National Insurance Program

Comprehensive Overview of Risk Assessment

TARRODAN GOVERNMENT

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1. Executive Summary

The growth in occurrences of extreme weather events has impacted many communities and industries alike. Among these, the insurance industry is responsible for alleviating the financial burdens faced by impacted communities and mitigating these risks for those vulnerable. In response to climate-driven disasters, many regions have become “uninsurable” where citizens within these regions face unaffordable premiums, prompting governments to establish national insurance programs to protect these areas.

This independent report aims to deliver a solution to the Tarrodan government in response to growing concerns about the risks surrounding earthen dams’ failures. It suggests the implementation of a national insurance program, a program that is designed to address the economic costs of protecting Tarrodan’s population and encourages the continued maintenance and improvement of the country’s existing earthen dams. This program includes an equitable pricing scheme, characterised by state-imposed levies and the development of hydroelectric plants on existing earthen dams, both of which contribute to a national pool to fund the program. This insurance provides full coverage across all regions and will be introduced alongside policies addressing development restrictions and maintenance and improvement mandates on existing Earthen Dams.

2. Objectives

2.1. Background

Tarrodan is nation rich in natural resources, with water being among its most valuable assets. Abundant rivers, lakes and reservoirs play a crucial in supporting the nation’s economy, communities and unique ecosystems. It is for this reason that its landscape is dotted with earthen dams–19,368 of them to be specific–whose role is crucial in water management, flood control and irrigation. However, despite having about 1 dam for every 5 citizens, many people of Tarrodan remains oblivious to the potential risks lurking among their everyday lives.

It is only in recent years that global disasters, involving dam failures, have brought the awareness and concern to the forefront of the minds of the public and policymakers. In response, the legislature has tasked the Earthen Dam Commission with developing a national insurance program aimed at providing financial relief for communities impacted, as well as promoting maintenance and improvement of dams.

2.2. Main objectives

The Actuarial Task Force, subordinate to the Commission, has set out to do just this. This report will detail the proposals for the insurance program with actuarial calculation and analysis. The main objective, in the word of Chief Actuary Rivera Shore, is to develop a “national insurance program for earthen dams to provide relief for communities impacted by failures and to encourage preventative maintenance and improvements of existing earthen dams”. Additional objectives include a regional equitable pricing structure, appropriate insurance and non-insurance features that can maximize the benefits of the scheme while minimizing the costs.

2.3. Key metrics

The actuarial team has identified several key metrics essential for monitoring the success of the proposed insurance program. These metrics are grouped into two categories—**Financial Health** and **Risk Mitigation**—and will be evaluated on a regular schedule to ensure the program's goals are being met over the selected timeframe.

Financial Health Metrics:

These metrics evaluate the insurance scheme's ability to maintain financial viability, generate revenue, and ensure profitability.

Metric	Evaluates	Reporting frequency
Profitability	Measures the program's surplus or deficit, indicating overall financial health and sustainability.	Quarterly
Levy revenue	Assesses income generated through income levy, tracking adequacy and stability of funding.	Annually (as part of government's budget)
Hydropower revenue	Monitors revenue from hydropower plants to ensure return on investment and stability of an independent funding source	Quarterly

All three are critical for tracking the program's ability to fund administrative overhead, cover claims, and ensure liquidity. Here, we wish to see either an increasing trend or at least a consistent high level, thus ensuring the stability of the insurance scheme for years to come.

Risk Mitigation **Metrics**:

These metrics evaluate the program's effectiveness in reducing risk exposure and potential losses, directly aligning with the program's risk management objectives.

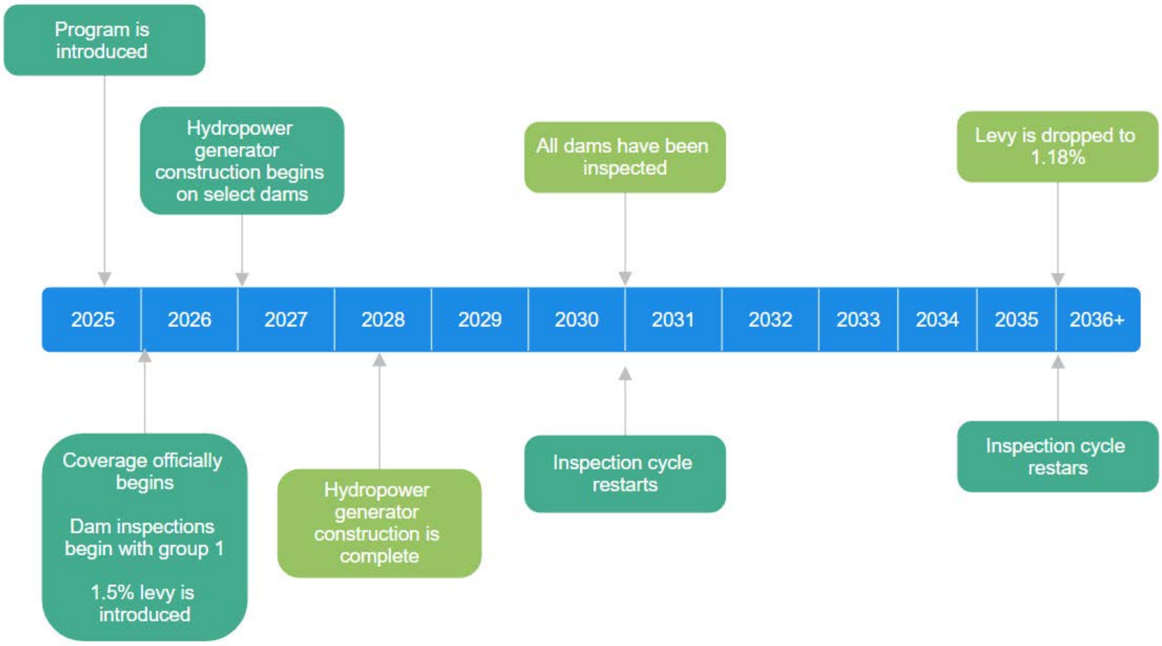
Metric	Evaluates	Reporting frequency
Dam failure probability	Measures the likelihood of dam failure, reflecting the effectiveness of risk mitigation and maintenance efforts.	Annually
Claims Frequency & Severity	Tracks the number and size of claims made, thus assessing the risk exposure and overall trend of losses.	Quarterly

With our non-insurance features in inspection and maintenance, we wish to observe falls in both dam failure probability and claim amounts or a consistently low level that allows the scheme to sufficiently support itself on a sustainable income levy and hydropower revenue.

