TARRODAN NATIONAL DAM INSURANCE

Navigating Risk, Securing Futures

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1. Objective of Analysis

1.1 Background

Tarrodan, encompassing Navaldia, Flumevale, and Lyndrassia, is home to 20,806 dams, many of which are earthen structures that pose significant risks to public safety and economic stability. The number of high-hazard potential dams is projected to increase by approximately 20% over the next decade (FEMA, 2023) where in the event of dam failures, the consequences can be catastrophic, endangering lives and resulting in substantial economic losses. Consequently, NORM Consulting proposes a comprehensive national dam insurance program to the government aimed at mitigating the economic impacts of dam failures while enhancing emergency preparedness and disaster response for citizens.

The Tarrodan National Dam Insurance Program is designed as a legally mandated obligation for both dam owners and citizens, ensuring universal participation and equitable risk sharing. The program, set for implementation in 2026 with a 10-year duration, will involve cost-sharing among public and private dam owners (65%) and Tarrodan citizens (35%). Private dam owners will pay premiums directly though the regional authority, while public dam premiums will be funded through the existing earthen dam budget. Premiums for each dam are calculated proportionally to each dam's share of the total expected present value of losses. On the other hand, citizens will contribute through a mandatory annual house tax, tailored to regional structures and house values, with payments collected by the federal government. This house tax is eligible for a government subsidy, which exempts the first Q40,000 of the house’s value from taxation, reducing the financial burden on citizens with lower economic capacity.

The insurance program’s contractual framework is irrevocably bound to this 10-year term to ensure stability and accountability. Termination before 2036 is prohibited to uphold actuarial assumptions, maintain solvency of the catastrophe bond (which matures at the program’s conclusion). This non-terminable structure safeguards against disruptions to risk-sharing mechanisms, ensures reinvestment of early surpluses to offset later deficits (**Table 2**), and guarantees uninterrupted protection against climate and operational hazards over the full decade.

1.2 Main Objectives

Tarrodan’s National Dam Insurance has the following key objectives:

i. Provide financial assistance to private and public dam owners for structural repairs.
ii. Enhance dam safety awareness among Tarrodan citizens through the Tarrodan Incentive Programs.
iii. Implementation of Emergency Preparedness Program to minimize risk to public safety and property.
iv. Push infrastructure improvement by providing financial assistance to both public and private dam owners, helping alleviate the burden on dam owners while ensuring long term viability of the nation’s dam infrastructure
v. Long term suitability of the program by promoting fair risk sharing and maintaining financial sustainability.

1.3 Key metrics

1. Dam Enhancement and Completion Report
   This report monitors dam enhancement progress to ensure annual targets are met.
   - Success indicator: Achieve a minimum of 90% fulfilment rate annually, ensuring all eligible dams are rehabilitated within the 10-year period.
   - Reporting Schedule: Annually, reported trough the regional dam centres.
2. Public Awareness and Engagement
   Tracks level of citizen participation in the Tarrodan Incentive Program
   - Success Indicator: Measure the success through participation rate in training programs and activity in the HydroSafe app
   - Reporting Schedule: Quarterly
3. Loss Reduction and Program Financial Sustainability
   Assesses the 95th percentile of potential financial losses of potential dam failures and premium cash flows against claim paid.
   - Success Indicator: Ensure the insurance program remains with a high probability of solvency.
   - Reporting Schedule: Annually

2. Program Design

The Tarrodan National Dam Insurance program not only offers financial resources for dam repair and third-party loss coverage but also integrates four key initiatives to enhance long-term loss reduction and safety: dam rehabilitation to decrease failure probability, real-time monitoring and emergency preparedness to mitigate failure impacts, community incentive programs to boost awareness and citizen engagement, and catastrophe bonds to bolster program solvency.

2.1 Rehabilitation Program

Our team has assessed that the enhancement of existing dams is a crucial strategy to mitigate losses and enhance citizen safety and security. However, with a total of 20,806 dams spread over 3 regions in Tarrodan, it would be impractical for each dam to undergo enhancement strategies due to budgetary and time constraints. In the process of selecting dams for enhancement, we prioritize dams with a high population at risk and a high likelihood of failure (FEMA, 2024). This approach focuses on those dams that could endanger large numbers of people in the event of failure, as well as those with conditions that indicate a significant risk of failure. With this approach, we aim to prioritize rehabilitation resources and funds on dams that need the most immediate attention, to reduce potential negative impacts on communities and improve overall public safety.

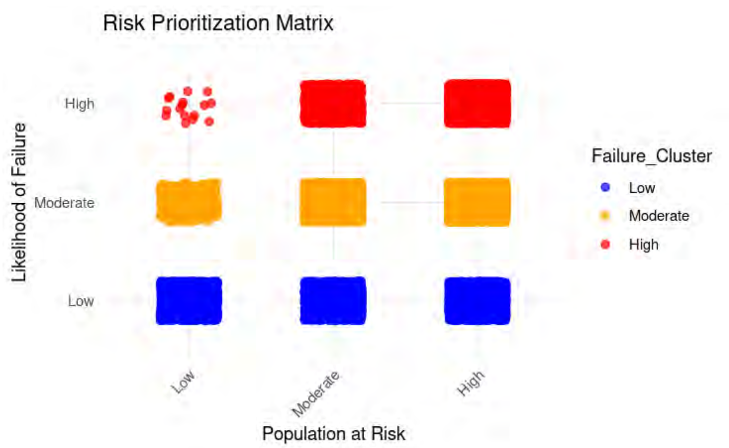


Figure 1. Risk Prioritization Matrix

To allocate resources effectively, we developed a risk prioritization matrix using clustering based on population at risk and likelihood of failure, categorized into Low, Moderate, and High. Dams in the High-High cluster are further assessed based on height, age, and condition rating, following criteria from ADSO 2023 (Appendix B.1). The analysis identifies 1,515 dams requiring enhancement, with a total funding need of Q4,866,564,885. In the first 10-year program, a total of 907 dams are designated for enhancement, determined by Tarrodan's estimated construction capacity. Reduction factors for each dam enhancement and annual targets for repairs, retrofits, and rehabilitations are outlined in Appendix **C.4.** Detailed strategies and costs for rehabilitation by region, based on dam height and age, are also provided in **Appendix B.1.** Quotas for each year are set using the 10- year program timeline (Mahler, 2020). All 907 listed dams must undergo enhancement within the 10-year timeframe and non-compliance will incur a penalty of $5,000 per dam.

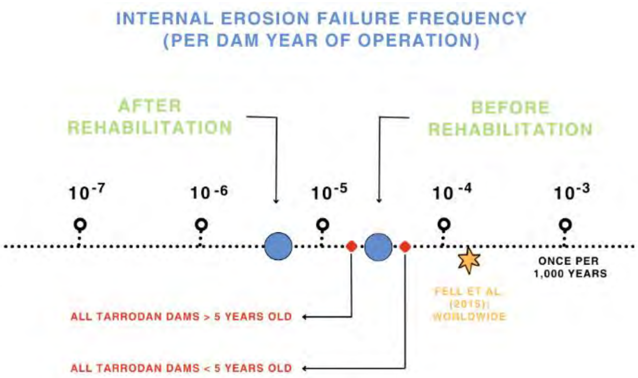


Figure 2. Risk Diagram for a Dam

Figure 2. illustrates a comparison between pre- and rehabilitation conditions (Statkraft, 2022). It demonstrates a 90% reduction in the probability of dam failure, indicating a substantial improvement in risk mitigation further underlining the importance of dam enhancement. Data from Fell et al. (2015) is also included to provide global context. This study highlights the various factors that influence the risk of failure, including structural condition, dam age and environmental impacts.

