The Catastrophe Relocation and Displacement Program (CRDP)

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2023 Student Research Case Study Challenge

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Executive Summary

With the continual growth of natural catastrophe risk in Storslysia, Relocation Station has carefully crafted a social insurance program capable of handling residents' exposure to displacement through government-provided benefits. Storslysia's Catastrophe Relocation and Displacement Program, known as the CRDP, will serve as a complement to a traditional homeowners insurance policy and focuses on ensuring resident safety during and after hazard events through evacuation, emergency, and temporary housing. Additional benefits offered within the displacement assistance feature will include food, transportation, child care, rental assistance for low-income families, and mental health support. Accompanying this will be an innovative voluntary relocation feature, focused on controlling costs and fatalities related to hazard events by incentivizing migration from hazardous regions to less hazardous regions.

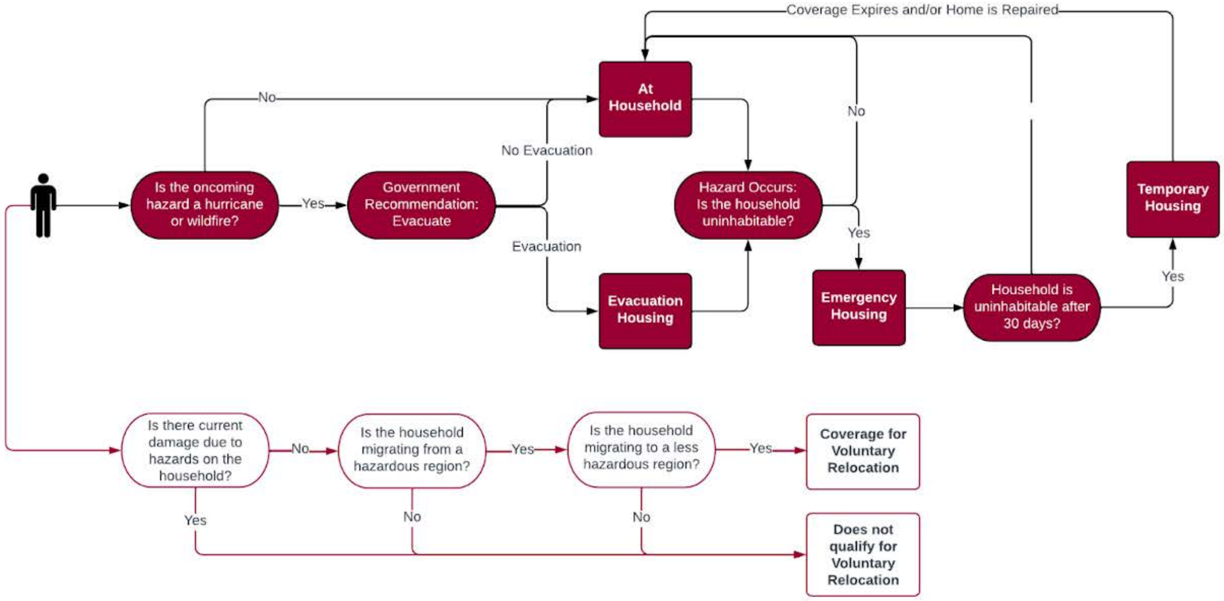
This report details the unique program features of the CRDP and clear justification behind each benefit. Actuarial analysis has been conducted to calculate costs related to involuntary displacement benefits and a voluntary relocation feature; this analysis demonstrates significant savings in displacement costs for Storslysia across all years if relocation incentives are provided. Additional risk assessment considers program risks including catastrophic annual losses, future environmental scenarios known as Shared Socioeconomic Pathways (SSPs), and inflation trends to ensure with high certainty that the program's total cost remains securely under the budgeted 10% of countrywide GDP. Storslysia residents remain the most important stakeholders for this program, and the report confidently illustrates the improvement in safety and the reduction in economic burden that residents can realize under the CRDP.

This design is set for full implementation beginning Jan. 1, 2025, and will remain in place for 20 years, with consideration to renew for future use dependent on whether displacement cost savings related to hazard events have been actualized. Due to the limited scope of available data used in modeling covered hazards, the recommendation is to maintain quarterly reports to monitor the frequency and severity of displacement costs as well as costs of the voluntary relocation program. Furthermore, hazard models should be assessed yearly while program features should be reevaluated every five years to ensure program solvency. As the 20-year program duration concludes, overall program performance, measured by resident utilization and cost savings, will be analyzed to determine if an extension is justifiable.

CRDP Program Design

The CRDP includes both a displacement assistance feature and voluntary relocation feature. Displacement assistance includes three main coverages, each with a unique purpose: evacuation housing, emergency housing, and temporary housing. Evacuation coverage is available for hurricanes and wildfires because of their high severity and early evacuation warning systems. Following a hazard event, a government assessor will deem properties unlivable to determine if residents meet the qualification for coverage. Finally, it is assumed throughout the duration of coverage, residents will be working towards the reconstruction of their households and will exit temporary housing once either safe conditions are established or coverage expires. The voluntary relocation feature is designed to benefit households taking initiative to proactively avoid hazard-related risk. The coverage and specific requirements of both programs are delineated below, as well as incentives for residents to participate in voluntary relocation (see Figure 1).

Figure 1: The CRDP Decision Process



Displacement Assistance Feature

Displacement due to natural hazards can last for weeks and has traditionally been a financial burden for residents. To support the people of Storslysia, the displacement assistance feature provides financial and logistical support for housing, food, transportation, and other living costs. Below is an overview of coverage and qualifications:

- **Basic Necessities:** Up to 90 days (dependent on hazard) of post-hazard housing, temporary goods, food, and transportation is available. Coverage is included for the duration of evacuation, emergency, and temporary housing.
- **Child Care:** Coverage is available to heads of households with children below age 10.
- **Housing Relief and Wage Support:** Full wage and housing relief is available for those below the poverty line throughout the duration of coverage.
- **Mental Health Coverage:** Up to 6 months of clinical visits with a licensed mental health professional is available to all displaced residents.

Impoverished persons are twice as likely to live in areas highly susceptible to catastrophe damage and often reside in more fragile housing (Amburn). For this reason, impoverished persons are expected to be displaced at a higher rate and therefore are given additional coverage to avoid further financial hardship (see Appendix A for details).

Displacement assistance is available to residents affected by the following hazards: hurricanes, wildfire, landslide, flooding, tornado, precipitation and wind (see definitions in Appendix B). It's important to note that the CRDP does not cover relocation due to heat and drought due to the high risk of moral hazard. Certain hazards such as hurricanes or tornadoes have proven to consistently cause higher damages, more fatalities, and more injuries. For this reason, more severe hazards are assumed to cause the displacement of more residents for longer periods of time. Appendix A details the breakdown of duration by hazard for evacuation, emergency, and temporary housing. To receive displacement assistance coverage, residents can relocate to any emergency and evacuation housing center. From there, residents must file a claim to be admitted into temporary housing. Once coverage has expired or residents return home, participants can file for reimbursement for all covered expenses incurred during displacement.

Voluntary Relocation Feature

The voluntary relocation feature encourages Storslysia residents to relocate to less hazardous regions, offering a buyout program and coverage for moving costs. Prior to utilizing the voluntary relocation feature, residents will submit applications if electing to proactively relocate, which will be reviewed by government assessors to ensure that the move is from a hazardous region (2, 3, 5) to a less hazardous region (1, 4, 6) and that the property is undamaged.

As an incentive to encourage relocation from hazardous regions, the CRDP buyout program will offer Storslysia residents the assessed value of their property. When the Storslysia government acquires properties through the buyout program, it will inhibit future occupancy of the properties. This will decrease the utilization of the displacement assistance feature and the number of injuries and fatalities, as fewer residents will live in hazardous regions. The Storslysia government can decrease net cost of the buyout program by repurposing the acquired properties.

CRDP Modeling and Pricing

Hazard Models

Projecting the expected costs of the displacement assistance feature required modeling of property damage for hazard events throughout the program duration. Hazard events were first grouped into overarching hazard categories, aligning with coverage design and shared weather characteristics (see Appendix C). After data transformations were applied, property damage from each hazard category was analyzed separately within each region, creating a two-dimensional modeling process for losses that considered the influence of both hazard and region. This methodology was motivated by the varying frequency and severity experience not only across hazard types but also across regions (see Appendix D).

Winter weather hazards tail off in more recent years, motivating the use of exponential time series smoothing (ETS) techniques to model total loss within each region. This model selection captured the noticeable relationship between time and total loss and also handled the non-stationarity within the data (see Appendix E). However, the sparseness of annual data for other hazard categories prompted the use of other parametric approaches for both loss frequency and severity (see Appendix E). The zero-inflated Poisson distribution was the predominant choice for frequency modeling, though hazard types with few occurrences were instead modeled with a Poisson distribution. Severity distributions were tailored to each region and hazard with Gamma and Weibull distributions as common choices.

Once each hazard type was modeled within each region (see Appendix F), 50,000 simulations for total cost per hazard were generated for each year within each region in accordance with a full credibility standard (see Appendix G). For winter weather events, losses were instead projected using bootstrapped versions of the respective time series instead of random sampling from a parametric distribution. The simulations were aggregated to create a loss distribution for projected property damage each year of the program duration (see Appendix H).

Economic and Demographic Models

Inflation rates were projected for the duration of the program using an ARIMA model based on Storslysia's historical average annual inflation rates. These projections were applied to accurately reflect program costs and countrywide GDP over the 20-year program duration (see Appendix I).

Worldwide GDP projections for each Shared Socioeconomic Pathway (SSP) were sourced from the Intergovernmental Panel on Climate Change's (IPCC) SSP dataset (Riahi et al.). This dataset provided projections by decade; however, worldwide GDP by year was necessary to determine the budgeted 10% of Storslysia GDP allocated to the CRDP. Quadratic models were fitted to the IPCC's existing projections to determine worldwide GDP in intermediate years. Each year of worldwide GDP was converted to Storslysia GDP using the ratio of the two GDPs in 2020. For each SSP, this ratio deviated slightly, as the worldwide GDP in 2020 differs under each assumption. See the detailed procedure and projected Storslysia GDP in Appendix J. Using similar methodology, Storslysia population by year was also projected for the program duration (see Appendix K).

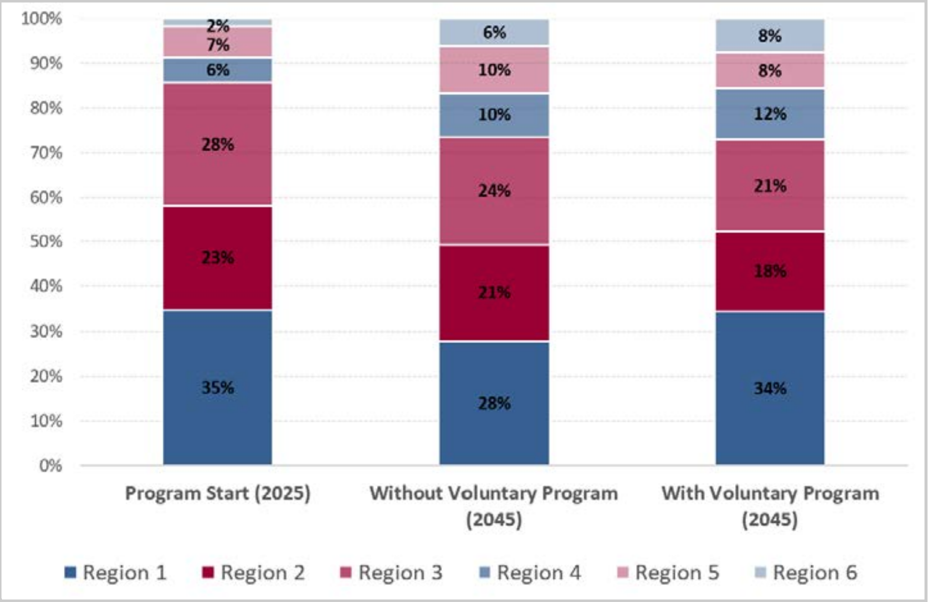
Migration Simulation

One key component within the modeling process was projecting migration rates and regional populations across years. Markov chains were selected to model regional populations and migration patterns based on academic literature regarding migration (Huang and Unwin). In these models, regions corresponded with Markovian states, and a transition matrix was constructed to describe migration between regions using several weighting transformations (see Appendix L). Of note is the environmental preference transformation, where individuals are more inclined to migrate to regions with different hazard types than their current region (Sheldon and Zhan).

Implementing the voluntary relocation feature, which incentivizes moving from hazardous regions (2, 3, 5) to less hazardous regions (1, 4, 6), required the creation of a second transition matrix (see Appendix L). The probabilities of migration are adjusted in the transition matrix, doubling the probability of favorable transitions (moving from hazardous to less hazardous regions) and halving the probability of unfavorable transitions (moving between hazardous regions). These probability adjustments aligned with program responses from the US-based Kentucky Relocation Assistance Program (Jia et. al.) and the anticipated desirability of Storslysia's voluntary program incentives. Appendix M provides the process to project regional populations and migration yearly with and without a voluntary program.

Figure 2 below illustrates how the voluntary relocation feature would redistribute Storslysia's population to reduce involuntary displacement and associated cost (see Appendix N). At the program start, only 43% of individuals reside in less hazardous regions (1,4,6). If a voluntary relocation feature is added, 54% of residents will be located in less hazardous regions (shaded in blue in Figure 2) by 2045 compared to only 44% of residents if no voluntary relocation is offered.

