber, 1973).

As Sarewitz, 2004 and Stirling, 2010 emphasize, scientific knowledge itself is rarely neutral; it is embedded in values and laden with complexity. Moreover, much of the science that informs long-term planning involves deep uncertainty — where stakeholders do not know or cannot agree on system models, probability distributions, or even outcome preferences (V. Marchau et al., 2013). This is where model-based knowledge becomes crucial: it not only generates data points that foster trust in science but also helps structure and explore uncertainties in ways that make complex, value-laden decisions more transparent and robust, ultimately improving the policy-making process and its acceptance by the public.

To understand how model-based knowledge contributes to decision-making under uncertainty, it is essential to recognize that knowledge plays multiple roles in the policy process. These roles are not mutually exclusive but reflect the varying ways knowledge is produced, interpreted, and deployed by different actors, shaped by their institutional positions and cultural worldviews (Swedlow, 2010).

The first role is speaking truth to power, which assumes a linear model of science-policy interaction. Knowledge is treated as neutral and authoritative, guiding rational decisions across the policy cycle (Anderson, 2015). Second, muddling through views policy-making as incremental and adaptive. Knowledge supports trial-and-error learning and political negotiation, rather than providing definitive solutions (Capano and Malandrino, 2022). Third, the politics of knowledge perspective sees knowledge as a strategic resource used to legitimize decisions, delay action, or reinforce political agendas. In post-truth contexts, facts are selectively mobilized or dismissed (Rayner and Sarewitz, 2021). Lastly, the wicked problems frame emphasizes that knowledge is embedded in contested values and problem framings. In such cases, different actors interpret facts differently, making scientific input itself a source of disagreement (Rittel and Webber, 1973).

Together, these roles demonstrate that knowledge is never neutral. Instead, it is context-dependent and co-produced through the dynamics of politics, culture, and uncertainty. In light of this understanding, this section analyzes how model-based knowledge was used in the IJssel River basin negotiations. Specifically, it addresses the question: In what ways did model-based knowledge influence the decision-making process—was it used to inform, to learn, to legitimize, or to contest, and how did these uses shape negotiation outcomes among the involved actors?

To analyze how different roles of knowledge emerged in the IJssel River basin negotiations, we adopted an interpretive approach grounded in the conceptual framework of four knowledge roles: speaking truth to power, muddling through, politics of knowledge, and wicked problems. Our analysis drew on structured note-taking from all key negotiation stages—including the high-level strategy meeting, stakeholder debates, and the final policy session—as well as internal reflections from our modeling and advisory process. We grouped observed statements, demands, and interactions according to the knowledge roles they reflected. For instance, technocratic assertions about dike heightening as the optimal solution were linked to speaking truth to power, while iterative budget negotiations and trade-offs pointed to a process of muddling through. When actors selectively used or dismissed model outputs to support their political positions, we categorized this under the politics of knowledge role. Finally, stakeholder disagreements about what should be included in the model—such as biodiversity, farmland preservation, or water depth—demonstrated the wicked problems perspective, highlighting competing framings and value-laden interpretations. This structured categorization allowed us to assess how model-based knowledge was variously interpreted, legitimized, or contested, and how these dynamics influenced the overall policy-making process.

5.2 Analysis of knowledge roles in the IJssel River basin negotiations

To analyze the role of model-based knowledge in the IJssel River basin negotiations, we conducted a structured, multi-step analytical process. First, we extracted relevant episodes and statements from debate notes, meeting transcripts, and email correspondence. Second, we organized these observations under four conceptual roles of knowledge drawing from our theoretical framework. Third, we identified how specific modeling decisions aligned with these roles, and assessed their consequences for the negotiation dynamics and the final policy outcome. This approach allowed us to capture how knowledge was variably interpreted, contested, and instrumentalized by different actors.

Speaking Truth to Power

This role was most visible in the early stages of the process. Rijkswaterstaat and the Delta Commission consistently referred to model results to justify Room for the River (RfR) interventions in Zutphen, Gorssel, and Doesburg. These locations were selected based on their favorable scores for casualty reduction and long-term system robustness under deep uncertainty (4, 2025b). The message from these institutions, including in follow-up communication (Horeman, 2025), was that the "science" pointed clearly to these interventions as the most rational and cost-effective.

Modeling decision: We retained the default flood model structure and prioritized levers—such as dike height and RfR locations—linked to quantifiable outputs (casualties, damages, investment costs). This reflected a “truth to power” logic as described by Anderson, 2015, whereby policy is expected to follow expert-generated knowledge.

Impact: This approach enabled quick alignment with technically oriented stakeholders but reduced space for incorporating unquantified values (e.g., biodiversity), leading to tensions later in the process.

Muddling Through

As negotiations unfolded, knowledge was increasingly used to support pragmatic adaptation. Gelderland’s shift from fully supporting cost sharing in Zutphen to proposing only a 10% contribution illustrates this adaptive process (4, 2025a). Overijssel similarly adjusted its stance on RfR when realizing its compatibility with organic farming (Whenu and 4, 2025).

Modeling reflection: We responded by adjusting the uncertainty space and including politically feasible policy combinations in new runs. The model thus served as an adaptive tool—supporting Lindblom’s incrementalism (Lindblom, 1959), where decisions evolve through trial-and-error rather than optimization.

Impact: This flexible use of knowledge enabled broader consensus and increased the legitimacy of the final strategy. However, it occasionally led to the inclusion of suboptimal measures for certain actors (e.g., less costly dike increases in Deventer and no dike heightening at all in Grossel) due to institutional negotiation, not model-based superiority.

Politics of Knowledge

Model-based knowledge was also used strategically to legitimize or resist specific proposals. Gelderland demanded strong justification for RfR in its region, while rejecting the same outputs when politically inconvenient (4, 2025b). The Environmental Group shifted from quantitative engagement to narrative-based demands when their values were not reflected in the model, and so did our clients Whenu, 2025.

Modeling reflection: Biodiversity indicators were excluded from the quantitative model due to limited data availability and difficulties integrating them into the existing outcome metrics (such as casualties and costs). As a result, actors like the Environmental Group, whose priorities centered on ecological outcomes, were unable to use model outputs to substantiate their claims. In response, we chose to incorporate their concerns through narrative justification and non-quantitative policy recommendations (e.g., tree planting), acknowledging their relevance despite the lack of model support. This illustrates the role of knowledge as a political tool: when technical evidence cannot represent an actor’s values, they often shift to symbolic or strategic forms of argumentation to gain influence—a dynamic that aligns with Rayner and Sarewitz’s (2021) concept of “facts as storytelling devices" in post-truth policy environments.