2.2 Real Time Monitoring and Emergency Response and Preparedness Program

Safe operation of dams is crucial for both Tarrodan's economic stability and public safety. Equally crucial is a swift response in case of failure, as timely warnings and rapid public action significantly reduce casualties. The primary function of instrumentation is to provide reliable and updated data that supports safety evaluation and identify potential issues at an early and preventable stage, enabling preventative measures to mitigate risks. The impact of early warning system can be seen in Baldwin Hills and Castlewood Canyon in the United State (Lee Mauney, P.E., 2025). Additionally, early warning systems (EWS) offer cost-effective risk mitigation, especially when rehabilitation funding is limited. Therefore, NORM Consulting proposes an integrated dam monitoring solution compromising key components to enhance dam safety and operational efficiency. This includes real-time monitoring through various sensors that measure pore pressure, water flow, lateral movement, deformation, stress, strain and temperature installed in each dam and its appurtant structure (Encardio Rite, 2018). Through real time monitoring, preparedness and emergency response can be better implemented in Tarrodan. The integration of real-time monitoring and the emergency preparedness program is reflected through these two key points (Thingslog, 2022).

1. Tarrodan DamSafe Network: This framework facilitates data logging, analysis, and visualization of information gathered from sensors installed in each dam. With the implementation of regional dam centers in Navaldia, Flumevale and Lyndrassia, engineering consultants and data analysts evaluate incoming data. In the event of a potential failure, alerts are issued to nearby residents, while a team of engineers and workers is **dispatched to assess the situation and administer immediate interventions**. This proactive emergency preparedness strategy aims to minimize dam failures and reduce casualties among the surrounding population.

2. HydroSafe mobile App: The HydroSafe app is designed to deliver **warnings and notifications** regarding potential dam failures. Through this platform, citizens can access real-time, updated data from regional dam centers, providing crucial information on current dam conditions. Additionally, the app aims to enhance public awareness about dam safety. It offers a weekly newsletter highlighting significant dam-related issues and includes comprehensive emergency measures such as evacuation plans and designated safe zones. To facilitate immediate assistance, the app features a direct hotline to emergency services. Moreover, it includes a dedicated section for the Dam Community Incentive Program, which encourages citizen engagement in discussions aimed at improving dam safety and mitigating hazard risks.

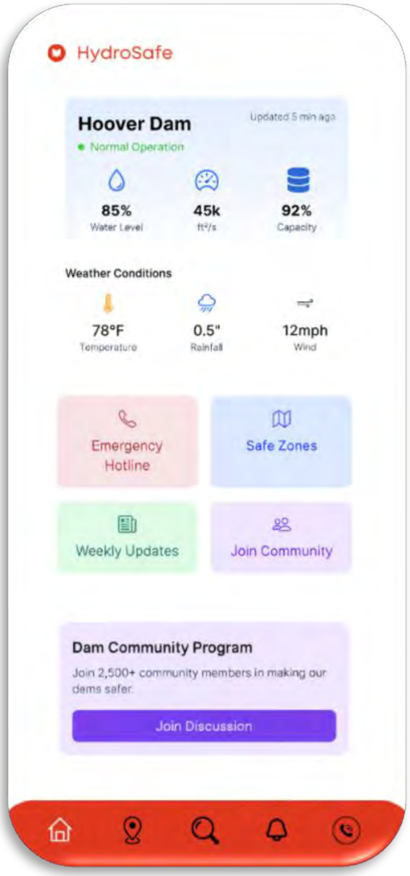


Figure 3. HydroSafe App

2.3 Dam Community Incentive Program

This program actively engages residents in dam safety and flood preparation, promoting collective efforts in risk mitigation (FEMA, 2023). Participants accumulate points through their involvement, which can be redeemed for vouchers to access public transportation or purchase essential goods at government-operated supermarkets, subject to an annual allocation limit, where details are provided in **Appendix B.4** Enrollment requires citizens to register their household ID, with each household permitted single account, and points are reset each year. This initiative not only enhances public safety and reduces the risk of dam-related incidents but also provides financial relief, thereby fortifying Tarrodan's resilience through a community-centric approach to disaster preparedness and risk reduction.

Action	Description	Points
Participating in Community Dam Training	Attending or completing local or online training programs on dam failure preparedness and flood safety.	100
Joining Local Dam Safety Committees or Initiatives	Actively participating in local community committees focused on dam safety and disaster preparedness.	200

Encouraging Neighbors to Participate in Dam Safety Programs	Encouraging and helping neighbors to take part in dam safety awareness, retrofitting efforts, and flood preparedness programs.	50
Documenting and Reporting Hazardous Dam Conditions	Reporting any signs of dam failure risk, such as cracks, erosion, or other structural concerns, to authorities.	100
Attending Flood Awareness Seminars	Participating in seminars or community meetings that raise awareness about dam failure risks and preparedness.	80
Maintaining Backup Power Systems for Emergency Flood Response	Installing and maintaining backup generators to power pumps and safety equipment during flood events.	200
Creating or Joining Local Disaster Response Teams	Form or join a community disaster response team that can assist during dam failure events, ensuring preparedness and faster response.	200
Reading the Dam Failure Manual	Citizens who read the **Dam Failure Manual.** Citizens can verify their completion by answering a short quiz or providing a certification of completion.	150
Daily Check-In on Hydrosafe App	Citizens who check in to the **Hydrosafe app** each day will receive **2 points** for daily engagement.	2/day

Table 1. What You Can Do to Get Credit

2.4 Catastrophe Bond

The catastrophe bond is designed as a financial instrument to hedge the nationwide dam failure insurance program in Tarrodan while also providing initial funding for the program's first-year benefits. The bond payout coupon annually with face value returned at the end of 10 years with the last coupon. With a total of 20,806 dams in the country, we use Monte Carlo simulations to simulate 10 year expected annual number of dam failures. The bond structure ensures that investors receive coupon if annual dam failures remain below 1,000. The annual payout is determined by the formula $\frac{1000-failures}{1000}$, meaning that as the number of failures increases, the coupon payout decreases proportionally. If failures exceed 1,000, no coupon is paid. At inception, the bond raised a total of 4.5 billion Qalkoon, ensuring a strong financial foundation for the program. This design incentivizes risk mitigation while securing necessary funds for insurance claims and benefits.

2.5 Program Implementation Timeline

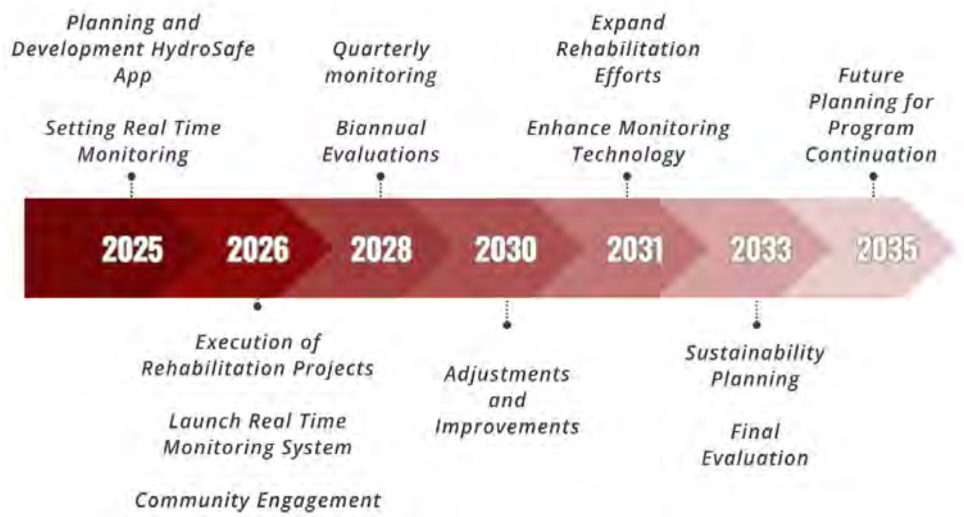


Figure 4. Program Implementation Timeline

3. Cost and Pricing

The 10-year insurance program requires level annual premiums paid at the beginning of each year, which cover various components including loss compensation, insurance administration, dam enhancement, real-time monitoring system setup and maintenance, and the Dam Community Incentive Program. The amount of loss given failure is assumed to occur at the beginning of the year and the VaR 95 is used for premium calculation such that it is 95% certain that the government has the required funds to pay for aggregate claims per year. Premiums for each dam are calculated as follows:

$$Premium_{dam} = \frac{Expected\ Loss_{dam}}{Total\ Expected\ Loss} x\ Premium\ from\ Dam\ Owners$$

