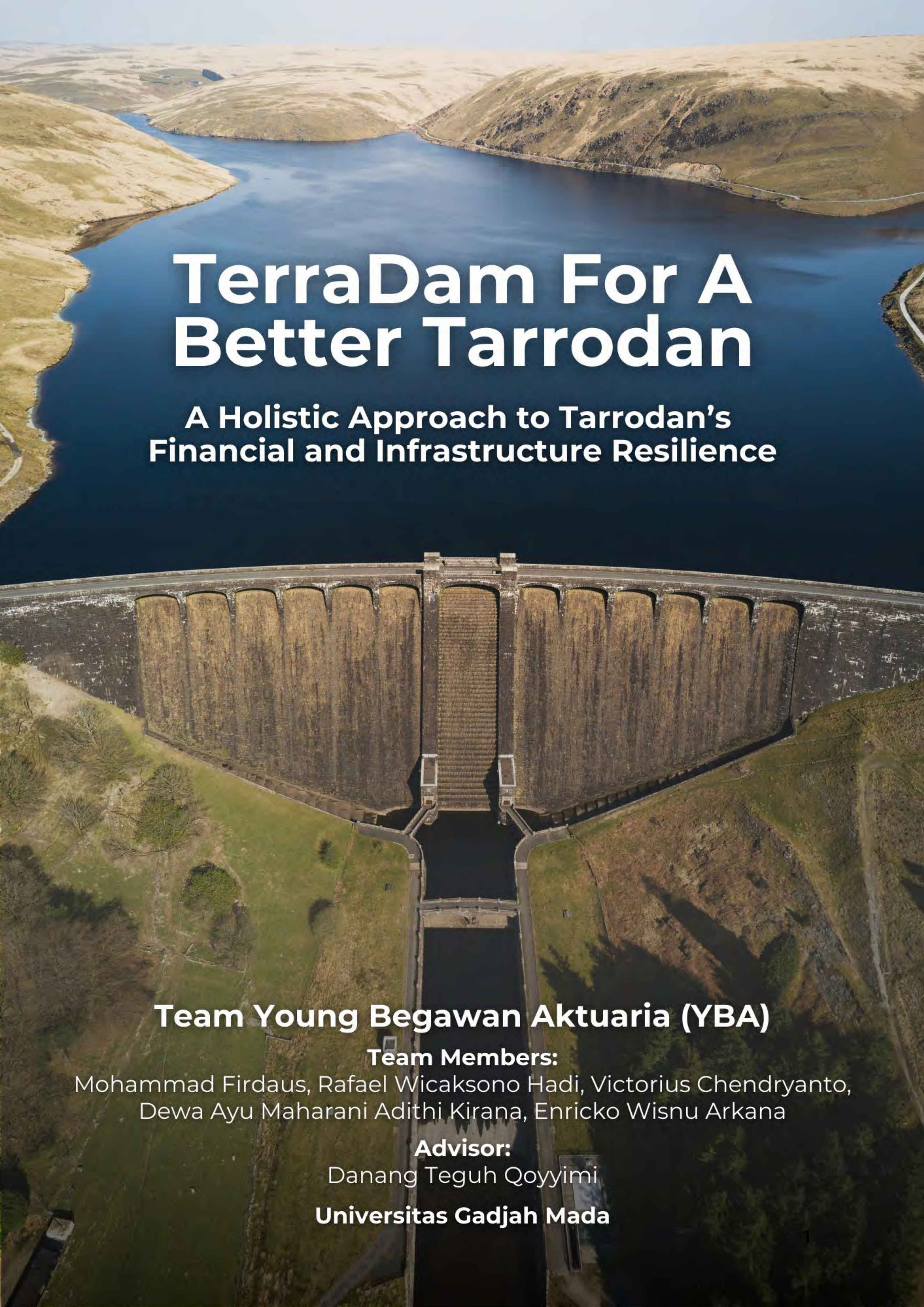


TerraDam For A Better Tarrodan

A Holistic Approach to Tarrodan's Financial and Infrastructure Resilience

Team Young Begawan Aktuaria (YBA)

Team Members:
Mohammad Firdaus, Rafael Wicaksono Hadi, Victorius Chendryanto, Dewa Ayu Maharani Adithi Kirana, Enricko Wisnu Arkana

Advisor:
Danang Teguh Qoyyimi

Universitas Gadjah Mada

1. Executive Summary

The high probability of dam failures in Tarrodan presents a critical threat to public safety and economic stability. An analysis of 20,806 dams indicates an average failure probability of 0.0939 over a 10-year period, meaning nearly one in ten dams could fail within a decade. With an estimated average loss of $181 million per failure, the potential economic damage could exceed $350 billion, excluding indirect social and environmental costs. These risks, combined with recent global disasters, have heightened the need for a comprehensive financial risk protection strategy.

To address these challenges, Young Begawan Aktuaria proposes the TerraDam Program, a national initiative designed to enhance financial security, improve infrastructure resilience, and promote long-term economic stability. This program provides a structured approach to risk management through both insurance and non-insurance mechanisms. It includes TerraDam Insurance, offering financial compensation for dam failure-related losses; TerraDam Regulation, which enforces stricter safety standards and risk management measures; TerraDam Grant, a funding initiative for infrastructure resilience; and TerraDam Token, a digital financial mechanism that incentivizes sustainable risk management practices.

By the end of 2025, the TerraDam Program is projected to achieve a positive cash flow of ℚ80,589 million, ensuring that citizens are not financially burdened by dam-related disasters. Additionally, the rehabilitation efforts are expected to reduce the risk of dam failure by 62%, lowering potential economic losses from ℚ128,547 million to ℚ48,513 million.

2. Objective

2.1. Main Objective

Tarrodan faces a critical threat as the region grapples with the risk of dam-related disasters. TarroDam aims to enhance the resilience of communities and infrastructure by addressing financial risks associated with earthen dam failures. The program is designed to balance affordability, sustainability, and risk mitigation through the following key objectives:

I. Provide financial relief for affected communities.
II. Encourage preventative maintenance and infrastructure improvements.
III. Establish an equitable pricing structure.
IV. Enhance long-term financial sustainability.
V. Support economic and environmental stability.

The TerraDam Program successfully fulfills all five objectives. The first three objectives directly benefit the citizens of Tarrodan, while the last two are outcomes resulting from the implementation of the program. Our findings indicate that TerraDam significantly reduces the financial burden of dam failures for both residents near dams and dam owners, lowers mortality risks associated with such disasters, and enhances the economic value of Tarrodan.

2.2. Key Metrics

The success of the TerraDam Program is primarily evaluated based on its financial impact. The rehabilitation of TerraDam is assessed by the extent to which it reduces the risk of dam failure for the citizens of Tarrodan, compared to a scenario in which the program is not implemented.

The evaluation metric for the whole program is the expected cash flow with and without the program. Additionally, other components of the program are measured by their effectiveness in mitigating financial risks when dam failure occurs.

3. Program Design

Our program is designed to maximize risk reduction at every phase of the risk management process, including pre-event (mitigation and preparedness), mid-event (response), and post-event (recovery and adaptation). This approach is based on the framework outlined in the article Risk Reduction Measures for Dams (FEMA, 2017), which emphasizes the importance of a comprehensive and phased risk management strategy.

3.1. TerraDam Insurance

To address financial risks associated with dam failures, TerraDam Insurance introduces two specialized insurance programs. The first program, **TerraDam Insurance A (Dam Insurance)**, is an optional insurance plan designed specifically for dam owners. It provides coverage for direct financial losses that would otherwise be the responsibility of the dam owner, including structural repair costs, third-party liabilities,and environmental damages resulting from dam failures. Premiums are calculated based on the individual risk profile of each dam. For details on the annual premium pricing and its formulation, refer to Appendix C.1.

Dam failures pose significant financial risks, affecting not only dam owners but also the broader public. It would be inequitable for either party to bear the full financial burden alone. By offering this insurance program, we provide dam owners with a structured and participatory solution to manage these risks effectively.

The second program, **TerraDam Insurance B (National Insurance)**, is a mandatory insurance plan for all Tarrodan residents, funded through a tax-based system with region-specific premium levels. This insurance covers essential needs, including medical and mental health services, evacuation costs, funeral expenses, and other indirect damages resulting from dam failures (Appendix E.1). Unlike dam-specific liabilities covered under TerraDam Insurance A, this national insurance ensures that all affected residents, whether dam owners or not, receive necessary financial support in times of crisis. Premiums are determined based on actuarial present value from benefits for citizens impacted by collateral damage from dam failure events then we normalize the premium with contribution rate for each region (Appendix C.2).

Region	Flumevale	Lyndrassia	Navaldia	Tarrodan
Region Pool (in ℚm)	12,924.38	492.97	8,500.99	21,918.34
Annual Premium (per person)	37.98 ℚ	1.45 ℚ	24.98 ℚ	64.40 ℚ
Monthly Premium	3.16 ℚ	0.12 ℚ	2.08 ℚ	5.37 ℚ
% Contribution	**58.97%**	**2.25%**	**38.78%**	**100%**

3.2. TerraDam Regulation

The TerraDam Regulation mandates dam owners to develop an Emergency Action Plan (EAP), conduct regular inspections, install alarm systems, and rehabilitate aging dams as required (Detail in Appendix C.3). Our review of last inspection dates reveals that 18,261 (94%) of earthen dams have not been inspected regularly, despite regulations requiring inspections every certain year. Proper inspections not only maintain dam functionality and cost efficiency but also enable early detection of deficiencies, thereby preventing potential failures (USBR, 1990).

The installation of alarm systems is another critical component of dam safety regulation, as a well-integrated system can reduce damages by up to 75.85% (Atika et al., 2024). However, its effectiveness depends on the accuracy and reliability of monitoring instruments. To detect critical failure modes such as internal erosion, piping, and slope instability, a standardized monitoring system is necessary. Relying solely on dam owners for instrument selection risks inconsistencies, leading to monitoring gaps and unreliable alarms. To mitigate this, a structured selection framework should be implemented. The Kentucky Division of Water (DOW) criteria, developed from practical experience, provide a strong reference, ensuring a balanced approach based on risk, cost, automation, and maintenance. The monitoring process and emergency response system are detailed in the flowchart in Appendix C.4.

The estimated cost per dam for alarm installation is 16,000 Q, while integrating the alarm system with mobile devices costs 5,565,053 Q (for full calculations, refer to Appendix E.3). The installation of alarms is mandatory; however, the government will provide grants to dam owners who are unable to bear the cost. Meanwhile, the cost of integrating alarms with mobile devices will be fully covered by the government. To ensure financial feasibility and equitable distribution of costs, the alarm integration program will be phased over three years—50% in 2025, 30% in 2026, and 20% in 2027.

Furthermore, rehabilitation of aging dams is crucial for public safety. Many older dams were built with outdated engineering standards, posing significant risks today (Appendix C.5). Without proper maintenance and upgrades, these dams could become hazardous. Investing in preventive measures reduces risks to public safety and economic assets, aligning with best practices in dam risk management (ASDSO, 2025).

3.3. TerraDam Grant

We recognize that many dam owners lack the financial capacity to comply with the TerraDam Regulation. Based on cost estimates from ASDSO (2025), 7,508 out of 13,004 dams are financially incapable of funding their own rehabilitation, while 9335/19393 (48.23%) dams cannot afford routine inspections and alarm system installations. To address this issue, we introduce the TerraDam Grant, allowing eligible dam owners to apply for financial assistance.

This program allocates 155 ℚm (Qalkoon Million) over 10 years for inspections and 152 ℚm over 3 years for alarm installations, ensuring full financial coverage for dam owners in need.. For rehabilitation efforts, however, financial aid will be selectively allocated to the most hazardous dams, using a prioritization matrix based on risk levels. This approach follows international best practices, including those implemented by the Ministry of Water Resources, India (Appendix C.6). By focusing resources on the most at-risk structures, we ensure that funds are utilized efficiently and effectively to enhance overall dam safety.

3.4. TerraDam Token

To ensure the sustainability of our program, strategic fundraising is essential. The finance industry, being the largest contributor to Tarrodan's GDP, offers a prime opportunity for targeted fundraising efforts. This also highlights the high level of financial literacy in Tarrodan, particularly in areas like cryptocurrency investments.

