SOA STUDENT RESERACH
CHALLENGE 2025

PROPOSAL

RESILIENCE DAM INSURANCE SCHEME (RDIS)

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DAMSGUARD
SOLUTIONS
ACTUARIIAL CONSULTING TEAM • WORKED GOVERNMENT DAM SECTOR PROJECTS

Contents

RESILIENCE DAM INSURANCE SCHEME

1 Executive Summary

Tarrodan's earthen dams, making up 90% of its dam systems, face significant risks, with potential aggregate losses of 700 billion Qualkoons over the next decade (see Appendix A for more statistics). Alarmingly, 66.5% of these failures could result in individual losses exceeding 100 million Qualkoons per dam, highlighting the high-cost, catastrophic nature of most incident. Despite this, the private insurance market remains inadequate. The Tarrodan Government, with its ability to cross-subsidize premiums and implement risk-reduction measures, is uniquely positioned to act [3]. In response to this urgent need, DamsGuard Solutions proposes the Resilience Dam Insurance Scheme (RDIS), a national program offering Reconstruction Sub-program and Resilience Sub-program to ensure financial protection and long-term Resilience for Tarrodan's infrastructure and communities as below:

Sub-Programm	Objective	Targeted Coverage	Key focus and metrics
Reconstruction Program	Insurance Program	Public infrastructure & Low-Income Population	Quick liquidity for underinsured sector
Resilient Program	Dam Improvements and Maintenance	High and Significant Hazardous Dams	Reduce dam failure events and economic loss

Table 1: Summary of Sub-Program Initiatives

DamGuardian shall outline the distinctive features of the RDIS program and provide a clear rationale for each gain. Careful calculations have been implemented to evaluate the impact of the program on Probability of dam failure, as well as economic loss. Methods of simulation have been conducted to ensure self-sustainability of the Government fund to immediately cover loss from dam failures. Actuarial statistics confidently proves the decrease in the frequency of dam failure by 30% and economic loss by 60 billion, plus the increase in sustainability.
This program will last for 10 years, launched at the beginning of 2024. In the first year, preparations and setups to upgrade dams shall be done. The positive impact of this feature will be noticed starting from the second year of the program. However, in order to handle extraneous factors, program evaluation should be implemented once every 5-year for overall analysis, modifications & timeline extensions. During its implementation, monthly, quarterly, and annually, as well as post-event analyses are to be carefully monitored to guarantee that the actuarial assumptions are suitable.

2 Program Design

The RDIS program includes two components which are Reconstruction Sub-Program with insurance feature & Resilience Sub-Program with non-insurance feature.

2.1 Reconstruction Sub-Program

This reconstruction program will directly collect premiums from Regional Government. With the aim to secure immediate liquidity and reduce financial uncertainty in the long run, premium payment schedule would be every 5-year, 2-year and 1-year for Flumevale, Nalvadia and Lyndrassia, respectively. Collecting premium at the beginning of the period would ensure a large lump sum of cash upfront, reduce the risk of cash flow turning negative in subsequent years. The premiums vary according to differences in risk exposure and are reassessed at renewal date (see more in Section 4: Modelling results). The sub-program runs for up to six months after a dam failure, providing immediate financial assistance to help affected individuals stabilize their lives. This quick support ensures liquidity, covering urgent needs for those in need, while private insurance claims are still being processed. The benefits are prioritized as follows [4]:

- **Emergency Response:** Immediate assistance during disaster, including: evacuation and rescue support, temporary housing, food and medical supply.
- **Public Infrastructure:** Essential public infrastructure repair, restoration and rebuilding, including utilities, transportation systems, public buildings and other facilities.
- **Low Income:** Financial aid for low-income individuals, including housing repair and rental expenses.
- **Other Support (if funds remain):** Support to individuals that complete application forms for further assistance and meet approval requirements.

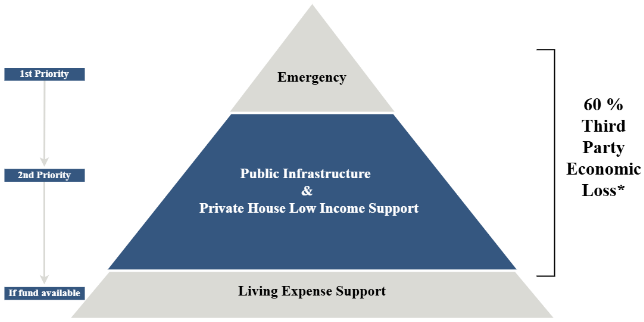


Figure 1: Economic Support Priority Hierarchy

The reconstruction program budget is expected to cover 60% of third-party liability loss per event (see Appendix B1 for more details). If funds remain after six months covering all expenses for emergency responses, low-income population support, and public infrastructure repairs, additional support will be provided until the budget is used up.
To avoid adverse selection and encourage the purchase of private insurance, the program is only available for individuals experiencing dam failure loss for the first time. For any subsequent incidents, no support will be provided.

2.2 Resilience Sub-Program

The Resilience Sub-Program applies for 6401 High or Significant hazard dams and ensures these dams to reach and maintain a Satisfactory assessment level, reducing the probability of dam failure through two features: Upgrading to improve dam conditions and Maintenance to sustain them.
The Upgrading Feature is a one-year initiative targeting Fair, Poor, Unsatisfactory, Not Rated and Not Available dams to be improved to Satisfactory condition through 10-year risk-free annual spot rate loans, reducing failure risks and financial outflows. Funding is generated via 10-year zero-coupon Government bonds, with annual repayments by dam owners.
The Maintenance Feature lasts for 10 years annually, ensuring dams remain at Satisfactory levels. Dams showing signs of deterioration (see Appendix B2.1 for more details) would receive upfront funding for repairs and must pass post-maintenance inspections (Appendix B2.2 for more details). This preserves dam safety and maintains low failure probabilities, supporting the Resilience Sub-Program's goals.

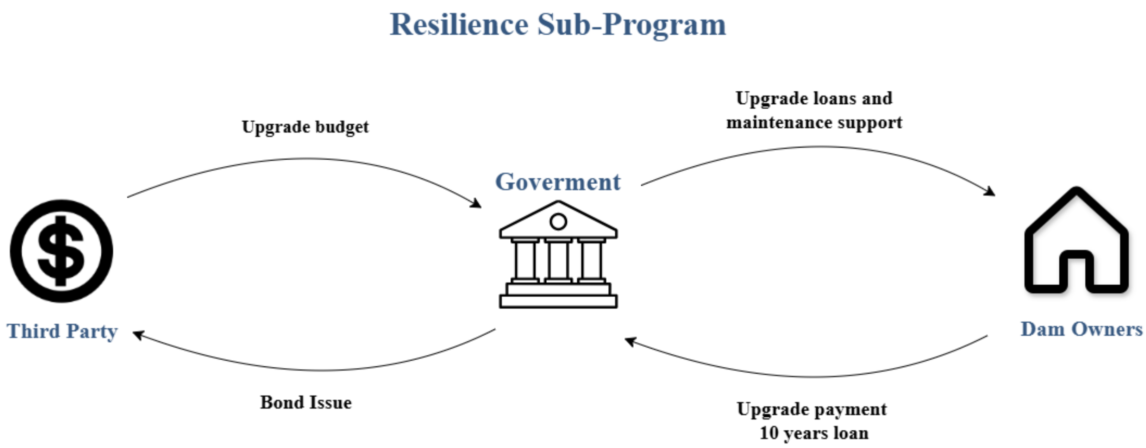


Figure 2: Resilience Program Funding Process

Government bond with risk-free rate issued at the beginning of 10-year process is to provide a significant amount of funds for immediate upgrade, while the loans payment schedule is designed to support dam owners to pay in long-term. Note that the Government will almost certainly expose to some default payments due to dam failure.

3 Modelling Process & Key Assumptions

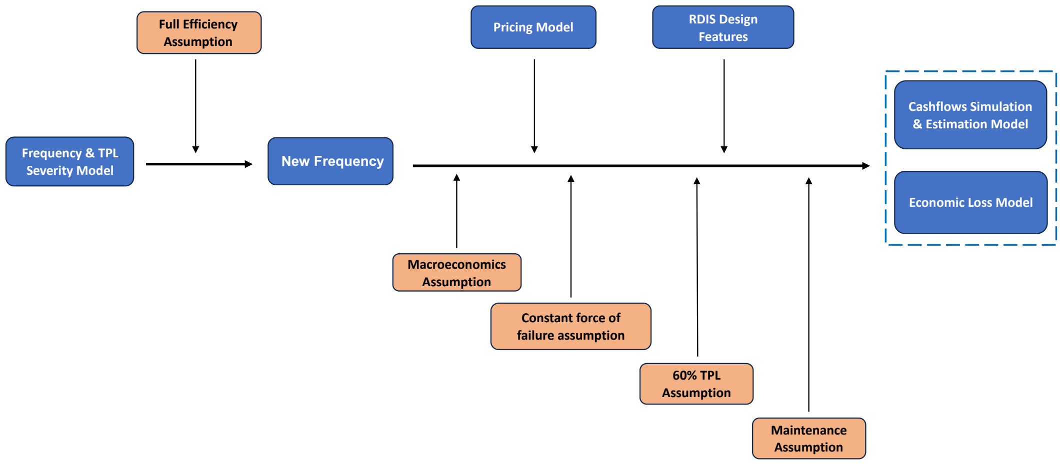


Figure 3: Modelling Process

Modelling process can be summarised as the figure above. While there are many assumptions that affect the performance of cashflows and economic value, Damsguard Solutions only identify the key assumptions as follow:

- Macro Assumptions: GDP Growth at 5-year CAGR; the median of flat risk-free interest rate and inflation in a 1962-2024 period will be set as the base scenario (see Appendix C).
- Constant Force of Failure Assumption: The program uses constant force of failure for fractional and assumes a stable rate after the first year, once the Resilience Sub-Program is implemented.
- 60% of Third-Party Loss Assumption: This is the target outflow per event. Considering that actual loss from low-income communities and public infrastructure might exceed the budget, the team models loss to distribute uniformly between 50% - 70%.
- Full Efficiency Assumption: The team assumes 100% of Goverment Upgrade loans and maintenance support will be spent to raise Assessment level and reduce frequency of dam failure and result in the reduction impact in section 4.1.
- Maintainance Assumption: Once the dam is on Satisfactory assessment level, the program supposes a likelihood of 10% per year that the dam needs maintenance.