Initial funding of Q4,633,882,442.75 for the first two components is secured through a catastrophe bond with a face value of Q4,500,000,000. To ensure affordability, the costs of the insurance programs are amortized over the decade, allowing for stable and manageable premiums each year

*in (000's) Q

Year			2026	2027	2028	2029	2030
Outflow		Rehabilition & Real time Monitoring	573,913	573,913	573,913	573,913	573,913
		Maintenance	212,793	217,624	222,553	227,583	232,715
		Incentive	732,500	732,500	732,500	732,500	732,500
	Before	VaR 95 of Loss given Failure	94,902,233	97,056,554	99,254,934	101,498,153	103,787,002
	After		91,059,197	92,507,329	93,586,030	98,073,228	97,316,991

Inflow		Premium from Dam Owners	68,772,702	68,722,702	68,772,702	68,772,702	68,772,702
		Premium from Citizens	37,004,532	37,004,532	37,004,532	37,004,532	37,004,532
Net Cash Flow (Before)			9,305,795	7,146,643	4,943,334	2,695,086	401,104
Expected Present Value Before program effects = 0							
Catastrophe Bond Expected Payout			4,500,000	-224,374	-224,397	-225,098	-224,566
Net Cash Flow (After)			13,805,795	7,762,400	5,748,880	3,579,354	2,102,741
Expected Present Value After Program Effects = 39,276,745							

Year			2031	2032	2033	2034	2035	2036
Outflow		Rehabilitation & Real time Monitoring	573,913	573,913	573,913	573,913	573,913	
		Maintenance	237,951	243,294	248,744	254,303	259,975	
		Incentive	732,500	732,500	732,500	732,500	732,500	
	Before	VaR 95 of Loss given Failure	106,122,285	108,504,815	110,935,418	113,414,931	115,944,200	
	After		100,388,851	102,275,464	103,776,835	110,973,479	112,902,550	
Inflow		Premium from Dam Owners	68,772,702	68,772,702	68,772,702	68,772,702	68,772,702	
		Premium from Citizens	37,004,532	37,004,532	37,004,532	37,004,532	37,004,532	
Net Cash Flow (Before)			-1,939,415	-4,427,288	-6,763,341	-9,248,413	-11,783,353	
Expected Present Value Before program effects = 0								
Catastrophe Bond			-224,448	-224,574	-281,031	-224,907	-224,608	-4,724,664
Net Cash Flow (After)			-1,934,329	-3,571,251	-5,335,661	-8,931,822	-10,533,936	-4,724,664
Expected Present Value After Program Effects = 39,276,745								

Table 2. 10-year cashflows Projection (in thousands Q)

Table 2 shows that the Expected Present Value (EPV) before program effects is 0, indicating a break-even at maturity, even in the worst scenario where no program effects occur. However, net cash flow is positive in the first five years and negative in the following 5 years. Therefore, to ensure financial stability throughout the program's duration, the cash inflows received in years 1 to 5 must be reinvested to generate returns that will help cover the negative cash flows occurring in years 6 to 10.

4. Data Limitations and Assumptions

Data Limitations	Assumptions
There is no historical data for frequency of failure for each dam. The data only gives the probability of failure in 10 years.	We assume that failure can only occur once per year for each dam and thus the frequency of failure is binomial distributed (Bernoulli distributed for probability of failure in 1 year).
Each dam has its own characteristics that lead to a highly varied loss between every dam.	We assume that each dam is independent but not identically distributed.
There is no historical loss data for each dam in the data.	We assume that the aggregate estimate of property and liability loss for each dam is Gamma distributed with α = 10.252. (Feby Indriana Yusuf, 2024) and a scale parameter proportional to each dam's expected aggregate loss.
There are missing values from the liability loss column in the data.	We imputed the data using the mean value of the dam's region's average liability loss.
Tarrodan inflation and 1 year risk free annual spot rate data were only available until the year 2024.	We model inflation rate using ARIMA(0,1,0) model and 1 year risk free annual spot rate using its latest value.

Table 3. Data Limitations and Assumptions

5. Risk and Risk Mitigation Considerations

5.1 Main Risks

Risk	Description	Mitigation Strategy
Underwriting Risk	Data used to underwrite policies or programs, such as housing assistance or insurance, is not regularly updated.	The government should update housing and census data annually and enhance support with additional funds, personnel, and technology for efficiency.
Social Attitude Change Risk	High premiums and obligations may deter Tarrodan citizens and dam owners from supporting the policy.	The government should raise social awareness of the program's benefits through effective communication and campaigns, helping the public understand the importance of financial reserves for emergency protection and disaster preparedness.
Market Rate Risk	When inflation rises faster than economic growth, it	The government should manage reserves to minimize risks and neutralize inflation impacts by

	leads to higher interest rates and impacts on the value of financial reserves.	selecting stable financial instruments, ensuring positive investment returns to protect reserves from inflation and interest rate changes.
Liquidity Risk	Surplus cash invested cannot be immediately withdrawn when needed.	The government should maintain reserves in cash or easily liquidated assets, despite potential losses due to inflation, ensuring funds remain available for emergency situations without waiting for investment maturity.
Climate Change Risk	Climate change can increase the frequency and intensity of dam failures due to natural disasters such as floods, droughts, and storms, potentially leading to loss of lives and property damage.	The government establishes alert rescue teams to evacuate citizens, constructs backup dams to reduce water flow if the main dam fails, and utilizes real-time monitoring systems to collect and analyze environmental data (e.g., weather, air quality, and soil conditions). This enables preventive measures to be taken before the situation worsens.

Table 4. Risk and Mitigation Strategy

In the risk matrix shown in **Figure 5**, most of the main risks have a low probability of likelihood, but a high impact on the insurance program performance. The consequences could be very adverse for the Tarrodan government. To address this, it is necessary to implement appropriate risk mitigation strategies to reduce the impact of such risks, so that the program can remain operational and uninterrupted by potential problems that may arise.

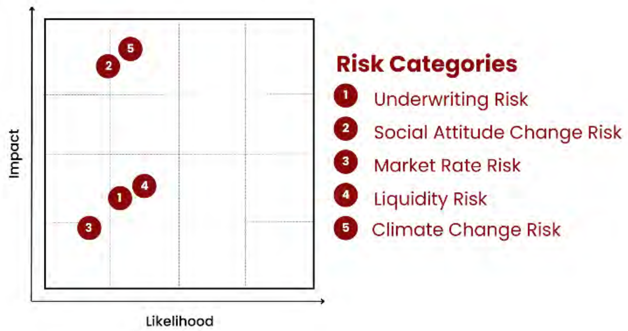


Figure 5. Risk Matrix

5.2 Climate Change Risk

The proposed national dam insurance considers climate change risk through a multifaceted approach that spans risk identification, data-driven modeling, adaptive program design, financial resilience mechanisms, and long-term monitoring. Climate change risk is explicitly defined as a high impact as it means an increased likelihood of natural disasters such as floods, droughts and earthquakes. These events increase the probability of dam failure as it causes erosion, sedimentation and hydraulic pressures. These climate driven failures surely threaten public safety and economic stability for all three regions as Flumevale experiences periodic river flooding, Lyndrassia experiences occasional earthquakes and Navaldia is subject to tropical storms and tsunamis. This risk is mitigated largely through the Tarrodan DamSafe Network as well as HydroSafe app to detect anomalies in climate sensitive parameters and notify nearby citizens for hazard during extreme weather. Moreover, through the catastrophe bond structure, cashflows for this insurance program are also built to be climate resilient. This is due to the nature of the bond where coupons decrease with increasing number of failures, redirecting the funds for immediate repair.