3. Program Design

3.1. Program description and implementation timeline

The national insurance program is designed to be a mandatory for both the citizens and dam owners of Tarrodan. The program has two separate avenues of funding: the first being a nationally imposed levy on each citizen and secondly the development of hydroelectric generators on existing earthen dams. Claims are to be fully covered by the government; however, reinsurance and the establishment of catastrophe bonds will ensure capital adequacy in the case of extreme circumstances. This program is to be implemented alongside policies that enforce new requirements surrounding earthen dam's inspection, maintenance and improvement.



3.2. Program Funding

This program is designed to be self-sufficient, requiring no external funding or allocation from Tarrodan's current budget. While many dams are primarily constructed for purposes such as flood management, water storage, and irrigation, we can expand their functionality to include power generation, specifically hydropower generation. By integrating hydropower facilities into existing dam structures, we can significantly enhance their utility and economic viability. This innovative approach not only diversifies the revenue streams associated with these infrastructures but also offers a sustainable solution to meet growing energy demands and most importantly, help offset the insurance scheme's cost.

To fund the remainder of the program, a nationwide levy will be imposed on all Tarrodan citizens. Each region is responsible for imposing the levy however the rate is to be consistent across regions being actuarially priced at 1.5%. This levy is a flat rate levy to ensure an equitable contribution of all Tarrodan citizens. Every working citizen must pay the levy as a proportion of their current income. Charging these premiums on each citizen rather than each region eliminates key equitable concerns. Lyndrassia has a high proportion of dams, a lower population and lower average income. If premiums were charged equally nominally among each region, a citizen in Lyndrassia would pay substantially more proportionally on average than a citizen of Navaldia. Charging at a percentage of income ensures that the levy impacts each individual more equitably and charging each individual the same levy regardless of riskiness eliminates inequitable pricing for people in Lyndrassia. This levy is to be imposed on Tarrodan for 10 years to fund the initial years of the program's inception before it drops to 1.18% as funding transitions to hydropower.

3.3. Disaster Insurance

Under this program the Tarrodan government will be responsible for insuring all the citizens of Tarrodan. Similar to Australia's Medicare program, the program acts as a form of mandatory insurance, where all taxpayers contribute to a shared fund that offers coverage to all citizens within the country. Businesses and individuals affected by Earthen Dam failures are to file claims with the government whereafter damages may be assessed and claims can be paid out. As a type of mandatory insurance, the program does not face a risk of adverse selection but may instead be vulnerable to moral hazard. Citizens and businesses may be inclined to construct property, and developments close to earthen dams knowing that they are fully covered by the program. To prevent this behaviour, we propose that building restrictions should be implemented in failure prone areas. Businesses and property developers would need to apply to the government to receive permission developing in these zoned areas. Non-essential developments would be heavily restricted to minimise potential losses incurred if a dam failure was to occur.

3.4. Reinsurance & Catastrophe Bonds

To ensure the Tarrodan government has sufficient funds to pay out claims, specifically under extreme circumstances, the program requires purchasing of reinsurance policies and issuing catastrophe bonds. These measures are designed to protect the government in case of a severe high claim environment, spreading the risk of extreme claim volumes among private reinsurers and investors. Reinsurance is to be handled by the private sector, if there are not enough adequate reinsurer's within Tarrodan, reinsurance may instead be purchased internationally by other reputable reinsurers across the globe. The type of reinsurance to be purchased is excess of loss with a threshold of $750 million with excess on claims exceeding this threshold to be paid by the reinsurer. Catastrophe bonds are the measure limiting risk of excessive claims under the program. These bonds are to be issued to market by the Tarrodan Government and would be publicly purchasable with a maturity period of one year. These bonds will be issued with a clearly defined parametric trigger, that being, if 30 dam failures were to occur within the bond's term the government is able to withdraw funds from these bonds to pay claims. These bonds will be issued with a yield of 10.5%, providing investors with a high yield investment opportunity with returns not traditionally linked to performance of financial markets. This yield was selected to compensate investors with a fair premium for the additional risk that they will take on. Including a parametric trigger that is separate to the reinsurance threshold will assist in dividing risk. In the event of multiple smaller dams failing across the nation the government may expend significant resources in assessing these claims. If these losses are moderate in size but do not reach the reinsurance threshold it may still pose a threat to the government's financial position.

3.5. Maintenance & Improvement Policies

In addition to the aforementioned insurance program, new policies and regulations will be introduced concerning the operations of Earthen Dams. One such regulation is the requirement of an updated maintenance procedure on these dams. This program recommends the establishment of a five-year inspection cycle for all earthen dams. Dams are to be split into separate groups based on the number of years since the last inspection took place.

Group	Classification – Years since last inspection	Amount
Group 1	Unknown	4886
Group 2	Unknown	4886
Group 3	> 5 years	8149
Group 4	< 5 years	2885
Group 5	Buffer if dams are missed	N/A

Each year all the dams within one of these groups will undergo inspections. Inspections are to begin with the dams in group 1, moving up numerically to group 5. Group 5 consists of any dams that missed their inspection date or any freshly built dams to prevent a build-up of inspections on other years. After the fifth year and dams within all five groups have been inspected, then the cycle will restart with inspections resuming from group 1. With this system we can ensure that all dams will be inspected continuously over a five-year period which will be crucial to the preventative efforts in reducing dam failure rates. Our analysis has concluded that the time since the last inspection has a significant impact on the 10-year probability of dam failure.