The impact of the program assumptions above will be discussed further in sections 4 and 5.

3.1 Frequency - Severity Modelling Process

Severity and Frequency Analysis is essential for evaluating and quantifying the impact of potential variables on the total loss distribution. Given the data given by TDA, the process involves two key stages: data processing and modelling.
Initially, we examined the univariate and bivariate relationships among the variables, grouped and transformed them into a categorical format. Binning a continuous variable can simplify risk assessment and pricing, with adjustments made to balance precision and practicality. [7]. Secondly, the MissForest algorithm fills missing data (assumed random) and handles both numerical and categorical data simultaneously. [10]. The results of the binning & filling missing process can be shown in Appendix C2.
After processing the data, Beta Regression techniques were applied to develop a frequency model. This approach would effectively capture the nuances of proportional data and provide robust estimates under non-normal conditions ([6]). Besides, the Generalized Linear Model (GLM) framework was utilized to model Loss Given Default (LGD) for third-party exposures, leveraging its flexibility to accommodate various loss distributional assumptions [7].
Dam with higher quality and more complex structure might have a lower probability of default but higher loss given failure. To accurately measure the program's impact, a robust model is needed to interpret the marginal effects of each variable on both frequency and severity, as some factors may reduce frequency but increase severity, and vice versa.

3.2 Pricing Model

Premium for the Reconstruction Subprogram for Flumevale, Lyndrassia and Navaldia follows loss cost method, based on their corresponding risk exposure to dam failure each year. In other words, given dam i with the corresponding Third Party Loss Given Failure TPL_i; inflation rate r; original probability failure ${}_tp_{i,x}$ and force of failure u_i :

$$P_i \times \ddot{a}_{x:\overline{10}|} = 0.6 \times TPL_i \times \int_0^{10} v^t (1+r)^t \; {}_tp_{i,x} \; \mu_{i,x+t} \, dt$$

$$P_i = 0.6 \times TPL_i \times \frac{1 - \exp(-10\mu)}{\ddot{a}_{x:\overline{10}|}}$$

the Premium of Region k will be

$$Premium_k = \sum_{i=1}^{n} P_i \cdot \mathbf{1}(i \in k)$$

where $\mathbf{1}(i \in k)$ is an indicator function that equals 1 if i is in k, and 0 otherwise.
The premium will be adjusted based on the payment scheme for each region, ensuring the program has enough funds to be self-sustainable while avoiding a one-time premium that is too high for provinces relative to their GDP. The idea is to keep the present value of premium payments the same across regions, but tailor the payment schedule to each region's GDP capacity.

	Flumevale	Nalvadia	Lyndrassia
Premium schedule	5 years	2 years	1 year
Payment	$P \times \ddot{a}_{x:\overline{5}|}$	$P \times \ddot{a}_{x:\overline{2}|}$	P

Table2: Premium Payment Schemes by Region

The expected premium contribution by Region will be shown in Appendix D1.

3.3 Economic Loss Model

Once the full impact of Resilience Sub-Program on the probability of failure of 19368 earthen dams is evaluated, a new expected survival matrix in 10 years will be created for all observations. In detail, denoting 2 Survival matrices including S_1 with the program and S_2 without the program with size 19368 * 10, the Economic Loss Reduction ELR_i for for year i (where $i = 1, \ldots, 10$) is computed using the following formulation:

$$ELR_i = \sum_{j=1}^{19368} (S_1[j,i] - S_2[j,i]) \times LGD_{j,i}$$

The Maintenance feature in the Resilience Sub-Program requires fundings from the Goverment funds. To represent this, a maintenance probability matrix (M) with size 6401 *10 for the 6,401 dams for 10 years in the program is used, in which each matrix value follows a Bernoulli distribution with p=0.1. The expected present value of Maintaince Features$_i$ outflow in year i are EMF_i:

$$EMF_i = \sum_{j=1}^{6401} M[j,i] \times \text{Maintain\_cost}_j$$

with the Maintain_cost$_j$ of dam j is defined in Appendix B.2.
Similarly, the cost for the Upgrade matrices comes from the default loans. Given the number of failures after the program implementation as Failure with size 6401 * 10, the expected present value loss for Upgrade feature year i EUF_i is defined as:

$$EUF_i = \frac{\text{PV(Loan value)}}{10} - \sum_{j=1}^{6401} S_1[j,i] \times \frac{\text{PV(Upgrading Cost}_j)}{10}$$

with PV(Upgrading Cost$_j$) for each dam defined in Appendix B.2 and S_2 be the survival matrix defined above.
Then the EPV of the economic gain of year i EG_i is defined as the difference between Economic Loss Reduction and the Outflow:

$$EG_i = EMF_i - EUF_i - EMF_i$$

3.4 Cashflows Simulation & Estimation Model

There are 6 components of cashflows in the estimation:

- Outflow from Dam Failure is defined as the expected expense to cover loss when dams fail, equal to number of failures per year multiplied by 50-70 % Third-Party Liability loss per event. In real life events, dam failure could happen at any time during the year, but to simplify, models assume that outflow from dam failures happens in the middle of the year.
- Outflow from Maintenance expense equals the number of dams qualified for Maintenance benefit multiplied by maintenance cost (see Appendix B2 for more details). The program only spends on active dams, and the maintenance funding will be granted at the beginning of the year.
- Outflow from Zero-Coupon bonds is defined as the payments the Government pays to bond holders, made at the end of the 10th year.
- Inflow from the Regional Government is the premium payments from 3 regions—Flumevale, Navaldia, and Lyndrassia, representing the risks of operating dams at the beginning of payment year.
- Inflow from Dam Loan Payment is defined as the money repaid by owners of operating dams to the Government, payable annually at the end of the year.
- Inflow from Daily Interest of fund value is calculated based on overnight risk-free rate. Damsguard Solutions leverages the significant capital from premiums in the first year, aiming for the fund's self-maintenance.

The program tracks all cash inflows, outflows, and year-end fund values to assess its ability to remain self-sustaining while improving dam safety over 10 years. Given the large number of dams and variability in failure-related outflows, fund value fluctuations are expected. Simulations will be conducted to evaluate financial sustainability with greater certainty.

4 Modelling Result

4.1 Frequency - Severity Modelling & Premium Modelling by Region

The Beta Regression suggests significant impact of Assesssment category "Satisfactory" across all observations for earthen dams. While Assessment category with higher levels shows notable frequency improvements, it has no significant effect on severity (Appendix D1). This suggests that the Resilience Program can reduce total loss primarily by lowering failure frequency. Before implementation, it also should be noted that the upgrade and maintenance expenditure would most recorded in Nalvadia and Flumevale, due to large number of hazardous dams regarding their conditions and size (Appendix D2).

Assessment Category	Proportion	Number of Dams
Fair	10.24%	1464
NA/Not Rated/Not Available	28.49%	2236
Poor	24.83 %	314
Unsatisfactory	46.29%	210
Total		**4224**

In terms of pricing process, the estimated ratio of Regional Premium to GDP is kept at lower than 1 % for each payment from Flumevale and Nalvadia. This is done to strengthen sustainability of the funds at first, while keeping it as an acceptable rate to the Regional Economies. Base on the figure below, the team suggests that Navaldia and Flumevale can offer Lyndrassia a loan with payment duration of 20 years instead of 10-year loan payment to the Government. This method may ensure that the cost for insurance in all 3 Regions consumes below 1.5 % of GDP, instead of 3% in Lyndrassia at the moment.