5.3 Sensitivity Analysis

Below is an overview of the sensitivity analysis on key assumptions affecting the net savings of the insurance program.

Assumption	Net Savings (in 000s Q)		Range
	Min	Max	
Discount Rate	39,087,158,411.12	45,836,792,499.40	The min. and max. scenarios are 1% lower and 1% higher than the assumed discount rate.
Inflation	37,372,435,799.39	41,284,812,514.55	The min. and max. scenarios are 1% lower and 1% higher than the assumed inflation rate.
A	39,276,745,136.09	50,100,421,982.50	The min. and max. scenarios are α= 5 and α=15.

Table 5. Sensitivity Analysis

6. Conclusion and Next Steps

The Tarrodan National Dam Insurance Program poses a transformative and multistakeholder initiative to mitigate the existential risks posed by aging earthen dams while fostering climate resilience, economic stability, and community preparedness. At the end of the insurance program, it is expected to complete rehabilitation of 907 high risk dams spread over the three regions, prioritized using climate risk assessments. Additionally, it is anticipated that over 5 million Tarrodan citizens are engaged through the HydroSafe app and the Dam Community and Incentive Program. This insurance program is also expected to have a 95% solvency rate underpinned by robust cash flow management as seen in **Table 2**.

At the end of the 10-year program, The Tarrodan National Dam Insurance is to undergo a comprehensive and data driven evaluation to assess the program's success, and financial health. Given that the program is proved to be efficient, the Tarrodan government can renew with a revised 10-year term and modify targets such as revising tax structure based on latest economic data. The Tarrodan National Dam Insurance Program is not merely a policy, it is a covenant between the government, dam owners, and citizens to prioritize safety over complacency and resilience over short-term gains. By embedding evaluation and adaptability, the program ensures that Tarrodan's dams and the communities they protect remain fortified against the uncertainties of a changing climate and evolving risks. The next decade will solidify this legacy, transforming a 10-year initiative into a perpetual pillar of national security.

Appendix
Appendix A - Exploratory Data Analysis (EDA)

We used the dataset given by the Society of Actuaries (SOA) team for this report. We then try to do some analysing and visualizing data as well as data imputations using programs like R and python. After that, we try to see the correlations for some of the variables using the correlation matrix below using python.

	Height (m)	Year Completed	Prob. Of Failure	Loss Given Failure - Prop	Loss Given Failure - Liab	Loss Given Failure - BI	Hazard
Height (m)	1	0.075754	0.040937	0.312416	0.102179	0.239051	0.333408
Year Completed	0.075754	1	0.012483	-0.160860	-0.002327	-0.171250	0.050901
Prob. Of Failure	0.040937	0.012483	1	0.064348	0.051219	-0.020038	0.295729
Loss Given Failure - Prop	0.312416	-0.160860	0.064348	1	0.101662	0.200470	0.317640
Loss Given Failure - Liab	0.102179	-0.002327	0.051219	0.101662	1	0.033997	0.522844
Loss Given Failure - BI	0.239051	-0.171250	-0.020038	0.200470	0.033997	1	0.083110
Hazard	0.333408	0.050901	0.295729	0.317640	0.522844	0.083110	1

Table 6. Correlation Matrix

For the hazard variable, we need to do a bit of data preprocessing by changing the data type from categorical to numeric so we can check the correlations. By doing so, we changed “Low” become 1, “High” become 3, “Significant” become 2 and “Undetermined” become NaN.

Here are some key findings based on the correlation matrix above:

a. Height vs Loss Given Failure → Moderate correlation (0.312416 with property, 0.239051 with business interruption)
b. Probability of Failure vs Hazard → Moderate correlation (0.295729), indicating a higher hazard level leads to a greater probability of failure
c. Year Completed vs Loss Given Failure → Negative correlation, suggesting newer dams may have lower loss impacts

Next, we check the distirbution for some of the variables by graphing them using R

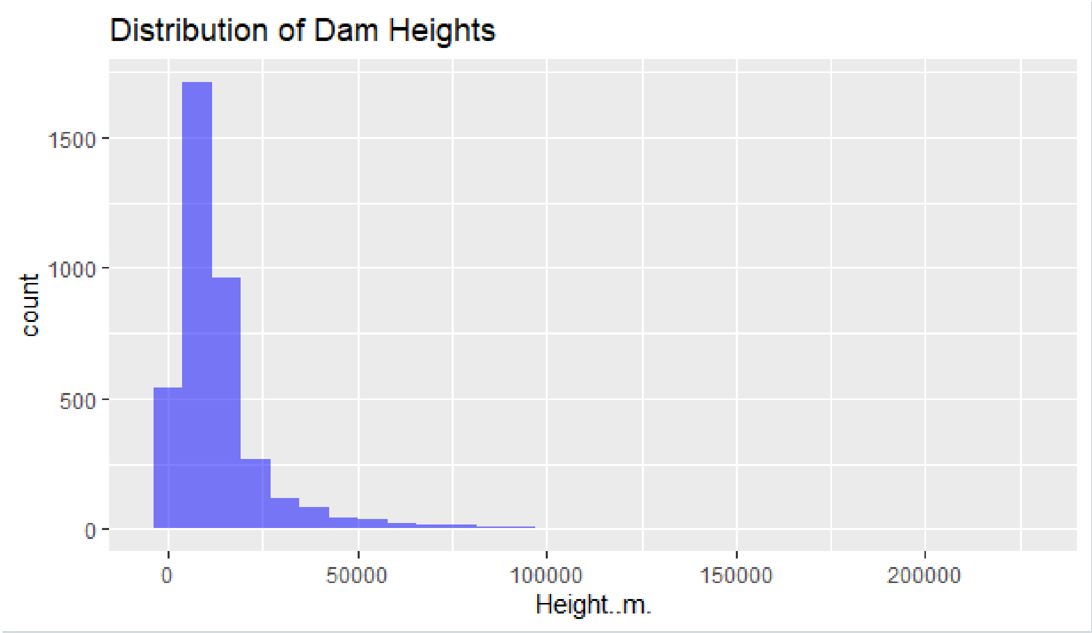


Figure 6. Distribution of Dam Heights

This is the distribution for dam heights. Here are the key findings:

a. The histogram shows a right-skewed distribution, meaning most dams are relatively low in height, with a few exceptionally tall ones. It also shows that most dams in Tarrodan are relatively short, with a concentration of heights below 10000 meters
b. Height variations may be due to the regional geography (e.g., taller dams in mountainous Lydrassia vs shorter dams in coastal Navaldia)