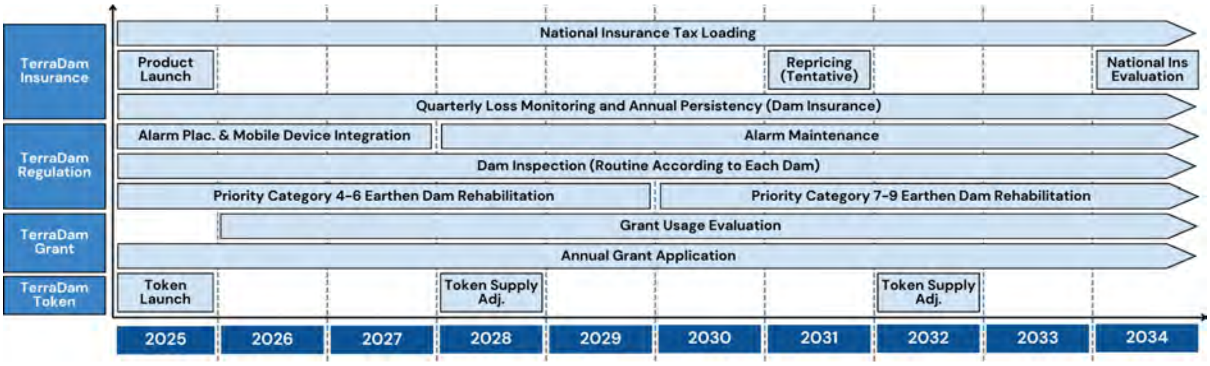
An interesting aspect of Tarrodan is its many dams. We view these dams as tangible assets that can be transformed into valuable intangible assets within the blockchain environment. Blockchain technology can utilize real-world assets as secure investment instruments due to its inherent security features (Du et al., 2023).

Some Tarrodan earthen dams generate cash flow from activities such as irrigation, water supply, hydroelectric power, and recreation. Before a dam can be "tokenized" into a Real-World Asset Token (RWAT), it must undergo a rigorous selection process based on two key criteria to ensure investor confidence and security. First, the dam must have been inspected and assessed within the last five years (California Department of Water Resources, 2018). Second, the dam must be properly regulated and managed in accordance with best practices (FEMA, 2012).

Once a dam is tokenized, the dam owner is entitled to 10% of the total token supply, with the remaining tokens available for trading on the financial market. This ownership incentive encourages dam owners to maintain their dam reputations and reduce the risk of failure, which in turn boosts and stabilizes the token price. Additionally, this approach reduces the likelihood of failure and mitigates the potential for significant economic losses due to dam failure.

3.5. Program Timeline

The program will be implemented in phases to ensure effectiveness and sustainability, with regular evaluations conducted over a 10-year period to monitor progress and make necessary adjustments. Assuming product development begins in early 2024, the official launch of TerraDam in 2025 would be feasible, with an initial stabilization period of one to two years. Continuous monitoring will be crucial, particularly in assessing the persistence of insurance coverage and participation in the program’s non-insurance features, to ensure its long-term success.



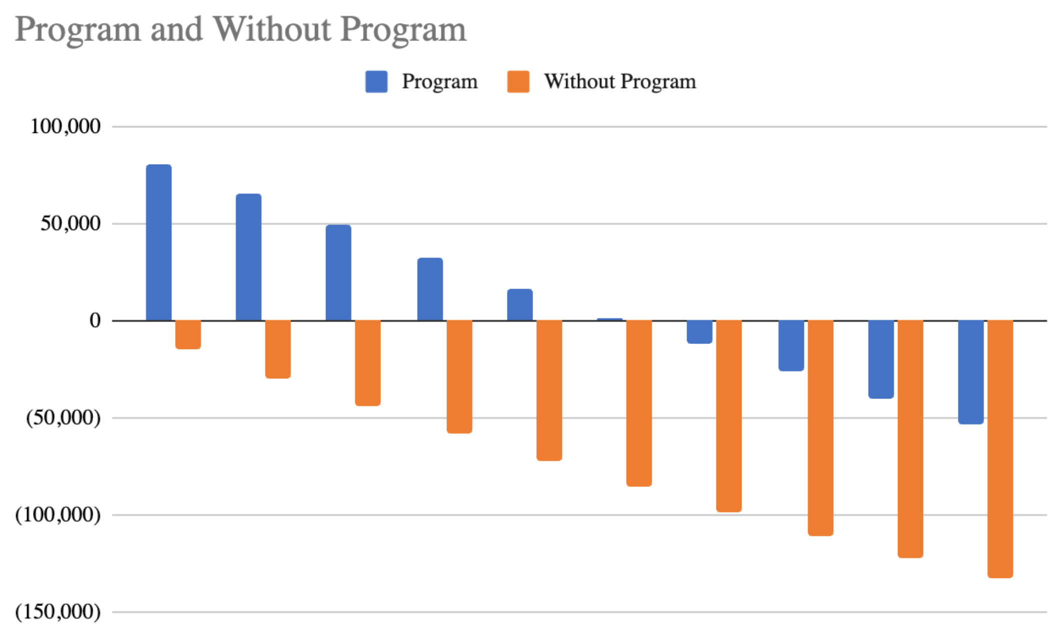
4. Financial Results

Given the high risk of dam failures, careful program design and funding are essential. The TerraDam token serves as a key mechanism for economic stability and efficient dam utilization in Tarrodan. Proceeds from dam tokenization will fund both financing and reserve accounts. To ensure sustainability, 80% of funds will be invested in Tarrodan Government Bonds, while the rest will be allocated to high-liquidity assets and token buybacks.

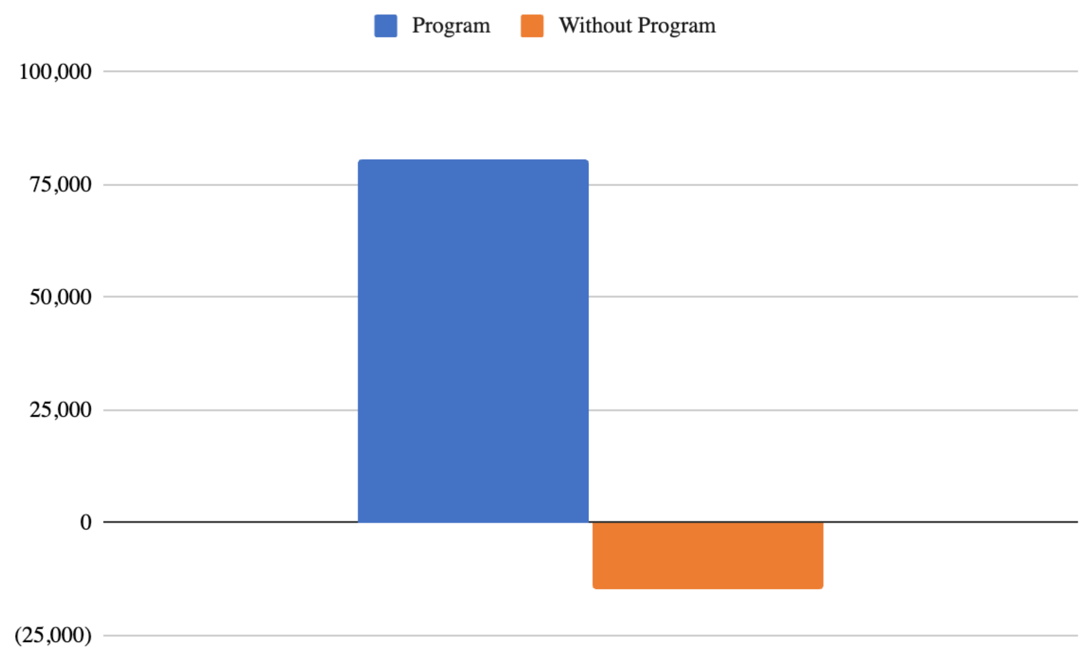
Each dam's valuation is based on the Discounted Cash Flow of Loss Given Failure of Business Interruption using projected interest rate, ensuring it reflects normal operational cash flows. If all tokens are sold, we expect to raise 326,396.72 ℚ million, representing 18.05% of the potential funds from full dam tokenization. These tokens will be launched on the cryptocurrency market, attracting both local and global investors.

	Flumevale	Lyndrassia	Navaldia	Tarrodan
All Dams (Qm)	700,772.89	392,416.70	715,183.51	1,808,373.10
Selected Dams (Qm)	268,531.91	11,591.70	46,273.11	326,396.72
Percentage (%)	**38.32%**	**2.95%**	**6.47%**	**18.05%**

Here is a comparison of the long-term cash flow (over 10 years) with and without the program. For the cash flow with the program, we have used assumptions based on the SSP population model (Appendix G), and it is evident that SSP Model 3 results in a more favorable cash flow. This model assumes a more optimistic outlook, with higher participation and more efficient cost management, leading to improved financial performance compared to the scenario without the program. This comparison highlights the potential financial benefits of implementing the program, demonstrating its positive impact on cash flow over the next decade.



It is evident that, through our program, we achieve a positive cash flow compared to the scenario without the program. The program generates better financial outcomes by optimizing revenue streams and reducing costs, resulting in a more sustainable and profitable cash flow over time. This comparison underscores the financial viability and advantages of implementing the program.



In the short-term cash flow, particularly within the first year, we observe a very positive outcome. This is primarily driven by the high premium income following the launch of the program. The results are further supported by the absence of policyholder lapses and the lack of high-cost events during this period. Additionally, strong participation rates, fueled by stringent regulations and positive responses from the market, contribute to the favorable financial performance in the short term. This early success sets a solid foundation for the program’s ongoing viability.

5. Assumptions

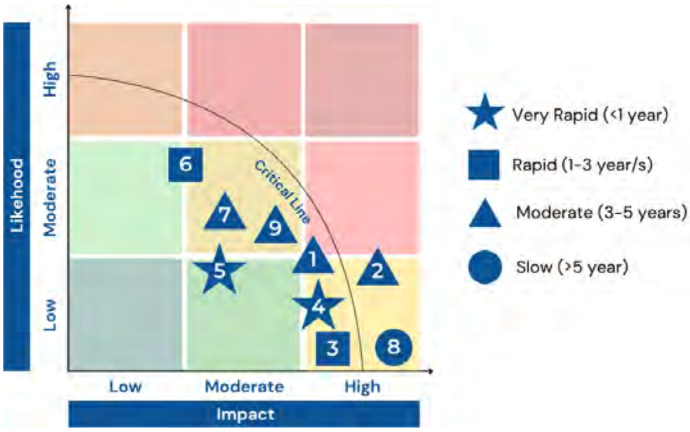
Metric	Assumption	Rationale
Data Quality (Missing Values)	Some variables that are missing or have unclear values are considered missing values and imputed accordingly. (Appendix B)	Based on the Dam Data Dictionary by the National Inventory of Dams (December 2021).
Insurance Benefit Cost	Insurance Benefit Cost (Appendix E.1)	We use current market prices for primary needs, including medical and mental health services, evacuation costs, and death benefits (funeral expenses), and convert them into Qalkoon for program budgeting.
Dam Inspection Cost	1,900 ℚ - 9500 ℚ size, location and hazard of the dams (Appendix E.2)	According to an article from the Wisconsin Department of Natural Resources, dam consultants charge inspection fees ranging from 2,000 to 10,000 USD.
Dam Alarm Cost	16,000 ℚ flat for all dams (Appendix E.3)	Calculated based on the Report of Findings by the Kentucky Division of Water, supported by the Science and Technology Directorate of the U.S. Department of Homeland Security, regarding *Critical Infrastructure and Flood Risk Management Innovation for Dam Safety Monitoring* (2020).
Dam Rehabilitation Cost	Ranging 381,679 ℚ - 90,935,115 ℚ according to height and hazard (Appendix E.4)	Refers to ASDSO (March 2025), "The Cost of Rehabilitating Dams in the U.S.", which are then converted to Qalkoon.
Participation Rate	Average Participation rate: Flumevale: 19.23% Lyndrassia: 1.81% Navaldia: 15.56% (Details annually on Appendix E.5)	We chose the logistic growth model to represent the dam tokenization participation rate, as it accurately reflects the adoption pattern of financial innovations—starting slow, accelerating as trust builds, and stabilizing as market saturation approaches.
Ability Threshold	An entity is considered "Able" if its revenue from the program can cover at least 90% of its costs, meaning its Program Cost/LGF-BI ratio remains below 10% and it does not apply for additional grants.	The 10% threshold from LGF-BI ensures that an entity is financially resilient and not overly dependent on external funding. It serves as a sustainability benchmark, indicating that the program can cover at least 90% of its costs independently, reducing financial risk and encouraging efficiency.
Probability Reduction	Dam Rehabilitation: 99.75%	Based on a study from probability reduction impact of dam rehabilitation in CHina (Yang et.al, 2011)

6. Risk and Risk Mitigation Considerations

Our program is a breakthrough in protecting the citizens of Tarrodan while reducing the likelihood of dam failures and economic losses. However, we must also acknowledge the potential challenges, including force majeure events and other risks that could impact the program's long-term sustainability.