Figure 2: Population Proportions With and Without Voluntary Program



Displacement Assistance Feature Cost Estimation

The expected costs of the displacement assistance feature account for the number of persons displaced and the displacement cost per person by region and hazard as shown in the equation below. Once these figures were determined, they were integrated with the projected property damage and then scaled to capture migration patterns as a result of the voluntary relocation feature.

$$Cost\ of\ Displacement\ Program(\Psi) = Displacement\ Cost\ per\ Person\ (\frac{\Psi}{Person}) * Number\ of\ Persons\ Displaced$$

The hazard data provided by the government of Storslysia includes property damage, injuries, and fatalities by hazard. To determine the number of persons displaced per hazard category for the calculation above, property damage in the dataset was converted to persons displaced per hazard using external data from the US Census Bureau and the National Oceanic and Atmospheric Administration (NOAA). Next, each benefit was priced per hazard category and then aggregated to create a displacement cost per person unique to each region. Per the equation above, these two values were then multiplied to determine the cost of the displacement assistance feature for each region (see Appendix O for the conversion calculation).

Voluntary Relocation Feature Cost Estimation

The voluntary relocation feature was designed to redistribute Storslysia residents from hazardous regions to less hazardous regions. Hazardous regions were identified by comparing the ratio of historical property damage per hectare across regions (see Appendix P). Regions 2, 3, and 5 had higher historical property damage per hectare compared to regions 1, 4, and 6. Therefore, the voluntary relocation feature covers relocation from the out-regions, 2, 3, and 5, to the in-regions, 1, 4, and 6.

The cost of the voluntary relocation feature includes moving costs, the expense of the buyout program, and administrative costs. A constant value was assumed for moving costs, and the buyout program expenses for a property were equivalent to the average assessed value of the property, assumed to be at 80% of property value, with property value capped at Ƥ2 million. The moving costs and buyout program expenses were converted to a per person basis using persons per household by region (2016-2020), and an administrative fee was applied (see Appendix Q). To determine the associated annual costs, the final per person cost was applied to the number of residents projected to migrate from an out-region to an in-region each year of the program's duration (see Appendix Q).

Final Program Results

CRDP costs are projected, and savings in displacement costs are observed across each year of the program duration. The total program expenditures are estimated to be less than 2% of projected GDP annually.

The expenditures and economic costs of the CRDP remain within the budget of 10% of GDP with a 99% probability as shown in Figure 3. The capital recommendation for the CRDP is to hold the calculated 95th percentile of expenditures in reserve annually to ensure solvency with a 95% degree of confidence without over-reserving (see Appendix R).

Figure 3: CRDP Expenditures Relative to Budget

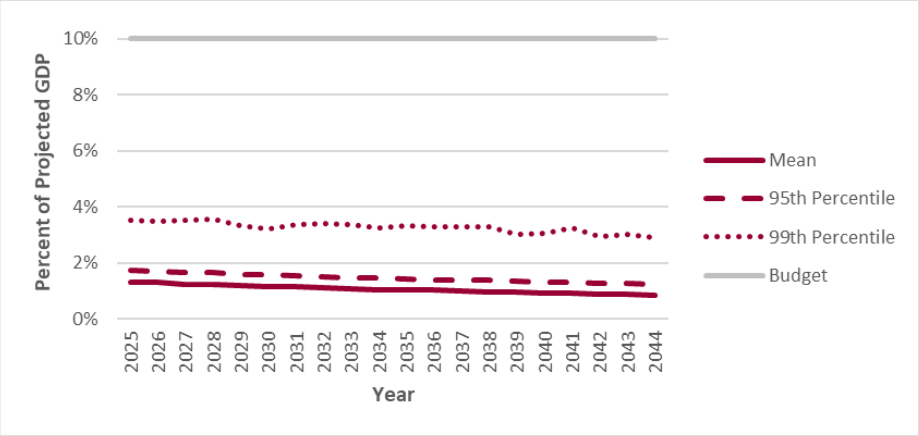
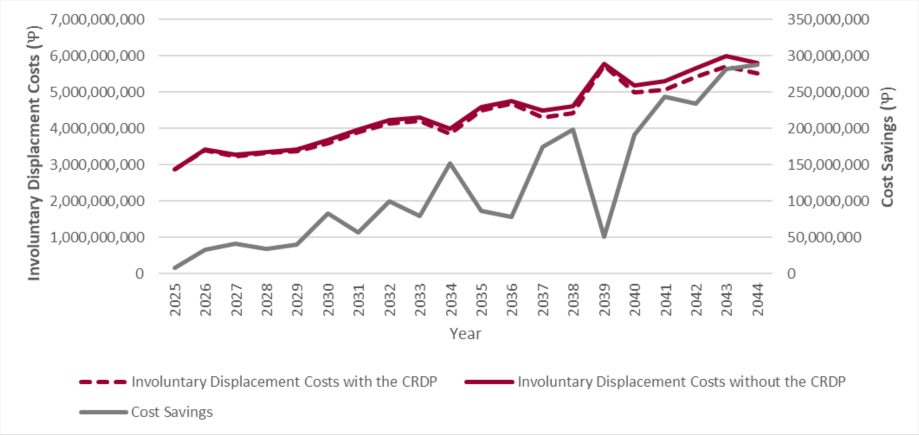


Figure 4: Involuntary Displacement Costs and Cost Savings from the CRDP



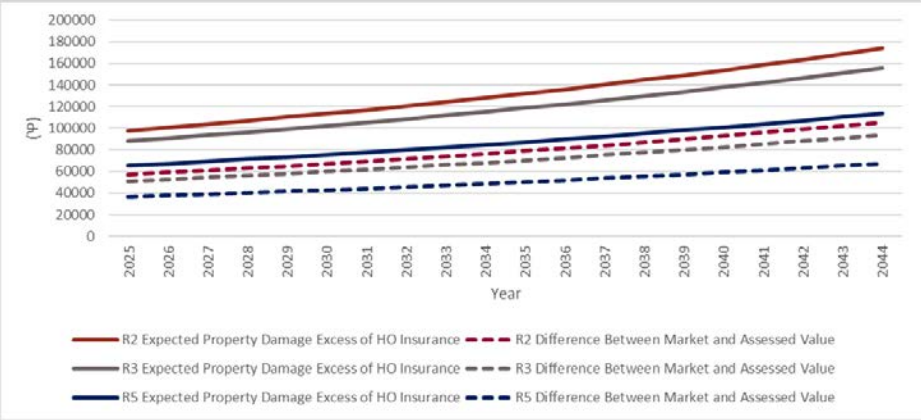
The acquisition of assets through the buyout program effectively reduces the economic cost impact of the CRDP. Thus the involuntary displacement costs, which are not impacted by the acquisition of assets, measure economic costs with and without the CRDP. The results are illustrated above in Figure 4 (see Appendix S for CRDP cost values).

While program expenditures are noticeably higher than the true economic costs, the expenses allocated for the voluntary relocation feature are intended to prioritize the lives and financial wellbeing of residents. Additionally, Storslysia has opportunities to recoup expenditures and further reduce involuntary displacement costs from assets gained through the buyout program. This can be achieved through avenues such as the creation of a landfill to generate revenue, or with the encouragement of nature-based hazard prevention measures, such as mangroves, which can provide protection from coastal storms, and wetlands, which can regulate flooding ("Nature-based solutions to disasters").

A resident's loss from selling their property at the assessed value rather than the market value through the buyout program is less than the cost of future hazard-related property damage in excess of a standard homeowners insurance policy.

While traditional homeowners insurance policies can prevent those residing in hazardous regions from shouldering the full cost of damage due to catastrophes, not all hazard events are covered under a standard policy and most still require cost sharing. The property damages in excess of homeowners insurance that residents are responsible for paying are compared with the potential loss of participating in the buyout program on a per household basis. As shown in Figure 5, for all regions eligible for the voluntary relocation feature, foregoing relocation proves to be more expensive (see Appendix T for details).

Figure 5: Cost-Benefit Analysis of Voluntarily Relocating



Residents who utilize the voluntary relocation feature and relocate to less hazardous regions will face fewer physical and mental health risks.

Those residing in hazardous regions are jeopardizing their health and wellbeing beyond the risk of injury or fatality. Catastrophic events can be traumatizing, leaving Storslysia residents with lasting psychological distress. After the Indian Ocean tsunami in 2004, survivors showed symptoms of anxiety, depression, and post-traumatic stress disorder (PTSD) (Makwana). In less hazardous regions, where catastrophic events are less frequent, residents will experience a lower likelihood of post-hazard psychological distress.

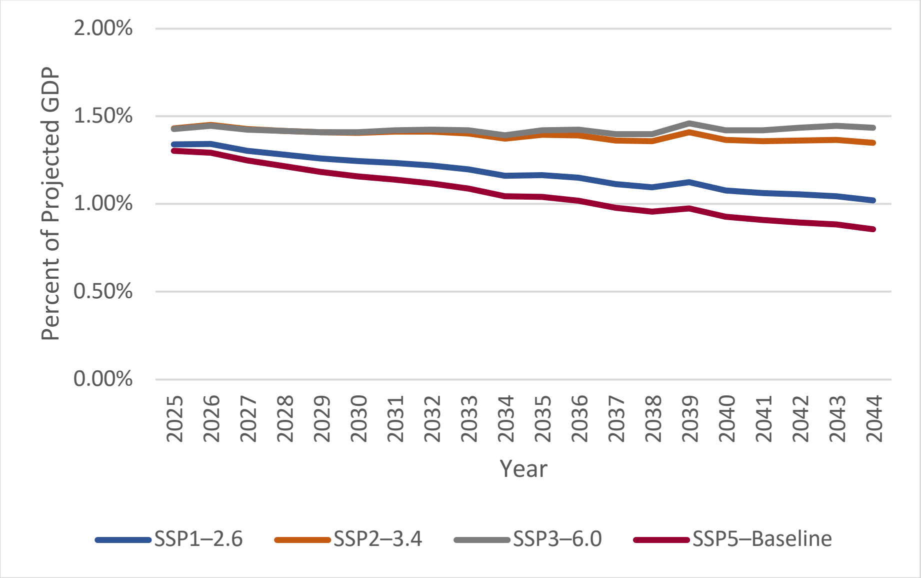
Scenario and Sensitivity Testing

Shared Socioeconomic Pathways (SSP) Scenario Testing

Each SSP projects a unique climate future with corresponding atmospheric concentrations of carbon dioxide, worldwide GDPs, and worldwide populations, which are all relevant to the program (see Appendix U). As the global surface temperature increases, the frequency and intensity of weather events will increase (Acevedo and Novta). Therefore, a risk amplification factor (RAF) is needed to adjust the expected amount of property damage from hazards over the program duration. Assuming the socioeconomic and technological factors of the world can be categorized as the baseline, SSP5, the RAFs allow for results to be adjusted for a range of scenarios. A linear model was constructed to capture the positive relationship between atmospheric concentration of carbon dioxide and log-transformed property damage. The detailed procedure for calculating the RAFs and the resulting values can be found in Appendix V.

In addition to the RAFs, worldwide GDP and population differ across SSPs while all other factors are assumed to remain constant for this scenario testing. The expected cost of the CRDP remained below 10% of Storslysia GDP under all SSPs. The costs of the CRDP were the greatest percentage of projected GDP under SSP3–6.0 due to the impact of high RAFs and lower projected GDP (see Figure 6).

Figure 6: SSP Scenario Testing



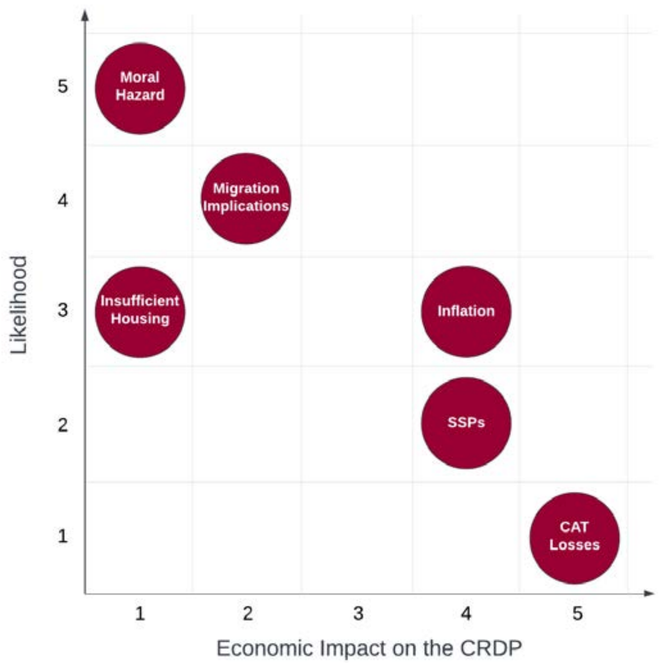
Inflation Sensitivity Testing

Deviations from the projected inflation rates will impact the expected cost of the program. Therefore, sensitivity testing was performed to better understand this risk, comparing the expected costs of the program under the projected inflation rates, under a constant low inflation rate of 1%, and under a constant high inflation rate of 5%. While a consistently higher inflation rate will lead to a significant increase in expected program costs over time, the GDP is also projected to increase, ensuring the expected program costs remain under 2% of Storslysia GDP year-to-year, as shown in Appendix W.

Risk and Risk Mitigation

The most significant risks to the program are displayed in Figure 7 in a risk matrix. Consider a baseline scenario with projected inflation and SSP5; the CRDP is projected to cost an average 1.03% of the GDP annually over the program duration. Note that in the most adverse scenario (SSP3–6.0, 5% inflation, and 95th percentile losses observed annually), the CRDP costs remain under budget at an average of 2.48% of GDP annually.