4. Financial Results

4.1. Projection of the inflows and outflows of resources of the program

In assessing the financial results, the evaluation will focus on analysing the cash inflows and outflows each year over both a short and long-term period. Key cash inflows for Tarrodan's insurers include premium income and reinsurance claims. Outflows include the: reinsurance premiums, insurance expenses and claim payments.

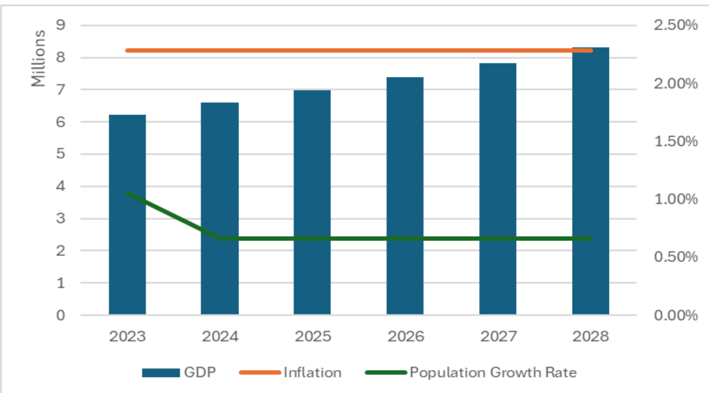
Insurer Net Cash Flow (50th percentile)	Year 1	Year 2	Year 3	Year 4	Year 5
Levy Income	117878	128570	140232	152951	166824
Reinsurance Premiums	-26531	-26815	-27260	-27287	-28083
Insurance Expenses	-26158	-26735	-27176	-27710	-28292
BI Claims	-1688	-2139	-2034	-2026	-2204
Liability Claims	-47209	-50410	-57024	-54472	-63326
Property Claims	-20012	-28452	-25747	-25291	-28033
Reinsurance	12685	25462	21296	20769	24208
Insurer Net Cash Flow	8962	19480	22284	36931	41093

Key cash inflows for Tarrodan's government include levy income and hydropower income. Outflows include reinsurance premiums, insurance expenses and claim payments.

Government Net Cash Flow	Year 1	Year 2	Year 3	Year 4	Year 5
Levy	29789	36368	44400	54205	66176
Hydropower	0	0	0	0	-75992
Inspection subsidy	-134	-154	-180	-189	0
CAT Bond interest (10.5% p.a.)	-1149	-1315	-1506	-1724	-1973
Govt. Net Cash Flow	31284	38293	46860	57359	-10906
Govt. Net Position	31997	75798	134706	212884	232563

4.2. Assessment of the long-term fiscal sustainability

In developing the program, we consider its long-term fiscal sustainability. Through a projection of selected economic measures, we can judge the magnitude of introducing this program on the country.



Due to the nature of funding for the program, as it does not require any extra allocation from Tarrodan's existing budget, this financial impact is not felt by the government. Instead, the financial burden falls on taxpayers through levies.

4.3. Projection of the other expenses without the proposed program

Through an additional assessment we have found the short run net present value and the long run net present value of the program for the government to be $10,448 and $506,398 respectively. With this assessment we find that no additional funding is required to maintain solvent. Our analysis also considers what the implications are for not introducing any policy addressing earthen dam failures. In the scenario that the program is not enacted, individuals will save money in the short term. Individuals are charged a higher levy than their expected loss to accommodate for other cash outflows such as, catastrophe bond yields, inspection costs and the construction of hydropower generators.

Projected Net Cash Flows Without the Program	Year 1	Year 2	Year 3	Year 4	Year 5	Year 10	Year 15	Year 20
Inspection Costs	198	69	98	86	105	98	129	103
BI Losses	2173	2078	2157	2226	2246	2524	2870	3176
Liability Losses	52447	53540	55248	56393	57477	64549	72438	81321
Prop Losses	24040	24462	25301	26107	26444	29523	33378	37149
Total Cash Flow (mean)	78263	79942	82509	84555	85958	96401	108429	121439

4.4. Summary of analysis

Breakdown of Cash flows by Categories

By region	Flumevale	Lyndrassia	Navaldia
Number of dams	3074	7920	8374
NPV of losses (5 years)	76711	116692	139840
NPV of levy (30 years)	2686769	429244	2499175
Number of hydropower plants	48	4	9
NPV of hydropower (30 years)	182089	19434	31146

By age of the dam	<1950	1950 - 1974	1975 - 1999	> 2000	Unknown
Number of dams	3641	10019	3641	926	1141
NPV of losses per dam (5 years)	23	16	14	11	22

By assessment	Satisfactory	Fair	Poor	Unsatisfactory	Not Rated
Number of dams	2833	1898	410	273	13954
NPV of losses per dam (5 years)	26	30	39	43	13

Years Uninspected	< 5 Years	5 – 10 Years	> 10 Years	Unknown
Number of dams	4573	1879	3124	1141
NPV of losses per dam (5 years)	32	23	13	90

5. Assumptions

Metric	Assumed value	Reasoning including analysis
Inflation rate	2.28%	Fitted ARIMA (0,1,0) model predicts a constant inflation rate of 2.28%
Yield curve (p.a.)	5.05% + 0.06% * years into the future	1-year annual spot rate is projected to be 5.11% using a fitted ARIMA (0,1,0) model To ensure an upward sloping yield curve (backed by Tarrodan's strong economic growth), the term spread between the 1-year and 10-year annual spot rate is projected using a fitted ARIMA (0,1,2) model (with ma1=0.0425, ma2=-0.5117) and divided by (10-1) to get the gradient for the yield curve.
Hydropower Revenue	$60 for 1MWh	Most hydropower revenue figures for the dams are unavailable online, so an estimate based on the average cost of 1 MWh was used for revenue calculation which was incorporated into the amount of hydropower generated by each respective dam (DCCEEW, 2023).
Cost of dam's inspection, maintenance and improv.	Refer to Appendix XYZ	Vary widely among different dams due to locations, geographical constraint, budget constraint, usage purpose, etc. The actuarial team therefore relies on flat, general values quoted from the real world, mostly different Department of Natural Resources around the U.S., instead of creating a model that would be constraint by the lack of data.