6.1. Main Risks

The risk analysis highlights the key risks that require mitigation and their corresponding strategies. Notably, Pricing Risk and Climate Risk are critical concerns due to their high impact and long-term consequences, necessitating close monitoring and proactive mitigation. A detailed breakdown of all risks and mitigation strategies is provided in Appendix F.



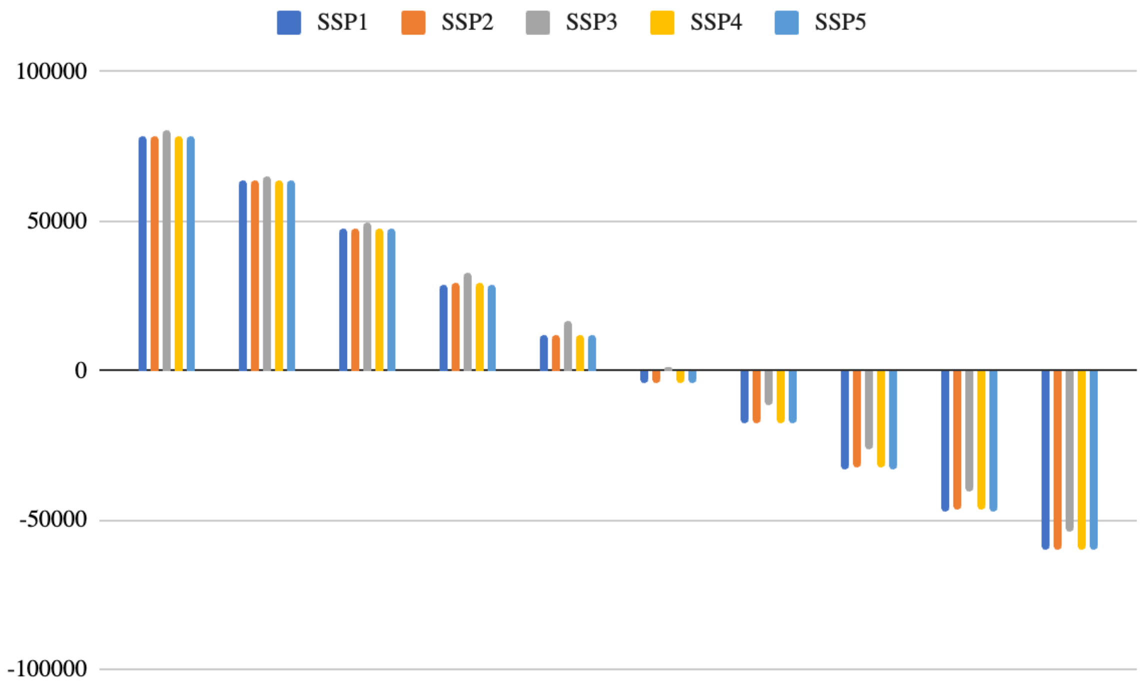
No	Risk Category	Description	Mitigation Strategies
1	Participation Risk	Low participation rates could lead to financial instability for the program.	Provide incentives, enforce penalties, and implement fraud prevention measures.
2	Pricing Risk	Incorrect pricing could cause financial imbalance, making the program unsustainable.	Conduct actuarial reviews and adjust pricing based on risk assessments.
3	Funding Risk	Token sales and external funding may be insufficient, especially during economic downturns.	Ensure transparency, conduct phased sales, and diversify funding sources.
4	Technological Risk	Alarm system failures could lead to undetected dam issues, increasing disaster risk.	Implement backup alert systems and real-time monitoring.
5	Fraud Risk	Participants may falsify information to gain unfair advantages.	Strengthen verification processes and cross-check government records.
6	Public Perception Risk	Misinformation or distrust in the program may reduce participation.	Launch public awareness campaigns and ensure transparency.
7	Operational Risk	Inefficiencies in inspections, claims processing, and enforcement could slow implementation.	Standardize procedures, invest in technology, and conduct regular audits.
8	Climate Change Risk	Increasing extreme weather events could lead to higher dam failures.	Incorporate climate risk into pricing models and promote sustainable maintenance.
9	Rehabilitation Cost Risk	Rehabilitation costs may exceed estimates, delaying repairs.	Conduct accurate cost forecasting and establish emergency reserve funds.

6.2. Sensitivity Analysis

Assumptions	Total Cost		
	Low Inflation	Projected Inflation	High Inflation

National Insurance Cost	23,881.20	21,363.55	18,438.05
Dam Insurance Cost	882,122.07	619,904.67	726,175.57

The sensitivity analysis highlights the potential variations in the costs of national and dam insurance under different scenarios. For national insurance, the costs range from a low estimate of 23,881.20 to a high of 18,438.05, with the projected cost being 21,363.55, reflecting the most likely outcome. For dam insurance, the costs vary from a low of 882,122.07 to a high of 726,175.57, with the projected cost at 619,904.67. These variations depend on factors such as participation rates, administrative efficiency, and unforeseen risk events like claims from dam failures. The analysis helps assess the financial impact of the program under different conditions and provides insight into the range of possible outcomes based on different assumptions.



Here is a comparison of the cash flow across different population scenarios based on the SSP models. As shown, the differences in cash flow between the scenarios are not significantly large, indicating that, regardless of the population assumptions, the financial impact remains relatively consistent. This suggests that the program’s viability is robust across various demographic projections.

7. Data and Data Limitations

7.1. Data Sources

Source	Description

Tarrodan Dam Data	This includes the dam data, dam data dictionary, encyclopedia entry and economic data provided by Earthen Dam Commission Actuarial Task Force.
External Inflation Rate (US & China)	US and China inflation rates were calculated from [US Inflation Calculator]() and [Statista](). These rates were used to adjust the costs obtained from external sources before converting them based on the exchange rate.

7.2. Data Limitations

Limitation	Description	Impact
Missing values	The dataset for Tarrodan Dam contains numerous missing values.	This limitation can lead to unreliable risk assessments, requiring imputation methods or alternative data sources to fill gaps.
Historical dam failure in Tarrodan's history	There is no provided data on dam failures in Tarrodan's history.	The absence of failure data may result in underestimating potential risks, requiring reliance on simulations, theoretical models, or data from similar dams for risk assessment.

8. Appendix

8.1. Appendix A - Data Quality Check

Variable	Type	Values/Mean	Missing Count
ID	Categorical	Alphanumeric (e.g., SOA00072, SOA01198)	0
Region	Categorical	Flumevale, Lyndrassia, Navaldia	0
Regulated Dam	Categorical	Yes, No	0
Primary Purpose	Categorical	Recreation; Water Supply; Flood Risk Reduction; Irrigation; Other; Tailings; Fish and Wildlife Pond; Debris Control; Hydroelectric; Fire Protection, Stock, Or Small Fish Pond; Grade Stabilization; Navigation; NA	1184
Primary Type	Categorical	Earth, Concrete, Rockfill, Timber Crib, Gravity, Stone, Arch, Buttress, Other, Masonry, Roller-Compacted Concrete, Multi-Arch, NA	257
Height (m)	Numerical	11.3	24
Length (km)	Numerical	0.4	2671
Volume (m3)	Numerical	211,241	9678
Year Completed	Numerical	1748–2023	1384
Years Modified	Categorical	Alphanumeric (e.g., 1987, 2003S; 2012H)	18995
Surface (km2)	Numerical	2.4	2798
Drainage (km2)	Numerical	1,976	2463
Spillway	Categorical	Uncontrolled, Controlled	12786
Last Inspection Date	Date	DD-MM-YYYY	10024
Inspection Frequency	Numerical	2.1	8116
Distance to Nearest City (km)	Numerical	19.7	10229
Hazard	Categorical	Low, High, Significant, Undetermined	0
Assessment	Categorical	Not Rated, Satisfactory, Fair, Not Available, Poor,	2537

		Unsatisfactory	
Assessment Date	Date	DD-MM-YYYY	9773
Probability of Failure	Numerical	0.47	0
Loss given failure – prop (Qm)	Numerical	132	7
Loss given failure – liab (Qm)	Numerical	185	12
Loss given failure – BI (Qm)	Numerical	4.5	10730

8.2. Appendix B - Data Imputation

Variable	Missing Count	Assumption	Action
ID	0	-	Not Imputed
Region	0	-	Not Imputed
Regulated Dam	0	-	Not Imputed
Primary Purpose	1184	Missing values = Missing	Imputed
Primary Type	257	Missing values = Missing	Imputed
Height (m)	24	"0" = Missing	Imputed
Length (km)	2671	Missing values = Missing	Imputed
Volume (m3)	9678	Missing values = Missing	Imputed
Year Completed	1384	Missing values = Missing	Imputed
Years Modified	18995	Missing values = No Modification Done	Not Imputed
Surface (km2)	2798	Missing values = Missing	Imputed
Drainage (km2)	2463	Missing values = Missing	Imputed
Spillway	12786	Missing values = Missing	Imputed
Last Inspection Date	10024	Missing values = No Inspection Done	Not Imputed
Inspection Frequency	8116	Missing values = Missing	Imputed
Distance to Nearest City (km)	10229	Missing values = Missing	Imputed
Hazard	0	"Undetermined" = Missing	Imputed
Assessment	2537	Missing values = Missing "Not Available" & "Not Rated" = Missing	Imputed
Assessment Date	9773	Missing values = No Assessment Done	Not Imputed
Probability of Failure	0	-	Not Imputed
Loss given failure – prop (Qm)	7	Missing values = Missing	Imputed
Loss given failure – liab (Qm)	12	Missing values = Missing	Imputed
Loss given failure – BI (Qm)	10730	Missing values = 0 = No Business Activity	Not Imputed

The presence of missing values in mixed datasets—comprising both categorical (nominal) and ordered (continuous/ordinal) variables—poses significant challenges for traditional imputation methods. Simple techniques such as mean or mode substitution introduce bias and fail to preserve inter-variable dependencies, while deletion strategies risk substantial data loss (e.g., discarding over 93% of observations in our dataset). Existing methods like MICE and missForest face limitations in scalability, compatibility with categorical variables, or uncertainty quantification.

To address these challenges, we employ the Extended Gaussian Copula (EGC) model (Zhao et al., 2022), a probabilistic framework designed for imputing mixed datasets. This method leverages a latent Gaussian structure to jointly model categorical and ordered variables while preserving their inherent properties. Key advantages include:

1. Robust Handling of Mixed Data: Explicitly models categorical variables via latent Gaussian vectors (avoiding arbitrary integer encoding) and ordered variables through quantile-preserving transformations.
2. Dependency Preservation: Captures correlations between variables (e.g., how Hazard ratings relate to Probability of Failure or Year Completed).
3. Hyperparameter-Free Estimation: Parameters are derived directly from observed data, eliminating manual tuning.
4. Scalability: Efficient EM-based algorithm supports large datasets (e.g., 20,806 dams) with minimal computational overhead.
5. Uncertainty Quantification: Generates multiple plausible imputations to propagate uncertainty into downstream analyses.

By addressing the limitations of traditional methods, the EGC ensures imputed values preserve the inherent statistical dependencies and marginal distributions of the datasets, enabling reliable risk assessments and actionable decision-making. Experimental results (Zhao et al., 2022) validate the method's superiority: it achieves 15-30% lower error rates for categorical variables and 10-20% higher accuracy for ordered variables compared to benchmarks like MICE and missForest, while maintaining enhanced computational efficiency–critical for scaling to large datasets like Taroddan's 20,806 dams.

8.2.1. Appendix B.1 - Model Formulation

Let X = (X_{cat}, X_{ord}) denote a mixed data vector. The EGC assumes a latent gaussian vector $Z \sim \mathcal{N}(0, \Sigma)$ generates X through transformations:

1. Categorical variables: for a k-category variable X_j ,
   $X_j = argmax(Z_{[j]} + N_{[j]}), Z_{[j]} \sim \mathcal{N}(0, I_k)$
   where $N_{[j]}$ ensures alignment with deserved marginal probabilities.
2. Ordered variables: for continuous/ordinal X_j ,
   $$X_j = f_j(z_j), f_j = F_j^{-1} \circ \phi,$$
   with F_j as the empirical CDF and ϕ the standard gaussian CDF.