Figure 7: CRDP Risk Matrix



SSPs: The SSPs impact population, GDP and feature costs. Compared to the baseline, all other SSPs result in higher budget usages. SSPs will become a greater risk in future years as environmental impacts become more significant; however, this would be of greater concern if the program duration is extended.

Inflation: Consistently high inflation poses the risk that total program costs will exceed projections, particularly in later years of the program. However, in the past 40 years, annual inflation above 5% has only been realized twice. If inflation trends upward during the duration of the program, CRDP cost projections should be reassessed.

CAT Losses: Catastrophic losses exceeding Ƥ1 billion have the largest potential to influence the expected cost of the CRDP. If catastrophic losses are observed at a higher frequency than expected, budget usage will increase significantly; however, the likelihood of catastrophic losses occurring is minimal. Thus, the overall risk to the program is not deemed as significant as SSPs or high inflation.

Moral Hazard: Participants of the program inappropriately filing claims will inflate costs associated with both features of the program.

Insufficient Housing: In instances of large catastrophic losses, the available evacuation, emergency, and temporary housing may not be sufficient to shelter those displaced. Therefore, there is a risk of additional costs incurred to construct new housing for the overflow of displaced residents.

Migration Implications: As part of the voluntary relocation feature, residents will be migrating at a higher rate to regions that may not have sufficient infrastructure to support them. This expedited development could lead to potential socioeconomic strain on regions 1, 4, and 6.

Risk Mitigation

Though the program remains within budget under the most adverse risk scenario, potential risk mitigation strategies are considered below to ensure that the CRDP costs are contained.

- **SSPs, Inflation, and Catastrophic Loss:** Investing in reinsurance will hedge against catastrophic losses but is not currently recommended because of the clear certainty of program solvency. However, the need for reinsurance should be reevaluated in the future following assessment of loss experience.
- **Moral Hazard:** Cost-sharing mechanisms like deductibles and coinsurance as well as clear program guidelines can reduce risk of fraud and overutilization.
- **Insufficient Housing:** Establishing robust contracts with local construction companies to begin development at the earliest indication of a housing shortage will decrease logistical concerns. In addition, the creation of an additional emergency reserve to fund excess housing needs will limit short-term borrowing with high bank lending rates.
- **Migration Implications:** Urban planning and policy making to prepare for the rapid influx of people will mitigate against infrastructure strain.

Data Limitations and Assumptions

The chart below shows key data limitations and assumptions (see additional assumptions in Appendix X).

	Data Limitations	Assumptions
Hazards	Property damage, injuries, and fatalities were given per hazard event; however, the number of displaced persons was not available.	Persons in the United States are displaced at a similar rate per US$ as the residents of Storslysia are per Ꝕ and can be used as a metric to determine displaced persons per event.
	Hazard events were not clearly defined in the dataset.	Hazard definitions coincide with the definitions outlined in the NOAA Storm Events Database.
	The time span of hazard data is limited to 60 years, and hazard categories within regions had insufficient occurrences and a low level of data granularity.	The severity and frequency of hazard categories (excluding winter weather) are independent of each and do not vary with time.
Economic and Demographic	Regional populations were only available in years 2019 to 2021, and regional migration rates were unavailable.	Regional migration rates follow a Markov process with fixed probabilities. Migration patterns were determined using US interstate migration rates and then adjusted for age distribution and environmental preferences ("Migration between States").
	Storslysia GDP and population were only available in 2020.	Worldwide GDP and population are converted to Storslysia GDP and population using the ratio of the Storslysia value to the worldwide value. As a result, Storslysia GDP and population change proportionally with worldwide GDP and population.
SSP	The atmospheric concentration of carbon dioxide, worldwide GDP, and population were only available by decade in the IPCC's SSP dataset.	For each quantity, quadratic models were fitted using data from years 2005, 2010, 2020, 2030, 2040, and 2050, and then applied to determine the intermediate year values.

Appendix

Appendix A: Coverage Specifications

- **Displacement Assistance:** Residents are eligible for displacement assistance coverage if their house is damaged by a covered hazard such that the household is deemed unlivable by a government assessor. The following are included coverages and their specifications.
    - **Food:** Reimburses up to Ᵽ20 per day per person throughout the duration of housing.
    - **Transportation:** All transportation to and from housing locations will either be provided by the CDRP or reimbursed in full.
    - **Housing:** Housing will be provided and fully covered throughout evacuation, emergency housing, and temporary housing until coverage expires.
    - **Temporary Goods:** Includes but is not limited to hygienic goods, clothes, and other basic necessities. Reimburses up to Ᵽ75 per day person.
    - **Child care:** Daily coverage of child care will be reimbursed for every child under 10 years old. This coverage is only available while in temporary housing.
    - **Housing Support:** If a citizen falls at or below the Storslysia poverty line, they are eligible for housing support. Here, rent or house payments will be covered in full (proof of house or rent payment necessary), for the duration of housing.
    - **Wage Support:** If a citizen falls at or below the Storslysia poverty line, they are eligible for wage support. Residents must provide proof of previous wages and will be reimbursed in full for the wages they would have received during the duration of housing.
    - **Mental Health Support:** For participants of the program, up to 6 months of coverage is available with a registered therapist.
- **Voluntary Relocation:** Residents are eligible for voluntary relocation coverage if they are moving from a designated out-region (2, 3, and 5) to a designated in-region (1, 4, and 6). The following are included coverages and their specifications:
    - **Moving Costs:** Participants of the voluntary relocation feature are eligible for reimbursement of moving costs up to Ᵽ1,060.
    - **Land Buy-Out:** Participants of the voluntary relocation feature are eligible for buyout of their land equal to 80% of the market value of their home.

Displacement Housing Coverage Duration (days)

Hazard	Hurricane	Wildfire	Landslide	Flooding	Tornado	Precipitation and Wind
Evacuation Housing	2	1	0	0	0	0
Emergency Housing	30	30	30	30	30	30
Temporary Housing	60	60	60	45	30	30

Appendix B: Hazard Definitions

The hazards covered under the CRDP are defined in the following manner:

- **Hurricanes:** Any weather event that is officially classified as a hurricane by the national weather service of Storslysia.
- **Wildfire:** Any fire that burns at least 10 acres of land and/or is recognized as a wildfire by the government of Storslysia.
- **Landslide:** Any movement of destabilized land, due to rainfall or erosion. Land movement caused by earthquakes is not covered under the CRDP.
- **Flooding:** Any water outside your home that flows inside at ground level. Flooding may be due to precipitation, river overflow, or any other excess water situation.
- **Tornado:** Any weather event that is officially classified as a tornado by the national weather service of Storslysia.
- **Precipitation and Wind:** Any precipitation (including rain, hail, and snow) and wind that cannot be classified into the groups above may be covered under this section of the CRDP.

Appendix C: Hazard Data Mappings

Category	Hazard Events
Flooding	Flooding
Flooding Storm	Flooding/ Severe Storm/Thunder Storm, Flooding/ Severe Storm/Thunder Storm/ Wind, Flooding/ Wind, Coastal/ Flooding, Flooding/ Lightning/ Severe Storm/Thunder Storm, Flooding/ Lightning/ Wind, Coastal/ Flooding/ Severe Storm/Thunder Storm/ Wind, Flooding/ Lightning, Flooding/ Hail, Flooding/ Hail/ Wind
Fog	Fog
Hail	Hail, Hail/ Wind
Heat/Drought	Heat, Drought/ Heat, Drought
Hurricane	Hurricane/Tropical Storm, Coastal/ Hurricane/Tropical Storm/ Wind, Hurricane/Tropical Storm/ Severe Storm/Thunder Storm, Coastal/ Hurricane/Tropical Storm/ Severe Storm/Thunder Storm/ Wind
Landslides	Coastal/ Flooding
Non-Flooding Storm	Severe Storm/Thunder Storm/ Wind, Lightning, Wind, Severe Storm/Thunder Storm, Hail/ Severe Storm/Thunder Storm/ Wind, Lightning/ Severe Storm/Thunder Storm, Hail/ Lightning/ Severe Storm/Thunder Storm/ Wind, Coastal/ Wind, Lightning/ Severe Storm/Thunder Storm/ Wind, Lightning/ Wind, Hail/ Lightning/ Wind, Coastal, Hail/ Severe Storm/Thunder Storm, Coastal/ Severe Storm/Thunder Storm/ Wind, Coastal/ Severe Storm/Thunder Storm, Hail/ Lightning/ Severe Storm/Thunder Storm, Hail/ Lightning, Severe Storm/Thunder Storm - Wind
Tornado	Tornado, Hail/ Tornado, Tornado/ Wind, Hail/ Tornado/ Wind, Lightning/ Tornado/ Wind
Wildfire	Wildfire
Winter Weather/Winter Storms	Winter Weather, Severe Storm/Thunder Storm/ Winter Weather, Wind/ Winter Weather, Severe Storm/Thunder Storm/ Wind/ Winter Weather, Hail/ Severe Storm/Thunder Storm/ Wind/ Winter Weather

Appendix D: Annual Hazard Frequency and Severity

Average Annual Hazard Frequency

Hazard Category	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Landslides	0.000	0.000	0.016	0.000	0.000	0.000
Flooding	1.000	1.164	2.918	0.689	0.541	0.279
Flooding Storm	0.459	0.262	0.230	0.230	0.213	0.131
Hail	0.557	2.410	0.869	0.607	0.590	0.230
Heat/Drought	0.410	0.377	0.426	0.328	0.311	0.311
Hurricane	0.115	0.525	0.164	0.148	0.148	0.082
Non-Flooding Storm	5.148	6.361	6.902	4.721	3.803	1.787
Tornado	0.443	0.770	0.295	0.705	0.311	0.246
Wildfire	0.049	0.082	0.049	0.049	0.049	0.049
Winter Weather/Winter Storms	1.951	0.934	0.934	0.852	0.984	0.951

Average Inflation-Adjusted Hazard Severity

Hazard Category	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Landslide	-	-	0	-	-	-
Flooding	6,926,701	8,384,073	2,978,663	9,171,655	409,635	907,273
Flooding Storm	1,686,154	310,215	429,011	424,255	140,965	203,267
Hail	196,518	94,002	70,181	67,839	305,521	120,387
Heat/Drought	6,803,376	8,070,811	6,623,217	7,915,938	8,848,388	9,417,965
Hurricane	1,146,156	675,948,944	94,901,800	131,580,577	750,560,860	1,234,650
Non-Flooding Storm	754,153	645,572	1,068,812	440,317	537,534	338,570
Tornado	6,390,829	8,611,050	18,244,605	1,694,975	3,388,478	5,017,584
Wildfire	643,129	194,262,247	625,343	654,827	633,836	641,325
Winter Weather/Winter Storms	3,210,609	6,480,691	668,700	688,937	637,076	620,673

Appendix E: Hazard Modeling Procedure

Data Cleaning

To properly model hazard losses within Storslysia, data transformation was first performed. After applying hazard groupings developed in Appendix M, losses were inflation-adjusted to present time values (last year of data was 2021) to make trending more accurate. Inflation was applied quarterly to properly match the data provided. Logarithmic transformations were also applied to total loss data and constructed severity data to handle extreme loss situations and create a well-designed model capable of predicting large losses with accuracy. Finally, the final data set incorporated losses starting from 1962 to present. Hazard models are highly dependent on past values, and with the small amount of data, the maximum number of years possible were selected. However, because inflation data was not available for years before 1962, they were excluded from the final data set.

Data Modeling Process: Winter Weather

A key assumption of projecting values by assuming the data to follow a parametric distribution lies in the frequency and severity of the hazard events not changing over time. However, for the winter weather/winter storms hazard category, across all regions, there was a noticeable decrease in total loss in the early 2000s, violating this assumption and resulting in preference for an alternative modeling approach. However, the limited scope of data and information given reduced the number of modeling approaches that were appropriate; thus, a time series modeling was used to project losses in the winter weather/winter storms hazard category.

Initially, ETS, ARIMA, and GARCH modeling approaches were considered; however, the limited observations present in the data caused concern for the accuracy of a GARCH process, so it was not utilized. ETS modeling was selected over ARIMA modeling, due to its ability to produce the lowest AIC.

Data Modeling Process: All Other Hazard Categories

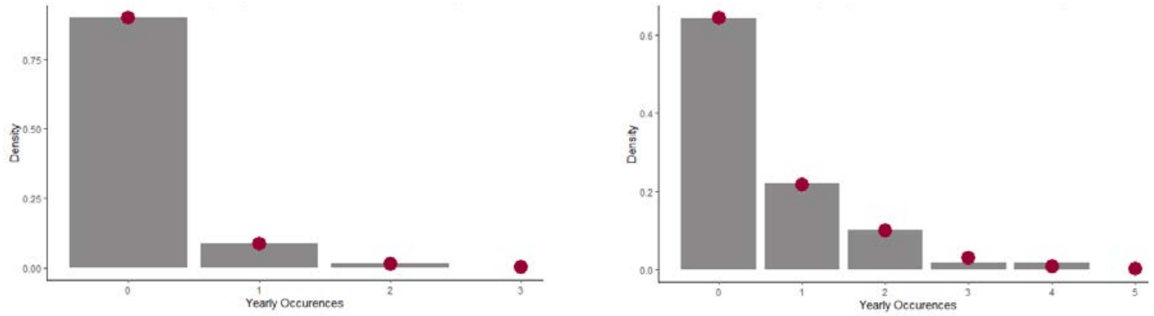
For all other hazards, the lack of observations in each year across regions made time series approaches highly inaccurate. This motivated the employment of a parametric approach instead, where frequency and severity data were each modeled with a parametric distribution that best fits data points.