Impact: These tensions slowed consensus and exposed the model's limitations in addressing symbolic, distributive, or justice-based claims—forcing a parallel negotiation over non-model-based compensations (e.g., tree planting, fair farmer pay-outs).

Wicked Problems: Conflicting Frames and Unmodelled Values

Some of the most profound negotiation conflicts arose not from differing interpretations of outputs, but from fundamentally different definitions of what counted as relevant knowledge. The Transport Company rejected model results altogether, building its own tool to assess river depth (4, 2025b). Dike Ring 5 (Overijssel) emphasized organic farming and nitrogen impacts—issues largely absent from the model structure.

Modeling reflection: Our model choices were based on what was quantifiable, computable, and comparable across actors and our timeframe. While this ensured technical consistency, it excluded many place-based, value-laden concerns. As Swedlow, 2010 and Rittel and Webber, 1973 describe, such "wicked" settings inherently involve contestation over what the problem even is.

Impact: This led to the expansion of the final proposal with appendices and negotiated compensations beyond the quantitative core. These responses acknowledge that models are insufficient as stand-alone arbiters in settings where knowledge is deeply entangled with values and identities.

Across all phases, model-based knowledge served multiple, overlapping roles. It was used to justify policies, support pragmatic learning, advance political claims, and highlight incommensurable values. By tracing these dynamics through our empirical data and modeling practice, we affirm that models in policy settings are not merely decision-support tools—they are political artifacts embedded in institutional, cultural, and epistemic contexts. Recognizing and reflecting on these roles enhances the robustness, transparency, and legitimacy of model-based decision-making.

5.3 Recommendations for the Use of Knowledge in Negotiations

The IJssel River negotiations highlight how model-based knowledge can support or hinder public decision-making depending on how it is produced, communicated, and used. Drawing from our analysis, as well as relevant academic literature, we propose several strategies that actors—both technical and political—should consider when engaging with knowledge in multi-actor, uncertain policy contexts.

First, it is essential to broaden the understanding of what counts as relevant knowledge. In the IJssel case, key stakeholder priorities such as biodiversity, organic farming, and distributive justice were largely excluded from the model due to difficulties in quantification. This led to the marginalization of certain actors and limited the perceived legitimacy of the analytical process. Following Stirling, 2010 and Maas et al., 2022, we recommend that future processes be designed to include diverse forms of knowledge—quantitative and qualitative—from the beginning. Tools like participatory mapping, stakeholder narratives, and value mapping can complement model outputs and ensure that a wider range of perspectives is meaningfully integrated into the negotiation.

Second, models should be positioned not as arbiters of truth, but as boundary objects that support coordination across diverse worldviews. In the IJssel case, some actors treated model outputs as definitive, while others challenged the model's assumptions or strategic use. For instance, Rijkswaterstaat and the Delta Commission frequently invoked model outcomes as objective evidence supporting Room for the River (RfR) in Zutphen and Gorssel, framing these as the "rational" solutions Horeman, 2025. Meanwhile, other actors—such as the Environmental Group and the Transport Company—felt excluded by the model structure, which omitted key variables like biodiversity and river navigability 4, 2025b; Whenu, 2025. Instead of sparking inclusive dialogue, the model at times reinforced existing power asymmetries by privileging certain forms of knowledge over others. This tension reflects a deeper divide between those who view models as decision tools and those who see them as instruments of power. van Enst et al., 2014 suggests that when used as boundary objects, models can facilitate productive dialogue rather than enforce closure. This requires transparency in assumptions, iterative use of scenarios, and room for contestation during deliberation.

A related recommendation is that institutional actors like Rijkswaterstaat should actively facilitate structured discussions on the boundaries, assumptions, and technical dimensions of the modeling process before moving into policy negotiations. In the IJssel case, much of the contestation around the model—such as the exclusion of biodiversity, river depth, or symbolic values—stemmed from a lack of early, shared understanding of what the model would and would not include. Rather than presenting model outcomes as fixed inputs to be acted upon, a preliminary phase focused on model scoping and co-framing could have built trust and alignment across actors. This aligns with findings from van Enst et al., 2014 on boundary work: surfacing assumptions early allows the model to function as a shared platform for deliberation, rather than a tool of technocratic persuasion. Such an approach could have reduced resistance later in the process and ensured that the final strategy reflected a more inclusive and negotiated knowledge base.

Third, it is important to acknowledge the inherently strategic use of knowledge in policy negotiations. As Rayner and Sarewitz, 2021 argue, facts in post-truth environments are often used to legitimize political preferences rather than to resolve disagreements. In the IJssel case, several actors invoked model outputs selectively—supporting them when results aligned with their interests and contesting them otherwise. Rather than denying this behavior, future processes should be designed for it. One way to do this is to combine model results with clearly stated actor preferences and allow for parallel narrative or symbolic expressions when quantitative alignment is not possible.

Fourth, modeling should support adaptive learning, not just optimization. Many of the decisions in the IJssel case—such as Gelderland's shift in cost-sharing or Overijssel's reversal on RfR costs—were shaped by political dynamics rather than technical rationality. These shifts are not failures of modeling, but evidence of incremental, real-world policymaking. Following V. A. Marchau et al., 2019, we recommend embracing frameworks like Dynamic Adaptive Planning that treat models as tools for exploring trade-offs and navigating change over time, rather than prescribing fixed solutions.

Finally, legitimacy must be built through transparent modeling practices and inclusive actor engagement. In several moments of the IJssel negotiations, trust in the modeling process was weakened—not only because of technical exclusions, but also due to unclear expectations and limited communication from key institutional actors. For instance, our collaboration with the province was marked by ambiguity: the analyst team did not clearly articulate what role our research was expected to play, what their expectations were, or how we could contribute meaningfully to the province's decision-making process. This disconnect left us underinformed and underutilized. While this may reflect organizational constraints or internal fragmentation, it also resonates with the politics of knowledge. As Rayner and Sarewitz, 2021 argue, knowledge flows in political contexts are often controlled to preserve power or maintain a strategic advantage. When key actors maintain tight boundaries around what information is shared, with whom, and for what purpose, it limits the opportunity for broader learning and co-production. We therefore recommend that future decision-making processes encourage more open channels of communication between knowledge providers and institutional actors—not only for legitimacy, but also to ensure that scientific contributions are aligned, timely, and impactful.

In sum, model-based knowledge can play a constructive role in negotiation and decision-making—but only if it is used reflexively, inclusively, and transparently. By embracing uncertainty, recognizing multiple knowledge types, and treating models as tools for dialogue rather than authority, actors can co-produce decisions that are both robust and legitimate in the complex context of flood risk management.