6. Risk and Risk Mitigation Considerations

The proposed national insurance program for earthen dams is designed to promote risk pooling, enhance dam safety, and protect the financial stability of communities and stakeholders reliant on these critical infrastructures. Despite these objectives, the program is exposed to several quantifiable and qualitative risks that could materially impact its success and financial sustainability. A structured risk analysis has been conducted to assess potential risks, mitigation strategies, and program sensitivity.

6.1. Key Risks

Risk	Description	Mitigation Strategy
Adverse Selection Risk	Only high-risk dam owners (poorly maintained or aging dams) enrol, while safer dams opt out, causing skewed risk pooling and unsustainable claims burden.	All dams are mandated to join the insurance scheme. In addition, dam owners can have their insurance revoked for not maintaining and inspecting their dam regularly. Inspection cost is subsidised to further encourage.
Catastrophic Failure Potential	A rare but severe event causing multiple dam failures simultaneously, thus overwhelming the insurance pool and triggering a financial collapse.	For loss beyond a threshold within the scheme, reinsurers and CAT bonds are involved.
Moral Hazard Risk	Insured dam owners reduce investment on inspection, maintenance, and improvement, thus neglecting proactive risk management in favour of relying on insurance payout.	Regular inspection and maintenance are made a key condition of coverage. Inspection cost is subsidised to further encourage compliance.
Interdependence Risk	Failures of interconnected dams or a cascading impact on a river system could result higher risk than previously calculated on an individual dam failure model	Since this insurance scheme has no underwriting process, it must rely on monitoring of high-risk river system and being stringent in enforcement of inspection and maintenance.

6.2. Risk Ranking

	Low Likelihood	Medium Likelihood	High Likelihood
Low Impact	Ethical & Equity Risk (7)	Moral Hazard Risk (4)	
Medium Impact	Adverse Selection Risk (2)	Pricing Risk (6)	
High Impact	Catastrophic Failure Potential (3) Climate Change Acceleration Risk (8)	Participation Risk (1) Interdependence Risk (5)	

As shown in the risk matrix, the most significant risks for the national insurance program for earthen dams generally cluster around low-to-medium likelihood but high potential impact on the program's financial sustainability. Catastrophic failures and climate change acceleration risks represent rare but highly impactful threats that could overwhelm the insurance pool. Participation, interdependence, and pricing risks also pose considerable concerns if not mitigated properly. Appropriate mitigation strategies—including mandatory participation, subsidies, strict inspection requirements, and risk transfer via reinsurance—are in place to reduce these risks and protect the program's long-term viability.

6.3. Risk Sensitivity

ASSUMPTION	Levy_Rate_0.01_Solvency		Recommended Change
	Scenario 1	Scenario 2	
Economic Growth and Inflation	1.15%	1.21%	The sensitivity analysis helps us understand how changes in economic conditions and dam failure risks affect the levy rate needed to keep insurers financially stable. When the economy is strong, with **higher growth (7%) and moderate inflation (3%)**, the required levy rate is **1.15%**. However, if economic growth slows to **5% with lower inflation (1%)**, the levy rate rises to **1.21%**, showing that weaker economic conditions put more pressure on funding requirements.
Yearly failure probability increment	1.22%	1.23%	Similarly, when we look at how often dams might fail, a **lower increase in failure probability (0.008%)** results in a levy rate of **1.22%**, whereas a **higher increase (0.005%)** pushes it slightly higher to **1.23%**. These findings suggest that setting the levy rate around **1.21%–1.23%** would provide a safer buffer, ensuring the financial sustainability of the program even in less favourable conditions.

6.4. Climate Risks

Climate change poses significant threats to Tarrodan's dams. Shifting weather patterns, including prolonged droughts, intense rainfall and more frequent extreme events, are pushing dams beyond their original design limits. Extended dry periods can cause soil shrinkage and cracking in earthen embankments, weakening structural integrity, while heavy rainfall increases the risk of overtopping, erosion and internal seepage (piping). Rising temperatures further compound these vulnerabilities through material degradation and thermal stress. As these pressures build, the risk of cascading failures, where one dam breach triggers others downstream, is an increasing concern, particularly in densely interconnected catchment systems.

To address these extreme weather conditions, the program will include two key components. First, all dams will be required to undergo mandatory annual inspections to ensure they remain in safe and functional condition. Second, following the program's implementation, civilians seeking to reside in higher-risk dam zones will be subject to a higher levy. This measure aims to discourage settlement in vulnerable areas and reduce potential exposure to dam-related hazards.

7. Data and Data Limitations

In addition to the data provided with the case study (e.g., dam types, failure rates from the data file), the following external data sources were identified and utilized to support the analysis and risk assessment for the national insurance program.

7.1. Data Sources

Source	Description
Tarrodan Dam Data	Includes everything: encyclopedia entry, earthen dam data, economic data from the nation of Tarrodan.
Hydropower calculations	Revenue was analysed using dam height, but other factors like geography and hydrology may also influence costs. Additionally, sample size of ~30 dams may risk of overfitting, limiting generalisation.