8.2.2. Appendix B.2 - Imputation Algorithm

Single Imputation:

- Compute $E[Z_{[M]}|X_O]$ via truncated gaussian conditioning.
- Apply inverse transformations f_j^{-1} to map latent expectations to data space.

Multiple Imputation:

- Sample $Z_{[O]}$ from the truncated gaussian $Z_{[O]}X_O$.
- Draw $Z_{[M]}|Z_{[O]}$ from the conditional gaussian distribution.
- Transform samples to data space using f_j .

8.2.3. Appendix B.3 - Parameter Estimation

1. Marginal estimation
   - For categorical variables, solve $N_{[j]}$ via Monte Carlo approximation.
   - For ordered variables, estimate f_j using empirical quantiles.

2. Copula correlation
    - Optimize Σ via EM algorithm, iteratively updating latent moments.
    - Enforce identifiability constraints to ensure $\Sigma_{[j],[j]} = I_k$.

8.3. Appendix C - Program Design Appendix

8.3.1. Appendix C.1 - Dam Insurance Rating Factor

The base premium for dam insurance is 7.03 Qm and the premium will be scaled from the base premium regarding the dam's risk profile based on the rating factors. The rating factors modelled for the dam insurance is shown below.

Rating_Factor	Level	Relativities_Freq	Relativities_Liab	Relativities_Prop	Pure_Premium (Qm)
Intercept	-	0.18	240.30	51.87	26.36
Region	Flumevale	0.89	0.97	1.10	0.92
Region	Lyndrassia	1.01	1.07	0.71	0.90
Region	Navaldia	1.00	1.00	1.00	1.00
Regulated_Dam	Yes	1.00	1.00	1.00	1.00
Regulated_Dam	No	1.06	0.70	0.86	0.83
Primary_Purpose	Recreation	1.00	1.00	1.00	1.00
Primary_Purpose	Debris Control	1.00	1.10	1.00	1.05
Primary_Purpose	Fire Protection, Stock, Or Small Fish Pond	1.07	1.08	0.71	0.96
Primary_Purpose	Fish and Wildlife Pond	1.00	0.90	1.22	1.06
Primary_Purpose	Flood Risk Reduction	1.02	0.93	1.00	0.98
Primary_Purpose	Grade Stabilization	1.00	0.77	1.00	0.88
Primary_Purpose	Hydroelectric	1.00	0.84	1.59	1.21
Primary_Purpose	Irrigation	1.04	0.88	1.19	1.07
Primary_Purpose	Navigation	1.00	1.03	1.00	1.01
Primary_Purpose	Other	0.98	1.06	1.00	1.01
Primary_Purpose	Tailings	1.00	0.78	1.00	0.89
Primary_Purpose	Water Supply	1.00	0.97	1.00	0.98
Age	Young	0.93	1.03	0.95	0.92
Age	Middle	0.97	0.95	0.96	0.93
Age	Old	1.00	1.00	1.00	1.00
Modified	Yes	0.95	1.01	1.51	1.20
Modified	No	1.00	1.00	1.00	1.00
Ins_Freq	0	1.23	0.06	15.38	9.53
Ins_Freq	0.5	1.23	0.73	1.36	1.29
Ins_Freq	1	1.27	1.01	1.08	1.33

Ins_Freq	2	1.21	0.95	1.00	1.18
Ins_Freq	3	1.16	0.87	1.00	1.09
Ins_Freq	4	1.04	1.08	1.00	1.08
Ins_Freq	5	1.00	1.00	1.00	1.00
Ins_Freq	6	0.89	1.42	0.91	1.04
Ins_Freq	7	0.82	0.20	1.00	0.49
Ins_Freq	10	0.70	1.35	0.68	0.71
Hazard	High	1.14	3.51	1.90	3.10
Hazard	Significant	1.52	2.00	1.76	2.85
Hazard	Low	1.00	1.00	1.00	1.00
Assessment	Fair	1.06	1.07	1.00	1.10
Assessment	Poor	1.08	1.03	1.00	1.10
Assessment	Unsatisfactory	1.10	1.03	1.00	1.11
Assessment	Satisfactory	1.00	1.00	1.00	1.00
Size	1	1.04	1.00	1.12	1.10
Size	2	1.03	1.05	0.92	1.02
Size	3	1.00	1.00	1.00	1.00
Size	4	0.98	0.94	1.49	1.18
Size	5	1.00	0.90	3.35	2.14
Size	6	1.02	0.82	6.78	3.86
Spillway	Controlled	1.01	1.03	0.97	1.01
Spillway	Uncontrolled	1.00	1.00	1.00	1.00

The premium is paid annually using an adjusted annuity factor considering the persistence rate. Based on a study on long-term care insurance (Friedberg et al., 2021), 41.1% of policies had lapse after 15 years, this translates into a 3.5% annual lapse rate.

$$Premium = \frac{Intercept \times \prod_{i=Region}^{Spillway}\left(\sum_{j=1}^{n}\left(Rating\_Factor_{ij} \times Level_j\right)\right)}{Adjusted\ Annuity\ Factor}$$

8.3.2. Appendix C.2 - National Insurance Premium Formula

$$Premium = \frac{PV\ of\ (Evacuation\ Benefit + Funeral\ Benefit) \times \sum_t Probability\ of\ Failure\ Dam_t \times Population\ at\ Risk\ Dam_t}{Annuity\ 10\ Years}$$

8.3.3. Appendix C.3 - Dam Regulation

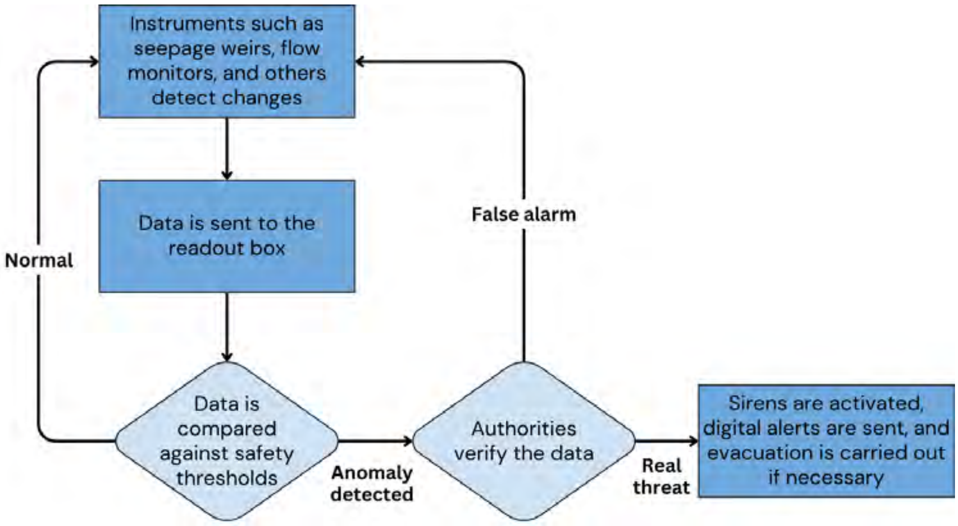
Program	Requirements	Financial Assistance	Reference
Emergency Action Plan (EAP)	Dam owners must develop an EAP. The EAP must include roles and responsibilities, incident classification, notification protocols, emergency response actions, and protective measures.Must contain monitoring	TerraDam Grant available for dam owners unable to fund EAP development.	Adapted from FEMA guidelines

	procedures and inundation maps showing flood-prone areas, critical infrastructure, and estimated travel times of flood waves.		
Inspection	Mandatory for all dams. Dam owners must conduct regular inspections to check structural integrity, including spillways and appurtenant features. Issues must be documented and addressed before they escalate into major risks.	TerraDam Grant available for dam owners unable to afford inspections.	Adapted from FEMA guidelines
Alarm System Installation	Mandatory for all dams. Alarms must be installed to ensure early warning in case of dam failure. The system should be tested periodically to confirm functionality.	TerraDam Grant available for dam owners unable to afford alarm installations.	
Rehabilitation	Mandatory based on hazard classification and priority levels. Follows the rehabilitation timeline as per the Rehabilitation Priority Timeline.	TerraDam Grant available for dam owners unable to fund rehabilitation.	Based on Hazard Classification Table

Rehabilitation Priority Timeline

Priority Level	Adjusted Rehabilitation Timeline	Justification
1-3 (Extreme Risk)	Immediate action (3 year)	No dams in these categories, so no immediate action required.
4-6 (Very High Risk)	Full rehabilitation within 5 years	Prioritize the highest-risk dams first. Phased approach allows for steady progress while ensuring safety.
7-9 (High Risk)	Full rehabilitation within 10 years	Large number of dams, requiring gradual rehabilitation. 10-year period balances feasibility and risk mitigation.
10-15 (Moderate Risk)	Full rehabilitation within 15 years	Moderate risk allows for an extended timeline. Regular inspections ensure early detection of worsening conditions.
16-22 (Low Risk)	Full rehabilitation within 20 years	Very low probability of failure, allowing a longer timeframe.
23-30 (Minimal Risk)	No immediate rehabilitation required	Periodic monitoring is sufficient.

8.3.4. Appendix C.4 - Alarm Mobile Device Integration Mechanism



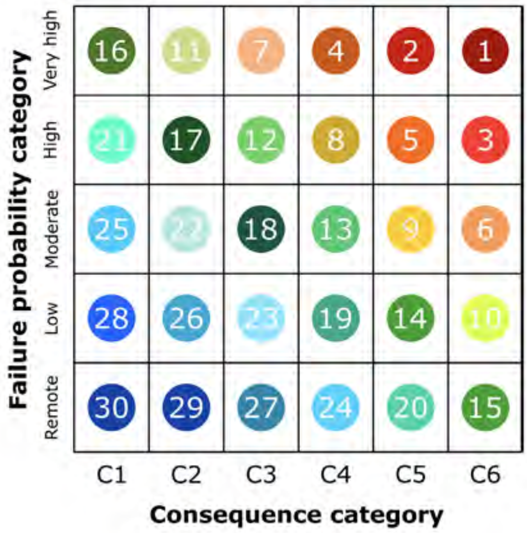
8.3.5. Appendix C.5 - Dam Rehabilitation Decision Table

The YBA team refers to ASDSO (2025), "The Cost of Rehabilitating Dams in the U.S." for the decision table using dam height as the primary criterion for rehabilitation cost estimation, refined by age and Condition Assessment ratings. The study also states that rehabilitation, repair, and retrofit are synonymous but are differentiated solely to classify cost magnitude (Appendix E.4).

Criteria	<50 years	>=50 years
Satisfactory	-	-
Fair	Repair	Retrofit
Unsatisfactory	Repair	Rehabilitation
Poor	Repair	Rehabilitation

8.3.6. Appendix C.6 - Dam Prioritization Matrix

The YBA team refers to the Ministry of Water Resources India (2019) guidelines for risk assessment thresholds, using Failure Probability Categories based on USBR and USACE (2014, 2015) recommendations and converting Consequence Categories from rupees to Qalkoon, rounded accordingly.



Consequence Category	
Category	**Loss (X)**
C1	≤ 5,500,000 Ꝗ
C2	< 5,500,000 & ≤ 55,000,000 Ꝗ
C3	< 55,000,000 & ≤ 550,000,000 Ꝗ
C4	< 550,000,000 & ≤ 5,500,000,000 Ꝗ
C5	< 5,500,000,000 & ≤ 55,000,000,000 Ꝗ
C6	< 55,000,000,000 Ꝗ

Failure Probability Category	
Category	**Loss (N)**
Remote	≤ 0.000001
Low	> 0.000001 & ≤ 0.00001
Moderate	> 0.00001 & ≤ 0.0001
High	> 0.0001 & ≤ 0.001
Very High	> 0.001 & ≤ 1

8.4. Appendix D - Financial Results Appendix

8.4.1. Appendix D.1 - Economic Rates Projection

Year	Government of Tarrodan Overnight Rate	1-yr Risk Free Annual Spot Rate	10-yr Risk Free Annual Spot Rate	Inflation Rate
2025	5.62%	3.88%	4.40%	2.28%
2026	5.59%	2.68%	4.06%	2.36%
2027	5.57%	2.21%	3.90%	2.43%
2028	5.57%	2.30%	3.90%	2.51%
2029	5.57%	2.70%	4.02%	2.56%
2030	5.57%	3.17%	4.21%	2.59%
2031	5.53%	3.53%	4.42%	2.62%
2032	5.52%	3.74%	4.62%	2.71%
2033	5.50%	3.84%	4.77%	2.77%
2034	5.51%	3.90%	4.90%	2.82%

Interest rate data has a negative AR(1) coefficient, it shows that the interest rate data supports mean reversion assumption. The same way for risk free rate and inflation rate. Based on Augmented Dicky-Fuller test, interest rate, inflation rate, and risk free rate data is stationary. So, based on this fact, we can utilize the Vasicek model for predicting the interest rate and inflation rate. On the other side, we utilize Vector Auto Regressive for a risk free rate.