5.4 Conclusion

This reflection has shown that model-based knowledge in the IJssel River basin negotiations played multiple and overlapping roles. Our proposed improvements emphasize inclusivity, transparency, and adaptability: encouraging models to serve as boundary objects, opening up to qualitative knowledge, and recognizing strategic behavior as part of legitimate negotiation. These approaches helped us interpret how knowledge was mobilized, shaped, and contested in practice.

However, while these strategies aim to enhance robustness and legitimacy, they are not without risks. First, embracing pluralism and qualitative inclusion can blur the boundaries between analysis and politics, potentially undermining credibility or decisiveness. As Stirling, 2010 cautions, opening up complex systems may make decisions more legitimate, but also slower and more vulnerable to contestation.

Second, expanding model boundaries without a clear process risks answering the wrong questions. Ackoff, 1979 famously warns that many analyses become exercises in optimizing irrelevant choices. This is precisely what happens when stakeholders are not engaged in framing early on. This risk was evident in the IJssel case, where concerns like biodiversity or navigability were excluded not because they were unimportant, but because they were not formalized into model metrics.

Third, and perhaps most fundamentally, there is the risk that modeling reinforces existing hierarchies under the guise of objectivity. As Tversky and Kahneman, 1985 demonstrate, the framing of knowledge fundamentally shapes how it is interpreted. Our analysis showed how model outputs were strategically framed by actors to support preferred narratives, a clear manifestation of the politics of knowledge. This dynamic is further exacerbated by institutional asymmetries: Turner, 2005 argues that technical experts often detach from political responsibility, contributing data without engaging in the power structures it influences. Our experience with the province, which failed to clarify expectations or meaningfully integrate us into political planning, reflects this dynamic.

Despite these limitations, our approach offers a path toward more reflective and socially grounded model use. Its value lies not in eliminating conflict or uncertainty, but in helping actors recognize where those tensions emerge and how they can be negotiated. Future applications would benefit from coupling technical analysis with structured facilitation, early scoping of model boundaries, and support for deliberative engagement across worldviews. In this way, model-based knowledge can serve not just as input for policy, but as a platform for inclusive, adaptive, and ultimately more democratic decision-making.

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A Appendix A: Internal Communications and Negotiation Records

This appendix includes internal communications, meeting notes, and stakeholder exchanges that informed our analysis of model-based decision-making in the IJssel River negotiations.

A.1 Stage 5 Notes – IJssel River Flood Management

Date: May 26, 2025 **Time:** 15:00 - 15:30 (approx.) **Topic:** Initial Policy Discussion for IJssel River Flood Management **Chair:** Rijkswaterstaat (William)

Participants:

- Rijkswaterstaat (William)
- Delta Commission (Delta)
- Province of Gelderland (Gelderland)
- Province of Overijssel (Overijssel)
- Transport Company (Transport)
- Environmental Interest Group (Environmentalists)

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1. Opening by Rijkswaterstaat (William)

- All participants agreed with the proposed order/agenda.
- Rijkswaterstaat outlined their strategic direction and overarching goals:
  - Reduce expected annual damages and casualties through proactive flood management.
  - Ensure broad support from all six main actors (4/6 votes required to pass, but 6/6 preferred).
  - Promote long-term robustness under conditions of deep uncertainty.
  - Keep costs proportionate to benefits, avoiding disproportionately high expenditures.
- Regarding the model and analysis:
  - The model structure should be kept consistent and as simple as possible.
  - New metrics proposed by actors should ideally correlate with the existing five model outputs.
  - Priorities that do not correlate (e.g., biodiversity, sustainability) can be added to an appendix as qualitative assessments. Any additions must be clearly documented and argued.

2. Initial Policy Proposal by Rijkswaterstaat

- **Room for the River (RfR) locations proposed:** Gorssel, Doesburg, and Zutphen.
  - These locations were selected based on feedback from informal sources and analyst input.
- **Dike Heightening:** No decision has been made yet regarding dike heightening; provinces are free to evaluate this measure.

3. Discussion & Actor Positions

- **Delta Commission (Delta):**

  - **Goals:**
    - Ensure water safety.
    - Guarantee freshwater supply for the next 25 years.

    - **Policy Preference:** Strong preference for Room for the River (RfR), viewing it as the most sustainable and long-term cost-effective option.
    - Expressed criticism of dike heightening, suggesting it may offer only short-term relief while potentially creating larger future costs and downstream problems.
    - Collaborating closely with Rijkswaterstaat to identify RfR locations.
    - Emphasized flexibility to negotiate trade-offs for regions that bear higher burdens from chosen measures.
    - **Priority:** Water safety for everyone; supports choosing RfR.
- **Transport Company (Transport):**
    - **Goals:** Ensure that waterways remain navigable at VA-level (requiring a 2.5m depth). This is critical for logistics and trade.
    - Indicated a need for more time to check the proposed RfR locations and their impact on navigability.
    - Water depth is not currently explicitly modeled but is a critical factor. They have built a custom model to track river depth impacts across locations.
    - **Policy Stance:** Open to RfR if waterway accessibility is preserved.
    - Suggested dike heightening as one way to support adequate water depth.
    - Proposed exploring potential water redistribution between the Rhine and IJssel, though acknowledging this lacks data and is likely outside the current scope (as noted by other actors).
    - Also suggested a solution involving the Waal.
        - Rijkswaterstaat: Deemed out of scope.
        - Gelderland: Questioned why it couldn't be included.
        - Delta Commission & Overijssel: Raised concerns about expanding the model scope too broadly, stating it would be too hard to evaluate for this project and that not all necessary national parties could be represented.
    - Emphasized the sector's economic value and willingness to collaborate on viable solutions.
    - Delta Commission requested Transport to quantify their ideas.
- **Province of Gelderland (Gelderland):**
    - **General Stance:** Not supportive of RfR projects in their region (stated as "not a big fan" in RWS notes).
    - Open to concessions but require stronger justification and evidence of benefit for any RfR measures in their territory.
- **Environmental Interest Group (Environmentalists):**
    - **Goals:** Promote biodiversity as a measurable policy output.
    - **Policy Preference:** Support RfR if biodiversity becomes a modeled metric.
    - They are developing and plan to share a modified model that adds biodiversity as an output without changing core policy levers.
    - Rijkswaterstaat reiterated that the basic model structure should remain unchanged, with new metrics needing to correlate or be qualitative.
    - Also expressed interest in adding sustainability indicators, including the effects of organic farming and nitrogen reduction and its link to biodiversity.