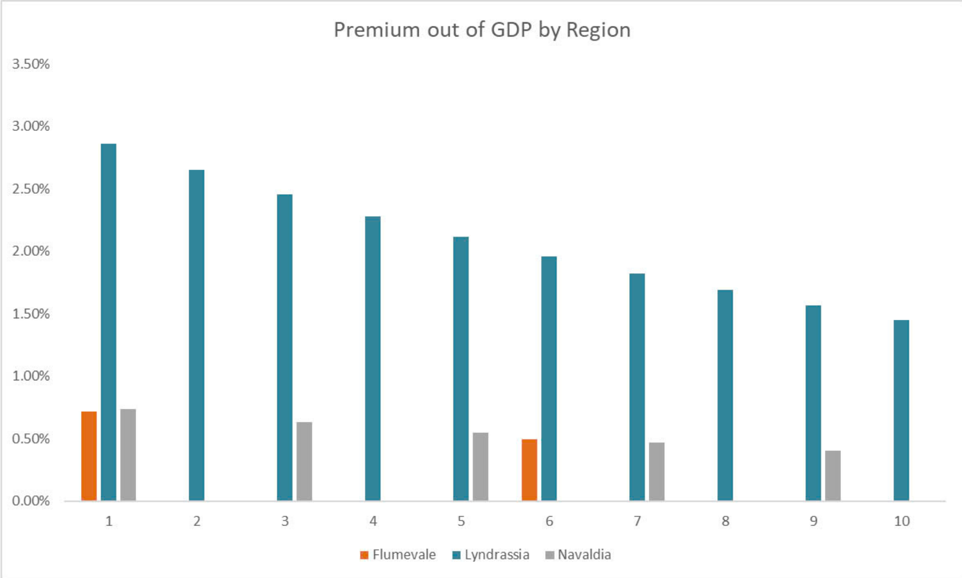


Figure 4: Premiums as of GDP by Region

4.2 Economic Results & Cashflow Results

Economic results are evaluated through two indicators which are economic gain from Resilience program and Fund value. Both indicators are expected to be positive, supporting two key metrics of RDIS:

- On average, when the total loss reduction outperforms the implementation cost at about 0.2 % GDP, there is an economic gain. Because reduction in the probability of failure is assumed to be in effect after 1 year, there is loss in the first year of implementation, as can be seen in the graph below.
- On average, the fund is self-sustainable, with the ending fund value of about 3 % GDP after 10 years.

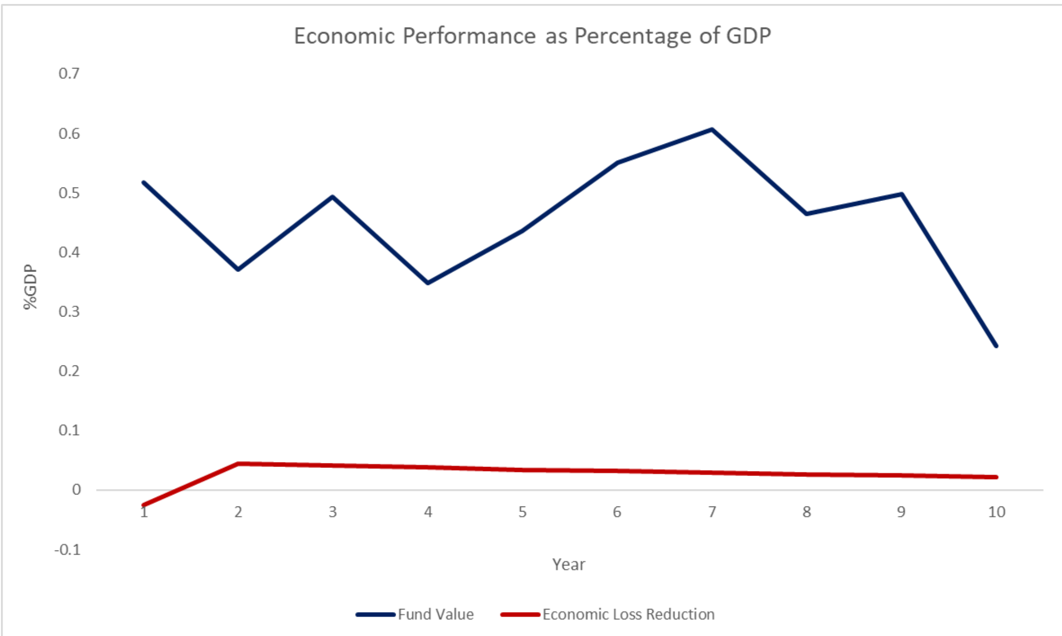


Figure 5: Fund value & Economic Loss Reduction

The impact of Resilience Program for High and Significant Hazard dams are also to be noticable with an average of 10 dams saved per year as can be seen in Figure 6 below.

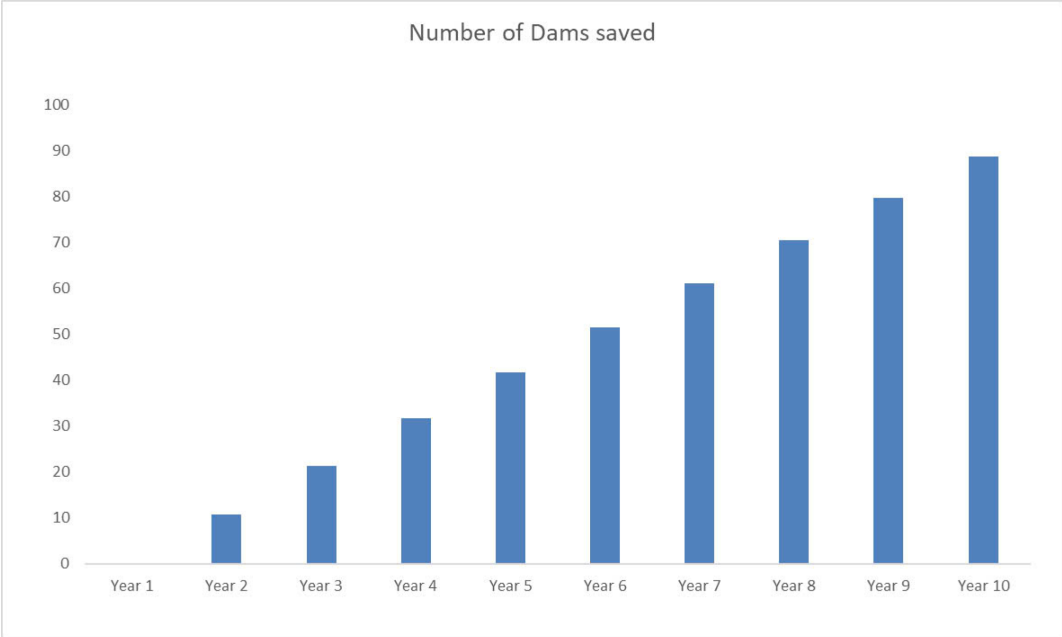


Figure 6: Number of High and Significant Hazard dams saved

4.3 Financial Sustainability

Under the program design and the base scenarios, it is expected that the fund will be self-sustainable at least 99.99 % of the time, which means that the fund value is always positive. This is achieved through a simulations process of 1000 times shown in Figure 7. It should be noted from an actuarial assessment that the minimum value of the fund will reach the lowest at the end of year 2 and year 4 in the program implementation duration, before experiencing a significant rise from year 4 to year 7.

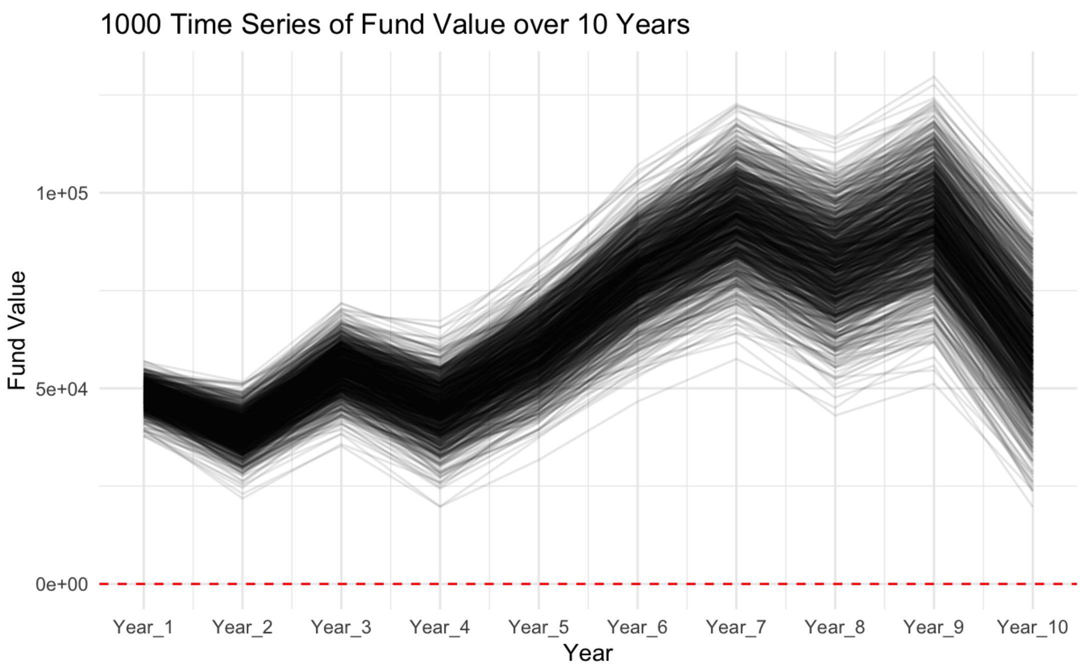


Figure 7: Fund Value Movement under 1000 scenarios

4.4 Cashflows Components

The projected cashflow components for the program can be seen in the Figure 8 below. Under the program design, negative cashflows usually happen, mostly attributed to the variability in premiums different for each Region.
In constrast,