For each hazard type and region combination, an identical process was performed to match distributions to observed frequency and severity. The process below will examine one particular combination, hurricanes in region 4, with the procedure repeatable for all other combinations. Total loss data for hurricanes within region 4 was first decomposed into frequency data, as the number of occurrences of the hazard event within a year, and severity data, as the amount of loss from each hazard event.

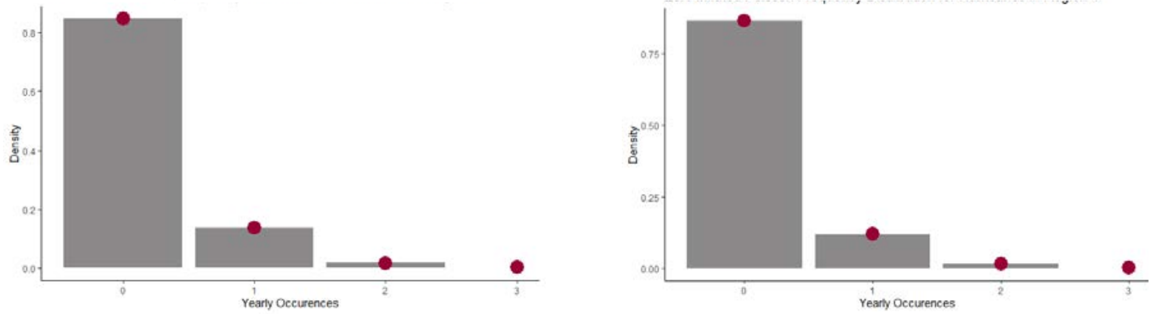
Frequency data for hurricanes in region 4 was modeled using several potential distributions including the zero-inflated Poisson, Poisson, and negative binomial distribution, with parameters calculated using maximum likelihood estimation. The final model was selected using the histogram that demonstrated the best fit between theoretical hurricane occurrences annually (predicted from the distribution) and the actual hurricane occurrences each year. The zero-inflated Poisson distribution was the best model for hurricanes in region 4 due to its match with the data's disproportionate number of zero occurrences seen in the figure below. This figure also shows the other five models constructed for hurricane events in the other regions. The zero-inflated Poisson was the final model for most hazard type and region combinations though the Poisson distribution was selected for incidents with few observations like landslides.

Hurricane Frequency with Zero-Inflated Poisson Model Across All Regions

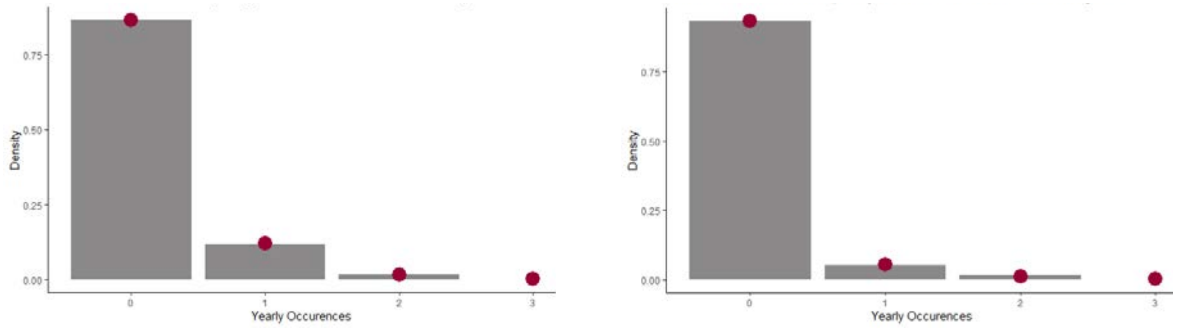
Hurricane, Region 1 *Hurricane, Region 2*



Hurricane, Region 3 *Hurricane, Region 4*



Hurricane, Region 5 *Hurricane, Region 6*



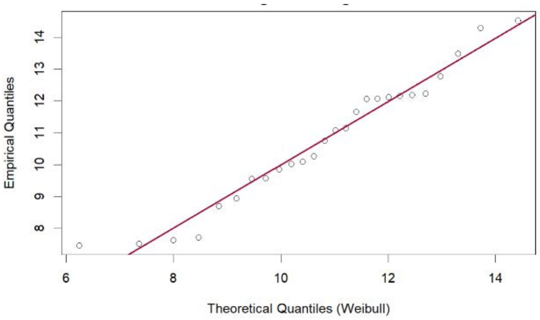
The severity model for hail in region 4, like other hazard/region combinations, was complicated by the potential for hazard occurrences with zero in property damage. To account for this, the probability of a zero loss was calculated historically and then used in a Bernoulli distribution within the simulation process later on to predict zero losses. The severity data was filtered for losses over zero and then log-transformed, and this final data was modeled to predict the severity of a loss given that it was not zero.

Several candidate distributions were chosen to model severity for hail in region 4 including the Gamma, Weibull, Lognormal, Normal, and Uniform distribution where parameters were again calculated using maximum likelihood estimation. The best model for hail in region 4 was assessed using examination of the empirical density distribution fitted with parametric model curves, Q-Q plots, and the Kolmogorov-Smirnov Test. For hail in region 4, the Weibull distribution was the final selection. Examples of Q-Q plots constructed for hail in region 4 as well as hail in all other regions are shown in the figure below.

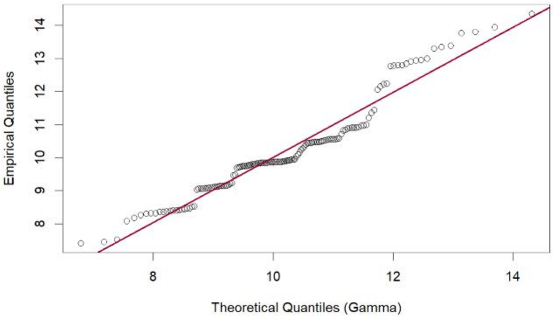
This same severity modeling process was repeated for all remaining hazard and region combinations. While Gamma and Weibull were commonly selected distributions to model severity, the Uniform distribution was selected for hazard types with a small number of observations within regions like wildfire and landslides.

Hail Severity with Parametric Models Across All Regions

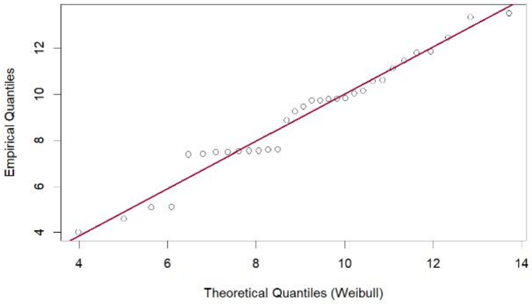
Hail Region 1 (Weibull)



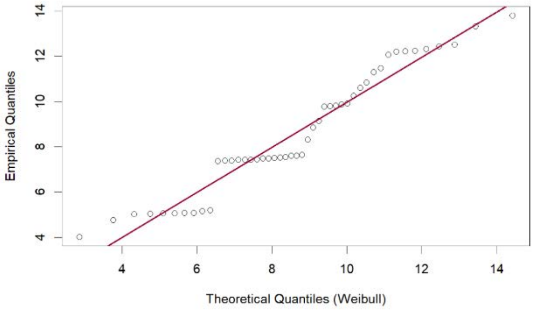
Hail Region 2 (Gamma)



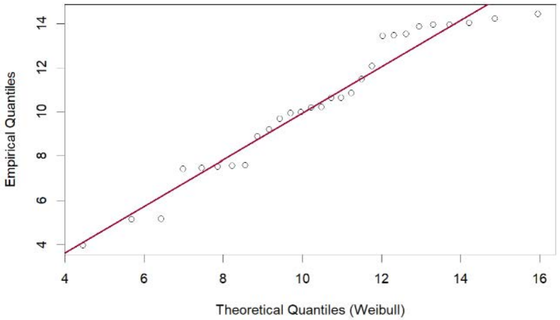
Hail Region 3 (Weibull)



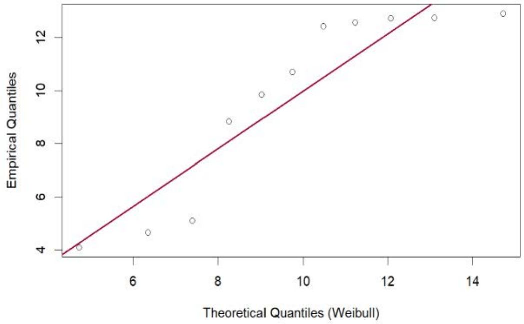
Hail Region 4 (Weibull)



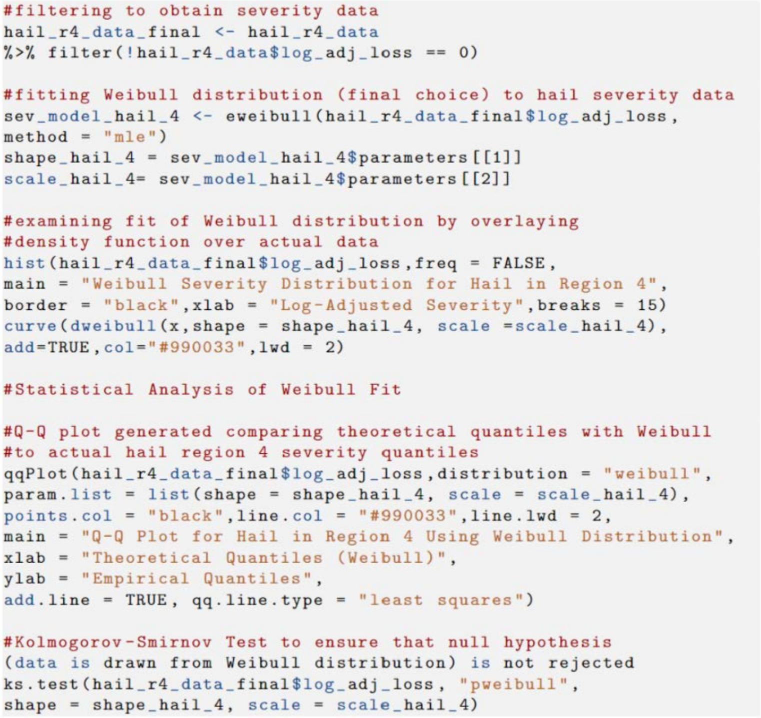
Hail Region 5 (Weibull)



Hail Region 6 (Weibull)



Example R Code: Severity Modeling



```
#filtering to obtain severity data
hail_r4_data_final <- hail_r4_data
%>% filter(!hail_r4_data$log_adj_loss == 0)

#fitting Weibull distribution (final choice) to hail severity data
sev_model_hail_4 <- eweibull(hail_r4_data_final$log_adj_loss,
method = "mle")
shape_hail_4 = sev_model_hail_4$parameters[[1]]
scale_hail_4= sev_model_hail_4$parameters[[2]]

#examining fit of Weibull distribution by overlaying
#density function over actual data
hist(hail_r4_data_final$log_adj_loss,freq = FALSE,
main = "Weibull Severity Distribution for Hail in Region 4",
border = "black",xlab = "Log-Adjusted Severity",breaks = 15)
curve(dweibull(x,shape = shape_hail_4, scale =scale_hail_4),
add=TRUE,col="#990033",lwd = 2)

#Statistical Analysis of Weibull Fit

#Q-Q plot generated comparing theoretical quantiles with Weibull
#to actual hail region 4 severity quantiles
qqPlot(hail_r4_data_final$log_adj_loss,distribution = "weibull",
param.list = list(shape = shape_hail_4, scale = scale_hail_4),
points.col = "black",line.col = "#990033",line.lwd = 2,
main = "Q-Q Plot for Hail in Region 4 Using Weibull Distribution",
xlab = "Theoretical Quantiles (Weibull)",
ylab = "Empirical Quantiles",
add.line = TRUE, qq.line.type = "least squares")

#Kolmogorov-Smirnov Test to ensure that null hypothesis
(data is drawn from Weibull distribution) is not rejected
ks.test(hail_r4_data_final$log_adj_loss, "pweibull",
shape = shape_hail_4, scale = scale_hail_4)
```

Appendix F: Final Hazard Model Selections

Hazard Type	Model Selection
Winter Weather	**Total Loss: Time Series** Exponential Smoothing Time Series (ETS)
Hail	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma (2) | Weibull (1,3,4,5,6)
Flooding	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma
Flooding Storm	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma (4,5) | Weibull (1,2,3,6)
Non-Flooding Storm	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma

Hazard Type	Model Selection
Heat/Drought	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma (1,4,5) | Weibull (2,3,6)
Hurricane	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Weibull
Tornado	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Gamma
Wildfire	**Frequency x Severity** ***(F)*** Zero-Inflated Poisson ***(S)*** Uniform
Landslides	**Frequency x Severity** ***(F)*** Poisson ***(S)*** Uniform

Note: Each hazard type was modeled for each region to obtain region-specific hazard model coefficients or parameters. The different severity distributions for certain hazard types account for the distinct behavior of hazards within different regions.

- ***(F)*** refers to the selected frequency model while ***(S)*** refers to the selected severity model for the hazard type. If more than one severity model was used across regions, the regions are specified for each parametric selection as numbers (1,2,3,4,5,6).