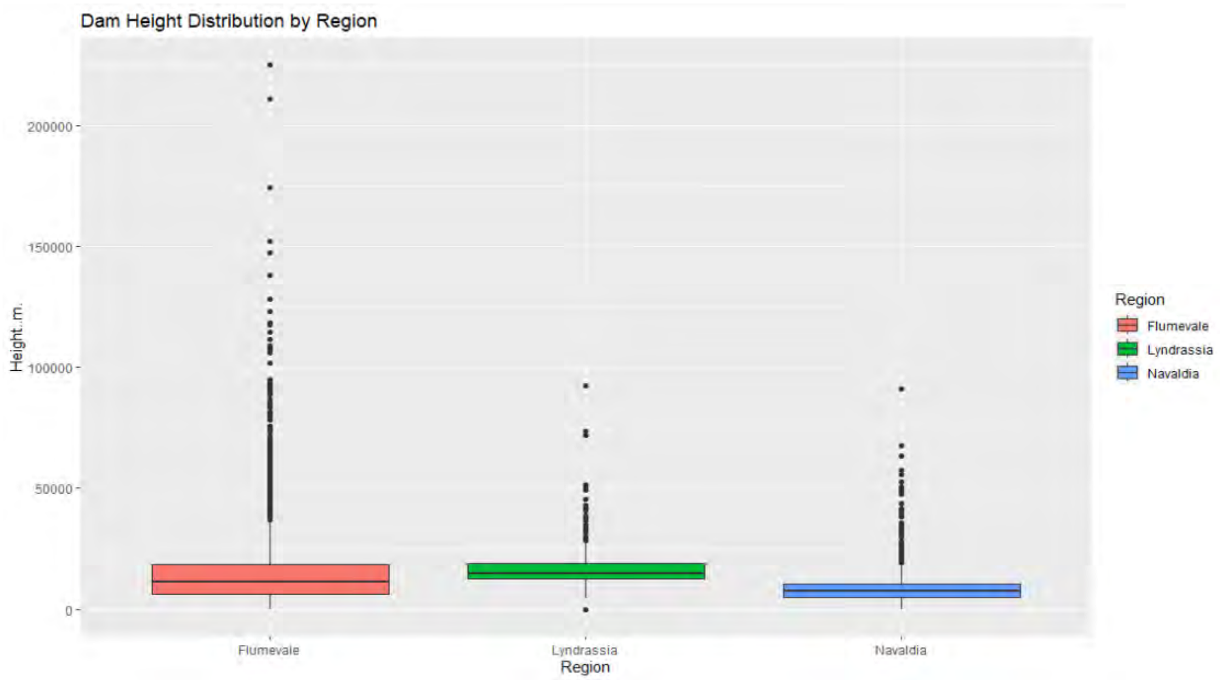


Figure 7. Dam Height Distribution by Region

This boxplot compares the dam heights across Flumevale, Lyndrassia, and Navaldia. Here are the key findings:

a. Flumevale and Lyndrassia have a slightly higher median dam height than Navaldia.
b. Flumevale has the most extreme outliers, with dam heights exceeding 200000 meters

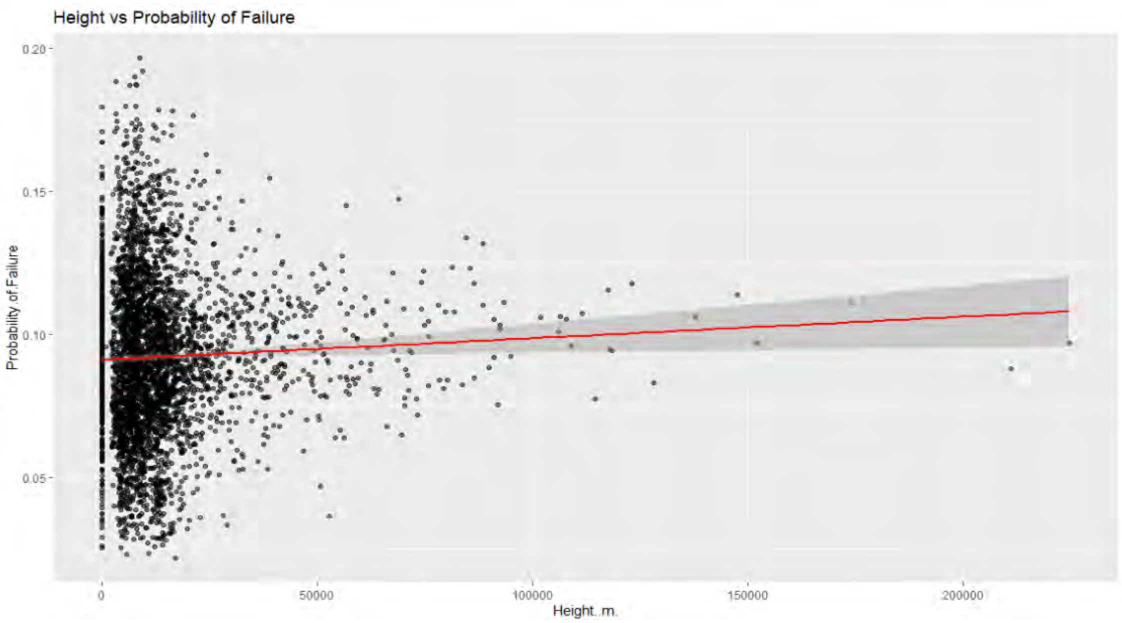


Figure 8. Height vs Probability of Failure

This is the relationship between dam height and failure probability. Here are the key findings:

a. This scatterplot reveals a weak positive correlation between height and failure probability. Taller dams tend to have slightly higher failure risks.
b. Most shorter dams (below 10000 meters) have failure probabilities around 10%, but some taller dams exceed 30%.
c. Flumevale and Lyndrassia (regions with taller dams) might have higher risk factors, possibly due to flooding or avalanches.

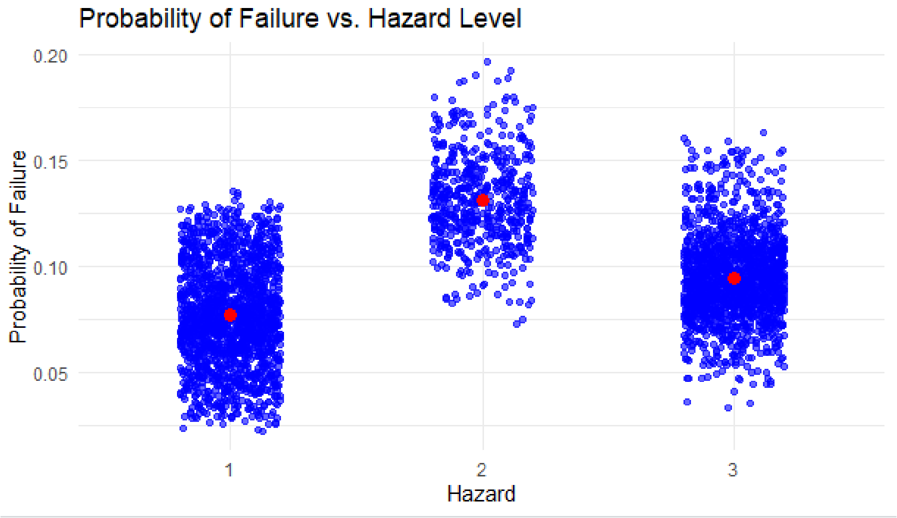


Figure 9. Probability of Failure vs Hazard Level

This is the scatterplot for Probability of Failure vs Hazard. Each blue dot represents an individual observation meanwhile the red dots indicate the mean probability of failure for each hazard level. Here are the key findings:

a. The probability of failure appears to increase slightly from low (1) to significant (2) but then decreases at high (3). The pattern suggests that a significant (2) hazard rating is associated with a slightly increased failure probability, but high (3) hazard ratings do not necessarily mean the highest failure risk.
b. The significant (2) hazard category has more points clustered at higher failure probabilities, indicating a potential risk group.