R Code:

```
#####INTEREST RATE#####
```

```r
set.seed(12345)
library(ggplot2)
library(writexl)
library(readxl)
library(tseries)
library(lmtest)
library(dplyr)

data <- read_excel("Economic Data.xlsx", sheet = "Inflation-Interest")
data$Year <- as.numeric(data$Year)

#Assumption Test
overnight_rate <- as.numeric(data$`Government of Tarrodan Overnight Rate`)
overnight_rate_ts <- ts(overnight_rate, start = 1962, end = 2024, frequency = 1)
plot(overnight_rate_ts, type = "l", main = "Overnight Rate Over Time", ylab = "Rate", xlab = "Year")

diff_series <- diff(overnight_rate_ts)
lagged_series <- stats::lag(overnight_rate_ts, -1)
lagged_series <- lagged_series[!is.na(lagged_series)]
diff_series <- diff_series[1:length(lagged_series)]

ar_model <- lm(diff_series ~ lagged_series)
summary(ar_model)

adf_test <- adf.test(overnight_rate_ts)
print(adf_test)

residuals <- residuals(ar_model)
hist(residuals, main = "Residual Histogram", xlab = "Residuals", col = "lightblue", border = "black")

qqnorm(residuals); qqline(residuals, col = "red")

shapiro_test <- shapiro.test(residuals)
print(shapiro_test)

bptest(ar_model)

acf(residuals, main = "Autocorrelation of Residuals")

Box.test(residuals, type = "Ljung-Box")

#Vasicek Modelling
mu <- mean(overnight_rate)
sigma <- sd(diff(overnight_rate))
theta <- acf(diff(overnight_rate), plot = FALSE)$acf[2]
num_paths <- 10000
num_years <- 10
dt <- 1
r0 <- tail(overnight_rate, 1)
simulate_vasicek <- function(mu, sigma, theta, r0, num_paths, num_years, dt) {
 paths <- matrix(0, nrow = num_paths, ncol = num_years + 1)
 paths[, 1] <- r0

 for (t in 2:(num_years + 1)) {
        dw <- rnorm(num_paths, 0, sqrt(dt))
        dr <- theta * (mu - paths[, t-1]) * dt + sigma * dw
        paths[, t] <- paths[, t-1] + dr
 }
```

```
  return(paths)
}

simulated_paths <- simulate_vasicek(mu, sigma, theta, r0, num_paths, num_years, dt)

average_path <- colMeans(simulated_paths)
year <- 0:num_years
df <- data.frame(year, average_path)

ggplot(df, aes(x = year, y = average_path)) +
  geom_line(color = "blue", size = 1.5) +
  labs(title = "Average Simulation for Interest Rate (10 Years)",
       x = "Year", y = "Interest Rate") +
  theme_minimal()

write_xlsx(df, "Predicted_Interest_Rate.xlsx")



#####GOVERNMENT BOND YIELD#####

library(tidyverse)
library(forecast)
library(tseries)
library(vars)
library(randomForest)
library(writexl)

data <- read_excel("Economic Data.xlsx", sheet = "Inflation-Interest")
head(data)
data %>%
  ggplot(aes(x = Year)) +
  geom_line(aes(y = `1-yr Risk Free Annual Spot Rate`, color = "1-year")) +
  geom_line(aes(y = `10-yr Risk Free Annual Spot Rate`, color = "10-year")) +
  labs(title = "1-year vs 10-year Risk-Free Annual Spot Rate",
       x = "Year", y = "Risk-Free Spot Rate") +
  scale_color_manual(name = "Spot Rates", values = c("blue", "red")) +
  theme_minimal()

adf_1yr <- adf.test(data$`1-yr Risk Free Annual Spot Rate`)
adf_10yr <- adf.test(data$`10-yr Risk Free Annual Spot Rate`)

print(adf_1yr)
print(adf_10yr)

if(adf_1yr$p.value > 0.05) {
  data$diff_1yr <- c(NA, diff(data$`1-yr Risk Free Annual Spot Rate`))
}

if(adf_10yr$p.value > 0.05) {
  data$diff_10yr <- c(NA, diff(data$`10-yr Risk Free Annual Spot Rate`))
}

adf_diff_1yr <- adf.test(na.omit(data$diff_1yr))
adf_diff_10yr <- adf.test(na.omit(data$diff_10yr))
```

```
print(adf_diff_1yr)
print(adf_diff_10yr)

cor_1yr_inflation <- cor(data$`1-yr Risk Free Annual Spot Rate`, data$Inflation)
cor_1yr_overnight <- cor(data$`1-yr Risk Free Annual Spot Rate`, data$`Government of Tarrodan Overnight
Rate`)

cor_10yr_inflation <- cor(data$`10-yr Risk Free Annual Spot Rate`, data$Inflation)
cor_10yr_overnight <- cor(data$`10-yr Risk Free Annual Spot Rate`, data$`Government of Tarrodan Overnight
Rate`)

print(cor_1yr_inflation)
print(cor_1yr_overnight)
print(cor_10yr_inflation)
print(cor_10yr_overnight)

if(abs(cor_1yr_inflation) > 0.5 | abs(cor_1yr_overnight) > 0.5) {
 var_model <- VAR(data[, c("1-yr Risk Free Annual Spot Rate", "10-yr Risk Free Annual Spot Rate", "Inflation",
"Government of Tarrodan Overnight Rate")], p = 2)
 forecasted_var <- predict(var_model, n.ahead = 10)
 par(mar = c(4, 4, 2, 2))
 plot(forecasted_var)
 par(mar = c(5, 4, 4, 2) + 0.1)

 forecasted_var_df <- as.data.frame(forecasted_var$fcst)
 write_xlsx(forecasted_var_df, path = "Forecasted Risk Free Rate.xlsx")

 cat("Forecast results written to 'forecasted_var_results.xlsx'\n")
} else {
 arima_model_1yr <- auto.arima(data$`1-yr Risk Free Annual Spot Rate`)
 forecast_1yr <- forecast(arima_model_1yr, h = 10)
 plot(forecast_1yr)

 arima_model_10yr <- auto.arima(data$`10-yr Risk Free Annual Spot Rate`)
 forecast_10yr <- forecast(arima_model_10yr, h = 10)
 plot(forecast_10yr)
}

x <- data$`Government of Tarrodan Overnight Rate`
if(abs(cor_1yr_inflation) > 0.5 | abs(cor_1yr_overnight) > 0.5) {
 rf_model <- randomForest(`1-yr Risk Free Annual Spot Rate` ~ Inflation + x, data = data)
 rf_forecast <- predict(rf_model, newdata = data.frame(Inflation = c(2.5), x = c(5.5)))
 print(rf_forecast)
}

data <- read_excel("Economic Data.xlsx", sheet = "Inflation-Interest")
inflation <- as.numeric(data$`Inflation`)

#Assumption Test
inflation_ts <- ts(inflation, start = 1962, end = 2024, frequency = 1)
plot(inflation_ts, type = "l", main = "Overnight Rate Over Time", ylab = "Rate", xlab = "Year")
diff_series <- diff(inflation_ts)
lagged_series <- stats::lag(inflation_ts, -1)
lagged_series <- lagged_series[!is.na(lagged_series)]
diff_series <- diff_series[1:length(lagged_series)]
```

```r
ar_model <- lm(diff_series ~ lagged_series)
summary(ar_model)

adf_test <- adf.test(inflation_ts)
print(adf_test)

residuals <- residuals(ar_model)
hist(residuals, main = "Residual Histogram", xlab = "Residuals", col = "lightblue", border = "black")

qqnorm(residuals); qqline(residuals, col = "red")

shapiro_test <- shapiro.test(residuals)
print(shapiro_test)

bptest(ar_model)

acf(residuals, main = "Autocorrelation of Residuals")

Box.test(residuals, type = "Ljung-Box")

#Vasicek Modelling
mu <- mean(inflation)
sigma <- sd(diff(inflation))
theta <- acf(diff(inflation), plot = FALSE)$acf[2]

num_paths <- 10000
num_years <- 10
dt <- 1
r0 <- tail(inflation, 1)

simulate_vasicek <- function(mu, sigma, theta, r0, num_paths, num_years, dt) {
 paths <- matrix(0, nrow = num_paths, ncol = num_years + 1)
 paths[, 1] <- r0

 for (t in 2:(num_years + 1)) {
       dw <- rnorm(num_paths, 0, sqrt(dt))
       dr <- theta * (mu - paths[, t-1]) * dt + sigma * dw
       paths[, t] <- paths[, t-1] + dr
 }

 return(paths)
}

simulated_paths <- simulate_vasicek(mu, sigma, theta, r0, num_paths, num_years, dt)

average_path <- colMeans(simulated_paths)

year <- 0:num_years
df <- data.frame(year, average_path)

ggplot(df, aes(x = year, y = average_path)) +
 geom_line(color = "blue", size = 1.5) +
 labs(title = "Average Simulation for Inflation Rate(10 Years)",
       x = "Year", y = "Inflation") +
 theme_minimal()

write_xlsx(df, "Predicted Inflation Rate.xlsx")
```

8.4.2. Appendix D.2 - Cashflow Comparison Program vs Without Program

Without Program											
		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Expenses											
1	Expected National Insurance Benefit	517.71	1,029.74	1,529.42	2,010.38	2,466.79	2,893.45	3,285.93	3,640.66	3,955.00	4,227.19
2	Expected Dam Insurance Benefit	14,330.38	28,566.19	42,613.97	56,382.47	69,783.67	82,733.84	95,154.41	106,972.81	118,123.23	128,547.25
Cash Outflow		**14,848**	**29,596**	**44,143**	**58,393**	**72,250**	**85,627**	**98,440**	**110,613**	**122,078**	**132,774**
Cash Flow		**(14,848)**	**(29,596)**	**(44,143)**	**(58,393)**	**(72,250)**	**(85,627)**	**(98,440)**	**(110,613)**	**(122,078)**	**(132,774)**
Cumulative Cash Flow		**(14,848)**	**(44,444)**	**(88,587)**	**(146,980)**	**(219,231)**	**(304,858)**	**(403,298)**	**(513,912)**	**(635,990)**	**(768,764)**

With Program											
		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Revenue Addition											
1	Expected National Insurance Premium	2,813.27	2,840.20	2,866.96	2,893.55	2,919.96	2,946.21	2,972.28	2,998.19	3,023.92	3,049.48
2	Expected Dam Insurance Premium	98,402.75	94,990.81	91,697.17	88,517.73	85,448.54	82,485.76	79,625.71	76,864.83	74,199.68	71,626.94
3	TarroDam Tokenization	1,762.19	1,006.90	1,468.67	2,009.77	2,522.77	2,844.74	2,844.74	2,522.77	2,009.77	1,468.67
4	Investment Returns	396.14	641.31	979.89	1,446.53	2,034.60	2,701.16	3,347.88	3,934.55	4,394.71	4,751.75
Cash Inflow		**103,374**	**99,479**	**97,013**	**94,868**	**92,926**	**90,978**	**88,791**	**86,320**	**83,628**	**80,897**
Expenses											
1	Expected National Insurance Benefit	517.71	1,029.74	1,529.42	2,010.38	2,466.79	2,893.45	3,285.93	3,640.66	3,955.00	4,227.19
2	Expected Dam	14,330.	28,566.	42,613.	56,382.	69,783.	82,733.	95,154.	106,972	118,123	128,547