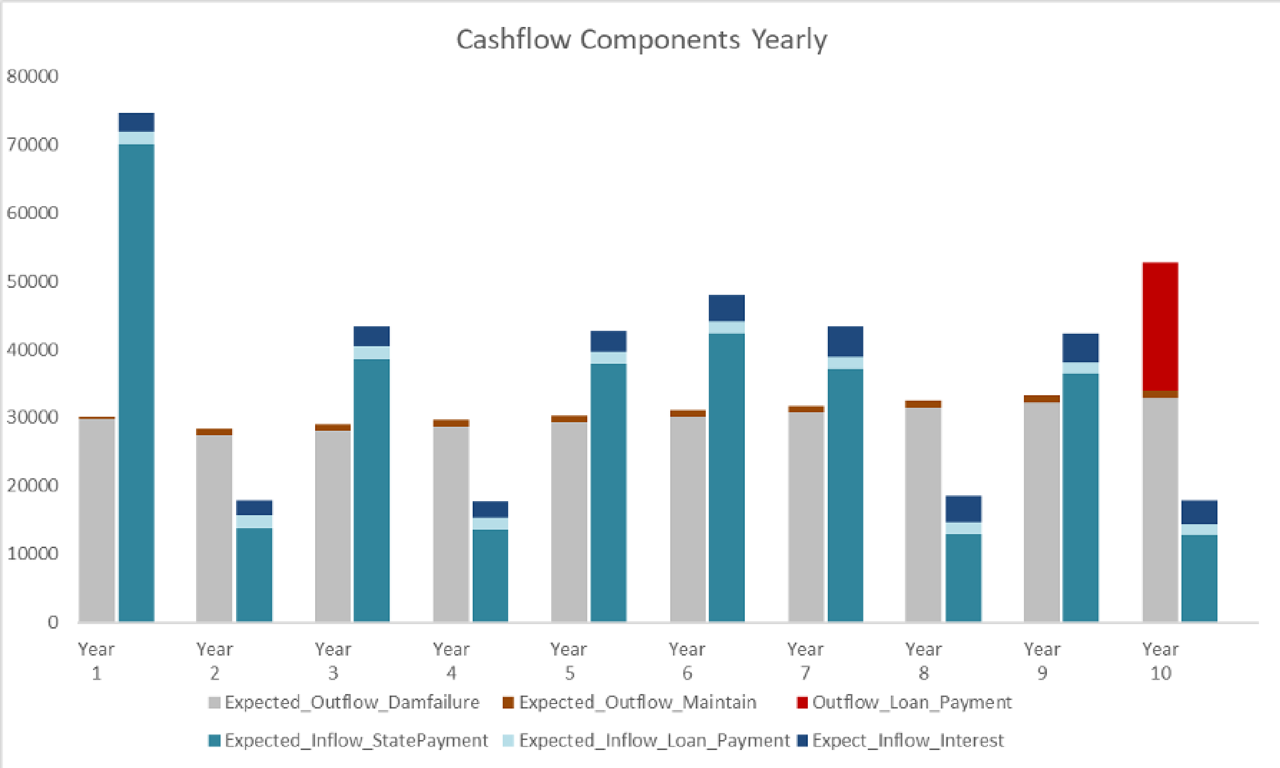


Figure 8: Cashflow Components Yearly

5 Risk Mitigation Strategy

5.1 Scenario Testing: Climate change assumptions

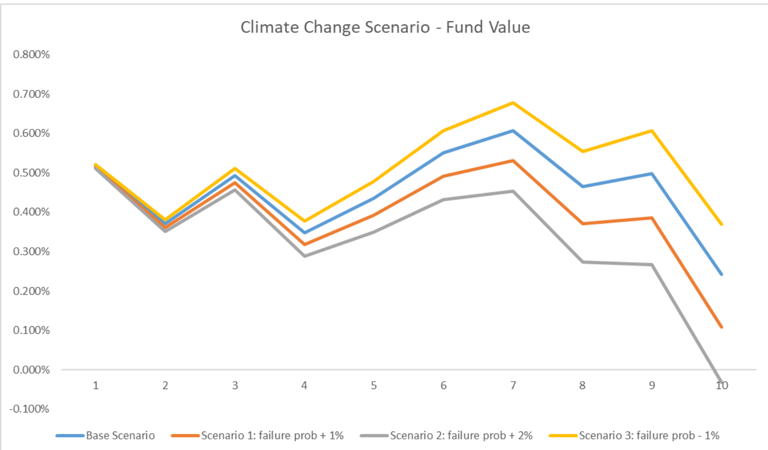


Figure 9: Scenario testing of fund value

The program was tested under three different climate scenarios. Climate change resulted in the probability of failure to

- Increase by 1% per year
- Increase by 2% per year
- Decrease by 1% per year.

As can be seen from the graph, the fund shows a strong performance throughout the years and it is only used up at the end of 10 years under a more stressful scenario. Furthermore, economic gain is also highly stable (see Appendix E).

5.2 Sensitivity Testing

This report considers the change in assumptions for Program Efficiency, Overnight Interest rate, Inflation for the sensitivity testing. Firstly, program efficiency has the positive correlation with both Fund value and Economic Gains. The rate of efficiency significantly affects on the economic gain in both directions, where 20 % change can result in about 35% in the output. As the economic gain mostly relates to inflation and probability of default, it is not affected by the change in interest rate assumptions.
For fund value, inflation and efficiency have the assymetric impact on ending fund value. It should be noted that Overnight interest rate has the highest senstivity towards the results, which can be intuitively explained by a high

capital surplus under the premium payment schedule discussed above. In summary, based on the sensivity testing, the program will have economic gain regardless of the extreme changes considered in the macro-economic and efficiency assumptions.

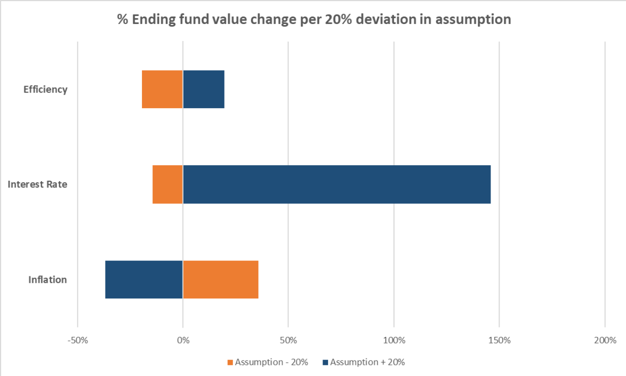


Figure 10: Further sensitivity analysis results

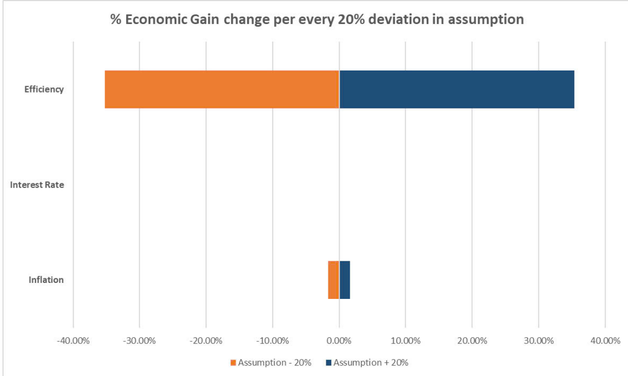


Figure 11: Further sensitivity analysis results

5.3 Risk Matrix

- **Multiple Cat Risk & Cat Risk: [1]** Multiple Cat Risk involves simultaneous catastrophic events like earthquakes or floods impacting multiple dams. Cat Risk refers to isolated events like extreme storms affecting individual dams. Mitigation requires implementing reinsurance arrangements and adding extra risk layers to enhance financial protection.
- **Climate Change (Possible, Serious): [8]** Climate change leads to an annual increase in the probability of dam failure (PD), rather than remaining constant over a 10-year period as previously assumed. It is essential to continuously monitor and assess PD changes by enhancing risk models with updated climate data.

RDIS RISK MATRIX	PROBABILITY			
IMPACT	EXTREMELY RARE	NOT VERY LIKELY	POSSIBLE	PROBABLE
VERY SERIOUS	Multiple Cat Risk			
SERIOUS		Cat Risk	Climate Change	
MILD			Adverse Selection; Efficiency Risk	Model Risk; Economic Factor Risk
INSIGNIFICANT				Overbudget Risk

Figure 12: Economic Support Priority Hierarchy

- **Adverse Selection:** This risk occurs when one party in a transaction has more information than the other, leading to high-risk individuals being more likely to participate. The solution is provided in Section 2.1.
- **Overbudget Risk:** This risk occurs when the cost of reconstructing public housing or delivering low-income support exceeds 60% of the total expected financial loss. To mitigate this risk, it is crucial to encourage public participation in private insurance, for example by purchasing property insurance.
- **Model Risk & Economic Factor Risk:**[9] Model Risk arises from flaws in financial models, such as coding errors or outdated data. Mitigation includes data quality checks, sensitivity testing, and third-party validation. Economic Risk stems from incorrect macroeconomic assumptions (e.g., GDP growth, inflation). When interest rates or inflation shift significantly, cost calculations should be reprocessed for accuracy.