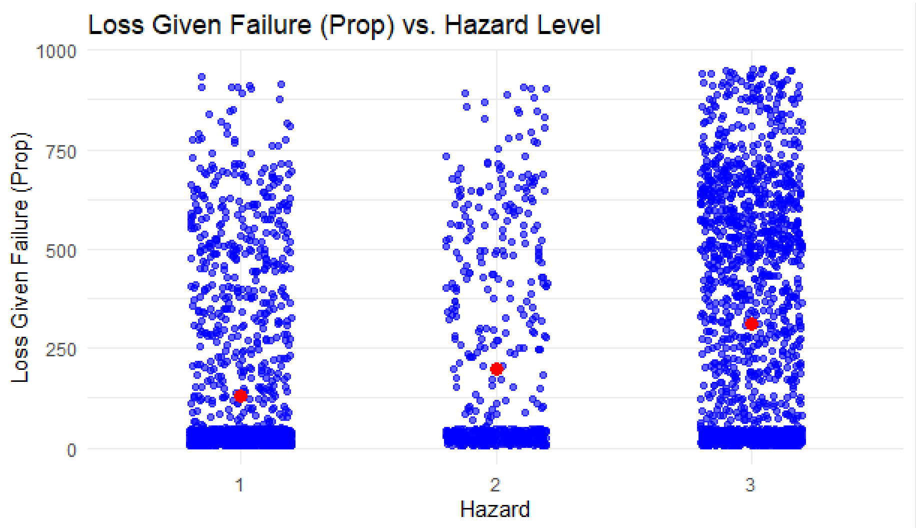


Figure 10. Loss Given Failure (Prop) vs Hazard Level

This is the scatterplot for Loss Given Failure (Prop) vs Hazard. Blue dots represent Individual observations of loss. Red dots indicate the mean loss for each hazard category. Here are the key findings:

a. For the low hazard (1), loss values are widely spread, but the mean loss is the lowest. For the significant hazard (2), the spread remains similar, but the mean loss slightly increases. For the high hazard (3), the spread of loss values increases, and the mean loss is the highest among the three groups. This suggests that higher hazard levels are associated with greater potential losses in property damage.
b. Hazard level and Loss Given Failure (Prop) have a positive trend meaning higher hazard levels tend to result in greater losses.

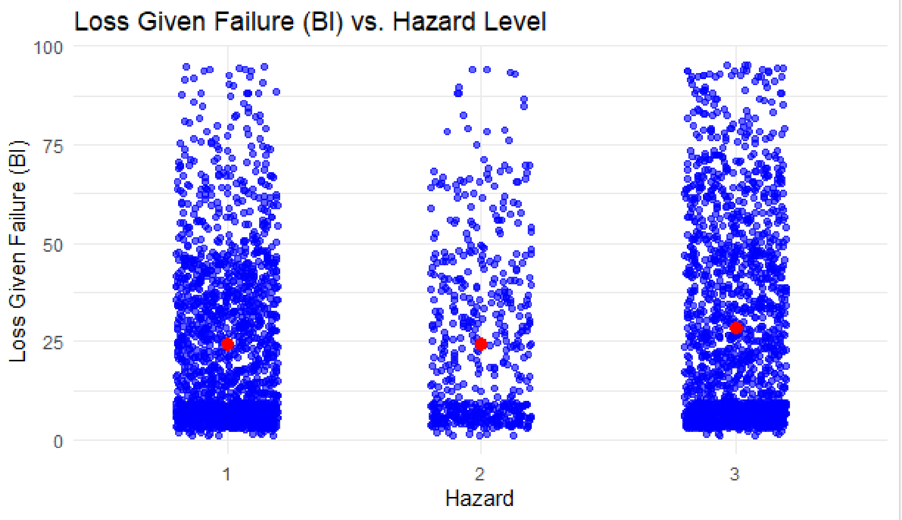


Figure 11. Loss Given Failure (BI) vs Hazard Level

This is the scatterplot for Loss Given Failure (BI) vs Hazard. Each blue dot represents an individual data point, while the red dots indicate the mean Loss Given Failure (BI) for each hazard level. Here are the key findings:

a. The data points are widely spread for all hazard levels, with some extreme values at the upper range.
b. There is a positive correlation between hazard level and loss given failure (BI), but it is not strong.

We also did some simulation using R to estimate the potential financial losses due to dam failures in the three regions. The simulation aims to:

a. Compute the mean simulated loss per region.
b. Calculate risk measures like Value at Risk (95% VaR) and Conditional Value at Risk (95% CVaR).
c. Check whether the simulated sample means follows a normal distribution using histogram and statistical tests.

Appendix B - Program Design Appendix

Appendix B.1 - Estimated Project Costs for Dams with a Condition Assessment Rating of Less than Satisfactory

Bins (Dam Heights in feet)	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
	Repair	Retrofit	Rehabilitation
1 (≤ 15)	Q381,679	Q1,316,794	Q2,738,550
2 (> 15 & ≤ 25)	Q753,817	Q1,803,435	Q2,547,710
3 (> 25 & ≤ 50)	Q1,345,420	Q3,816,794	Q5,944,656
4 (> 50 & ≤ 100)	Q1,297,710	Q4,580,153	Q8,187,023
5 (> 100 & ≤ 200)	Q2,938,931	Q19,083,969	Q22,748,092
6 (>200)	Q8,759,542	Q25,133,588	Q90,935,115

Table 7. Estimated Project Costs for Dams with a Condition Assessment Rating of Less than Satisfactory

The table above estimates the cost of dam rehabilitation based on the height and age categories of the dams, as well as their condition assessment (State, 2025). The table categorizes dams into those younger than 50 years and those older than 50 years, with a breakdown of costs for repairs, retrofitting, and rehabilitation. The dam condition assessment is divided into three categories: satisfactory, good, and poor/unsatisfactory, each of which affects the type of rehabilitation measures required. The costs listed reflect the significant financial requirements for maintaining dam safety, especially for dams with high hazard potential.

Duration for each dam enhancement are estimated as follows:

- Repair – 1 year
- Retrofit – 1 year
- Rehabilitation – 5 years

Appendix B.2 - Features to Include in the HydroSafe mobile App

Features	Description
Real Time Monitoring Data	- The app will display real-time information regarding critical parameters such as water levels, structural health of the dam, amount of rainfall, and current weather conditions. This ensures users have access to the latest data for better decision-making. - Users can view interactive maps highlighting affected areas and potential risk zones, thereby improving situational awareness and understanding of conditions around the dam.
Emergency Measures and Alerts	- The app will provide details of emergency actions, such as evacuation plans and safe zones, to help users respond quickly to emergency situations.

	- The app will send push notifications for alerts, such as an increase in water level or risk of dam failure, so that users can take necessary actions immediately.
Three-Tiered Warning System	- Low Risk: normal conditions, no immediate action required. - Medium Risk: enhanced monitoring recommended, be prepared for potential action. - High Risk: immediate action required, follow emergency protocols.

Table 8. HydroSafe mobile App Features

Appendix B.3 - Dam Monitoring Instruments

Instrument	Description
Vibrating Wire Piezometer 	It measures pressure to monitor pore water pressure, phreatic water levels in the dam embankment, and reservoir levels. High pore pressure can indicate slope instability and increase pressure on the embankment, while excessive pressure in the foundation may cause heave, resulting in a zero effective stress condition.
Thermistor String 	This is a high-strength steel cylinder designed to endure heavy loads and extreme conditions. It contains 3 to 5 deformation sensors mounted parallel to the longitudinal axis to measure compression. A central hole enables the attachment of anchors, rock bolts, and tendons for easy integration into construction and structural monitoring applications.
In-Place Inclinometer 	It measures slope or tilt. When installed inside a dam embankment, they serve to monitor horizontal shifts. If this shift exceeds reasonable limits, it can indicate potential instability in the dam structure.
Vibrating Wire Total Earth Pressure Cell 	It measures pressure on a flat surface and is installed at the foundation interface. When combined with a piezometer, it calculates the effective pressure of the soil, which is crucial for understanding soil conditions beneath structures like dams and assessing soil stability.
Vibrating Wire Liquid Settlement Cell 	It measures vertical displacement and is installed at the foundation interface to monitor settlement or heave in the dam foundation. This tool is essential for assessing the stability of the dam structure by detecting changes in vertical position.
Vibrating Wire Multi-point Borehole Extensometer 	It measures vertical displacement within the dam body. It is designed to detect vertical deformation at various depths, enabling monitoring and prediction of settlement during and after the construction process.
Water Quality Probe	These sensors measure water properties such as conductivity, temperature, and pressure, providing comprehensive

	information about water quality. Installed in wells downstream of the dam, they can detect harmful chemical leaks.
Weir Monitor & V-Notch Weir 	This tool is used to measure water flow. Monitoring seepage flow is very important, as increased flow may indicate that the phreatic surface has risen too high or that internal erosion and potential piping is occurring. These conditions can lead to failure of the dam structure
VW Crack Gauge 	This tool is used to measure displacement. When installed on embankment berms, it can detect surface movement that may be an early sign of internal erosion and potential piping.
Anchor Load Cell 	This tool is used to measure loads on ground anchors. Ground anchors are often used to stabilize abutments on structures, such as dams. This tool is designed to provide important information about how effective the anchor is at stabilizing the structure by measuring the load it receives.
Rain Gauge 	This tool measures rainfall, which affects soil stability in embankments. A rain gauge collects rainwater in a container to provide data on rainfall volume over time, as heavy rainfall can increase soil moisture and impact embankment stability.
Gateway 	The gateway serves as the main hub for collecting raw data from all sensors through wireless nodes. It transfers this data via the internet to third-party visualization software like sensemetrics and GeoAxiom, enabling easy access and analysis for effective monitoring of the structure's condition and performance.