	Insurance Benefit	38	19	97	47	67	84	41	.81	.23	.25
3	TarroDam Grant - Dam Rehabilitation	7,858.48	4,737.68	3,158.45	3,913.32	3,913.32	3,913.32	1,956.66	1,956.66	1,956.66	1,956.66
4	TarroDam Grant - Dam Inspection	1.05	13.98	17.98	16.17	17.30	23.88	21.92	12.77	16.10	13.76
5	TarroDam Grant - Dam Alarm	77.62	45.10	30.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Outflow		**22,785**	**34,393**	**47,350**	**62,322**	**76,181**	**89,564**	**100,419**	**112,583**	**124,051**	**134,745**
Cash Flow		**80,589**	**65,087**	**49,663**	**32,545**	**16,745**	**1,413**	**(11,628)**	**(26,263)**	**(40,423)**	**(53,848)**
Cumulative Cash Flow		**80,589**	**145,676**	**195,338**	**227,884**	**244,628**	**246,042**	**234,414**	**208,151**	**167,728**	**113,880**

8.5. Appendix E - Assumptions Appendix

8.5.1. Appendix E.1 - National Insurance Benefit Cost

Region	Dam Failure Impact	Total Benefit/Person	Frequency
Navaldia	Primary Needs	8.18 Ꝗ	Daily
	Medical + Mental Health Services	0.89 Ꝗ	
	Evacuation Cost	**9.06 Ꝗ**	
	Property Benefit	100% Value	One Time Cash
	Death Benefit (Funeral)	359.11 Ꝗ	
	Sum Insured	**359.11 Ꝗ**	
	Total Payments	**368.18 Ꝗ**	
Flumevale	Primary Needs	0.61 Ꝗ	Daily
	Medical + Mental Health Services	9.33 Ꝗ	
	Evacuation Cost	**9.94 Ꝗ**	
	Property Benefit	100% Value	One Time Cash
	Death Benefit (Funeral)	412.83 Ꝗ	
	Sum Insured	**412.83 Ꝗ**	
	Total Payments	**423.39 Ꝗ**	
Lyndrassia	Primary Needs	0.44 Ꝗ	Daily
	Medical + Mental Health Services	6.68 Ꝗ	
	Evacuation Cost	**7.12 Ꝗ**	
	Property Benefit	100% Value	One Time Cash
	Death Benefit (Funeral)	295.62 Ꝗ	
	Sum Insured	**295.62 Ꝗ**	
	Total Payments	**303.18 Ꝗ**	

8.5.2. Appendix E.2 - Dam Inspection Cost

```
library(readxl)
## Warning: package 'readxl' was built under R version 4.3.2
library(writexl)
## Warning: package 'writexl' was built under R version 4.3.3
Data_APV <- read_excel("Data_APV.xlsx")
## New names:
## • `` -> `...28`
Region <- as.factor(Data_APV$Region)
Size <- as.factor(Data_APV$Size)
Hazard <- as.factor(Data_APV$Hazard)

assign_uniform <- function(Region, Size, Hazard) {
  region_levels <- c("Lyndrassia", "Navaldia", "Flumevale")
  size_levels <- 1:6
  hazard_levels <- c("Low", "Significant", "High")
  region_rank <- match(Region, region_levels) - 1
```

```
size_rank <- match(Size, size_levels) - 1
hazard_rank <- match(Hazard, hazard_levels) - 1

weight_region <- 0.2
weight_size <- 0.4
weight_hazard <- 0.4

norm_value <- (region_rank * weight_region)/2 +
          (size_rank * weight_size)/5 +
          (hazard_rank * weight_hazard)/2

value <- 2000 + norm_value * 8000

return(value)
}

Data_APV$Inspection_Cost <- mapply(assign_uniform, Data_APV$Region, Data_APV$Size, Data_APV$Hazard)

write_xlsx(Data_APV, "Data_Inspection.xlsx")
```

8.5.3. Appendix E.3 - Dam Alarm Cost

Instrumentation	Risk/Failure Monitoring	Cost	Difficulty of Installation	Difficulty of Automation	Required Maintenance
Seepage Weirs	Monitors one failure mode (Internal Erosion/Piping)	Moderate cost	Medium	Medium	Medium
Flow Monitors	Monitors one failure mode (Internal Erosion/Piping)	Moderate cost	Medium	Low	Medium
Soil Extensometers	Monitors slope instability (due to tatic, seismic, or rapid drawdown)	Approximately $3,000 in material cost (assumes 3 sensors in series with cables run 500 feet) and $3,000 in installation cost	Medium – requires shallow trench to install	Low	Medium
Vibrating Wire Piezometers	Monitors slope instability (due to tatic, seismic, or rapid drawdown)	Approximately $1,500 in material cost (assumes 2 piezometers and cable run 200 feet) and $3,000 in installation cost	Low for sites that already have piezometers (i.e. utomating existing instrumentation) and High for sites that do not have piezometers (i.e. installing new instrumentation)	Low	Medium
In-Place Slope Inclinometers	Monitors slope instability (due to tatic, seismic, or rapid drawdown)	Approximately $8,000 in material cost (assumes a 50-foot deep inclinometer) and $2,500 in installation cost	Medium – can be installed in a day with a two-man crew	Low	High

Low-Pressure Transducers	Monitors three failure modes (Overtopping of Spillway or Crest) and Rapid Drawdown	Approximately $1,500 in material cost (assumes a 50-foot deep inclinometer) and $2,500 in installation cost	Medium – can be installed in a day with a two-man crew	Low	Medium
IoT Flood Sensors	Monitors three failure modes (Overtopping of Spillway or Crest) and Rapid Drawdown	Approximately $1,000 each in material cost, approximately $3,000 in installation cost	Medium	Low	Medium
Fiber Optic	Monitors slope instability (due to tatic, seismic, or rapid drawdown)	Moderate cost	High	Low	Medium
Ultrasonic Sensors	Monitors three failure modes (Overtopping of Spillway or Crest) and Rapid Drawdown	Moderate cost	Medium	Low	Medium

The total installation cost of the alarm system was calculated by averaging the material and installation costs of all instruments. Instruments without specific cost details and labeled as having a "moderate cost" were assumed to have the same cost as the average of the other instruments. This total was then combined with the readout box cost. Since the cost data we obtained was from the year 2020, we adjusted it using the U.S. inflation rate from the end of 2020 to the end of 2024, as we are evaluating these costs at the beginning of 2025. Finally, the adjusted cost was converted based on the USD-Qalkoon exchange rate, resulting in an estimated alarm system cost per dam of 15,954.56 Qalkoon, which was rounded to 16,000 Qalkoon.

The cost of integrating the alarm system with mobile devices is derived from the journal "Cost-benefit analysis of the Wuxikou Integrated Flood Management Project considering the effects of flood risk reduction and resettlement" by Zeng, P. et al. (2023). This cost is obtained by summing the expenses for the Master Plan for Integrated Flood Risk Management, Flood Risk Management Decision Support System, Awareness Raising and Community Engagement, and Specialized Technical Training for Flood Management Agencies, resulting in a total of 5,565,053 Qalkoon. These cost components were selected because they encompass the essential elements required for an effective alarm integration system.

8.5.4. Appendix E.4 - Dam Rehabilitation Cost

The YBA team refers to ASDSO (March 2025), "The Cost of Rehabilitating Dams in the U.S." to estimate dam rehabilitation costs, which are converted to Qalkoon.

Height (Feet)	Repair	Retrofit	Rehabilitation
≤ 15	381,679 Ⓠ	1,316,794 Ⓠ	2,738,550 Ⓠ
>15 & ≤ 25	753,817 Ⓠ	1,803,435 Ⓠ	2,547,710 Ⓠ
>25 & ≤ 50	1,345,420 Ⓠ	3,816,794 Ⓠ	5,944,656 Ⓠ
>50 & ≤ 100	1,297,710 Ⓠ	4,580,153 Ⓠ	8,187,023 Ⓠ
>100 & ≤ 200	2,938,931 Ⓠ	19,083,969 Ⓠ	22,748,092 Ⓠ
>200	8,759,542 Ⓠ	25,133,588 Ⓠ	90,935,115 Ⓠ

8.5.5. Appendix E.5 - Dam Tokenization Participation Rate

We chose the logistic growth model to represent the dam tokenization participation rate, as it accurately reflects the adoption pattern of financial innovations—starting slow, accelerating as trust builds, and stabilizing as market saturation approaches.

$$P_t = \frac{P_{max}}{1 + e^{-r(t-t_0)}}$$

Where:

- P_t = Participation rate at year t
- P_{max} = Maximum expected participation rate (assumed to be 80%)
- r = Growth rate (assumed to be 0.5)
- t_0 = Inflection point when participation accelerates (assumed to be 5)

The Maximum Expected Participation Rate (P_{max} = 80%) reflects the reality that not all investors will engage due to risk tolerance, regulatory barriers, or alternative investment options. Growth Rate (r = 0.5) represents a moderate adoption speed—fast enough to achieve significant participation but not unrealistically rapid. The Inflection Point (t_0 = 5 years) assumes that early adopters will drive initial interest, but broader participation requires time for awareness, market trust, and regulatory adjustments to take effect. Additionally, the participation rate is weighted based on GDP contribution from the finance industry in each region, ensuring that areas with a stronger financial sector and greater investment activity have a proportionally higher participation rate, leading to a more accurate estimation of token adoption.

Dam Tokenization Participation Rate			
Year	**Flumevale**	**Lyndrassia**	**Navaldia**
2025	3.19%	0.30%	2.58%
2026	5.01%	0.47%	4.05%
2027	7.67%	0.72%	6.20%
2028	11.30%	1.07%	9.15%
2029	15.87%	1.50%	12.84%
2030	21.01%	1.98%	17.00%
2031	26.16%	2.47%	21.17%
2032	30.73%	2.90%	24.86%
2033	34.36%	3.24%	27.80%
2034	37.02%	3.49%	29.95%
Average	**19.23%**	**1.81%**	**15.56%**

8.6. Appendix F - Risk and Risk Mitigation Appendix

No	Risk Category	Description	Mitigation Strategies

1	Participation Risk	A significant risk is the low participation rate of dam owners in the insurance program. If uninsured, dam owners must cover compensation costs themselves, which could lead to non-payment and financial losses. Some participants may also attempt to evade mandatory enrollment through fraudulent means, weakening the program.	To mitigate this, incentives will be provided to encourage participation, while strict penalties will be enforced for non-compliance. Fraud detection systems, including government verification processes, will be implemented. Public awareness campaigns and a government-backed fund will help increase trust and participation.
2	Pricing Risk	Errors in pricing calculations may result in excessively high costs for participants or insufficient funds to cover damages, endangering the program's financial sustainability.	Pricing will undergo actuarial reviews and adjustments based on real-time risk assessments. Scenario analysis and stress testing will be conducted to ensure long-term viability.
3	Funding Risk	The reliance on token sales for funding may be overly optimistic, as economic downturns could reduce investor confidence. If funds are insufficient, dam rehabilitation and insurance payouts could be delayed.	To maintain funding stability, the program will ensure full legal compliance, implement phased token sales, and attract diversified investors. Emergency financial reserves will also be established.
4	Technological Risk	The failure of alarm systems to activate could result in undetected dam safety incidents, leading to greater disaster risk and loss of life. Without proper alerts, affected communities may not evacuate in time.	Backup alert mechanisms (SMS, sirens, and community alarms) will be installed. Real-time monitoring, automated alerts, and emergency response training will be implemented.
5	Fraud Risk	Participants may falsify residency or insurance claims to gain unfair premium reductions, causing financial imbalances and undermining the program.	Residency verification processes will be enforced, including cross-checking government databases and requiring official address proof. Insurance claim audits will prevent fraudulent claims.
6	Public Perception Risk	Public distrust, misinformation, or resistance to mandatory participation could lead to lower enrollment, reducing financial sustainability.	A comprehensive public education campaign will highlight program benefits and ensure transparency in fund allocation.
7	Operational Risk	Inefficiencies in inspections, claims processing, and enforcement could slow down the program's implementation and effectiveness.	The program will establish clear operational guidelines, invest in digital tools for streamlined processing, and conduct regular audits.
8	Climate Change Risk	Increasing frequency and severity of extreme weather events could lead to more dam failures, raising insurance costs and liabilities.	Climate risk assessments will be integrated into pricing models, and preventive maintenance funding will be prioritized.
9	Rehabilitation Cost Risk	Rehabilitation costs may exceed initial estimates, leading to funding shortfalls and delays in dam repairs. This could increase the risk of structural failures.	Phased rehabilitation plans, accurate cost forecasting, and the establishment of emergency reserve funds will help mitigate financial strain.