- **Province of Overijssel (Representing Deventer, Gorssel):**

    - **Goals:** Protect downstream regions from unintended effects of upstream policy decisions.
    - **Policy Stance:** Support RfR projects, especially those in Gorssel and Deventer.
    - Noted that RfR can support biodiversity but stressed the need for compensation for farmers if they are affected.
    - Highlighted that some local farmers are organic and seek sustainable solutions, aligning with RfR.
    - **Priority:** Clarification on funding mechanisms: Who pays for RfR? Dikes? Compensation?

4. Model Development & Technical Discussions

- **Model Timeframe:**
    - The default timeframe for analysis is 200 years.
    - A proposal was made (by Overijssel, based on analyst recommendation) to shorten it, possibly to 100 years, for computational manageability and realism.
    - No consensus was reached; some actors warned that shortening the timeframe might reduce the robustness of the analysis. Rijkswaterstaat later questioned if the 200-year default should be kept.
- **New Metrics Proposed by Actors:**
    - Water level depth (Transport Company).
    - Biodiversity (Environmental Interest Group).
    - Sustainability/Nitrogen (Environmental Interest Group/Overijssel).
    - Rijkswaterstaat's stance: These must correlate with the existing five model outputs or be added qualitatively in an appendix.
- **Scope Expansion Concerns:**
    - Water redistribution solutions (proposed by Transport) were deemed too complex or outside the current project scope by most actors present.
    - A focus on refining current levers and metrics was encouraged.

5. Funding Discussion

- Overijssel and Rijkswaterstaat raised the question of funding responsibilities.
- Rijkswaterstaat noted that the Delta Commission and Overijssel have some funds.
- Delta Commission stated they have a tight budget, not "piles of money."

6. Timelines and Next Steps

- **Model Availability:** Rijkswaterstaat indicated the model should be ready by the following week.
- **Consensus Goal:** Rijkswaterstaat aims for consensus on the policy before the final debate.
    - The Delta Commission agreed but emphasized that the budget allocation (who pays for what) must also be decided by then.
- **Deadlines:**

    - **Initial model & policy draft:** Due Tuesday, June 3rd @ 23:59. This submission should include results, explanation, priorities, metrics, and budget estimates. (RWS notes: model result deadline).
    - **Final policy consensus:** To be reached by Tuesday, June 10th, ideally before the final debate. (RWS notes: deadline for agreeing on model approx. June 10th).
- **Negotiation Period:** The period between June 3rd and June 10th is for bilateral discussions to reach general terms of consensus. Negotiations are encouraged via email, Teams, or in-person.
- **Final Debate:** Will allow for minor revisions, but the main consensus should be established beforehand.
- **Budget Information:** Each actor should include budget information in their June 3rd submission.
- **Qualitative Reporting:** If unable to model certain aspects (e.g., nitrogen reduction), these can be added in qualitative reports.
- **Report Preparation:** Actors were advised to begin preparing the final model report promptly to avoid time pressure near the final deadline.
- **Communication:** Rijkswaterstaat will send an email summarizing all relevant information.

A.2 Stage 3 Notes – High-Level Strategy Meeting

Stage 3 - Meeting notes

Rijkswaterstaat

1. To develop a solution that significantly reduces expected annual damages and casualties;

2. To ensure that the solution enjoys broad support among all actors involved in the decision-making process;

3. To promote the long-term robustness of the system under deep uncertainty.

4. Make sure that costs are not disproportionally high.

Their preferred policy package includes:

- Dike reinforcements
- Selective implementation of Room for the River (RfR)
- Optimized evacuation planning

They acknowledge that trade-offs will be necessary and invite feedback on how others can include their goals in the model.

Transport company

- Represent family-owned river transport businesses (75% of the sector).
- Rivers are a way of life; flood risk must be minimized throughout the river.
- River depth must be at least 2.5m at all points – currently not always the case.
- Droughts severely affect business: in 2018, there were ~163 non-operational days causing €6,000/day in eco-costs.
- Support for sustainable transport and more environmentally friendly ships—but need subsidies and policy support.
- Open to RfR but concerned about side effects like sediment buildup in main river channels, which can:
    - Reduce navigable depth
    - Increase dredging needs
    - Damage the riverbed ecosystem

Delta Commission

- Focus on water safety and freshwater access.
- Prioritize spatial adaptation to prepare for climate change impacts (heat, drought, etc.).
- Emphasize robust, future-proof policy.
- Prefer **Room for the River** as a solution:
    - Higher upfront cost but cheaper long-term

- Provides flood protection and freshwater storage

Environmental interest group

- Strongly favor **Room for the River** over dike heightening due to:
    - Long-term ecological benefits
    - Sustainable flood management
    - Freshwater access
- Strategy includes:
    - Inserting biodiversity and ecological resilience into the decision matrix
    - Avoiding symbolic policies without follow-through
    - Demanding tangible ecological output metrics
- Biodiversity and flow indicators are currently missing from the model.
- Seeking alternative ways (e.g., literature support) to quantify and include these in policy design.

Debate Highlights

- General concern: current shared model lacks key actor-specific variables (e.g., biodiversity, water level). There was discussion on how to **incorporate actor-specific interests** into the model.
- Suggestions: If they wish to integrate their metrics, they must submit their models within one week. They ask for other actors's interest and they will check and see whether they see consensus /Use literature-backed metrics or qualitative analysis

(1 = least important, 5 = most important to minimize, - no opinion; not as important)

	Delta	Environmental	Transport
Expected Annual Damage	4 – Considered important, but part of a broader focus on robustness and long-term safety.	-	5 – Highest priority. Want to minimize damages and casualties due to strong community impact.
Dike Investment cost	3 - Favor Room for the River (RfR) over dikes; aim to limit dike-related investments.	5 – Strongly oppose dike heightening; prefer RfR entirely.	-
Number of deaths	5 – Top priority. Policy must minimize fatalities.	4 – Public safety is a key concern.	3 – Important, but secondary to economic/ecological disruptions caused by river inaccessibility.
RfR total costs	1 – Willing to invest in RfR despite high initial	1 – Willing to accept higher costs to prioritize	-

	costs, as it is more cost-effective long-term.	ecological outcomes through RfR.	
Expected evacuation cost	4 – Evacuation effectiveness is important in system robustness and safety.	-	-

A.3 First Debate Notes

First debate

Stances:

- Waterboard …(pedram)
    - Concern about water quality and water pollution
    - Said that they want to work collaboratively with the other province
    - There might be others policy intervention options other than that already implemented in the model
- Waterboard … (downstream)
    - Want to apply rfr across all location (upstreeam to downstream)