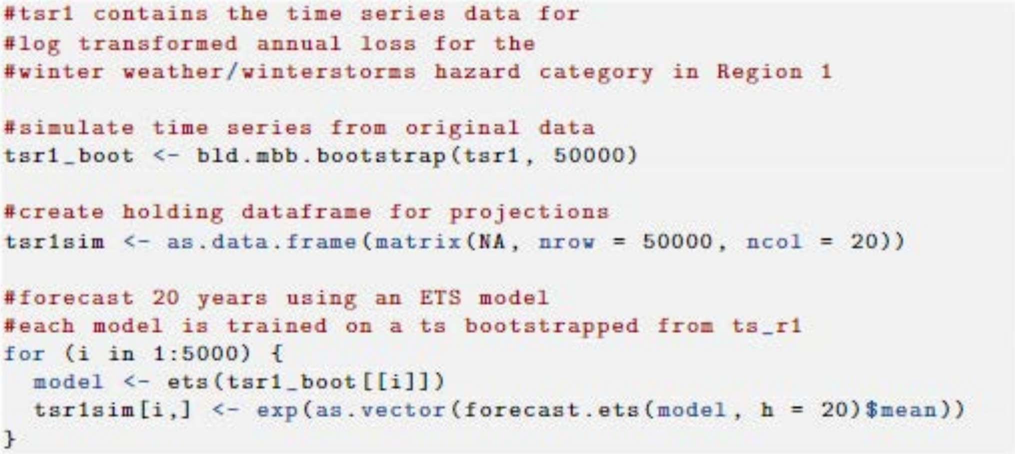
Appendix G: Full Credibility Standard

Utilizing the sample mean and variance of annual loss adjusted to be in 2021 pecunias, an estimate for the full credibility standard was calculated, such that the annual total loss is within 5% of the true value with 95% probability. This returned a full credibility standard of 49475.41. Thus, 50,000 simulations were calculated to achieve the full credibility standard.

Hazard Simulation Procedure: Winter Weather

Bootstrapping was used to simulate 50,000 total annual losses for each region and year of program duration for the winter weather/winter storms hazard category. This was done with the bld.mbb.bootstrap() function in the forecast package, in which Box-Cox decomposition is utilized along with a moving block bootstrap to generate bootstrapped versions of the winter weather/winter storms time series for each region. This is implemented for region 1 in the code below.

Winter Weather Total Loss Simulations in Region 1



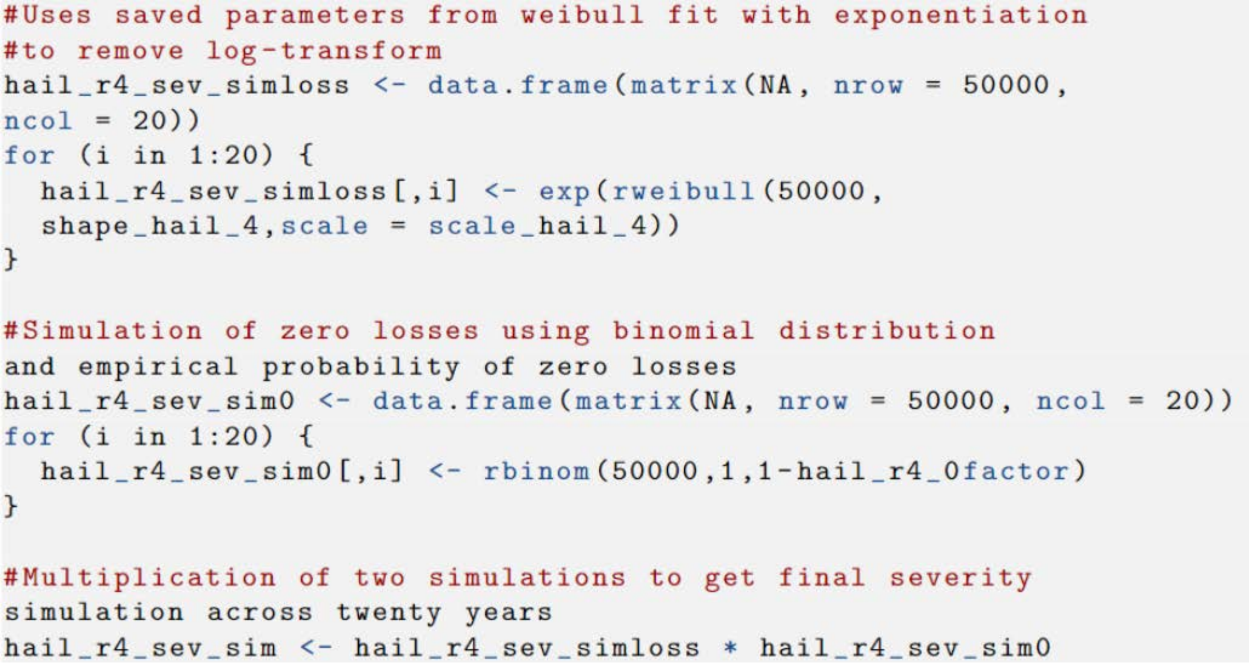
```
#tsr1 contains the time series data for
#log transformed annual loss for the
#winter weather/winterstorms hazard category in Region 1

#simulate time series from original data
tsr1_boot <- bld.mbb.bootstrap(tsr1, 50000)

#create holding dataframe for projections
tsr1sim <- as.data.frame(matrix(NA, nrow = 50000, ncol = 20))

#forecast 20 years using an ETS model
#each model is trained on a ts bootstrapped from ts_r1
for (i in 1:5000) {
  model <- ets(tsr1_boot[[i]])
  tsr1sim[i,] <- exp(as.vector(forecast.ets(model, h = 20)$mean))
}
```

Hazard Simulation Procedure: All Other Hazards

All simulations of yearly losses due to hazard events were performed in R and separately for each remaining region and hazard category combination through the duration of the program (20 years). For each combination, 50,000 simulations of hazard frequency were generated for each of the twenty years of program duration.

For severity projections, 50,000 log-adjusted losses were simulated using the selected severity distribution for each year, and these values were then exponentiated back to undo the log-transformation. In addition, 50,000 simulations of a Bernoulli distribution were generated for each year to predict the number of losses with an amount of 0 (connected to empirical percentage of zeroes). These two simulations were multiplied together across all years, with the Bernoulli values randomly converting some simulate severities to zero at a probability similar to the experience period. The final product from this calculation was the simulated 50,000 severity amounts across twenty years for any potential number of occurrences. The code to construct this for one example, hail in region 4, was constructed below.

Hail Severity Simulation in Region 4



```
#Uses saved parameters from weibull fit with exponentiation
#to remove log-transform
hail_r4_sev_simloss <- data.frame(matrix(NA, nrow = 50000,
ncol = 20))
for (i in 1:20) {
  hail_r4_sev_simloss[,i] <- exp(rweibull(50000,
  shape_hail_4,scale = scale_hail_4))
}

#Simulation of zero losses using binomial distribution
and empirical probability of zero losses
hail_r4_sev_sim0 <- data.frame(matrix(NA, nrow = 50000, ncol = 20))
for (i in 1:20) {
  hail_r4_sev_sim0[,i] <- rbinom(50000,1,1-hail_r4_0factor)
}

#Multiplication of two simulations to get final severity
simulation across twenty years
hail_r4_sev_sim <- hail_r4_sev_simloss * hail_r4_sev_sim0
```

The final frequency simulations and severity simulations were then multiplied to create total loss simulations for each hazard/region combination for each of the 20 years of program duration.

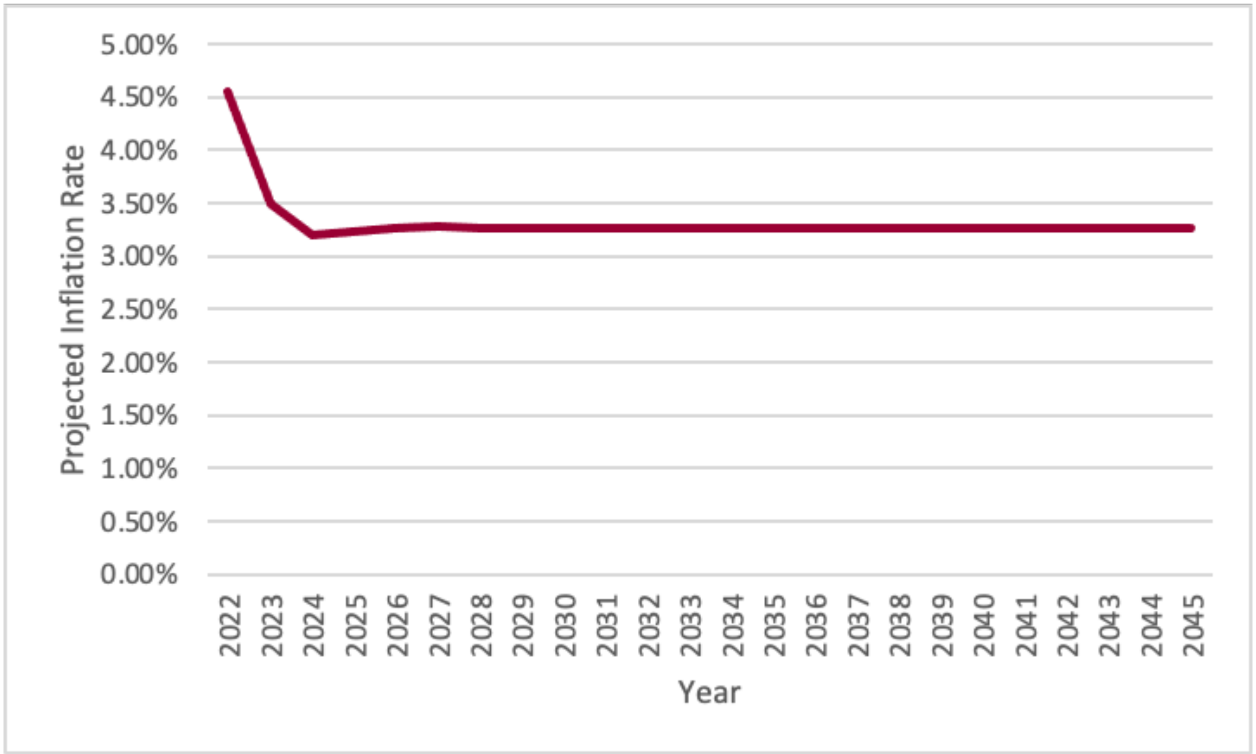
Aggregate Projection

The final total loss simulations for each hazard and region were all added to create 50,000 aggregate loss simulations for all of Storslysia. These simulations could be utilized to calculate expected values and percentiles of total property damage for each year of the program duration, enabling the calculation of final program costs following the necessary conversions and considerations.

Appendix I: Inflation Rate Projection

1. 60 values of the average annual inflation rate were analyzed. Inflation rate in 2003 appeared to be a data entry error and was replaced by an estimate found through linear interpolation of the inflation rate in years 2002 and 2004.
2. An ARIMA time series model was applied to capture the fluctuations in inflation rate over time, and then project inflation rate throughout the program duration. The R function auto.arima() was used to determine the parameters p, d, and q.
3. auto.arima() selected an ARIMA(0, 1, 0) model, which was used to project inflation rates.

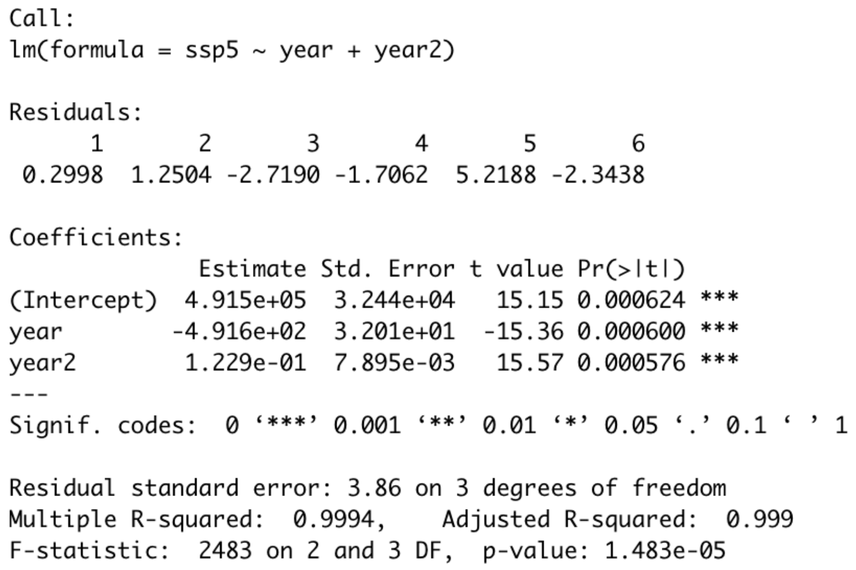
Projected Inflation Rates



Appendix J: Storslysia GDP Projection

1. To determine the CRDP’s annual budget, annual Storslysia GDP is required. However, The IPCC’s SSP database only includes worldwide GDP by decade. Quadratic models were fitted to the IPCC’s worldwide GDP projections under each SSP to determine the worldwide GDP in the intermediate years. A quadratic model was chosen after visualizing the relationship between year and worldwide GDP.
2. Actualized data, years, 2005, 2010, and 2020, along with projections that encompass the program duration, years 2030, 2040, and 2050, were used to fit the quadratic models.
3. Quadratic models perfectly capture the IPCC’s worldwide GDP projections. As shown below, in the summary of the quadratic model fit to the baseline, SSP5 worldwide GDP.