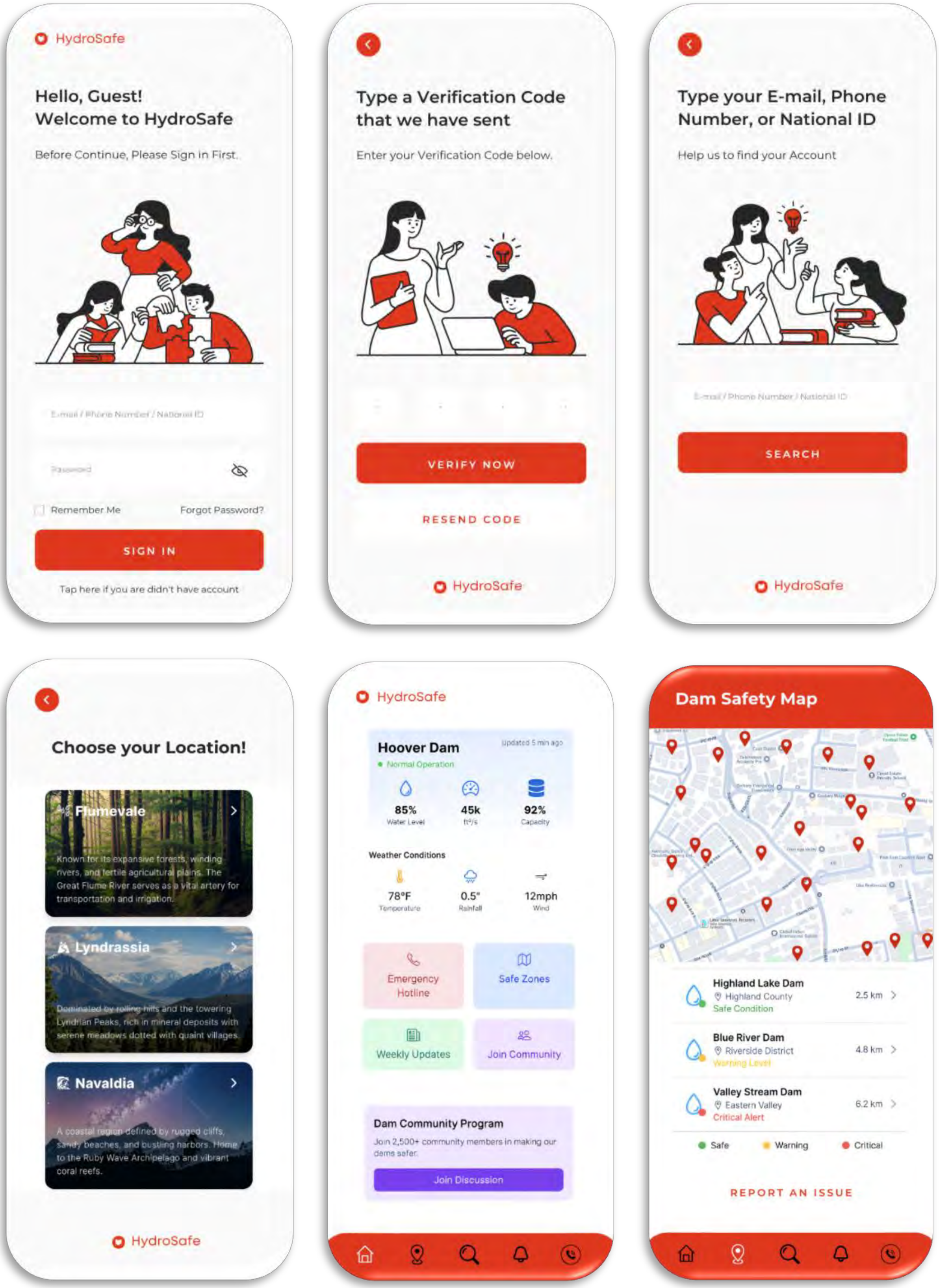
Table 9. Dam Monitoring Instruments (Geosense, 2020)

Appendix B.4 - DamSafe Engagement System

Level	Points	Reward Voucher	Quota
Community Leader	3,000	Q150	500,000
Active Citizen	2,500	Q100	1,000,000
Prepared Citizen	2,000	Q75	2,500,000
Contributor	1,500	Q50	4,000,000
Engaged Citizen	1,000	Q20	5,000,000
Basic	500	Q10	7,000,000

Table 10. DamSafe Tier and Rewards

Appendix B.5 – HydroSafe App



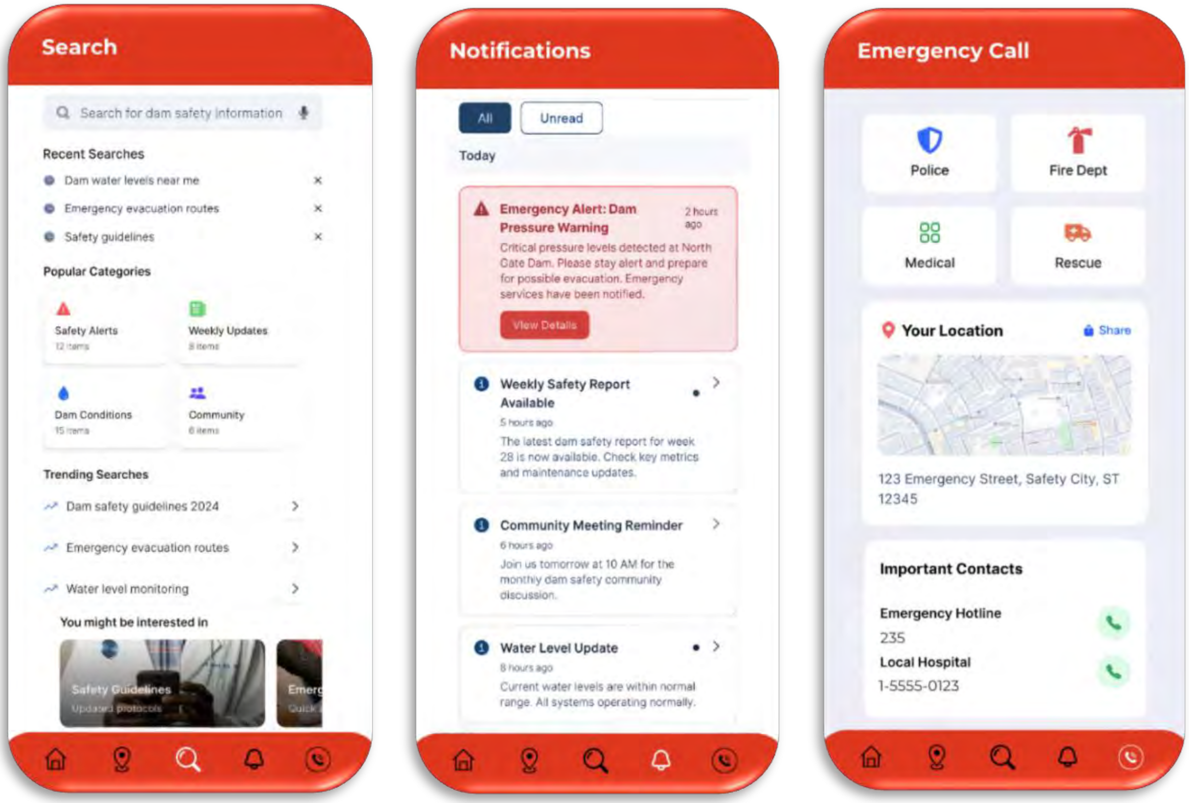


Figure 12. HydroSafe App

Appendix C - Cost Analysis

Appendix C.1 - Cost Calculation Methodology

The expected loss due to dam failures in a year is calculated using Monte Carlo Simulations, by converting the probability of dam failure in 10 years into probability of dam failure in 1 year. This probability is then utilized to generate scenarios where dams either fail or remain operational. If a dam fails, the expected loss from property damage and third-party claim is added to the total loss. This process is repeated for all dams and iterations, enabling the calculation of expected annual loss, 95% VaR and risk adjusted premiums.