Upstream cannot increase dike

Cost: who pays

- Dike increase?
- Rfr might be paid for by delta commission
- Gorssel: rfr can be used too for farmland -> future compensation for farmers when rfr is done
- OI: future comp. is not yet factored in the model. Need an estimate for the amount of future compensation
- G: you can get the number from the delta commission
- OI: the numbers are needed (money contributed by dike rings) or how money is needed (basically all money value) for the final debate

Models

- Water board: need to consider other things outside of the model
- D: dike heightening depends on the budget possibilities

Additional

- Transport group: not talking
- G: organic farmland is priority, and nitrogen levels -> what is this
- OI: model the nitrogen levels things so we can quantify it
- G: too complex to model from scratch
- OI: not to make it a numbers game too much

- Waterboard pedram: action is needed because drought is happening, etc. Pushes for urgency
- Everybody: prefer RfR compared to dike increase
- G: 5 dm is the limit
- D: 5 dm is around the limit

Post debate discussion

- Inter dike-ring heightening affect, how D effects G bcs G is more upstream than D
- Design what kind of upstream policy is best for the downstream
- Stance: dike increase should not be implemented by the upstream -> bcs if so, downstream needs to heightening too
- Goal: RfR in upstream
- Others: good comp strategy if dike is breached
- What happens if upstream dike increases by 5 dm results in 250 mio cost -> total cost PF3

To figure out:

- D: Costs of dike failing
- G: Missed opportunity cost of organic farmland overflooding
- Maximum dike height -> D has more budget
- Organic farming means possible higher water levels and easier to do rfr

Dike rings will come up with policies to test out on thurs, 5th june. Deadline to model: 9th of June

Try working on PF5 to disaggregate by time and space

Monday 2nd June meet G and D

D and G are meeting with waterboards of OI on June 5th, and afterwards want to meet with Zutphan (most downstream dike ring in Gelderland)

A whatsapp group is made for reps of G, D, WBU, WBD, and analysts

Final phase first debate:
RWS: RfR in dike rings gorssel, zutphan, doesburg

DC: Prioritize water safety and freshwater insurance for the next 25 years so good with RfR. Dike increase is dependent on long term costs

GD: not a fan of RfR

EG: primary goal: adopt RfR, align with safety from DC, added increase biodiversity in the rivers, but not in the model yet. Aim to make biodiversity measurable in the model -> being done by analysts

OI: in favor of RfR, but also need compensation for farmers. How is the funding structure -> DC doesn't have unlimited budget so each can use their own budget

TC: waterways need to be go through. Currently some waterways are tight or not available -> not in the model -> done by analysts. Open for RfR as long as still able to do trade. Currently looking into another solution => redistribute water from the rhine and the Ijssel

Redistribution might not be viable bcs involves other actors (other provinces) not in the debate.

OI: Organic farming reduces nitrogen, aligns with the biodiversity model expansion with EG

OI: need to agree on the time span and steps -> currently align with system default

RWS: deadline by Tuesday midnight (before wed) 3rd june = initial policy to be distributed (models, with budget). Tuesday June 10th consensus

START ON REPORT

A.4 Final Debate Notes

- Our recommendations of a dike increase of>5 were undercut by the analysts of our province and the overrisjel province despite the dike ring wishes.
    - Di >5 is good for deaths, but di <5 is good for costs, that's why
- RfR are problematic for some actors because it would reduce the depth of the river and reduce the possibility of water trade, but the RfR brochure ensure that this doesn't happen -> technical solution and compensation existsso the worry is unbased.
- It's hopeful to see that at universal level also Rfr is and dike heightening is agreeable among actors, btu we might need to sacrifice grossel
    - Except environmentalists who only want a limited amount of hightening (they're okay with it being in Deventer if something more relevant doesn't present itself)
    - This is not horrible for grossel as they were very insistent on safety (which is at a decent level already and will be improved with deventer heightening **(CHECK!)** and protecting their farmers and soil and environment which can be achieved with noo lever.
- The exploratory analysis was very sueful in coming up with policy negotiation proposals, then MOEA to find compromise and finalisation between actors and the results of our analyst team + the analyst teams of other actors
- "Model is not incorporating this, or that" - a lot of actors are complaining about the limitations of the simulation....
    - You cannot guarantee reliable decision-making without a realistic and complex model that considers stakeholder interests -> should have integrated stakeholder also in model building :) because not all their desired outcomes are being measured
- First policy proposal:
    - The Room for the River (RfR) measures include interventions in Dike Rings A2 (Cortenoever), A3 (Zutphen), and A5 (Deventer), all implemented at timestep 0 to enhance flood resilience. These measures are designed to provide a warning period of three days in advance of potential threats. Complementing the RfR efforts, dike heightening measures are planned for A1 (Doesburg), A4 (Gorssel), and A5 (Deventer), with implementation also scheduled for timestep 0 and a height increase of 50 centimeters. Together, these interventions aim to reinforce flood protection in critical areas while maintaining early warning capabilities.
- Second:
    - The final policy includes a combination of Room for the River (RfR) and dike heightening measures aimed at enhancing flood resilience across key dike rings. RfR interventions are confirmed for Dike Ring A2 (Cortenoever), A3 (Zutphen), and A5 (Deventer), all scheduled for

implementation at timestep 0. These measures are designed to maintain a three-day advance warning in the event of a threat. In parallel, dike heightening will be carried out in A3 (Zutphen), A4 (Gorssel), and A5 (Deventer), with each dike raised by 50 centimeters at timestep 0. This integrated policy approach strengthens flood defenses while preserving early warning capabilities.