6 Data limitations

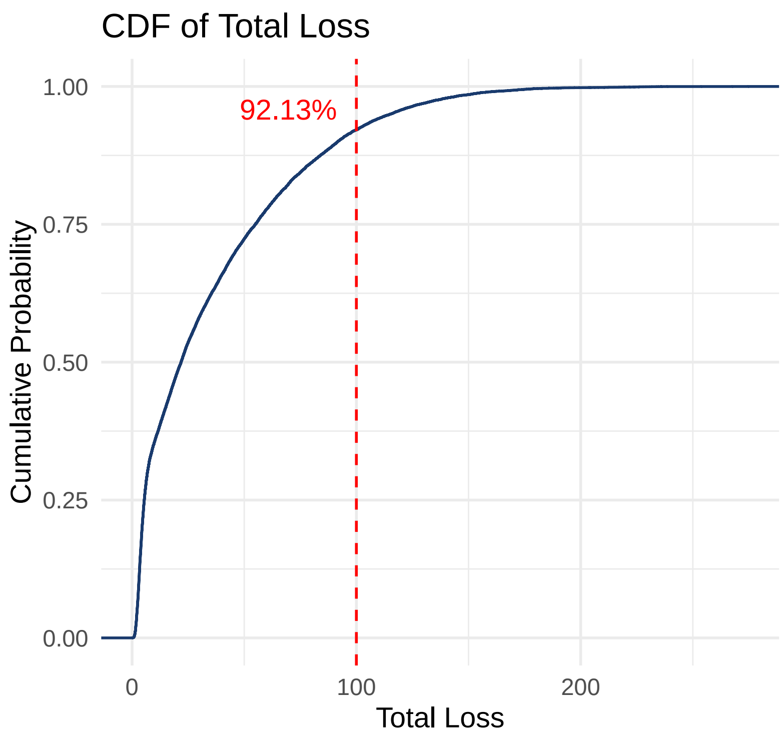
The table below shows key data limitations.

Category	Limitation	Assumption
Economics	Insufficient data on house repair costs, rental prices, and minimum wages for low-income individuals.	Utilize national averages from U.S. datasets for estimation.
	Unclear scope of losses covered under liability in the event of failure.	Assume third-party liability extends to infrastructure, economic damages, and private property and not cover undirect loss.
	No available statistics on private insurance coverage rates.	Reference the average coverage percentage across U.S. states following disasters.
Dam Expense	Lack of cost estimates for dam upgrades and ongoing maintenance.	Incorporate figures from "Costs of Rehabilitating Dams in the U.S." by ASDSO.
Dam Condition	Uncertainty in the timeline for dam condition deterioration.	Model degradation probability over two years using a Bernoulli distribution with $p = 0.1$.
Dependent risk	Absence of historical systematic risk on Failures, such as impact of climate change data.	Suppose climate increase the Probability of failures at a fixed rate annually .

Table 3: Summary of Limitations and Assumptions

7 Appendix

Appendix A: Loss Distributions by Regions



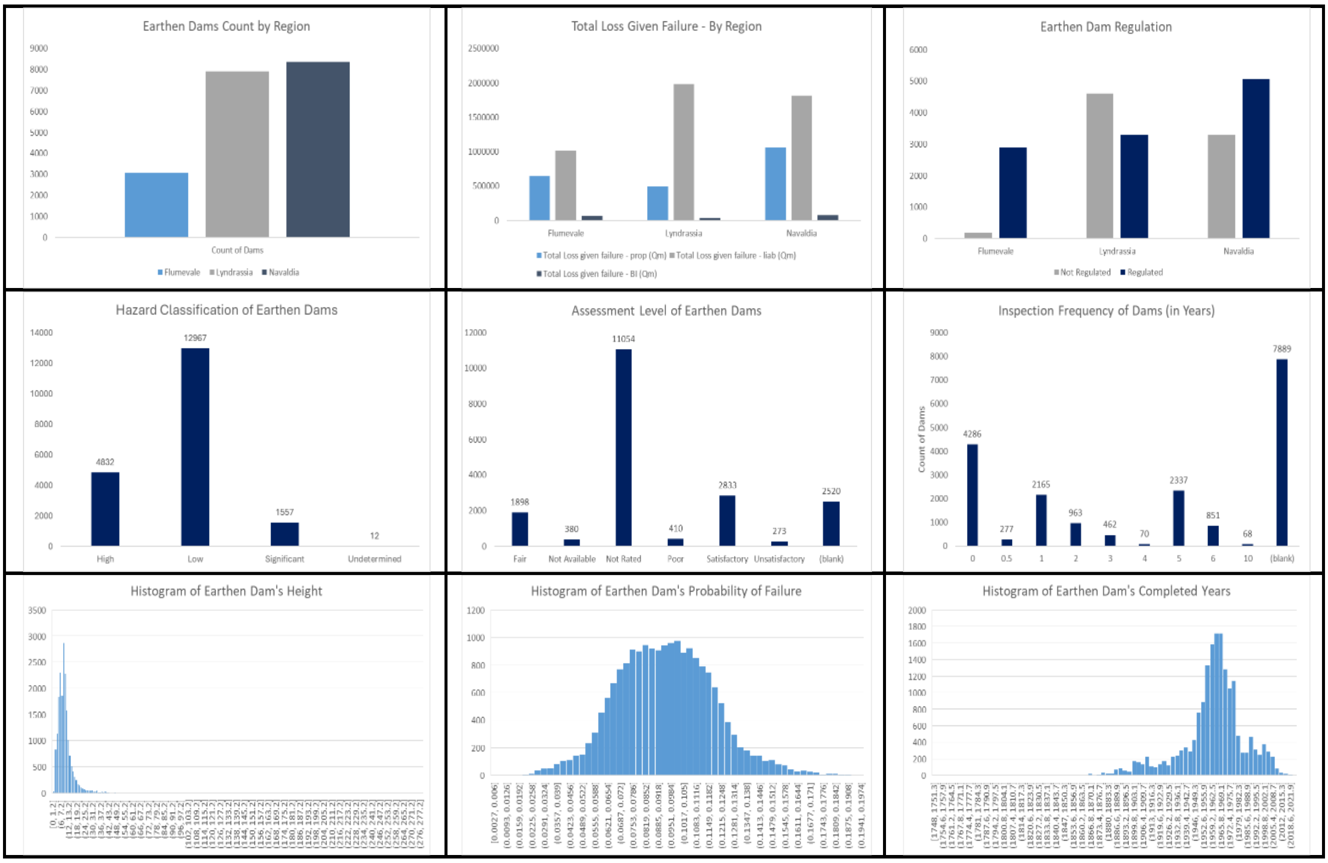


Figure 13: Visualization of key feature

Appendix B: Coverage Specification

Appendix B1: Reconstruction program

Third parties losses included public infrastructure and residents housing are available for reconstruction program coverage if they are damaged in a dam failure. To be more specific, coverages are listed as following [5]:

- **Emergency Response:**
  - **Evacuation and Rescue Support:** Guiding people to move to safety areas, providing search and rescue operations for injured people.
  - **Temporary House:** Available for 30 days to individuals whose primary residence has been rendered uninhabitable due to the dam failure. Both homeowners and renters are eligible.
  - **Food and Medical Supply:** Providing essential food and healthcare services through a one-time payment of 150 Qalkoons per person.
  - **Debris Removal:** Clearing debris to restore access to affected areas.
- **Public infrastructure and non-insured individuals** Coverage are disbursed at the same time:

	Category	Description
Public infrastructure	Essential Services Restoration	Water Supply Systems: Restore clean water distribution and treatment facilities.
		Sanitation Systems: Repair sewage systems to prevent health hazards.
		Electricity and Energy: Reestablish power grids and energy supply chains.
	Transportation Infrastructure	Roads and Highways: Focus on main roads for connectivity and accessibility.
		Airports and Ports: Restore critical transportation hubs for economic recovery.
		Public Transportation: Revitalize bus and rail services for community mobility.
	Public Buildings and Facilities	Schools and Education Facilities: Prioritize educational infrastructure for community stability.
		Hospitals and Healthcare Facilities: Ensure medical services are available.
		Government Buildings: Restore administrative functions for governance and service delivery.
Low-Income Population	For individuals who have their houses damaged	Support housing repair expenses up to 20,000 Qualkoons.
	For individuals living in rental properties impacted by dam failure	Provide rental expense up to 20,000 Qualkoons or living expense of 1100 Qualkoons for 6 months. If a dam failure occurs, the government will choose one of the two options for each recipient. The eligibility and selection of the appropriate option will be determined through government assessment.

- **Additional Coverage (if funds are available):** Other individuals affected by the dam failure may submit an application form to request financial assistance.