7.2. Data Limitations

Limitation	Description	Impact
Ownership data	Data relating to split between public/private ownership of Tarrodan's dam is not given	Assumptions were made during the calculation of premium – especially where the burden of payment lies
Spatial dam data	Spatial data, especially regarding the geography and location, is very important in determining the safety and risk level of the dam	The team is forced to assume that all dams are independent – hence dams' failure rates are independent as well

8. Conclusions

The implementation of a national insurance program for earthen dams in Tarrodan is a critical step toward safeguarding communities, mitigating financial risks, and promoting infrastructure resilience. This report has outlined a structured approach that balances financial sustainability, equitable contributions, and risk management strategies to ensure the program's long-term success. Through a combination of state-imposed levies and hydroelectric revenue, the program is designed to be self-sustaining, eliminating the need for external government funding. The risk transfer mechanisms, including reinsurance and catastrophe bonds, ensure capital adequacy even in the face of extreme dam failures. Additionally, policy measures such as mandatory inspections, development restrictions, and maintenance enforcement will proactively reduce dam failure risks over time. The sensitivity analysis highlights the financial stability of the program under varying economic conditions and failure probabilities, reinforcing its adaptability. Climate risks remain a major challenge, but the program's inspection mandates, and location-based levies provide a proactive framework to mitigate these threats. Overall, this insurance scheme is not just about financial protection—it is about ensuring public safety, enhancing infrastructure resilience, and fostering economic stability. By integrating insurance with proactive risk management and sustainable funding sources, Tarrodan can build a future-proof solution that safeguards its citizens, supports responsible development, and secures the nation's critical water infrastructure for generations to come.

9. Appendix

9.1. Hydropower Generation

To explore the feasibility of this initiative, we conducted an analysis of 30 real-life dams located across the globe. We considered three categories: dam height, initial implementation costs for hydropower systems, and annual revenue generated. The dataset allows us to examine a range of scenarios and outcomes, providing a comprehensive understanding of the potential benefits and challenges associated with hydropower integration. We developed two distinct revenue and cost forecasting models using R programming. These models are tailored to assess the financial viability of hydropower installations suitable within the Tarrodan context. Our analysis aims to project not only the immediate financial impacts but also the long-term sustainability of these projects, ensuring that our insurance products are consistently financed over the next decade and beyond. On a side note, we must consider the fact that all dams are not perfect candidates for generating hydropower energy. In theory any dam can be used to generate electricity; however, we should only consider dams that are large in height to generate sufficient energy amounts. To assess which ones can, dams must be 100m or above in height. Overall, we found 61 dams from Tarrodan which fit this criterion. Using R code, we established a regression model to analyse the relationship between the height of a dam (in meters) and the revenue generated from hydropower:

```
> summary(model1)

Call:
lm(formula = Revenue ~ Height)

Residuals:
       Min         1Q     Median         3Q        Max 
-2.296e+09 -7.908e+08 -3.203e+08  6.619e+08  4.314e+09 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)  
(Intercept) 338036777  654578007   0.516   0.6101  
Height        8775810    4045751   2.169   0.0398 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.452e+09 on 25 degrees of freedom
  (1027803 observations deleted due to missingness)
Multiple R-squared:  0.1584,	Adjusted R-squared:  0.1247 
F-statistic: 4.705 on 1 and 25 DF,  p-value: 0.03978
```

The resulting equation is $Revenue = 338036777 + (8775810 * Height)$

The model suggests that for every additional meter in dam height, the revenue generated increases by approximately $8,775,810. This linear relationship indicates a strong correlation between dam height and revenue, highlighting the potential for greater financial returns as the height of the dam increases. To validate the robustness of our regression model, we assessed its statistical significance. The p-value of Height (0.0398) obtained from the analysis is below the threshold of 0.05, which corresponds to a 95% confidence interval. This result indicates that we can reject the null hypothesis and conclude that there is a significant relationship between the height of the dam and the revenue generated. The generated income from the hydropower facilities was further utilised to model the relationship between the initial implementation cost of hydropower systems and the revenue produced. This analysis is crucial for understanding financial profits of integrating hydropower into dam infrastructure. The resulting equation from our regression analysis is as follows:

```
Call:
lm(formula = Cost ~ Revenue)

Residuals:
       Min         1Q     Median         3Q        Max 
-1.014e+10 -3.850e+09 -8.495e+08  3.181e+09  1.639e+10 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 1.804e+08  1.591e+09   0.113    0.911    
Revenue     4.153e+00  7.017e-01   5.918 3.05e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.661e+09 on 26 degrees of freedom
  (1027802 observations deleted due to missingness)
Multiple R-squared:  0.5739,	Adjusted R-squared:  0.5575 
F-statistic: 35.02 on 1 and 26 DF,  p-value: 3.046e-06
```

The equation is as follows: $Initial\ Cost = 0.911 + (3.05e - 06 * Revenue)$

This equation indicates that there is a positive linear relationship between the revenue generated and the initial cost of implementing hydropower. Specifically, for each unit increase in revenue, the initial implementation cost increases by approximately 3.05×10^{-6}. The p-value of Revenue (3.05e-06) obtained from the analysis is below the threshold of 0.05, which corresponds to a 95% confidence interval. This result indicates that we can reject the null hypothesis and conclude that there is a significant relationship between the Revenue of the dam and the Initial cost.

Overall, considering all factors: the Revenue and Cost each dam in Tarrodan is as follows:

	Estimated_Revenue	Estimated_Cost
1	1220470800	5249015232
2	1530564046	6536832484
3	1557891919	6650325138
4	1290852796	5541311662
5	1454644514	6221538667
6	1435478145	6141940736
7	2107108436	8931221334
8	1284806263	5516200410
9	1267123006	5442761843
10	1312239445	5630130416
11	1360278229	5829635485
12	1272116442	5463499583
13	1283454788	5510587736
14	1377452489	5900960188
15	1462849896	6255615619
16	1224305829	5264942107
17	1283893579	5512410033
18	1267877726	5445896194
19	1561674293	6666033338

With the average cost of dams spread over a nine-year period, the overall estimated cost will be evenly distributed across those years. After this period, the dams are expected to generate consistent estimated revenue every year.