Appendix C.2 - Housing Tax Structure

Class	Value (Qalkoon)	Flumevale	Lyndrassia	Navaldia	Tarrodan	Median Value
D	< 50,000	446,720	206,940	871,223	1,524,903	25,000
	50,000 - 99,999	552,111	414,955	1,593,970	2,561,036	75,000
	100,000 - 149,999	887,815	471,356	2,169,919	3,529,090	125,000
C	150,000 - 199,999	1,219,671	448,956	2,505,863	4,174,490	175,000
	200,000 - 299,999	2,730,435	572,280	3,816,207	7,118,922	250,000
	300,000 - 499,999	2,521,934	532,740	3,186,207	6,244,476	400,000
B	500,000 - 999,999	5,165,736	268,786	1,825,774	7,260,296	750,000
A	≥ 1,000,000	2,386,698	51,349	351,150	2,789,197	1,500,000
	Total	15,911,120	2,967,382	16,323,908	35,202,410	

Table 11. Housing Tax Structure

Appendix C.3 - Tax structure based on their GDP Per Capita

Tax Rate	Tax structure based on their GDP Per Capita			Total
	Flumevale	Lyndrassia	Navaldia	
D	0.0001	0.00005	0.00005	24,219,854
C	0.0005	0.0001	0.0002	868,813,214
B	0.0015	0.00025	0.001	7,732,215,240
A	0.0035	0.0005	0.002	14,252,796,670
Tax Income	19,996,208,832	3,124,126,056	11,558,027,916	34,678,362,804

Table 12. Tax structure based on their GDP Per Capita

Housing tax scheme with government subsidy of Q40,000

$$Tax_{house} = (House\ Value - 40{,}000) * Tax\ rate$$

Appendix C.4 - Expected Loss and 95% Value at Risk (VaR) for Tarrodan

Year	Expected Loss	95% VaR
1	78,754.24	92,495.72
2	78,557.36	91,987.99
3	78,689.26	91,828.33
4	78,456.54	91,777.00
5	78,555.10	91,069.07
6	78,898.05	92,590.50
7	78,614.11	91,953.60
8	78,910.17	91,361.96
9	78,686.91	92,348.17
10	78,459.49	91,791.28

Table 1313. Expected Loss and 95% Value at Risk (VaR) for the whole country

Appendix C.5 - Expected Loss and 95% Value at Risk (VaR) per Region

	Navaldia	Lyndrassia	Flumevale	Total
E[S]	32,491,697,190	27,804,504,650	19,091,668,020	79,387,869,860
Var[S]	3.1081715E+19	1.9824271E+19	1.9678359E+12	7.0584345E+12
Var_95 Agregat	92,791,200,000			

Table 14. Expected Loss and 95% Value at Risk (VaR) per Region

Appendix C.6 - Dam Enhancement Assumptions

Year	Retrofit	Rehabilitation (Statkraft, 2022)	Repair	Monitoring (Kumar, 2024)
1	0.75	0.9	0.5	0.05
2	0.7125	0.882	0.45	0.05
3	0.675	0.864	0.4	0.05
4	0.6375	0.846	0.35	0.05
5	0.6	0.828	0.3	0.05
6	0.5625	0.81	0.25	0.05
7	0.525	0.792	0.2	0.05
8	0.4875	0.774	0.15	0.05
9	0.45	0.756	0.1	0.05
10	0.4125	0.738	0.05	0.05

Table 15. Dam Enhancement Reduction Factors

For dams undergoing dam enhancement, the probability of dam failure each year is reduced by the above reduction factors, where reduction factors are assumed to decrease linearly every year. With dams undergoing Retrofit and Repair experience a reduction in probability in the following year, and rehabilitation will experience reduction after 5 years.

$$Probability\ of\ dam\ failure\ (t+1) = Probability\ of\ dam\ failure\ (t) * (1 - reduction\ factor)$$

Year	Retrofit	Rehabilitation	Repair
1	43	32	17
2	43	32	17
3	43	32	17
4	43	31	17
5	43	31	17
6	43	31	17
7	43	31	16
8	43	31	16
9	42	31	16
10	42	31	16

Table 16. Limit Quota

Appendix C.7 - Catastrophe Bond Pricing

From Monte Carlo simulation, we get the expected number of dam failures per year. Using simulation results and using time value of money, we calculated the coupon by solving for the bond price to be 4.5 billion Qalkoon using goal seek in Microsoft Excel.

Year	Cashflow
1	4,500,000,000
2	-224,374,373.3
3	-224,396,901.4
4	-225,098,088.9
5	-224,565,862.3
6	-224,447,589.7
7	-224,574,310.3
8	-281,031,366.6
9	-224,906,600
10	-224,608,102.5
11	-4,724,664,423

Table 17. Expected Catastrophe Bond Cashflow

Appendix C.8 - Projected Inflation Rates

Year	Inflation	Interest Rate
2025	0.02275035374	0.051066367
2026	0.022700428	0.051066367
2027	0.022650503	0.051066367
2028	0.022600578	0.051066367
2029	0.022550652	0.051066367
2030	0.022550652	0.051066367
2031	0.022550652	0.051066367
2032	0.022450802	0.051066367
2033	0.022400876	0.051066367
2034	0.022350951	0.051066367
2035	0.022301026	0.051066367
2036	0.022201175	0.051066367

Table 18. Projected Inflation Rates

Appendix D - Sensitivity Analysis

Discount Rate	Net Savings at 1% Lower Discount Rate	Net Savings at Baseline	Net Savings at 1% Higher Discount Rate
3R	6,828,291,216.32	7,538,871,143.91	12,172,273,204.10
Monitoring	29,234,185,852.24	31,737,873,992.18	34,499,370,655.56
Catastrophe Bond	3,024,681,342.56	0.00	-834,851,360.26
Net Program Savings	**39,087,158,411.12**	**39,276,745,136.09**	**45,836,792,499.40**
Inflation Rate	**Net Savings for 1% Low Inflation/Year**	**Net Savings at Baseline**	**Net Savings for 1% High Inflation/Year**
3R	7,128,506,083.40	7,538,871,143.91	7,973,309,182.45
Monitoring	30,243,929,715.99	31,737,873,992.18	33,311,503,332.09
Catastrophe Bond	0.00	0,00	0,00
Net Program Savings	**37,372,435,799.39**	**39,276,745,136.09**	**41,284,812,514.55**
Gamma α	**Net Savings for $\alpha = 5$**	**Net Savings for $\alpha = 10.252$**	**Net Savings for $\alpha = 15$**
3R	2,828,349,304.98	7,538,871,143.91	10,340,766,515.94
Monitoring	41,617,225,469.76	31,737,873,992.18	39,759,655,467.00
Catastrophe Bond	**0.00**	**0.00**	**0.00**
Net Program Savings	**44,445,574,774.75**	**39,276,745,136.09**	**50,100,421,982.95**

Table 19. Full Sensitivity Analysis

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