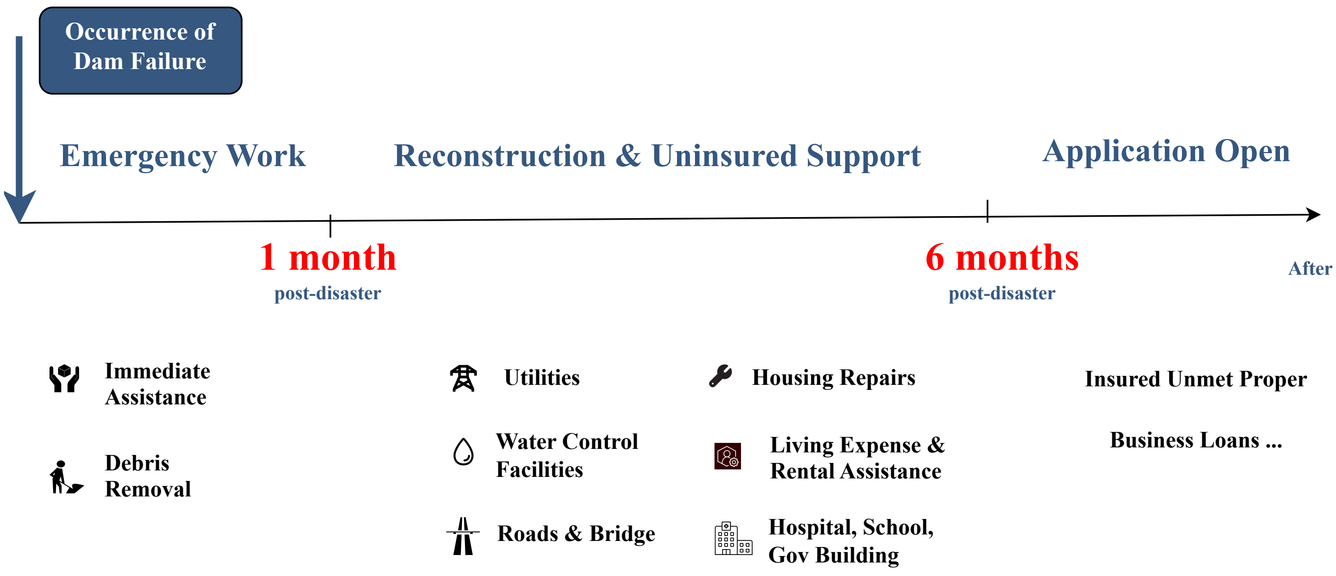


Figure 14: Timeline of post-dam failure recovery

- **Emergency Work (First Month)** Immediate response includes debris removal and emergency assistance to ensure safety and basic needs.
- **Reconstruction & Uninsured Support (Up to Six Months)** Focuses on infrastructure restoration, housing repairs, and public service recovery.
- **Application Open (Beyond Six Months)** Addresses unmet insured needs and business recovery support.

Appendix B2: Resilience Sub-Program

Only High and Significant Hazard dams qualify for this Resilience Program.

Appendix B2.1: Upgrading Feature

- **Purpose:** From Assessment: Poor, Not Rated, Not Available, Fair and Unsatisfactory to Satisfactory.
- **Source of funding:** The government acts as an intermediary, issuing a 10-year bond with an interest rate of 6.47% to immediately generate a capital of 17,083 Million Qalkoons.
- **Use of funding:** This capital is used for dam owners' loans under the upgrading component program. The loan program is mandatory for qualified dam owners, requiring them to improve the dam's assessment level to at least Fair and Satisfactory group.
- **Timeline:**
  - The upgrade process must be completed in the first year.
  - Dam owners are required to repay the upgrade loan annually over a 10-year period at a simple interest rate of 10%.
  - Dams that experience failure during any given year will be exempted from debt repayment starting from that year.

Dam Heights	Dams Less than 50 Years Old	Dams Greater than or Equal to 50 years old	
	Less than Satisfactory Condition	Fair Condition	Poor and Unsatisfactory Condition
0-4.57	284,091	980,114	2,038,352
4.57-7.62	561,080	1,342,330	1,896,307
7.62-15.24	1,001,420	2,840,909	4,424,716
15.24-30.48	965,909	3,409,091	6,093,750
30.38-60.96	2,187,500	14,204,545	16,931,818
>60.96	6,519,886	18,707,386	67,684,659

Figure 15: Estimated Upgrading Cost for Dams [2]

The total upgrading costs for each region are presented in the table below

Region	Total Upgrading Costs
Flumevale	4,671,365,000
Lyndrassia	4,182,271,000
Navaldia	8,719,456,000

Appendix B2.2: Maintenance Feature

Only dams that show signs matching the descriptions in the table below qualify for the maintenance benefit.

Triggering factors/ Scenerios	Tools	Description
After extreme events or disasters	Visual inspection	Floods: After severe flooding that stresses the dam structure.
		Earthquakes: If an earthquake occurs near the dam, affecting its stability.
		Landslides or debris flows: If geological events alter the dam's surroundings.
Sign of abnormalities	Visual inspection, monitoring equipments, Community or Expert feedbacks	Leakage: Unusual water seepage from the dam body or foundation.
		Structural deformations: Cracks, settlements, or other visible deformations.
		Changes in water levels or pressure: Sudden or unexpected changes in reservoir operations.
Periodic or long-term operation		Routine assessments: Typically every 5–10 years or as required by regulations.
		Aging dams: Older dams that may have degraded over time.
Environmental or geological changes	Ecosystem Indiators	Climate change: Changes in rainfall patterns, temperature, or flow regimes.
		Geological shifts: Erosion, landslides, or foundation changes.
Safety or performance concerns	Visual inspection, monitoring, Community or Expert feedbacks	Reduced efficiency: If the dam is no longer performing as designed.
		Community or expert concerns: If safety concerns are raised by locals or professionals.

- **Purpose:** Maintain dams' assessment level at Satisfactory.
- **Source of funding:** Government fund.
- **Use of funding:** Funding amount is classified:

Dam Heights	Maintenance Costs
0-4.57	284,091
4.57-7.62	561,080
7.62-15.24	1,001,420
15.24-30.48	965,909
30.38-60.96	2,187,500
>60.96	6,519,886

- **Timeline:**
  - The maintenance feature is ongoing for 10 years.
  - Any parties have the right to propose to the Government to maintain the dam's assessment level.
  - Post-maintenance inspections are required to ensure that the dam's conditions satisfy the Satisfactory standards.

Area	Criteria	Standard	Requirement
Reservoir Conditions	Water Level Monitoring	100m ± 2m	Recorded within 7 days
	Water Quality (Turbidity, pH)	Turbidity < 5 NTU, pH 6.5 – 8.5	Reported annually
	Debris Management	Remove debris > 500 kg per inspection	Documented per inspection
Structural Integrity	Crack & Erosion Inspection	No cracks > 5mm width, Erosion depth < 50 cm	Included in comprehensive report
	Settlement Monitoring	Settlement < 0.3m/year	Included in comprehensive report
Mechanical Systems	Valves & Gates Operation	Full operation within 3 minutes	Reported annually
	Turbine Efficiency	Operational efficiency > 90%	Recorded within 7 days
	Emergency Systems	Response time < 5 seconds	Checked annually

– Dam owners are obligated to follow the process and any requirements of the Government. Non-compliance may result in penalties.