9.2. Earthen Dam Risk Management

9.2.1. Identification of each dam type

By using the unique function in RStudio, we can identify all the possible types of dams present in Tarrodan. There are 12 different types: Earth, Concrete, Rockfill, Timber Crib, Gravity Stone, Arch, Buttress, Masonry, Roller-Compacted Concrete, Multi-Arch, and Other. Note that some dams have not been classified at all. Next, we might be interested in the numerical distribution for each type of dam. Using the table function, we can obtain the following table:

Arch	Buttress	Concrete	Earth	Gravity
44	73	259	19368	393
Masonry	Multi-Arch	Other	Rockfill	RC Concrete
17	12	106	221	14
Stone	Timber Crib	NA		
30	12	257		

As we can see, earthen dam completely dominates as the most-widely used type in Tarrodan. As such, our research will focus solely on it. However, we will keep in mind other types of dams to when looking at maintenance and possible improvement of earthen dam.

9.2.2. Inspecting an Earthen Dam

Owning a dam is expensive and time-consuming work, regardless of whether it is privately or publicly owned. However, it is much less expensive compared to the catastrophic damage of a dam failure. In fact, prior to 9/11, the worst man-made disaster in the US is the South Fork Dam collapse in 1889, killing 2,209 people and causing $450 million in damage (Nebraska DNR, 2024). As such, it is crucial for all dam owners and inspectors to closely monitor the condition of the dam and immediately remedy any emerging risk. An effective inspection program is essential for monitoring a dam. It should involve 3 types of inspections: (1) periodic technical inspections, (2) periodic maintenance inspections (e.g. every 3-4 months and after every major rainfall), and (3) informal observations by operating personnel (FEMA, 1987). Technical inspection should be done by specialists familiar with the design and construction of the dam. This is the often quite expensive, with the Montana Department of Natural Resources & Conservation estimating $27,000 per dam for a Five-year dam Inspection & Safety Evaluation. In our dataset, we shall inspect all dams (1) whose last assessment date is five years ago or more from current date, (2) that have no assessment data, or (3) that are not regulated. Meanwhile, a maintenance inspection can be performed more frequently by non-specialist professional or trained individual with the appropriate checklist. Lastly, the third type of inspection is an ongoing effort by onsite personnel (e.g. powerhouse operators, dam tenders) to provide the first 2 inspection teams with the most up-to-date information and any immediate threat to the dam. Regarding maintenance inspection, there are 4 main aspects to consider: spillways are not plugged or obstructed, seepage from the dam has not emerged or increased, soil erosion has not developed, and holes or cracks in the dam have not appeared. Particular attention should be paid to the principal spillway and the downstream slope. An example checklist can be found on the Nebraska Department of Natural Resources website. In addition to visual observations done informally by on-site operators, very large and/or at significant risk dams should also implement and instrumentation program. This will allow inspectors to determine if the structure is functioning as intended and provide a round-the-clock ability to survey the dam for any unsafe developments. An example of a comprehensive instrumentation program would include (JETIR, 2019):

Tilt meter	Measure tilt/inclination to detect movement & deformation, indication of instability
Piezometers	Measure pore water pressure within dam/foundation, charting seepage pattern and dam stability
Seismometer	Detect and measure seismic and vibrational activity, checking structural integrity
Temperature sector	Measure temperature change, which can indicate seepage/other issues
V-notch weir	Measure flow rate of water seeping through or around dam
Stress meter	Measure stress within dam's materials and chart its response to loads and pressures
Uplift pressure cell	Measures the upward pressure exerted by water seeping under the dam

When considering the financial aspect of implementing monitoring and instrumentation program for earthen dam, it is important to consider reliability, simplicity and life cycle cost instead of just the total price tag. When faced with the catastrophic cost of dam failure and the labour cost required to ensure stringent structural safety standard, it may sometimes be cost-effective to install redundant equipment (FERC, 2020). All these considerations can mean that an effective and reliable instrumentation and monitoring program can be expensive, ranging from 1% to even 3% of total construction cost of the dam (Bamane, 2014)

9.2.3. Maintaining an earthen dam: methodology and cost

Maintaining an earthen dam is a continuous and ongoing effort to promote the safety of the structure and the communities in its proximity. Maintenance work can range from simple top-up of soil or rock protection to costly and time-consuming full-scale engineering project. Luckily, for the majority of cases, it is the former, and it is these regular and adequate maintenance that prevent a simple issue from spiralling into a disaster. The main areas to look for are the spillways and the embankment crest. Generally, spillway can be repaired in such a way that the designated flood capacity is not reduced. It should also be clear of debris accumulation, which can be achieved with trash racks and clearing away any material capable of clogging near the spillway. The piping leading to the spillway should also be fitted with anti-seep collar to prevent seepage along the pipes, thus preventing internal erosion. Regarding the embankment, the crest should be wide and stable enough to allow service vehicles and crews to access. Minor repairs on eroded section of the dam's wall should be immediate and top-up with protective topsoil to prevent further erosion (NRE Tasmania, 2024). Vegetation, especially any hearty variety of grass, is crucial for covering the embankment crest and slope (DES New Hampshire, 2020). This prevents erosion and retain soils from being washed away. Finally, always maintain a freeboard, the distance between maximum anticipated water level and the top of the dam should be maintained to prevent wind induced wave overtopping the dam. The cost for an effective maintenance program can widely varied, but it is mostly depended on the size and geographical characteristics of the earthen dam. Vegetation control, soil top-up and removal, as well as regulatory costs should be the majority of where the cost is coming from. A source from the Michigan DNR shows that "EGLE dam safety inspections and routine maintenance" cost about $6,000 per dam annually. In addition, "annual operations and maintenance would cost roughly $600 per acre" for any expansion. From another source, it is stated that "annual O&M costs, expressed as a % of final dam cost, varies from 0.14% to 0.35%, though these O&M costs do not include major upgrades" (Petheram, 2019).