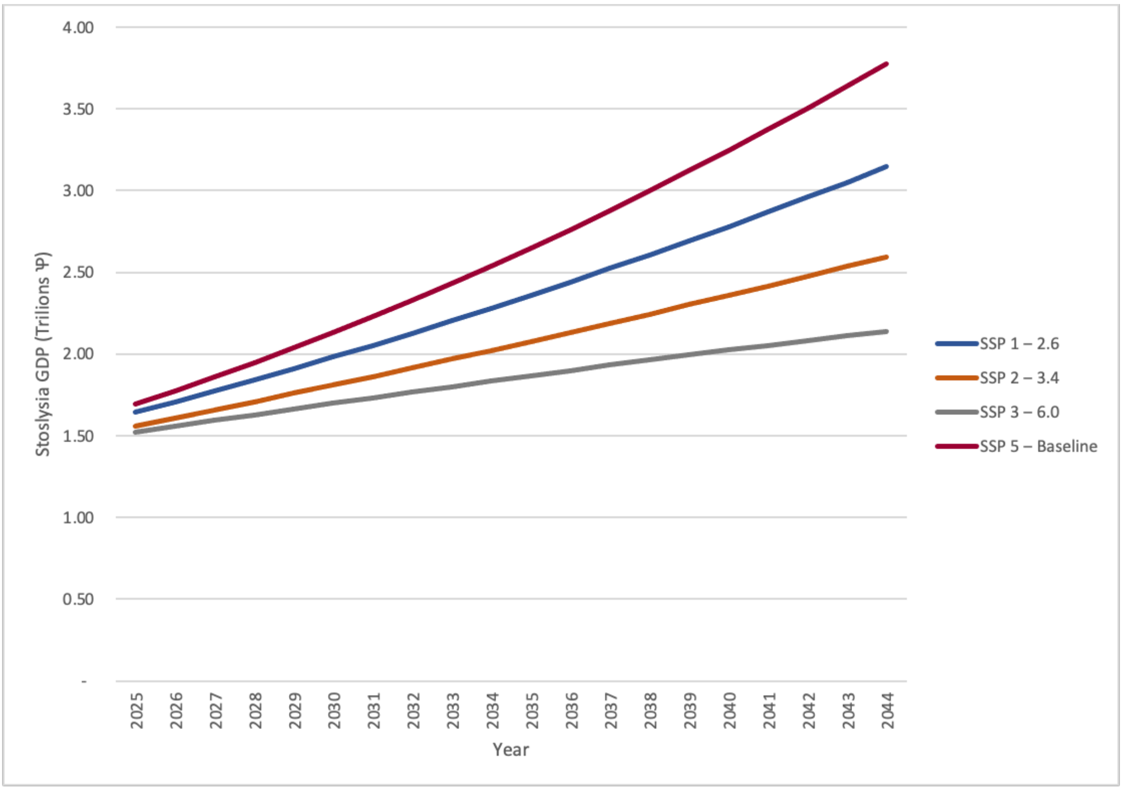
Quadratic Model R Output



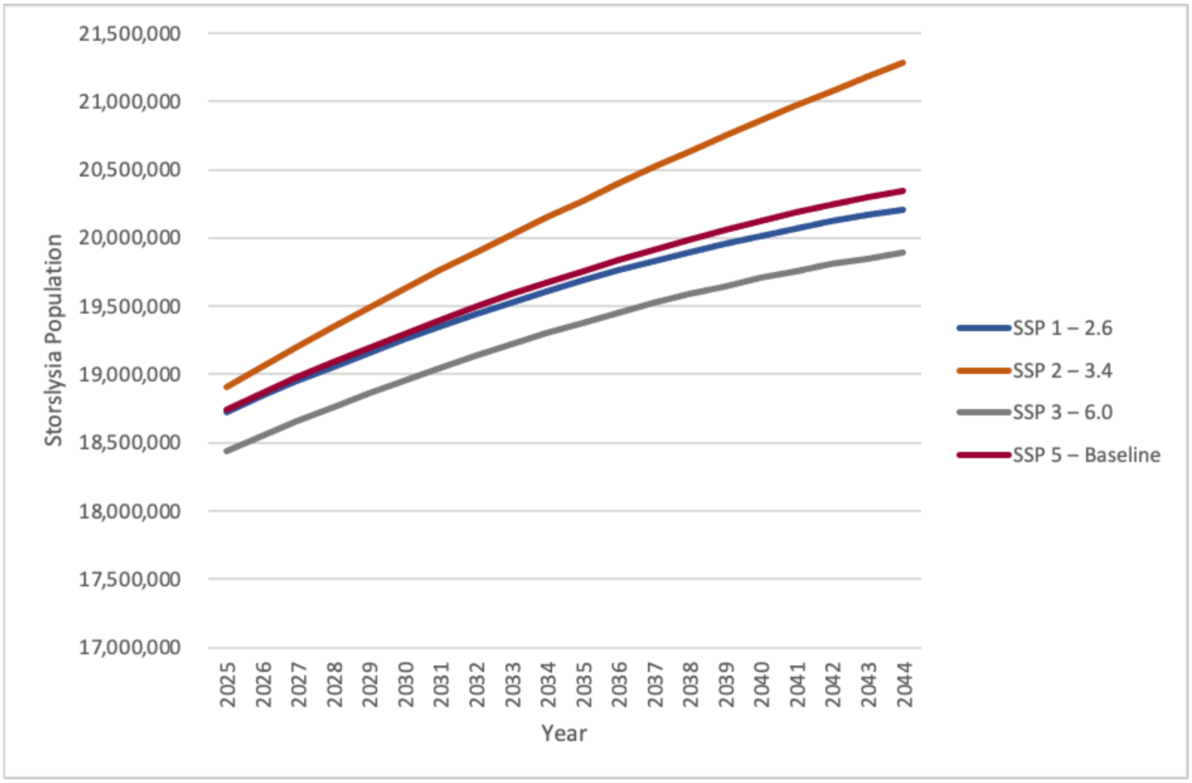
```
Call:
lm(formula = ssp5 ~ year + year2)

Residuals:
      1       2       3       4       5       6 
 0.2998  1.2504 -2.7190 -1.7062  5.2188 -2.3438 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  4.915e+05  3.244e+04   15.15 0.000624 ***
year        -4.916e+02  3.201e+01  -15.36 0.000600 ***
year2        1.229e-01  7.895e-03   15.57 0.000576 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.86 on 3 degrees of freedom
Multiple R-squared:  0.9994,	Adjusted R-squared:  0.999 
F-statistic:  2483 on 2 and 3 DF,  p-value: 1.483e-05
```

4. The quadratic model was applied to the intermediate years, completing the annual worldwide GDP data by SSP.
5. Worldwide GDP data was then converted from US$ to Ƥ, using the constant exchange rate.
6. Worldwide GDP data was then converted to Storslysia GDP, using a constant ratio of Storslysia GDP in 2020 to worldwide GDP in 2020. Data from 2020 was used, as Storslysia GDP is available only in 2020. This ratio differed across SSPs, as the worldwide GDP in 2020 differed across SSPs.

Projected Storslysia GDP by SSP



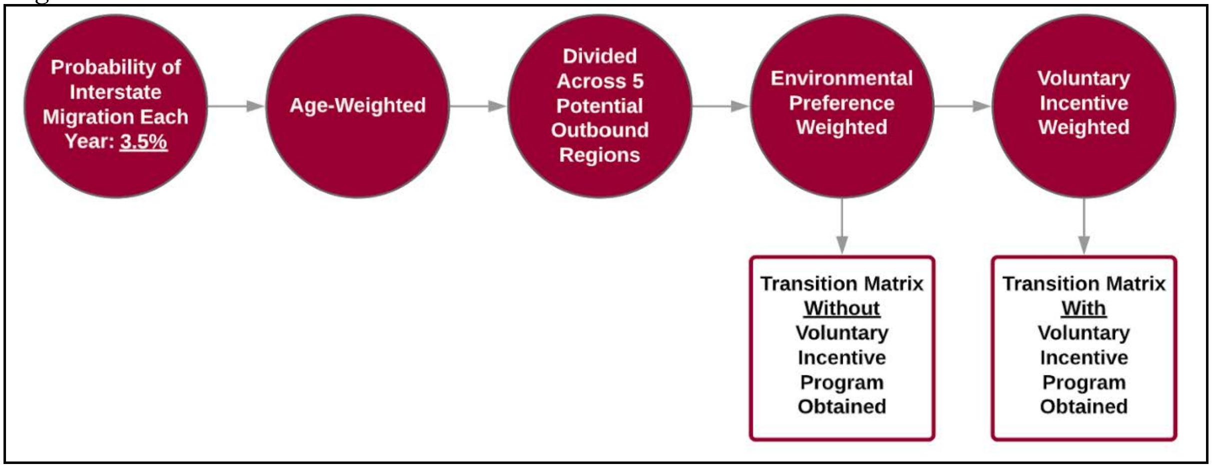
Appendix K: Projected Storslysia Population by SSP



Appendix L: Migration Transition Matrix Construction

Within the migration model, regions correspond with Markovian states, and probabilities are calculated using industry research and several weighting steps.

Migration Transition Construction Process



- **Starting Probability**
  - The average probability of interstate migration per year in the United States since 2007 is 3.5% (Policy Circle). Because regional populations in Storslysia are comparable to state populations within the United States, interstate and interregional migration can be approximated as roughly the same.
- **Age-Weighting**
  - Older individuals domestically migrate less than younger populations, where after age of 65, the migration rate drops about 50% (Zaiceva). Therefore, a new probability is obtained as a weighted average using weights derived from percentage of population over 65 within each region (Dataset: *SOA Eco-Dem Data*),
- **Regional Division**
  - An individual leaving their current region has 5 possible regions to migrate to; therefore, the probability of outward migration is evenly distributed among 5 regions.
- **Environmental Preference Weighting**
  - Individuals are more likely to migrate to a region that does not share similar catastrophe exposures to the region they are currently living in (Sheldon and Zhan). In reference to Storslysia, an individual in region 2, where severe hurricanes are prevalent, will be more inclined to relocate to region 1 (where hurricanes are infrequent and mild) compared to region 3 (where hurricanes are relatively common and strong).
  - The relative prevalence of each hazard category within each region is calculated using adjusted total duration of the category divided by land area. Preferred transitions are calculated for each region using the idea that for each hazard, an individual will select other regions with less overall adjusted duration. Preferred transitions are then aggregated for each out-region/in-region combination (36 in

    total). These final values are used to weight transition probabilities by taking the preferred transitions to a region divided by the total preferred transitions across all possible regions.
  - **The final transition matrix is obtained for migration under CRDP without a voluntary relocation feature.**
- **Incentive Weighting**
  - The presence of a voluntary relocation feature will motivate different transition patterns in regions eligible for the program (region 2, 3, and 5). These incentives emphasize "favorable" transitions (relocating to region 1, 4, and 6) over "unfavorable" transitions (relocating to region 2, 3, and 5) for eligible individuals. Using estimates aligned with program responses offered by US-based Kentucky Relocation Assistance Program (Jia et al.) and Storslysia's incentives, the probability of "favorable" transitions are expected to double while the probability of "unfavorable" transitions will be halved. These probability alterations are then applied to the previous transition matrix to create a new transition matrix.
  - **The final transition matrix is obtained for migration under CRDP with a voluntary relocation feature.**

*Transition Matrix **Without** Voluntary Feature*

Finish

Start

$$\begin{array}{c|cccccc} & R1 & R2 & R3 & R4 & R5 & R6 \\ \hline R1 & 0.9843 & 0.0032 & 0.0029 & 0.0035 & 0.0030 & 0.0031 \\ R2 & 0.0025 & 0.9873 & 0.0024 & 0.0028 & 0.0025 & 0.0026 \\ R3 & 0.0026 & 0.0026 & 0.9871 & 0.0027 & 0.0024 & 0.0026 \\ R4 & 0.0012 & 0.0012 & 0.0012 & 0.9938 & 0.0012 & 0.0015 \\ R5 & 0.0012 & 0.0012 & 0.0012 & 0.0013 & 0.9940 & 0.0012 \\ R6 & 0.0010 & 0.0010 & 0.0009 & 0.0010 & 0.0010 & 0.9952 \end{array}$$

*Transition Matrix **With** Voluntary Feature*

Finish

Start

$$\begin{array}{c|cccccc} & R1 & R2 & R3 & R4 & R5 & R6 \\ \hline R1 & 0.9922 & 0.0016 & 0.0014 & 0.0017 & 0.0015 & 0.0016 \\ R2 & 0.0049 & 0.9819 & 0.0012 & 0.0056 & 0.0012 & 0.0051 \\ R3 & 0.0053 & 0.0013 & 0.9817 & 0.0054 & 0.0012 & 0.0051 \\ R4 & 0.0006 & 0.0006 & 0.0006 & 0.9969 & 0.0006 & 0.0007 \\ R5 & 0.0024 & 0.0006 & 0.0006 & 0.0026 & 0.9915 & 0.0023 \\ R6 & 0.0005 & 0.0005 & 0.0005 & 0.0005 & 0.0005 & 0.9976 \end{array}$$