Appendix C: Modelling Process and Key Assumptions

Appendix C1: Macroeconomics Assumptions

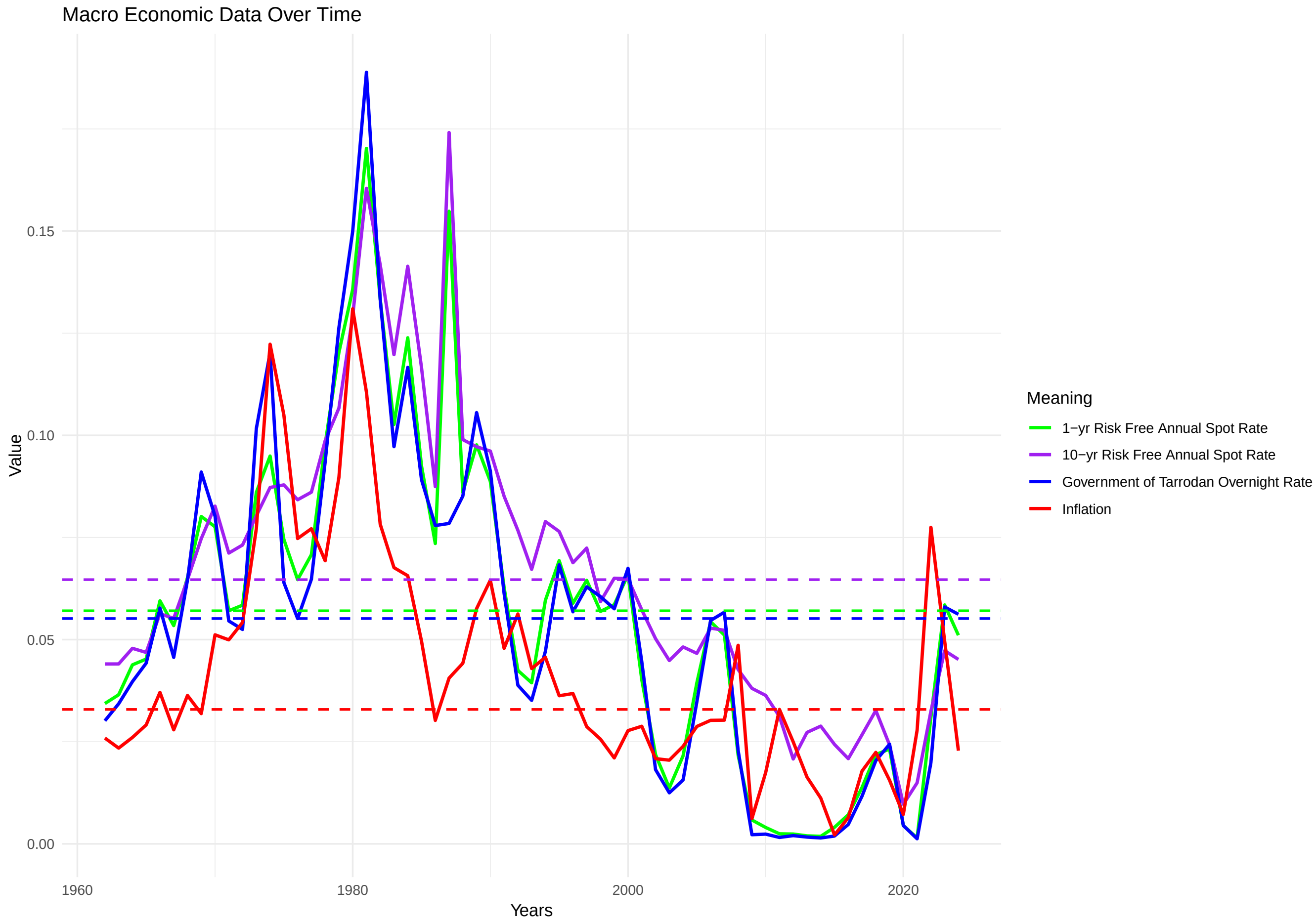
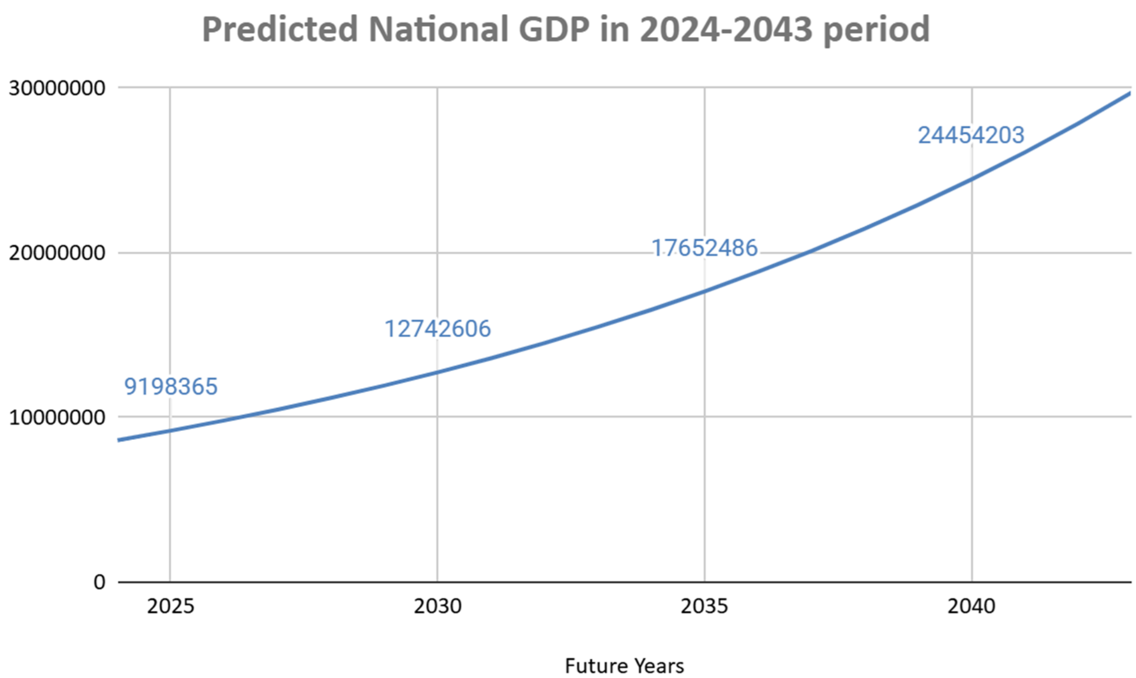


Figure 16: Visualization of Macroeconomics factors



Appendix C2: Data grouping and bining

The final variables for the grouping process are shown below:

Variable Names	Original Values	Grouping
Height (m)	Numeric (meters)	Under 15 feet, 15-25 feet, 25-50 feet, 50-100 feet, 100-200 feet, 200 feet+
Length (km)	Numeric (kilometers)	Under 0.25 km, 0.25-1 km, 1-10 km, 10km+
Volume (m3)	Numeric (cubic meters)	Under 1e4, 1e4-1e5, 1e5-1e6, 1e6+
Surface (km2)	Numeric (square kilometers)	Under 0.1, 0.1-1, 1-10, 10+
Age_Completed	Numeric (years) or NA	0-50, 50+ (NA as 50+)
Age_Assessment	Numeric (years)	0-2, 2-10, 10+
Drainage (km2)	Numeric (square kilometers)	Under 5, 5-50, 50-500, 500+
Spillway	Categorical (Controlled, Uncontrolled, NA)	Uncontrolled & NA, Controlled
Age_Modified	Numeric (years)	Under 10, 10-50, 50+
Distance to Nearest City (km)	Numeric (kilometers) or NA	Under 2, 2-10, 10-50, 50+ (NA as 50+)
Hazard	Categorical (Low, Significant, Undetermined, High)	Low, Significant + Undetermined, High
Assessment	Categorical (Satisfactory, Fair, Poor, Unsatisfactory, Not Rated, Not Available, NA)	Satisfactory, Fair, NA + Not Rated + Not Available, Poor, Unsatisfactory
Inspection_Frequency_Group	Categorical (0, 0-1, 1-2, 2-4, 4-6, 6-10, NA)	0, NA-6-10, 2-6, 1-2, 0-1
Primary Purpose	Categorical (e.g., Grade Stabilization, Irrigation, Recreation, Hydroelectric, etc.)	Grade Stable, Other, Recreation + Debris, Hydro

Table 3: Categorization of dam variables in the resilience program dataset. Each variable is transformed from its original values into discrete groups for analysis, supporting the assessment of dam conditions and risks in regions like Flumevale, Navaldia, and Lyndrassia.

Appendix D: Modelling result

Appendix D1: Frequency and Severity Modelling Result

```
Call:
glm(formula = `Loss given failure - prop (Qm)` ~ Region + `Regulated Dam` +
    `Height (m)` + `Length (km)` + `Surface (km2)` + `Volume (m3)` +
    Age_Completed + `Drainage (km2)` + Spillway + `Distance to Nearest City (km)` +
    Hazard + Assessment + Inspection_Frequency_Group + `Primary Purpose` +
    Age_Assessment + Age_Modified, family = gaussian(link = "log"),
    data = df_Model2 %>% filter(`Loss given failure - prop (Qm)` >
        0))

Coefficients:
                                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                               2.467162   0.149377  16.516  < 2e-16 ***
RegionLyndrassia                         -0.074935   0.023697  -3.162 0.001568 **
RegionNavaldia                           -0.075048   0.019620  -3.825 0.000131 ***
`Regulated Dam`Yes                        0.082069   0.019538   4.200 2.68e-05 ***
`Height (m)`15-25 feet                   -0.118292   0.024325  -4.863 1.17e-06 ***
`Height (m)`25-50 feet                   -0.123328   0.022550  -5.469 4.58e-08 ***
`Height (m)`50-100 feet                  -0.193754   0.024789  -7.816 5.72e-15 ***
`Height (m)`100-200 feet                 -0.208854   0.029026  -7.195 6.45e-13 ***
`Height (m)`200 feet+                    -0.195109   0.035569  -5.485 4.18e-08 ***
`Length (km)`0.25-1 km                    0.170497   0.015440  11.042  < 2e-16 ***
`Length (km)`1-10 km                      0.268111   0.019466  13.773  < 2e-16 ***
`Length (km)`10km+                        0.247116   0.052209   4.733 2.23e-06 ***
`Surface (km2)`0.1-1                      1.785567   0.060149  29.686  < 2e-16 ***
`Surface (km2)`10+                        2.558574   0.062683  40.818  < 2e-16 ***
`Volume (m3)`1e4-1e5                     -0.369779   0.019326 -19.134  < 2e-16 ***
`Volume (m3)`1e5-1e6                      0.020869   0.019092   1.093 0.274360
`Volume (m3)`1e6+                        -0.055058   0.024325  -2.263 0.023623 *
Age_Completed50+                         -0.005004   0.015032  -0.333 0.739221
`Drainage (km2)`5-50                      0.107797   0.018496   5.828 5.69e-09 ***
`Drainage (km2)`50-500                    0.323137   0.019160  16.865  < 2e-16 ***
`Drainage (km2)`500+                      0.315887   0.023158  13.641  < 2e-16 ***
SpillwayControlled                        0.040218   0.021109   1.905 0.056763 .
`Distance to Nearest City (km)`2-10       0.037112   0.019760   1.878 0.060376 .
`Distance to Nearest City (km)`10-50      0.044399   0.019126   2.321 0.020278 *
`Distance to Nearest City (km)`50+        0.136213   0.018751   7.264 3.90e-13 ***
HazardSignificant + Undetermined          0.303173   0.024434  12.408  < 2e-16 ***
HazardHigh                                0.307637   0.020072  15.326  < 2e-16 ***
AssessmentFair                            0.007982   0.016555   0.482 0.629697
AssessmentNA + Not Rated + Not Available -0.017580   0.017211  -1.021 0.307050
AssessmentPoor                            0.001744   0.025888   0.067 0.946276
AssessmentUnsatisfactory                 -0.046029   0.034875  -1.320 0.186906
Inspection_Frequency_GroupNA-6-10        -1.004815   0.719885  -1.396 0.162791
Inspection_Frequency_Group2-6             0.599904   0.039826  15.063  < 2e-16 ***
Inspection_Frequency_Group1-2             0.721850   0.044414  16.253  < 2e-16 ***
Inspection_Frequency_Group0-1             0.739826   0.043384  17.053  < 2e-16 ***
`Primary Purpose`Hydro                    0.183144   0.127068   1.441 0.149515
`Primary Purpose`Other                    0.221730   0.124377   1.783 0.074648 .
`Primary Purpose`Recreation + Debirs      0.300482   0.124678   2.410 0.015959 *
Age_Assessment2-10                       -0.032315   0.015443  -2.093 0.036399 *
Age_Assessment10+                         0.006083   0.017873   0.340 0.733604
Age_Modified10-50                         0.106625   0.043061   2.476 0.013290 *
Age_Modified50+                          -0.001961   0.041930  -0.047 0.962691
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 17: Severity Modelling