9.2.4. Rehabilitating an Earthen Dam: Methodology and Cost

Dam rehabilitation, at least in the U.S., has been researched quite extensively and luckily for us, there are data on the cost associated with rehabilitating a dam. Even better, dam height–the most complete data column in our dataset–has been identified as the single most effective indicator of overall size and cost of repair (Dam Safety, 2016). Below is the data:

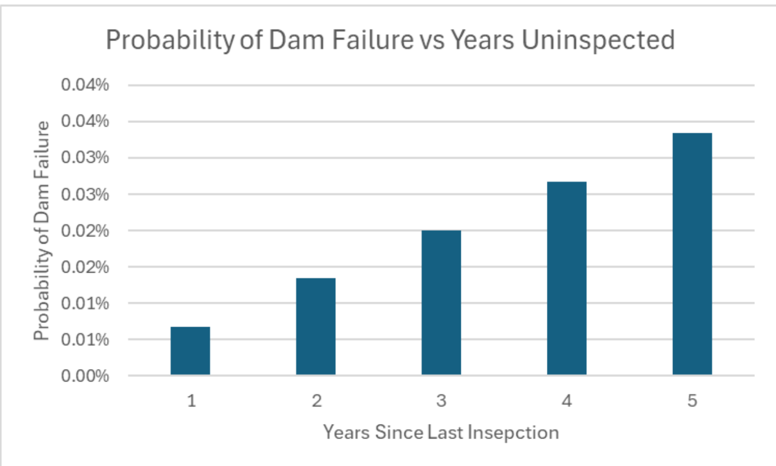
Size-based category	*Cost estimate per rehab project*
<= 15 ft	$276,098/project
16 ft <= 25ft	$649,821/project
26 ft <= 50 ft	$1,685,834/project
50 ft	$8,851,025/project

*This is quite comprehensive and shall be the benchmark for improvement cost for dams (1) assessed "*Unsatisfactory*" or lower, or (2) whose "Years Modified" is 50 years or more from the current date (2025).*

9.3. Additional Risks

Pricing Risk	Incorrect calculation of premiums, leading to difference between liability and income. Therefore, the scheme may become insolvent.	Since private insurers are the involved, a lot of the due diligence will be done by them. However, the Task Force has already calculated using very conservative measures (e.g. no income growth to further fund levy). In addition, cashflow monitoring and repricing are possible considerations.
Ethical and Equity Risk	Disadvantage to small or low-income dam owners who may be unable to afford the premium and/or the cost of inspection and maintenance	All dam owners receive a flat subsidy that is large enough to pay off the premiums for all owners in the bottom 30th percentile. In addition, inspection fee is subsidised for all.
Climate Change Acceleration Risk	Increase in abnormal, extreme weather events around the world. This can accelerate risk associated with dam deterioration and dam failures.	The subsidy for inspection should help dam owners react adequately and in time to any issue arising. In addition, the task force has performed stress test and conservative estimate to account for worsening condition.
Participation Risk	Lower-than-expected enrolment of dam owners/operators into the insurance program, reducing the effectiveness of risk pooling.	All dams are mandated to join the insurance scheme. In return, all dam owners are subsidised by a flat sum, thus proportionally helping out smaller dams.