- final
  - In the financial discussions led by Rijkswaterstaat, a cost-sharing agreement was reached among various stakeholders. Gelderland initially agreed to fully fund the dike heightening in Zutphen but later requested to limit its contribution to 10%, a request that Rijkswaterstaat accepted. Overijssel committed to covering 20% of the cost for dike heightening in Deventer. Rijkswaterstaat also committed to compensating farmers impacted by the Room for the River and dike measures and pledged to plant 500 trees as part of its environmental compensation efforts. The Delta Commission expressed support for the cost-sharing model, noting it aligns with standard practices where provinces typically contribute 10–20% of implementation costs. The transport company endorsed the full package, including the compensation platform for those affected by spatial changes. While the environmental sector did not provide direct financial input, it agreed to the proposal based on the tree-planting initiative and preservation of Room for the River measures.
-

A.5 Email – Follow-up and Next Steps After Monday's Debate

Subject:	Fw: Follow-up and Next Steps After Monday's Debate
Date:	Wednesday, 28 May 2025 at 14:59:16 Central European Summer Time
From:	Ada Precup
To:	Akmal Akmal Umar, Muhammad Muhammad Haidar Ramadhani, Alessandro Dell'Orto
Attachments:	Stage 5 Notes - IJssel River Flood Management.pdf, Stage 3 Notes - High-level startegy meeting.pdf

Kind regards,
Ada Precup

From: William Horeman <W.L.Horeman@student.tudelft.nl>
Sent: Wednesday, May 28, 2025 12:55:38 PM
To: Amaryllis Brosens <A.M.K.Brosens@student.tudelft.nl>; Julia Rozenberg <J.H.A.Rozenberg@student.tudelft.nl>; Ayoub Ghamas <A.Ghamas@student.tudelft.nl>; Ada Precup <A.M.Precup-1@student.tudelft.nl>; Ben Schäfer <B.S.Schafer@student.tudelft.nl>; Meike Bos <M.H.R.Bos@student.tudelft.nl>; Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>; Ameera Ameera Raissa Shafa <AmeeraRaissaShafa@student.tudelft.nl>; Jet Beelen <J.M.C.Beelen@student.tudelft.nl>; Tan Dieltjes <T.W.T.Dieltjes@student.tudelft.nl>; Swen Jansen <S.O.Jansen@student.tudelft.nl>; e.l.l.brouwer@umail.leidenuniv.nl <e.l.l.brouwer@umail.leidenuniv.nl>; Jan Tilman <J.H.S.Tilman@student.tudelft.nl>; Sanne van Oudenaarde <S.vanOudenaarde@student.tudelft.nl>; J.M.Bruning@outlook.com <J.M.Bruning@outlook.com>; Toon de Ruiter <T.C.deRuiter@student.tudelft.nl>; Myriam Kammüller Pont <M.KammullerPont@student.tudelft.nl>; Jesse Poort <J.N.Poort@student.tudelft.nl>; Daan van der Hoeven <D.vanderHoeven-1@student.tudelft.nl>; Ralph van Engelen <R.M.J.Engelen@student.tudelft.nl>; Evalie van Oijen <E.I.vanOijen@student.tudelft.nl>; Xiao Scherpbier <X.J.Scherpbier@student.tudelft.nl>; Bjarne Timmer <B.E.J.Timmer@student.tudelft.nl>; Aline Mellersh <A.G.C.Mellersh@student.tudelft.nl>; Kian Gerasimov Tel <K.GerasimovTel@student.tudelft.nl>
Cc: Ameera Ameera Raissa Shafa <AmeeraRaissaShafa@student.tudelft.nl>; Berend Domhof <B.B.W.M.Domhof@student.tudelft.nl>; Tobias Schmeink <T.Schmeink@student.tudelft.nl>
Subject: Follow-up and Next Steps After Monday's Debate

Dear fellow Actors and Analysts,

Thank you very much for your valuable contributions during the debate last Monday. We truly appreciate your engagement and insights. As promised, we would like to follow up by providing more clarity on our perspective going forward and the steps ahead. The minutes of the two debates are included (see attachment).

1. Our Goals Revisited

As Rijkswaterstaat, our goals are centered on developing a resilient and widely supported flood management policy. Our priorities, in order of importance and for the majority alligned with the Delta Commission, are:

1. To develop a solution that **significantly reduces expected annual damages and casualties**;
2. To ensure that the solution **enjoys broad support among all actors** involved in the decision-making process; Do note that the **final policy only needs 4 main actors in favor**, so please try to think about how much consensus you can find with your specific poliy.
3. To promote the **long-term robustness of the system under deep uncertainty**;
4. To ensure that **costs are not disproportionately high**.

We believe that by working collaboratively, we can achieve a balanced and effective outcome that meets these objectives. By being transperant about our goals and about the minutes we hope find consensus on the final policy.

2. Policy Direction & Collaboration

- As previously discussed, our potential policy direction includes solutions under the *Room for the River* program in Zutphen, Gorssel, and Doesburg.
- To ensure a viable and widely supported policy, **shared financing is key**. We expect all parties to:
  - Submit budget information and proposed contributions.
  - Indicate any objections or concerns with the current policy direction as soon as possible.
  - Note that financing can be reallocated among actors, if that leads to more consensus.

3. Model and Metrics

To align our analyses and improve the chances of consensus, we kindly ask each actor to submit the following:

- Your **proposed policies**, including:
  - Value per policy lever, including timestep and location.
  - Maximum amounts you are willing to allocate per cost type.
- Your **model**, including a **README** file.
- A **short report** explaining your model results and corresponding policies in detail.
- Note: Metrics can be adjusted, but **policy levers should remain consistent to the current model** to ensure comparability and alignment.
- Policies not directly linked to the model can still be submitted for consideration and may be added as an appendix to the final policy document.

4. Upcoming Timeline & Deadlines

Please refer to the attached document for the minutes of the meeting. This includes a summary of the discussion and key metrics from our first session.

- Deadline for submission of budget contributions and policy proposals**: June 3rd**
- Deadline general consensus among main actors: **June 10th**
- In between these two dates there will be room for bargaining and negotiation between actors.

We aim to incorporate all actor input for the final policy before the final debate and would prefer that the various dike rings align under a shared provincial framework.

Please don't hesitate to reach out if you have questions or concerns.

Sincerely,

Rijkswaterstaat

A.6 Email – Analyst Request and Actor Clarifications

Tuesday, June 17, 2025 at 3:27:54 PM Central European Summer Time

Subject: Re: Model-based decision-making: Analyst request
Date: Tuesday, 20 May 2025 at 11:32:53 Central European Summer Time
From: Ada Precup
To: Tadé Whenu
CC: Alessandro Dell'Orto, Muhammad Muhammad Haidar Ramadhani, Akmal Akmal Umar

Thanks for getting back to me Tade!

We'll investigate it and come back with an answer by the end of the week.

Cheers,
Group 4

From: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Date: Monday, 19 May 2025 at 16:41
To: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Cc: Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>, Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>, Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>
Subject: Re: Model-based decision-making: Analyst request

Dear Ada,

Total costs, evacuations costs and investment costs are important, but not our main priority. Therefore, there is no hard criteria on maximising or minimising them.

Regarding total casualties and damages, we would like to minimize them, especially since our citizens are in the most vulnerable areas. Lastly, room for the river projects can be a direct threat to our organic farmlands, so we would like to minimize that as well.

Regarding your analysis, could you inform us which inputs are most influential on the outcomes? Moreover, if there are unexplored inputs, like which lands are used etc, could you also let us know if you know about any? We are looking into this from the articles side as well, but it would be great if we can complement it with your views.