```
Call:
betareg(formula = `Probability of Failure` ~ Region + `Regulated Dam` + `Height (m)` + `Surface (km2)` +
    Age_Completed + `Drainage (km2)` + Spillway + `Distance to Nearest City (km)` + Hazard + Assessment +
    Inspection_Frequency_Group + `Primary Purpose` + Age_Assessment + Age_Modified, data = df_Model,
    link = "logit")

Quantile residuals:
    Min      1Q  Median      3Q     Max
-5.7029 -0.6544  0.0620  0.7192  3.1699

Coefficients (mean model with logit link):
                                          Estimate Std. Error  z value Pr(>|z|)
(Intercept)                             -2.7388873  0.0243379 -112.536  < 2e-16 ***
RegionLyndrassia                         0.2163653  0.0078692   27.495  < 2e-16 ***
RegionNavaldia                           0.1372256  0.0070167   19.557  < 2e-16 ***
`Regulated Dam`Yes                       0.0070238  0.0049866    1.409 0.158972
`Height (m)`15-25 feet                   0.0393816  0.0062838    6.267 3.68e-10 ***
`Height (m)`25-50 feet                   0.0213887  0.0061083    3.502 0.000463 ***
`Height (m)`50-100 feet                  0.0160620  0.0079830    2.012 0.044217 *
`Height (m)`100-200 feet                 0.0502487  0.0135580    3.706 0.000210 ***
`Height (m)`200 feet+                    0.0617303  0.0218858    2.821 0.004794 **
`Surface (km2)`0.1-1                    -0.0015849  0.0037054   -0.428 0.668858
`Surface (km2)`10+                       0.0247353  0.0115948    2.133 0.032898 *
Age_Completed50+                         0.0347268  0.0041647    8.338  < 2e-16 ***
`Drainage (km2)`5-50                     0.0073187  0.0048084    1.522 0.127990
`Drainage (km2)`50-500                  -0.0595293  0.0059249  -10.047  < 2e-16 ***
`Drainage (km2)`500+                    -0.0984379  0.0069569  -14.150  < 2e-16 ***
SpillwayControlled                      -0.0280829  0.0161004   -1.744 0.081118 .
`Distance to Nearest City (km)`2-10     -0.0166524  0.0065889   -2.527 0.011494 *
`Distance to Nearest City (km)`10-50    -0.0085675  0.0058016   -1.477 0.139744
`Distance to Nearest City (km)`50+      -0.0226712  0.0057698   -3.929 8.52e-05 ***
HazardSignificant + Undetermined         0.5006910  0.0066078   75.773  < 2e-16 ***
HazardHigh                               0.1695242  0.0054067   31.354  < 2e-16 ***
AssessmentFair                           0.1024108  0.0070167   14.595  < 2e-16 ***
AssessmentNA + Not Rated + Not Available 0.2849590  0.0061941   46.005  < 2e-16 ***
AssessmentPoor                           0.2483163  0.0115344   21.528  < 2e-16 ***
AssessmentUnsatisfactory                 0.4628925  0.0117057   39.544  < 2e-16 ***
Inspection_Frequency_GroupNA-6-10       -0.7296447  0.0366235  -19.923  < 2e-16 ***
Inspection_Frequency_Group2-6           -0.1495326  0.0066826  -22.376  < 2e-16 ***
Inspection_Frequency_Group1-2            0.0883032  0.0099145    8.906  < 2e-16 ***
Inspection_Frequency_Group0-1            0.1289748  0.0086248   14.954  < 2e-16 ***
`Primary Purpose`Hydro                   0.0977567  0.0224733    4.350 1.36e-05 ***
`Primary Purpose`Other                   0.0221545  0.0097699    2.268 0.023353 *
`Primary Purpose`Recreation + Debirs     0.0007433  0.0102310    0.073 0.942083
Age_Assessment2-10                       0.0366833  0.0071724    5.115 3.15e-07 ***
Age_Assessment10+                       -0.0375150  0.0078664   -4.769 1.85e-06 ***
Age_Modified10-50                        0.0121359  0.0190765    0.636 0.524665
Age_Modified50+                          0.0554296  0.0182376    3.039 0.002371 **

Phi coefficients (precision model with identity link):
      Estimate Std. Error z value Pr(>|z|)
(phi)  231.446      2.354   98.32   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 18: PD Result

Appendix D2: Dam Risks & Improvements costs by Region

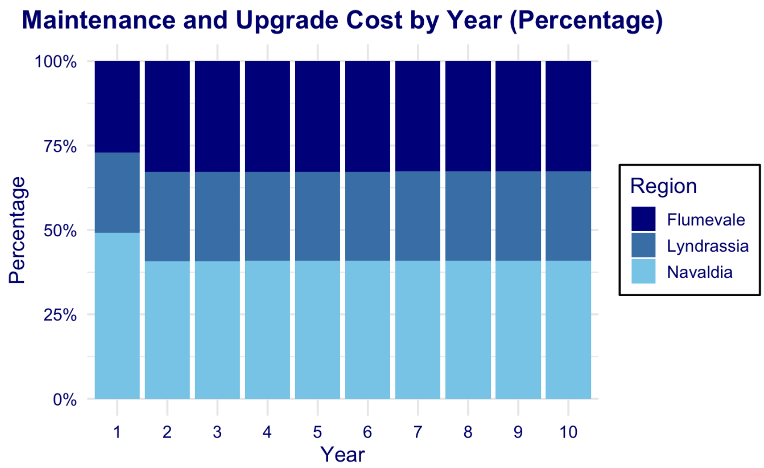


Figure 19: Resilience Outflows by Regions

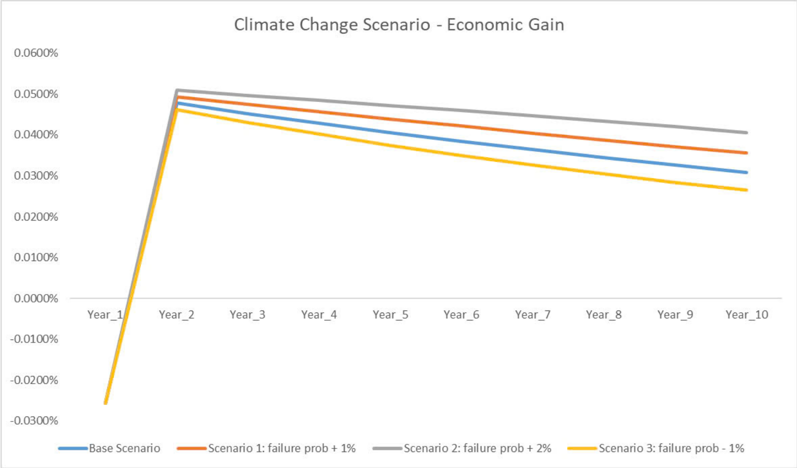
Region	Number of Non Low Hazard Dams
Flumevale	1548
Lyndrassia	1858
Navaldia	2995

Figure 20: The number of Non-Low Hazard Dams by category or region

Region	Count	Total	Percentage
Flumevale	2565	3074	83.44
Lyndrassia	5506	7920	69.52
Navaldia	6730	8374	80.37

Figure 21: Percentage of dams older than 50 years

Appendix E: Scenarios Testing for Economic Gain



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