8.7. Appendix G - Shared Socioeconomic Pathways (SSPs)

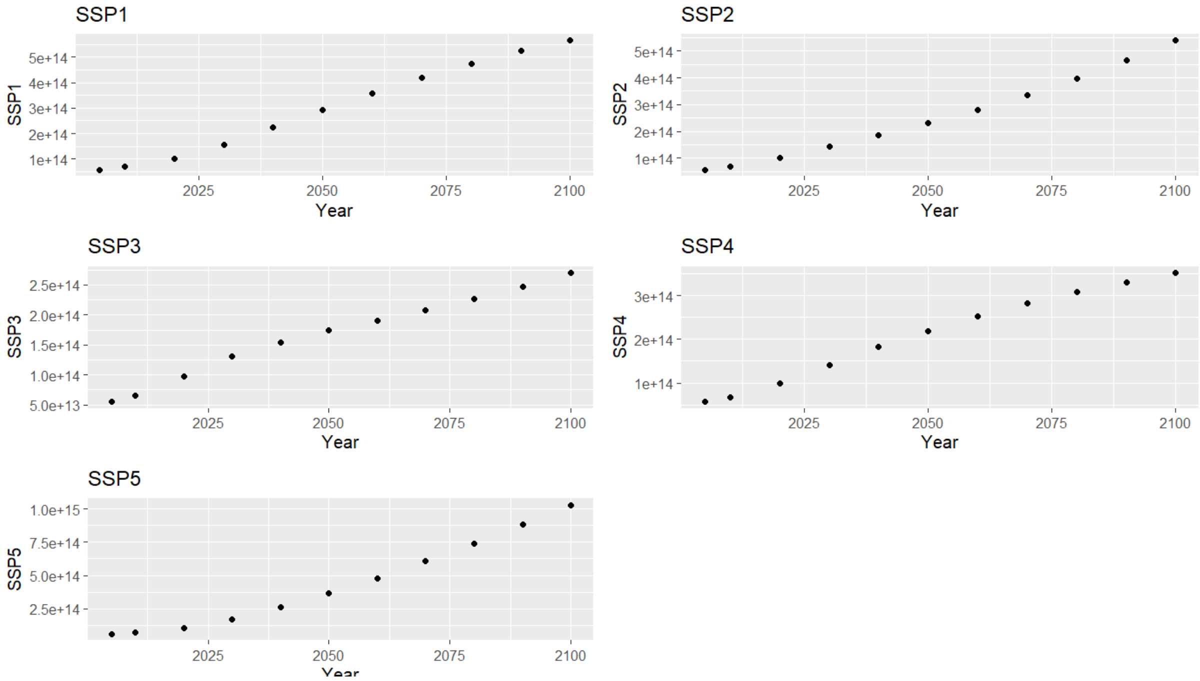
Shared Socioeconomic Pathways (SSPs) are scenarios that describe alternative socio-economic futures and their implications for global challenges, particularly climate change.

These pathways help in assessing potential interactions between societal trends and mitigation or adaptation strategies (Riahi et al., 2017). SSPs consist of five narratives:

- SSP1: Sustainability ("Taking the Green Road")
  This scenario envisions a world moving toward sustainability. It is characterized by rapid technological progress, reduced inequalities, and a strong commitment to environmental protection.
- SSP2: Middle of the Road
  In this scenario, historical trends continue with moderate economic, social, and technological development. The challenges for both mitigation and adaptation are neither extreme nor minimal, reflecting a balanced or "middle-of-the-road" future.
- SSP3: Regional Rivalry ("Fragmentation")
  This pathway depicts a fragmented world with strong national or regional interests, where international cooperation is limited. Economic growth is slow, technological development is uneven, and both mitigation and adaptation challenges are high due to a focus on national security and competitiveness.
- SSP4: Inequality ("A Road Divided")
  SSP4 features a future marked by significant inequality—both within and between countries. A highly unequal society leads to disparate levels of access to technology and resources, resulting in moderate challenges for mitigation but very high challenges for adaptation, particularly for disadvantaged groups.
- SSP5: Fossil-fueled Development ("Taking the Highway")
  This scenario is characterized by rapid economic growth driven by intensive fossil fuel use. While technological progress may improve adaptive capacities, the heavy reliance on fossil fuels leads to high greenhouse gas emissions and thus high challenges for mitigation.

8.8. Appendix H - GDP Projections

To project GDP for the regions of Taroddan–Navaldia, Flumevale, and Lyndrassia–we utilized data from the Shared Socioeconomic Pathways (SSP) under five different scenarios: SSP1, SSP2, SSP3, SSP4, and SSP5. Initially, a scatter plot was generated for each SSP scenario, revealing a nonlinear pattern in the GDP trends.



As shown above, this observation led to the adoption of a nonlinear logistic growth model to interpolate annual global GDP values. As shown below, the model demonstrated an excellent fit, accurately capturing the trends observed in the SSP dataset.

```
Formula: SSP1 ~ SSlogis(Year, phi1, phi2, phi3)

Parameters:
      Estimate Std. Error t value Pr(>|t|)
phi1 6.251e+14  1.074e+13   58.17 8.47e-12 ***
phi2 2.054e+03  1.029e+00 1995.17  < 2e-16 ***
phi3 2.161e+01  6.190e-01   34.91 4.96e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.708e+12 on 8 degrees of freedom

Number of iterations to convergence: 0
Achieved convergence tolerance: 5.519e-07
```

Given that the original SSP data is provided in decadal intervals, the logistic growth model was then used to generate annual GDP estimates for each SSP scenario. Finally, the projected global GDP values were downscaled to the regional level by applying the average GDP shares of each region per SSP. The final GDP projections for each region and SSP scenario are presented below.

Projected GDP under SSP1

Year	Navaldia	Lyndrassia	Flumevale
2025	3,328,370,000,000.00	479,976,000,000.00	4,275,560,000,000.00
2026	3,451,940,000,000.00	497,795,000,000.00	4,434,280,000,000.00

2027	3,578,790,000,000.00	516,088,000,000.00	4,597,240,000,000.00
2028	3,708,920,000,000.00	534,855,000,000.00	4,764,400,000,000.00
2029	3,842,320,000,000.00	554,092,000,000.00	4,935,760,000,000.00
2030	3,978,960,000,000.00	573,796,000,000.00	5,111,290,000,000.00
2031	4,118,810,000,000.00	593,963,000,000.00	5,290,940,000,000.00
2032	4,261,830,000,000.00	614,587,000,000.00	5,474,650,000,000.00
2033	4,407,960,000,000.00	635,661,000,000.00	5,662,380,000,000.00
2034	4,557,160,000,000.00	657,177,000,000.00	5,854,030,000,000.00

Projected GDP under SSP2

Year	Navaldia	Lyndrassia	Flumevale
2025	3,204,870,000,000.00	462,046,000,000.00	4,115,350,000,000.00
2026	3,293,690,000,000.00	474,850,000,000.00	4,229,400,000,000.00
2027	3,384,520,000,000.00	487,946,000,000.00	4,346,040,000,000.00
2028	3,477,390,000,000.00	501,335,000,000.00	4,465,300,000,000.00
2029	3,572,330,000,000.00	515,022,000,000.00	4,587,200,000,000.00
2030	3,669,340,000,000.00	529,008,000,000.00	4,711,770,000,000.00
2031	3,768,440,000,000.00	543,296,000,000.00	4,839,030,000,000.00
2032	3,869,660,000,000.00	557,889,000,000.00	4,969,010,000,000.00
2033	3,973,010,000,000.00	572,788,000,000.00	5,101,710,000,000.00
2034	4,078,490,000,000.00	587,995,000,000.00	5,237,160,000,000.00

Projected GDP under SSP3

Year	Navaldia	Lyndrassia	Flumevale
2025	3,155,940,000,000.00	454,947,000,000.00	4,051,950,000,000.00
2026	3,228,950,000,000.00	465,473,000,000.00	4,145,700,000,000.00
2027	3,302,610,000,000.00	476,092,000,000.00	4,240,270,000,000.00
2028	3,376,880,000,000.00	486,797,000,000.00	4,335,620,000,000.00
2029	3,451,700,000,000.00	497,583,000,000.00	4,431,680,000,000.00
2030	3,527,040,000,000.00	508,444,000,000.00	4,528,410,000,000.00
2031	3,602,840,000,000.00	519,372,000,000.00	4,625,740,000,000.00
2032	3,679,070,000,000.00	530,361,000,000.00	4,723,610,000,000.00
2033	3,755,680,000,000.00	541,404,000,000.00	4,821,960,000,000.00
2034	3,832,600,000,000.00	552,493,000,000.00	4,920,740,000,000.00

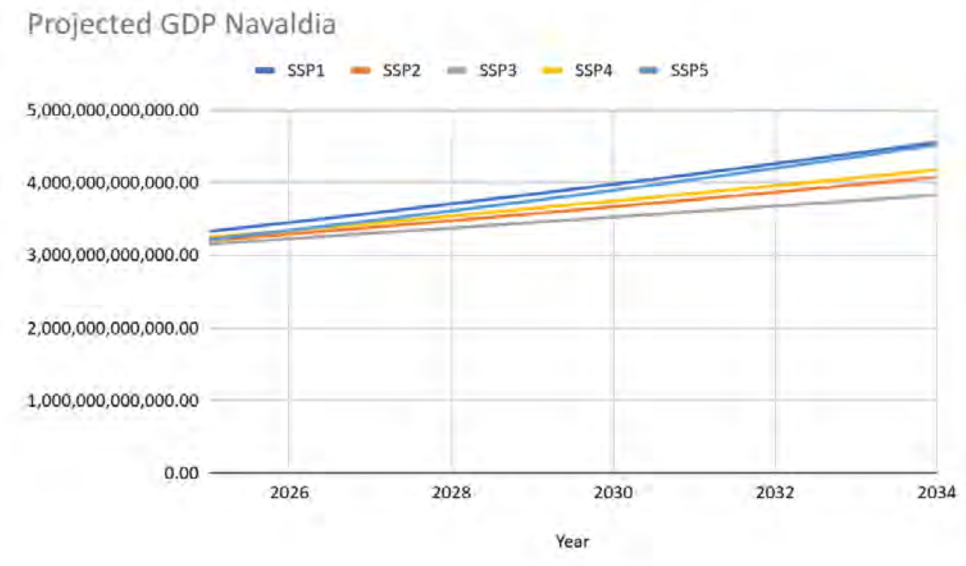
Projected GDP under SSP4

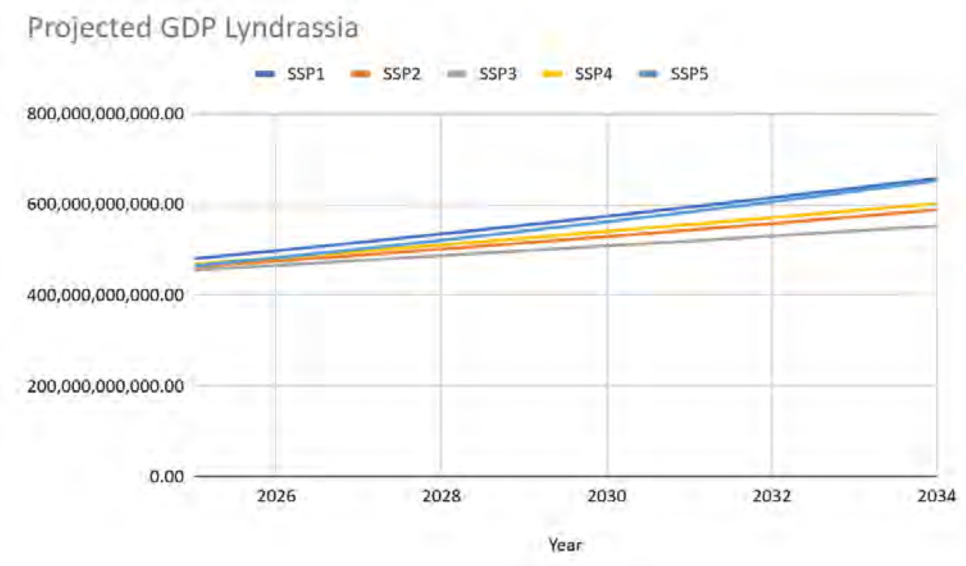
Year	Navaldia	Lyndrassia	Flumevale
2025	3,244,540,000,000.00	467,808,000,000.00	4,166,850,000,000.00
2026	3,342,460,000,000.00	481,927,000,000.00	4,292,610,000,000.00
2027	3,441,890,000,000.00	496,263,000,000.00	4,420,300,000,000.00
2028	3,542,750,000,000.00	510,806,000,000.00	4,549,840,000,000.00
2029	3,644,990,000,000.00	525,548,000,000.00	4,681,140,000,000.00
2030	3,748,540,000,000.00	540,476,000,000.00	4,814,120,000,000.00
2031	3,853,300,000,000.00	555,582,000,000.00	4,948,670,000,000.00
2032	3,959,210,000,000.00	570,853,000,000.00	5,084,680,000,000.00
2033	4,066,180,000,000.00	586,276,000,000.00	5,222,060,000,000.00
2034	4,174,130,000,000.00	601,840,000,000.00	5,360,690,000,000.00