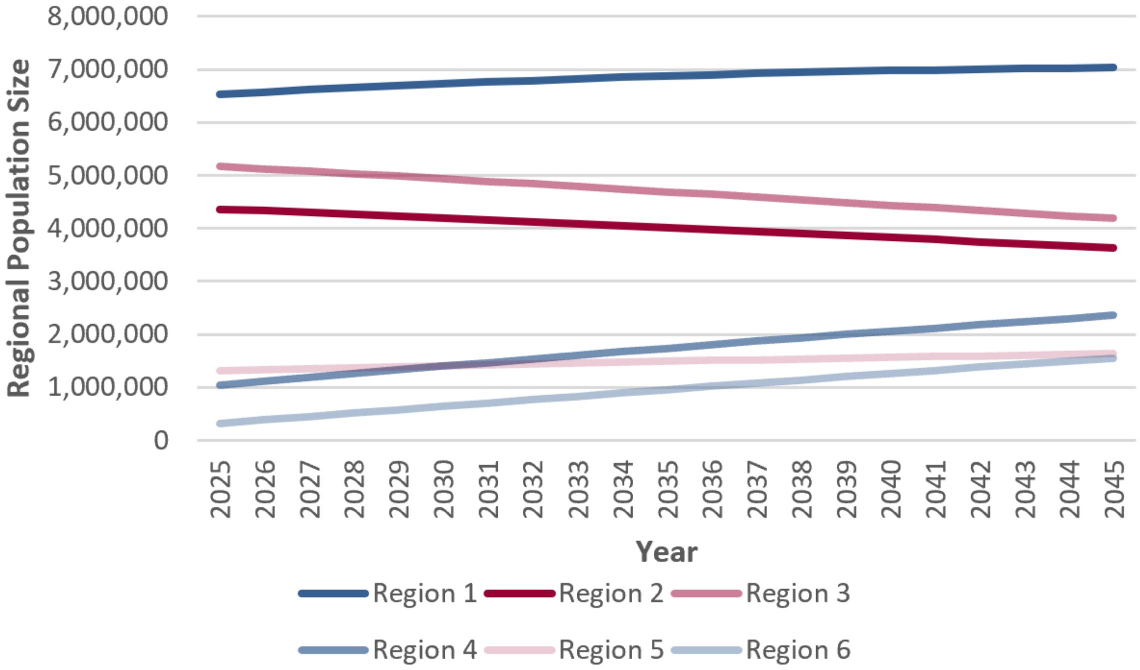
Starting with the scenario with no voluntary relocation feature, an assumption must be made that the Markov chain is stationary (probabilities of transition do not change) throughout the program duration. With this assumption, each year's transition distribution can then be calculated by putting the respective transition matrix to the power of time elapsed (integer value in years). For example, the transition distribution at the end of the last year of the program will have this transition matrix to the power of twenty.

With all twenty transition matrices obtained across years, the population and migration projection can be calculated with an identical procedure starting with region 1. The state vector for region 1 is multiplied by each year's transition matrix to calculate the probability of an individual remaining within region 1 for each year as well as the probability for an individual to migrate to any of the other regions. These obtained annual probabilities are then multiplied by the original region 1 population to determine the annual dispersion of region 1 individuals among all regions. This will directly provide the number of individuals migrating from region 1 to every other region on a yearly basis. This process can be repeated for all other regions to obtain their annual dispersion of individuals across regions and yearly migration patterns. Once all of 6 population distributions are constructed, they can all be summed across years to obtain the population for each region annually, accounting for individuals remaining and the 5 migration amounts from the other 5 regions.

This final regional population projection does not account for population growth across years. This is remedied by applying population growth as scale factors to each region identically to obtain a sum of regional populations equivalent to the population projection, and these scale factors are also applied to construct adjusted migration patterns. These population scaling factors will also allow for simulated regional populations and migration patterns in other potential SSPs.

With population adjustments completed, the final regional population distribution and migration patterns are projected across all years of the program, seen in the figure below. This entire procedure is then reproduced to create regional migrations and population across years for the scenario adding in voluntary relocation features, with the corresponding transition matrix altering values due to different probabilities of transition.

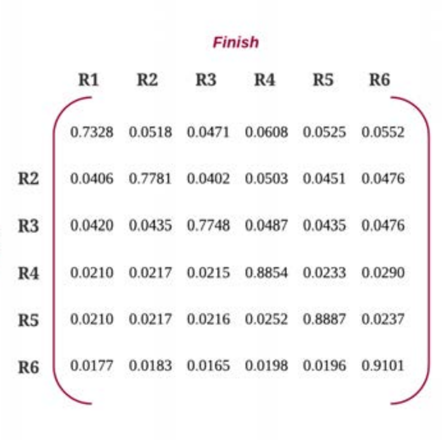
Regional Population Across Program Duration



Appendix N: Comparing Regional Population With and Without Program

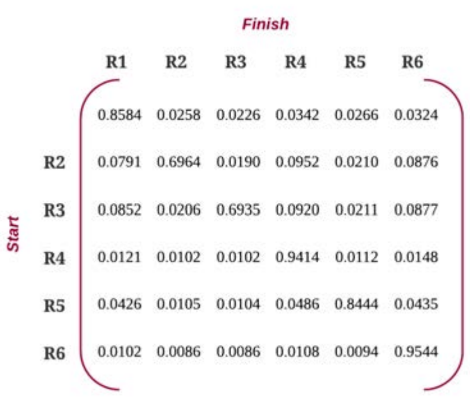
With the relocation incentives offered by a voluntary program, there will be clear differences in regional population distribution if it is added. From a logical perspective, the presence of a voluntary program will cause an increase in residents in regions 1, 4, and 6 (less hazardous regions) and a decrease in residents in regions 2, 3, and 5 (hazardous regions). In addition, there will be more resident migrations from these hazardous regions to less hazardous regions and less between all the hazardous regions. The final transition distribution after twenty years (the transition matrices to the power of twenty) demonstrate this reality as seen in the figure below. There is a higher probability of remaining in regions 1, 3, and 5 across twenty years for the “with voluntary” transition matrix compared to the “without voluntary” transition matrix. In addition, examining specific transition probabilities in the matrices demonstrate migration alterations for hazardous regions.

20-Step Transition *Matrix*
***Without** Voluntary Feature*



	R1	R2	R3	R4	R5	R6
	0.7328	0.0518	0.0471	0.0608	0.0525	0.0552
R2	0.0406	0.7781	0.0402	0.0503	0.0451	0.0476
R3	0.0420	0.0435	0.7748	0.0487	0.0435	0.0476
R4	0.0210	0.0217	0.0215	0.8854	0.0233	0.0290
R5	0.0210	0.0217	0.0216	0.0252	0.8887	0.0237
R6	0.0177	0.0183	0.0165	0.0198	0.0196	0.9101

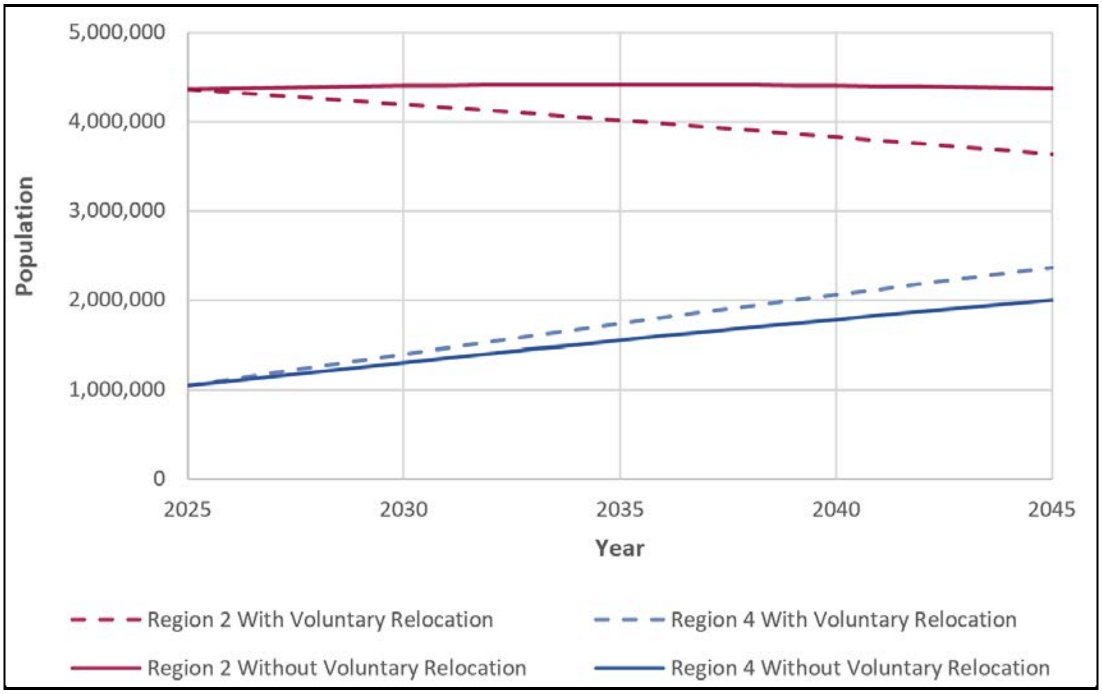
20-Step Transition *Matrix*
***With** Voluntary Feature*



	R1	R2	R3	R4	R5	R6
	0.8584	0.0258	0.0226	0.0342	0.0266	0.0324
R2	0.0791	0.6964	0.0190	0.0952	0.0210	0.0876
R3	0.0852	0.0206	0.6935	0.0920	0.0211	0.0877
R4	0.0121	0.0102	0.0102	0.9414	0.0112	0.0148
R5	0.0426	0.0105	0.0104	0.0486	0.8444	0.0435
R6	0.0102	0.0086	0.0086	0.0108	0.0094	0.9544

These population growth differences with and without a voluntary relocation feature can be isolated to each region to see the program’s influence. The figure below provides the population size in region 2, an unfavorable region, and region 4, a favorable region, with and without relocation incentives across the program timeframe. The graphic clearly shows a larger growth in region 4’s population and a larger decline in region 2’s population with the addition of a voluntary program.

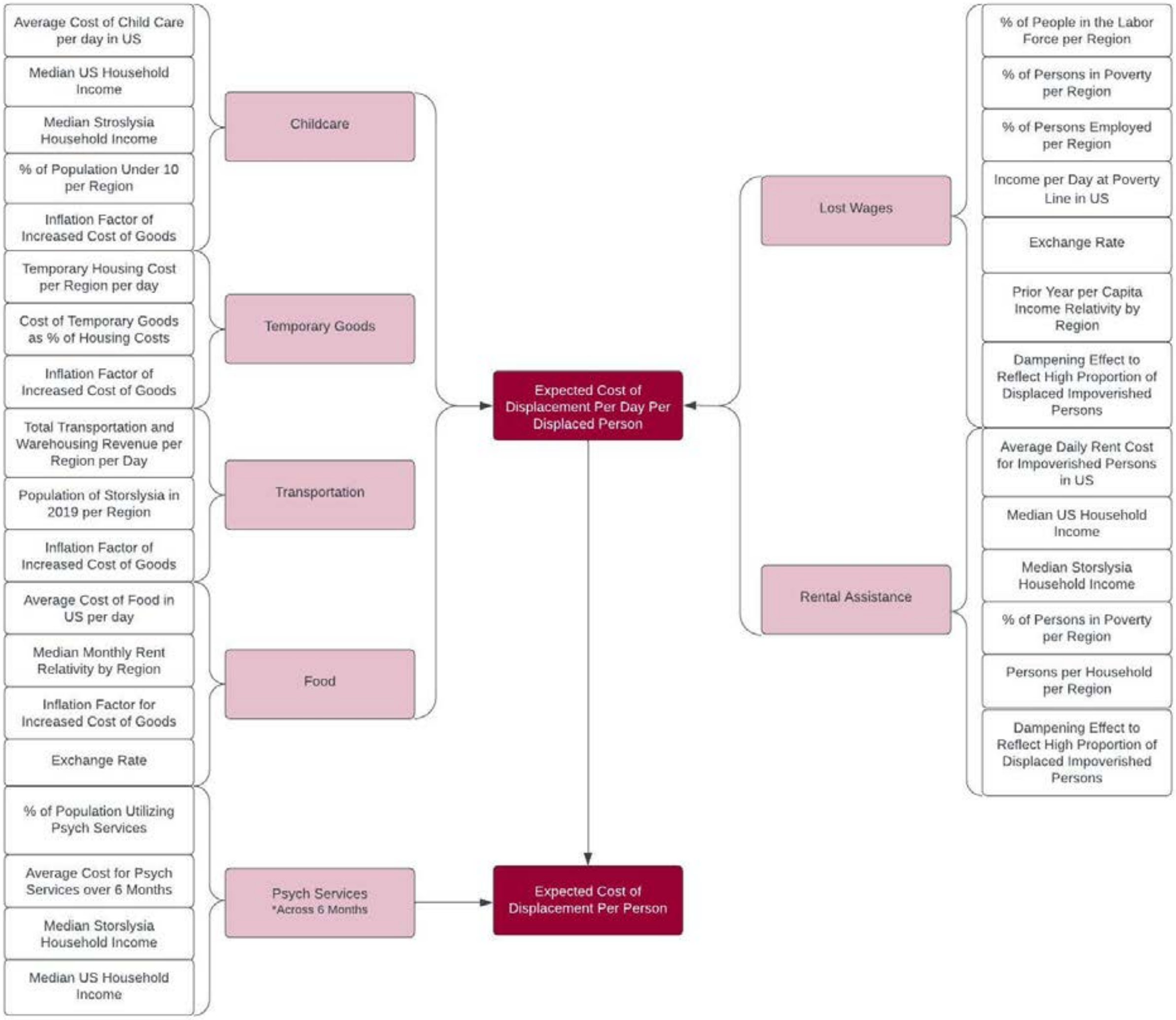
Population Size With and Without Voluntary Relocation Feature: Region 2 and 4



Appendix O: Displacement Assistance Feature Cost Procedure

1. Calculate the expected cost per day per displaced person by hazard category and region as depicted in the diagram below. There was also an expense ratio of 27% included in the final calculation.