Best regards,
Tadé Whenu

From: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Date: Monday, 19 May 2025 at 15:21
To: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Cc: Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>, Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>, Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>

Subject: Re: Model-based decision-making: Analyst request

Hey Tade,

Thanks for your reply. To move forward with our analysis, we kindly request you provide us with a more specific description of what a desirable future would look like for you. To this end, please clarify which of the following parameters would you like to maximize/minimize:

- Total costs
- Evacuations costs
- Investment costs
- Total casualties
- Expected damages
- Room for River project costs

To understand your position, please tell us how these potential effects of a new policy can work in your favor to protect organic farming.

From: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Date: Monday, 19 May 2025 at 09:48
To: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Cc: Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>, Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>, Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>
Subject: Re: Model-based decision-making: Analyst request

Dear Ada,

Thank you for your email. From our side we would like to provide you already with some of our standpoints for the debate, which you can find below.

- In the current discourse, the protection of highly industrialised farming and the city itself is of higher priority than our organic dike ring. However, this has some serious consequences. First, we provide, just like the other regions, crucial nutrition to the inhabitants of the city and villages in our area.
- Moreover, we provide organic, natural, more nutritious vegetables than our industrialised colleagues. Especially in times of crisis - floods - we deem it necessary to have the healthiest food locally available to support our local communities.
- Besides, if we are to be compensated, we believe it is necessary to compensate our organic farmers significantly better in comparison to conventional farms, due to the robust and climate resilient farming methods our farmers ought to use.
- Lastly, we would like to underline that fair compensation does not equal justice. Farmers working hard to provide food in an organic and climate resilient manner should not also start bearing the burden for flood risk. There is already an

enormous pressure on their shoulders.

During today's lecture, we propose to have an informal discussion during the break, to further discuss these points and our collaborations in the coming weeks. In the meantime, you may send us a text at +31 6 31 23 43 31 for any quick questions you might have.

We hope to see you soon!

Best regards,
Tadé Whenu
On behalf of team 7

Van: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Verzonden: Thursday, May 15, 2025 2:50:47 PM
Aan: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
CC: Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>; Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>; Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>
Onderwerp: Model-based decision-making: Analyst request

Dear Team 7,

My name is Ada, and I am contacting you in the position of “Analyst” for your cause. My team has started the scenario discovery task for the preliminary debate, and we hope to be able to provide you with some conclusions on the non-aggregated futures in which your policy should be robust for the river case.

To enhance your performance in the debate, please let us know if there is anything else we can research or provide you with to help your cause.

On behalf of Team 4,
Ada Precup

Kind regards,
Ada Precup

A.7 Email – Preparations Meeting Dike Ring 4

Subject: Re: Preparations meeting Dike Ring 4
Date: Thursday, 22 May 2025 at 13:14:02 Central European Summer Time
From: Ada Precup
To: Tadé Whenu
CC: Akmal Akmal Umar, Alessandro Dell'Orto, Muhammad Muhammad Haidar Ramadhani

Cool!

Will update.

From: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Date: Thursday, 22 May 2025 at 13:08
To: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Cc: Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>, Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>, Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>
Subject: Re: Preparations meeting Dike Ring 4

Dear Ada,

There is a small update. We are more in favour for the Room for the River project, since it might benefit our organic farming grounds as well. This means, although earlier on mentioned otherwise, we would like the RfR costs may be higher.

I hope this helps in the modelling.

Best regards,
Tadé Whenu

From: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Date: Thursday, 22 May 2025 at 13:03
To: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Cc: Akmal Akmal Umar <AkmalUmar@student.tudelft.nl>, Alessandro Dell'Orto <A.Dellorto@student.tudelft.nl>, Muhammad Muhammad Haidar Ramadhani <MuhammadHaidarRamadhani@student.tudelft.nl>
Subject: Re: Preparations meeting Dike Ring 4

Dear Tade,

We will share some insights about Dike Ring 5 as well, but rest assured your desired outcomes are in perfect alignment!

We have created some insights into what other allegiances would be best for your cause, and we can catch up after the lecture so we can talk about it.

Ada and Team

From: Tadé Whenu <T.K.D.Whenu@student.tudelft.nl>
Date: Thursday, 22 May 2025 at 12:52
To: Ada Precup <A.M.Precup-1@student.tudelft.nl>
Subject: Preparations meeting Dike Ring 4

Dear Ana,

How are you?

We would like to get to know better Dike ring 4 - Deventer. They are our neighbours in the province, and we feel it is useful to align visions and see how we can support each other.

Could you let us know what their viewpoints and inputs for you are so far, in order for us to prepare our meeting with them?

We could also have a short informal meeting during the lecture break or during the lab session. Let us know what suits you best.

With kind regards,
Tadé Whenu
Dike Ring 5 Gorssel

Student MSc Industrial Ecology
Motivated to make this planet a better place, for everyone.
T: +31 6 31 23 43 31
@: t.k.d.whenu@student.tudelft.nl

A.8 Proposed Flood Risk Management Strategy

Tuesday, June 17, 2025 at 3:29:10 PM Central European Summer Time

Subject:	Proposed Flood Risk Management Strategy for IJssel Region
Date:	Tuesday, 10 June 2025 at 09:39:44 Central European Summer Time
From:	William Horeman
To:	Amaryllis Brosens, Julia Rozenberg, Ayoub Ghamas, Ada Precup, Ben Schäfer, Meike Bos, Tadé Whenu, Jet Beelen, Tan Dieltjes, Swen Jansen, e.l.l.brouwer@umail.leidenuniv.nl, Jan Tilman, Sanne van Oudenaarde, J.M.Bruning@outlook.com, Toon de Ruiter, Myriam Kammüller Pont, Jesse Poort, Daan van der Hoeven, Ralph van Engelen, Evalie van Oijen, Xiao Scherpbier, Bjarne Timmer, Aline Mellersh, Kian Gerasimov Tel
CC:	Tobias Schmeink, Berend Domhof, Ameera Ameera Raissa Shafa
Attachments:	WhatsApp Image 2025-06-09 at 21.38.50.jpeg, Stage 5 Notes - IJssel River Flood Management.pdf, Stage 3 Notes - High-level startegy meeting.pdf

Dear fellow Actors and Analysts,

Thank you so much for your input and thinking with us.

Based on your input, as well as the results from our own analysts, we would like to propose the following policy.