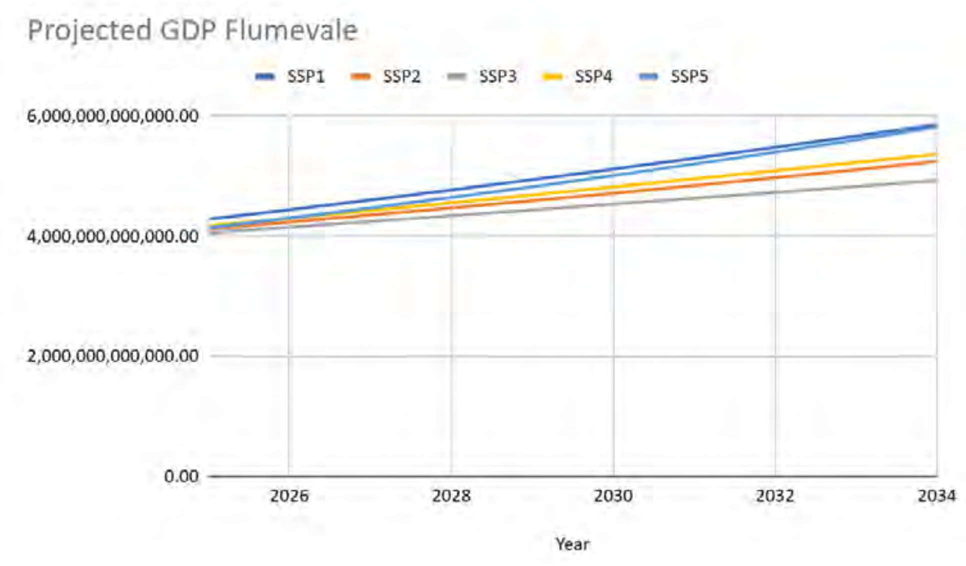
Projected GDP under SSP5

Year	Navaldia	Lyndrassia	Flumevale
2025	3,219,840,000,000.00	464,338,000,000.00	4,136,310,000,000.00
2026	3,346,090,000,000.00	482,545,000,000.00	4,298,490,000,000.00
2027	3,476,700,000,000.00	501,380,000,000.00	4,466,280,000,000.00
2028	3,611,760,000,000.00	520,858,000,000.00	4,639,790,000,000.00
2029	3,751,390,000,000.00	540,993,000,000.00	4,819,150,000,000.00
2030	3,895,670,000,000.00	561,801,000,000.00	5,004,500,000,000.00
2031	4,044,710,000,000.00	583,294,000,000.00	5,195,960,000,000.00
2032	4,198,600,000,000.00	605,487,000,000.00	5,393,660,000,000.00
2033	4,357,440,000,000.00	628,393,000,000.00	5,597,700,000,000.00
2034	4,521,310,000,000.00	652,025,000,000.00	5,808,220,000,000.00

And we also attach the GDP projection graphs for each region under each scenario.

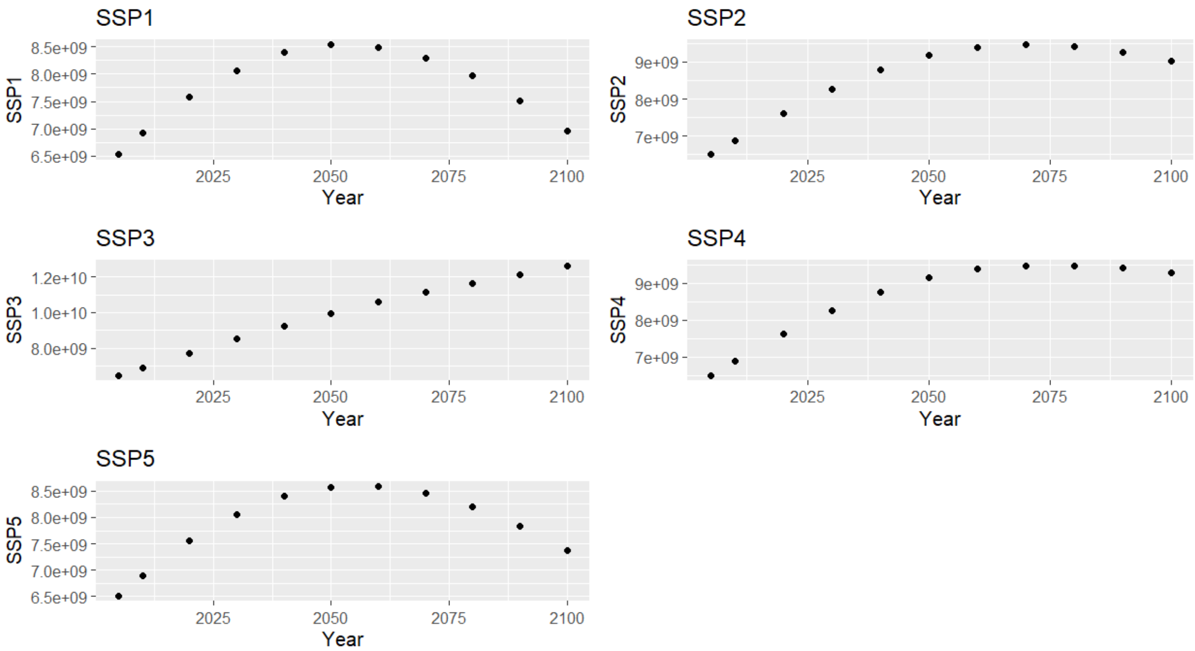

Projected GDP Navaldia
SSP1
SSP2
SSP3
SSP4
SSP5
5,000,000,000,000.00
4,000,000,000,000.00
3,000,000,000,000.00
2,000,000,000,000.00
1,000,000,000,000.00
0.00
2026
2028
2030
2032
2034
Year


Projected GDP Lyndrassia
SSP1
SSP2
SSP3
SSP4
SSP5
800,000,000,000.00
600,000,000,000.00
400,000,000,000.00
200,000,000,000.00
0.00
2026
2028
2030
2032
2034
Year


Projected GDP Flumevale
SSP1
SSP2
SSP3
SSP4
SSP5
6,000,000,000,000.00
4,000,000,000,000.00
2,000,000,000,000.00
0.00
2026
2028
2030
2032
2034
Year

8.9. Appendix I - Population Projections

To project the population or the regions of Taroddan–Navaldia, Flumevale, and Lyndrassia– we used the same methodology as in our GDP projections. As shown below, instead of logistic growth model the SSP-based decadal population data revealed a quadratic trend when plotted against time.



The quadratic model was chosen after visualizing the scatter plots, which suggested a polynomial trend. As shown below. The model fit proved to be highly accurate effectively capturing the trends in the SSP dataset.

```
Call:
lm(formula = SSP3 ~ Year + I(Year^2), data = global_pop)

Residuals:
      Min        1Q    Median        3Q       Max
-36933994 -20354896   3702628  21820451  34169499

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.165e+12  4.631e+10  -25.15 6.69e-09 ***
Year         1.080e+09  4.515e+07   23.92 9.94e-09 ***
I(Year^2)   -2.474e+05  1.101e+04  -22.48 1.62e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 29690000 on 8 degrees of freedom
Multiple R-squared:  0.9998,    Adjusted R-squared:  0.9998
F-statistic: 2.545e+04 on 2 and 8 DF,  p-value: 6.096e-16
```

Using this model, we converted the decadal SSP projections into annual estimates. Finally, we applied the average population shares of each region per SSP to downscale the projections at the regional level. The final population projections for each region under all SSP scenarios are presented below.

Projected Population under SSP1:

Year	Navaldia	Lyndrassia	Flumevale
2025	41,813,445	7,329,300	46,703,958
2026	42,061,804	7,372,833	46,981,365
2027	42,301,673	7,414,879	47,249,290
2028	42,533,053	7,455,437	47,507,732
2029	42,755,944	7,494,506	47,756,692
2030	42,970,344	7,532,088	47,996,169
2031	43,176,255	7,568,181	48,226,164
2032	43,373,677	7,602,786	48,446,676
2033	43,562,609	7,635,903	48,657,705
2034	43,743,051	7,667,532	48,859,252

Projected Population under SSP2:

Year	Navaldia	Lyndrassia	Flumevale
2025	42,107,320	7,381,010	47,034,387
2026	42,433,507	7,438,187	47,398,742
2027	42,752,820	7,494,160	47,755,419
2028	43,065,261	7,548,928	48,104,419
2029	43,370,827	7,602,491	48,445,740
2030	43,669,521	7,654,849	48,779,384
2031	43,961,340	7,706,002	49,105,351
2032	44,246,287	7,755,950	49,423,639
2033	44,524,360	7,804,694	49,734,250
2034	44,795,560	7,852,233	50,037,184

Projected Population under SSP3:

Year	Navaldia	Lyndrassia	Flumevale
2025	42,378,733	7,428,757	47,339,449
2026	42,784,411	7,499,871	47,792,615
2027	43,187,509	7,570,532	48,242,899
2028	43,588,027	7,640,740	48,690,299
2029	43,985,964	7,710,496	49,134,817
2030	44,381,320	7,779,800	49,576,453
2031	44,774,096	7,848,651	50,015,205
2032	45,164,291	7,917,050	50,451,075

2033	45,551,905	7,984,997	50,884,062
2034	45,936,939	8,052,491	51,314,167

Projected Population under SSP4:

Year	Navaldia	Lyndrassia	Flumevale
2025	42,065,373	7,373,625	46,987,178
2026	42,383,062	7,429,312	47,342,037
2027	42,694,591	7,483,920	47,690,016
2028	42,999,961	7,537,448	48,031,116
2029	43,299,172	7,589,897	48,365,336
2030	43,592,224	7,641,266	48,692,676
2031	43,879,117	7,691,555	49,013,136
2032	44,159,851	7,740,765	49,326,717
2033	44,434,425	7,788,895	49,633,417
2034	44,702,841	7,835,945	49,933,238

Projected Population under SSP5:

Year	Navaldia	Lyndrassia	Flumevale
2025	41,575,117	7,287,540	46,437,926
2026	41,839,576	7,333,895	46,733,317
2027	42,096,160	7,378,871	47,019,913
2028	42,344,872	7,422,467	47,297,714
2029	42,585,710	7,464,682	47,566,722
2030	42,818,674	7,505,518	47,826,935
2031	43,043,765	7,544,973	48,078,353
2032	43,260,982	7,583,048	48,320,977
2033	43,470,327	7,619,743	48,554,807
2034	43,671,797	7,655,058	48,779,843

8.10. Appendix J - People and Property at Risk Model

To calculate people and property at risk, we first determine the affected area, which follows a pattern similar to an exponential model. This is because when a dam breach occurs, the water initially spreads rapidly but gradually loses momentum as it travels further, causing the flood extent to diminish over distance—consistent with the characteristics of an exponential function.

$$Area\ affected\ (km^2) = Surface\ (km^2) \times e^{(-distance \times \beta)}$$

with β = 0.0025 for Lyndrassia, β = 0.005 for Navaldia, dan β = 0.01 for Flumevale.
The selection of the beta parameter (β) is based on the geographical characteristics of each region:

- Lyndrassia, a mountainous area, has the lowest β since water flows more rapidly down steep slopes.
- Flumevale, a heavily forested region, has the highest β because trees and vegetation obstruct water movement, slowing its spread.
- Navaldia, a coastal area with relatively flat terrain, is assigned a moderate β as water disperses more evenly compared to mountainous or forested regions.

The formulas for People at Risk and Property at Risk are derived as follows:

$$People\ at\ Risk = Area\ affected \times Population\ density$$

$$Property\ at\ Risk = Area\ affected \times Property\ density$$

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