9.4. Additional Risks



9.5. R Codes

```
setwd("C:/Users/61416/OneDrive/Desktop/Projects/2025 SOA Case Study")

econ_data <- read.csv("srcsc-2025-economic-data-summary.csv", header=T, skip=5)
econ_data <- econ_data[-c(6,7)] # remove empty rows
names(econ_data) <- c("Year", "Infl", "GoT_Overnight", "RFA_Spot_1", "RFA_Spot_10")

econ_data$Infl <- as.numeric(sub("%","",econ_data$Infl))/100
econ_data$GoT_Overnight <- as.numeric(sub("%","",econ_data$GoT_Overnight))/100
econ_data$RFA_Spot_1 <- as.numeric(sub("%","",econ_data$RFA_Spot_1))/100
econ_data$RFA_Spot_10 <- as.numeric(sub("%","",econ_data$RFA_Spot_10))/100
econ_data$Term_Spread <- econ_data$RFA_Spot_10 - econ_data$RFA_Spot_1 # created

attach(econ_data)

data.frame(Year, Infl)

### INTEREST AND INFLATION RATE

plot(Year, Infl, col="white", ylim=c(0,0.2), ylab="Rate")
lines(Year, Infl)
lines(Year, GoT_Overnight, col="blue")
lines(Year, RFA_Spot_1, col="red")
lines(Year, RFA_Spot_10, col="orange")
lines(Year, Term_Spread, col="yellow")

library(forecast)
library(tseries)
library(vars)

# Stationarity tests (conclusion: all require differencing)
# adf.test(ts(Infl)); adf.test(ts(diff(Infl))) # p-value = 0.3457, 0.01 (differencing required)
#  adf.test(ts(GoT_Overnight));  adf.test(ts(diff(GoT_Overnight)))  #  p-value  =  0.2743,  0.01
(differencing required)
# adf.test(ts(RFA_Spot_1)); adf.test(ts(diff(RFA_Spot_1))) # p-value = 0.3287, 0.01 (differencing
required)
#  adf.test(ts(RFA_Spot_10));  adf.test(ts(diff(RFA_Spot_10)))  #  p-value  =  0.4325,  0.04354
(differencing required)
#  adf.test(ts(Term_Spread));  adf.test(ts(diff(Term_Spread)))  #  p-value  =  0.2009,  0.01
(differencing required)

# Fitting
infl_model <- auto.arima(Infl) # ARIMA(0,1,0) (random walk with trend)
goto_model <- auto.arima(GoT_Overnight) # ARIMA(0,1,2); ma1=0.2547, ma2=-0.5117 (cyclically (2
years) self-correcting? )
spot1_model <- auto.arima(RFA_Spot_1) # ARIMA(0,1,0) (random walk with trend)
spot10_model <- auto.arima(RFA_Spot_10) # ARIMA(0,1,1); ma1=-0.419 (self-correcting)
ts_model <- auto.arima(diff(Term_Spread)) # ARIMA(0,1,2); ma1=0.0425, ma2=-0.7464

# Forecasts
par(mfrow=c(2,2))
plot(forecast(infl_model)) # predicts a constant inflation rate of 2.28%
plot(forecast(goto_model)) # predicts a long-run government overnight rate of 3.85%
plot(forecast(spot1_model)) # predicts a constant 1-year spot rate of 5.11%
plot(forecast(spot10_model)) # predicts a constant 10-year spot rate of 4.22%
insolv_perc <- c(0.01) # in increasing order

ts_fcst <- tail(Term_Spread, 1) + cumsum(forecast(ts_model, h = 10)$mean); ts_fcst # predicts a
long-run term spread of 0.5314%
plot(c(Term_Spread, ts_fcst), main = "Term Spread Forecast", xlab = "Time", ylab = "Term Spread")

plot(forecast(spot1_model)$mean + ts_fcst) # artificially predicts a long-run 10-year spot rate
of 5.64% (artificially restricted to >1y)
# high compared to US but justified by strong economic growth of Tarrodan
```

```
# FINAL YIELD CURVE (5.05% + 0.06% * yrs)
ts_fcst[10]/9 # YIELD CURVE GRADIENT
forecast(spot1_model)$mean[10] - ts_fcst[10]/9 # YIELD CURVE Y-INT



### OTHER DATA PROCESSING (encyclopedia data)

## Economy statistics

# Nominal GDP for years 2019-23
nom_gdp <- data.frame(2019:2023,
                      c(3306924, 3313625, 3691682, 3963845, 4197489),
                      c(369632, 370374, 407195, 447382, 480201),
                      c(2544348, 2460436, 2798390, 3202171, 3396363),
                      c(6220904, 6144435, 6897267, 7613398, 8074053))
names(nom_gdp) <- c("Year", "Flumevale", "Lyndrassia", "Navaldia", "Tarrodan")

# Deflator (1 + inflation rate) for years 2019-23
defl <- 1+Infl[58:62]

# Real GDP for years 2019-23
real_gdp <- nom_gdp
for (i in 2:5) {
  real_gdp[,i] <- real_gdp[,i] / defl
}

# Economic growth for years 2019-23
e_growth <- data.frame(c("2019-20", "2020-21", "2021-22", "2022-23"))
for (i in 2:5) {
  e_growth[,i] <- diff(real_gdp[,i])/real_gdp[-5,i]
}
names(e_growth) <- c("Year", "Flumevale", "Lyndrassia", "Navaldia", "Tarrodan")

# Distribution of GDP by Industry
gdp_indus <- data.frame(c("Agriculture", "Entertainment", "Construction", "Education", "Finance",
"Information", "Manufacturing", "Mining", "Professional Services", "Retail", "Transportation",
"Utilities", "Trade", "Government", "Other"),
                        c(0.059, 0.047, 0.041, 0.076, 0.188, 0.075, 0.100, 0.007, 0.122, 0.060,
0.033, 0.014, 0.054, 0.106, 0.018),
                        c(0.019, 0.046, 0.049, 0.101, 0.155, 0.032, 0.109, 0.088, 0.102, 0.069,
0.037, 0.015, 0.067, 0.087, 0.024),
                        c(0.007, 0.036, 0.059, 0.090, 0.188, 0.039, 0.113, 0.007, 0.129, 0.062,
0.055, 0.018, 0.088, 0.090, 0.019))
names(gdp_indus) <- c("Industry", "Flumevale", "Lyndrassia", "Navaldia")

## Housing statistics
house_vals <- data.frame(c("<Q50k", "Q50-100k", "Q100-150k", "Q150-200k", "Q200-300k", "Q300-
500k", "Q500k-1m", ">Q1m", "Total"),
                         c(446720, 552111, 887815, 1219671, 2730435, 2521934, 5165736, 2386698,
15911120),
                         c(206960, 414955, 471356, 448956, 572280, 532740, 268786, 51349,
2967382),
                         c(871223, 1593970, 2169919, 2505863, 3816207, 3189802, 1825774, 351150,
16323908),
                         c(1524903, 2561036, 3529090, 4174490, 7118922, 6244476, 7260296, 2789197,
35202410))
names(house_vals) <- c("Value", "Flumevale", "Lyndrassia", "Navaldia", "Tarrodan")
```

```
# Population growth for years 2019-23
pop_growth <- data.frame(c("2019-20", "2020-21", "2021-22", "2022-23"))
for (i in 2:5) {
  pop_growth[,i] <- diff(popul[,i])/popul[-5,i]
}
names(pop_growth) <- c("Year", "Flumevale", "Lyndrassia", "Navaldia", "Tarrodan")

# Population distribution
urbanisation <- data.frame(c("Urban (>50k)", "Urban (<50k)", "Rural"),
                           c(0.882, 0.057, 0.061),
                           c(0.524, 0.16, 0.316),
                           c(0.388, 0.239, 0.373))
names(urbanisation) <- c("Type", "Flumevale", "Lyndrassia", "Navaldia")

## Population density
pop_dens <- c(67.4, 13.0, 53.2)
names(pop_dens) <- c("Flumevale", "Lyndrassia", "Navaldia")



### FINAL STATISTICS
nom_gdp; real_gdp; e_growth # Q millions
gdp_indus # 2023
house_vals # distribution of number of housing units by value
popul; pop_growth
urbanisation # 2023
pop_dens # km2, 2023

### LONG-RUN RATES
LR_overn <- 0.0385
LR_ycurve <- function(yr) {0.0505 + 0.0006 * yr}
LR_infl <- 0.0228
# Due to the limited data available (n=4) and high variability in the data for econ + pop growth, we
will use the mean as our LR econ. growth
LR_egrowth <- mean(e_growth$Tarrodan)
LR_popgrowth <- mean(pop_growth$Tarrodan) # assume constant population growth
```

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