Room for the River (RfR) measures:
- Dike Ring A2 - Cortenoever (0_RfR, timestep: 0)
- Dike Ring A3 - Zutphen (2_RfR, timestep: 0)

Days to Threat:
- 3 days in advance

Dike Heightening Measures:
- A1 - Doesburg (1_RfR, timestep 0): 50 cm
- A4 - Gorssel (4_RfR, timestep: 0): 70 cm
- A5 Deventer (3_RfR, timestep: 0): 80cm

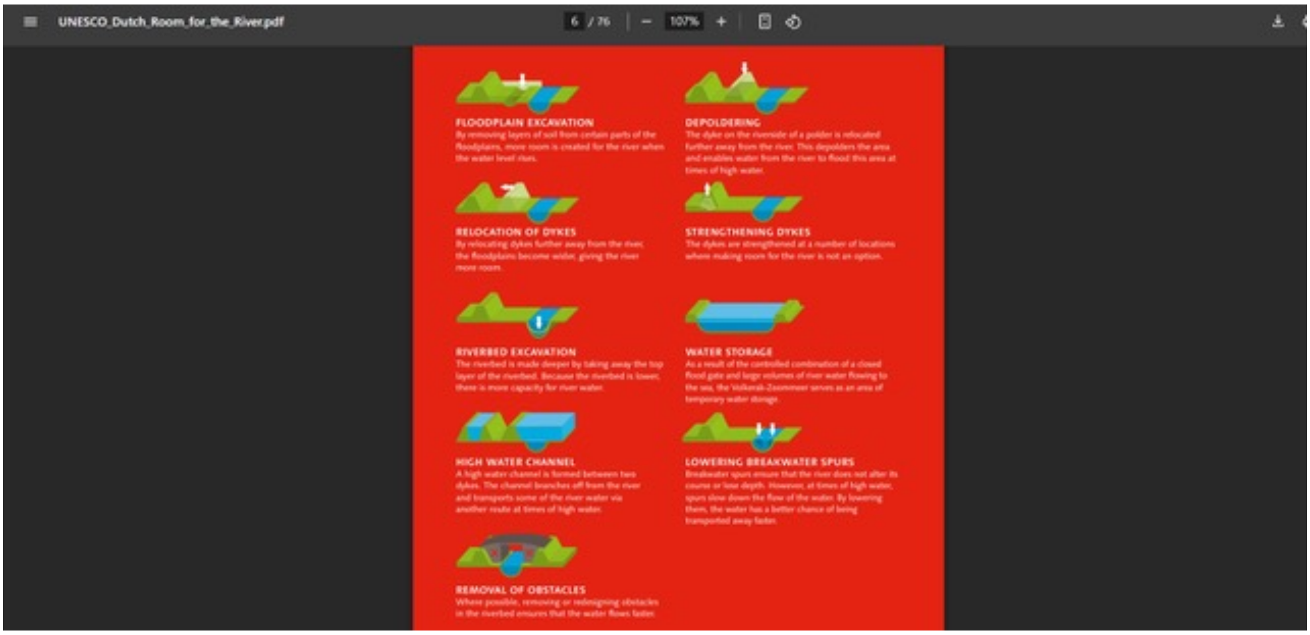
We are aware that the dike heightening in Gorssel and Deventer entail high implementation costs while offering limited effectiveness, given their downstream locations. On the other hand Cortenoever and Zutphen have low implementation costs, while offering high effectiveness. In light of this and the fact that all proposed measures are located within the province of Gelderland, we propose to **financially compensate Gelderland** and its associated dike rings for the implementation costs and lost revenues of farmers.

At last, for all actors concerned that room for the river results in shallower water, we would like to stress that this is not the case. Please see the image in the attachment for the explanation (based on the brochure put on brightspace). https://en.wikipedia.org/wiki/Groyne also shows how groynes can be used to increase flow velocity in the middle of river river, which decrease sedimentation and therefore maintains a deep river. This is a measure used all over the Netherlands to increase navigability throughout her rivers.

Please let us know what you think. We aim to have reached a final policy before Thursday.

Best regards,

Rijkswaterstaat



On 28 May 2025, at 12:55, William Horeman <W.L.Horeman@student.tudelft.nl> wrote:

Dear fellow Actors and Analysts,

Thank you very much for your valuable contributions during the debate last Monday. We truly appreciate your engagement and insights. As promised, we would like to follow up by providing more clarity on our perspective going forward and the steps ahead. The minutes of the two debates are included (see attachment).

1. Our Goals Revisited

As Rijkswaterstaat, our goals are centered on developing a resilient and widely supported flood management policy. Our priorities, in order of importance and for the majority alligned with the Delta Commission, are:

1. To develop a solution that **significantly reduces expected annual damages and casualties**;
2. To ensure that the solution **enjoys broad support among all actors** involved in the decision-making process; Do note that the **final policy only needs 4 main actors in favor**, so please try to think about how much consensus you can find with your specific poliy.
3. To promote the **long-term robustness of the system under deep uncertainty**;
4. To ensure that **costs are not disproportionately high**.

We believe that by working collaboratively, we can achieve a balanced and effective outcome that meets these objectives. By being transperant about our goals and about the minutes we hope find consensus on the final policy.

2. Policy Direction & Collaboration

- As previously discussed, our potential policy direction includes solutions under the *Room for the River* program in Zutphen, Gorssel, and Doesburg.
- To ensure a viable and widely supported policy, **shared financing is key**. We expect all parties to:
    - Submit budget information and proposed contributions.
    - Indicate any objections or concerns with the current policy direction as soon as possible.
    - Note that financing can be reallocated among actors, if that leads to more consensus.

3. Model and Metrics

To align our analyses and improve the chances of consensus, we kindly ask each actor to submit the following:

- Your **proposed policies**, including:
    - Value per policy lever, including timestep and location.
    - Maximum amounts you are willing to allocate per cost type.
- Your **model**, including a **README** file.
- A **short report** explaining your model results and corresponding policies in detail.
- Note: Metrics can be adjusted, but **policy levers should remain consistent to the current model** to ensure comparability and alignment.
- Policies not directly linked to the model can still be submitted for consideration and may be added as an appendix to the final policy document.

4. Upcoming Timeline & Deadlines

Please refer to the attached document for the minutes of the meeting. This includes a summary of the discussion and key metrics from our first session.

- Deadline for submission of budget contributions and policy proposals**: June 3rd**
- Deadline general consensus among main actors: **June 10th**
- In between these two dates there will be room for bargaining and negotiation between actors.

We aim to incorporate all actor input for the final policy before the final debate and would prefer that the various dike rings align under a shared provincial framework.

Please don't hesitate to reach out if you have questions or concerns.

Sincerely,

Rijkswaterstaat