Displacement Assistance Feature Cost Inputs



2. Calculate the “persons displaced per Ƥ of property damage” by hazard using displacement data from the US Census Bureau and property damage data from the National Oceanic and Atmospheric Administration (NOAA).
3. Combine the expected cost of the displacement assistance program per person by region and hazard with the persons displaced per Ƥ of property damage by hazard to create 54 final conversion factors. The equation utilized and a table of the factors can be seen below.

$$\mathit{Conversion\ Factor} = \mathit{Cost\ of\ Displacement\ Per\ Person}\ (\Psi) * \frac{\mathit{Persons\ Displaced}\ \ (\mathit{Persons})}{\mathit{Property\ Damage}\ (\Psi)}$$

Displacement Assistance Feature Conversion Factors

Hazard Category	R1	R2	R3	R4	R5	R6
Winter Weather/Winter Storms	29.968	26.931	28.809	24.458	25.250	23.836
Non-Flooding Storm	13.541	12.169	13.018	11.051	11.410	10.771
Hail	38.544	34.637	37.053	31.456	32.476	30.657
Flooding	4.599	4.122	4.416	3.729	3.853	3.651
Heat/Drought	0.000	0.000	0.000	0.000	0.000	0.000
Hurricane	2.859	2.552	2.734	2.287	2.378	2.272
Flooding Storm	4.599	4.122	4.416	3.729	3.853	3.651
Tornado	9.084	8.103	8.658	7.223	7.573	7.264
Wildfire	22.570	20.223	21.682	18.298	18.873	17.880
Extreme Events	132.206	117.971	126.406	105.659	109.908	105.050

4. Apply the calculated factors to each of the 50,000 property damage simulations with separation by year, hazard category, and region.
5. Sum across hazard categories to see projected involuntary displacement costs prior to adjusting for inflation and adjusting for population growth and migration.
6. Multiply involuntary displacement costs per region per year by the calculated population growth and migration factors.
7. Sum across regions to calculate total yearly projected involuntary displacement costs with adjustments for population growth and migration influenced by the voluntary relocation feature.
8. Adjust for inflation by multiplying by projected cumulative inflation.
9. Construct an empirical distribution of involuntary displacement costs for each year of the duration of the program, from which mean and Value at Risk at the 95th percentile were calculated.

Appendix P: Historical Property Damage by Region

Region	Property Damage (Ψ)	Land Area (hectares)	Property Damage per Hectare
1	1429363879.00	2442659	585.17
2	24410089611.00	3522311	6930.13
3	2464541725.00	2353615	1047.13
4	1965893504.00	3438613	571.71
5	7174364554.00	2067059	3470.81
6	351683572.00	1556199	225.99

Appendix Q: Voluntary Relocation Feature Cost Procedure

1. The costs associated with the voluntary relocation feature are moving costs, the buyout program expenses, and administrative costs.
2. A constant value, the U.S. average moving cost of Ꝓ1060, was assumed for moving costs (Perry). A constant value was assumed, as the distance of the move, a key factor in determining moving costs, is unknown.
3. The buyout program expenses for a property were equivalent to the average assessed value of the property, assumed to be at 80% of property value, with property value capped at Ꝓ2 million. The average property value by region was found using a weighted average.
4. The constant moving cost and expected assessed value are on a per household basis. To convert to a per person basis, using Storslysia's persons per household by region (2016-2020) of the out-region. The costs differ by out-region, due to differing expected assessed values and differing persons per household.
5. A 6% administrative cost was applied to the per person cost to get finalized cost per person. This 6% accounts for the costs associated with application review, as well as other logistical processes.

Voluntary Relocation Feature: Cost Per Person (Ꝓ)

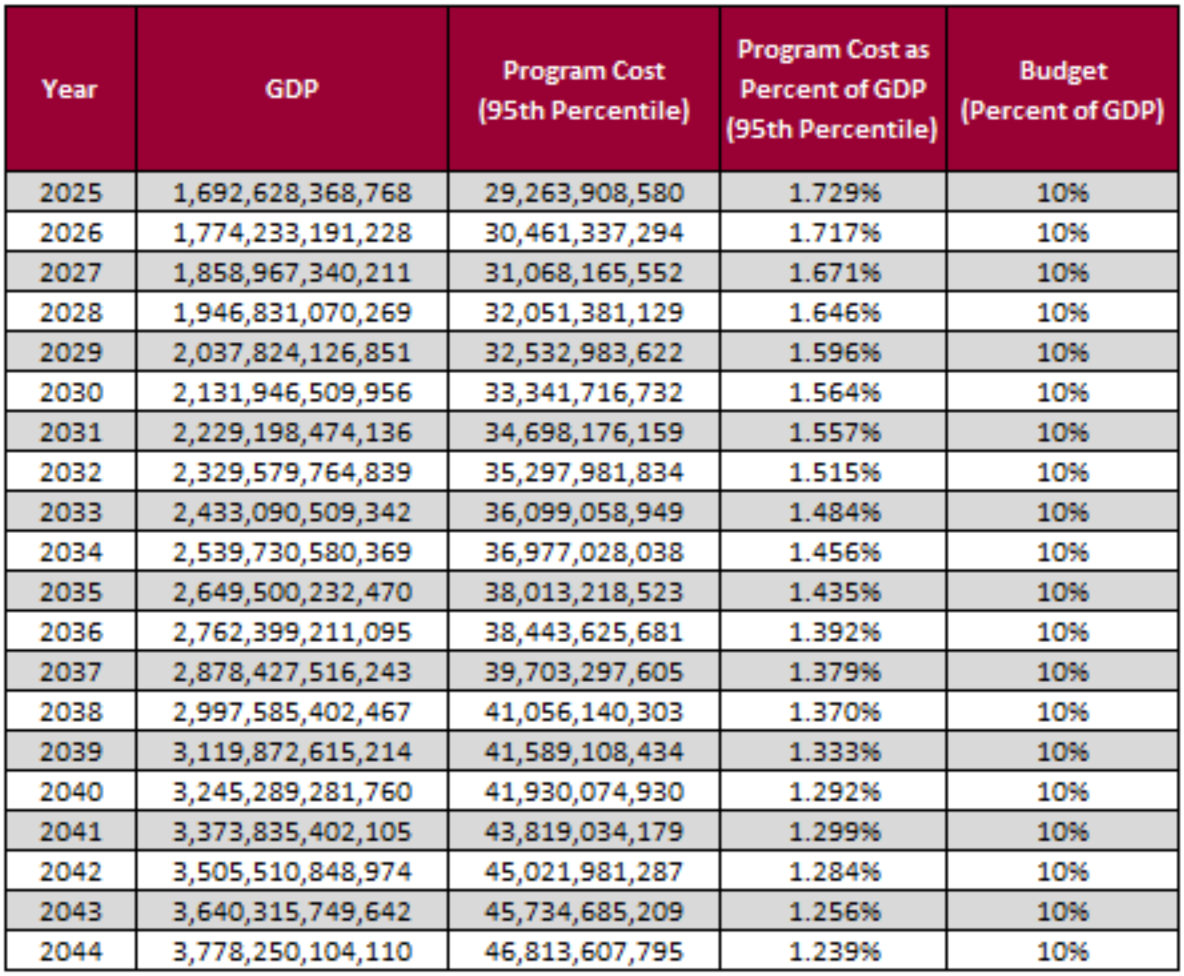
Out-region	Cost per person (Ꝓ)
2	107,492.70
3	104,568.62
5	71,309.39

6. Per person cost was applied to the amount of Storslysia residents who are projected to migrate from an out-region to an in-region for each year within the program duration.

Total Voluntary Relocation Feature Costs (Billions Ᵽ)

Year	SSP1–2.6	SSP2–3.4	SSP3–6.0	SSP5–Baseline
2025	19.169	19.445	18.870	19.193
2026	19.543	19.913	19.180	19.572
2027	19.920	20.387	19.494	19.954
2028	20.299	20.865	19.811	20.338
2029	20.680	21.350	20.131	20.725
2030	21.064	21.839	20.454	21.115
2031	21.450	22.334	20.780	21.508
2032	21.838	22.834	21.109	21.904
2033	22.229	23.339	21.441	22.302
2034	22.621	23.850	21.776	22.702
2035	23.016	24.365	22.114	23.106
2036	23.412	24.886	22.456	23.512
2037	23.810	25.411	22.800	23.920
2038	24.210	25.942	23.148	24.330
2039	24.612	26.477	23.499	24.743
2040	25.015	27.017	23.852	25.158
2041	25.420	27.562	24.209	25.576
2042	25.826	28.111	24.569	25.995
2043	26.233	28.664	24.932	26.417
2044	26.642	29.222	25.297	26.840

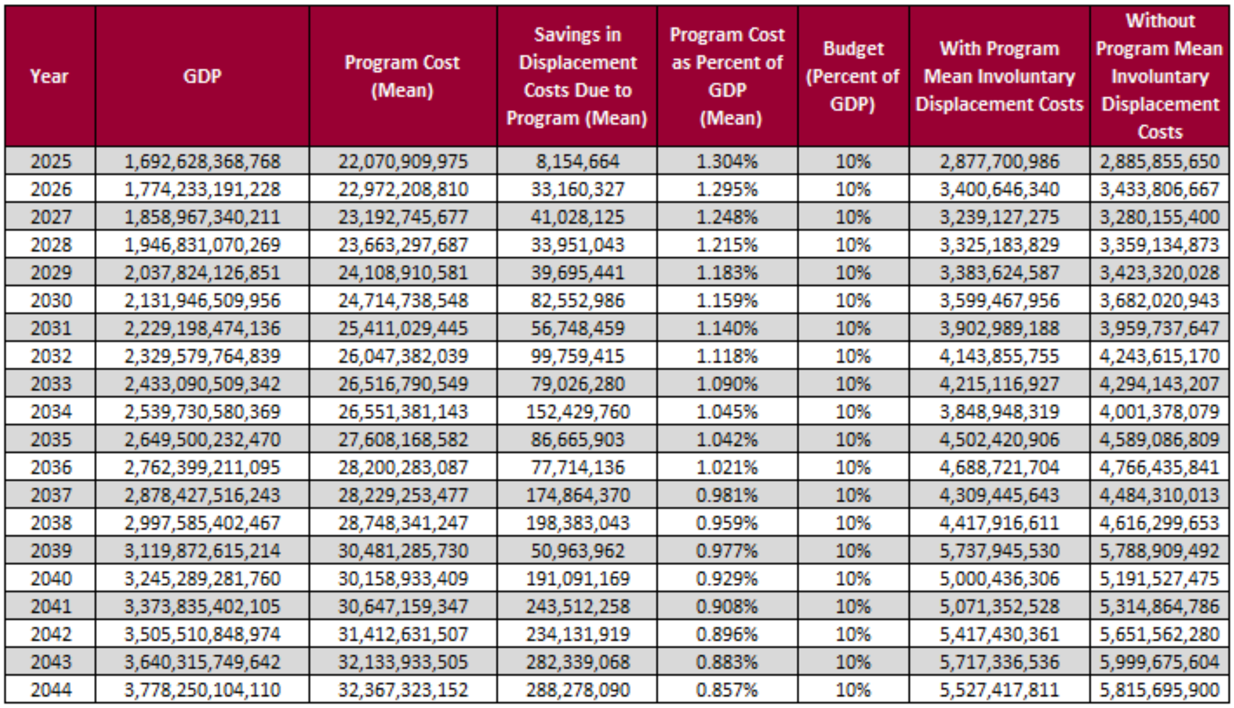
Appendix R: Reserve and Solvency Details



Year	GDP	Program Cost (95th Percentile)	Program Cost as Percent of GDP (95th Percentile)	Budget (Percent of GDP)
2025	1,692,628,368,768	29,263,908,580	1.729%	10%
2026	1,774,233,191,228	30,461,337,294	1.717%	10%
2027	1,858,967,340,211	31,068,165,552	1.671%	10%
2028	1,946,831,070,269	32,051,381,129	1.646%	10%
2029	2,037,824,126,851	32,532,983,622	1.596%	10%
2030	2,131,946,509,956	33,341,716,732	1.564%	10%
2031	2,229,198,474,136	34,698,176,159	1.557%	10%
2032	2,329,579,764,839	35,297,981,834	1.515%	10%
2033	2,433,090,509,342	36,099,058,949	1.484%	10%
2034	2,539,730,580,369	36,977,028,038	1.456%	10%
2035	2,649,500,232,470	38,013,218,523	1.435%	10%
2036	2,762,399,211,095	38,443,625,681	1.392%	10%
2037	2,878,427,516,243	39,703,297,605	1.379%	10%
2038	2,997,585,402,467	41,056,140,303	1.370%	10%
2039	3,119,872,615,214	41,589,108,434	1.333%	10%
2040	3,245,289,281,760	41,930,074,930	1.292%	10%
2041	3,373,835,402,105	43,819,034,179	1.299%	10%
2042	3,505,510,848,974	45,021,981,287	1.284%	10%
2043	3,640,315,749,642	45,734,685,209	1.256%	10%
2044	3,778,250,104,110	46,813,607,795	1.239%	10%

The 95th percentile program cost should be held in reserve to ensure solvency with 95% probability.

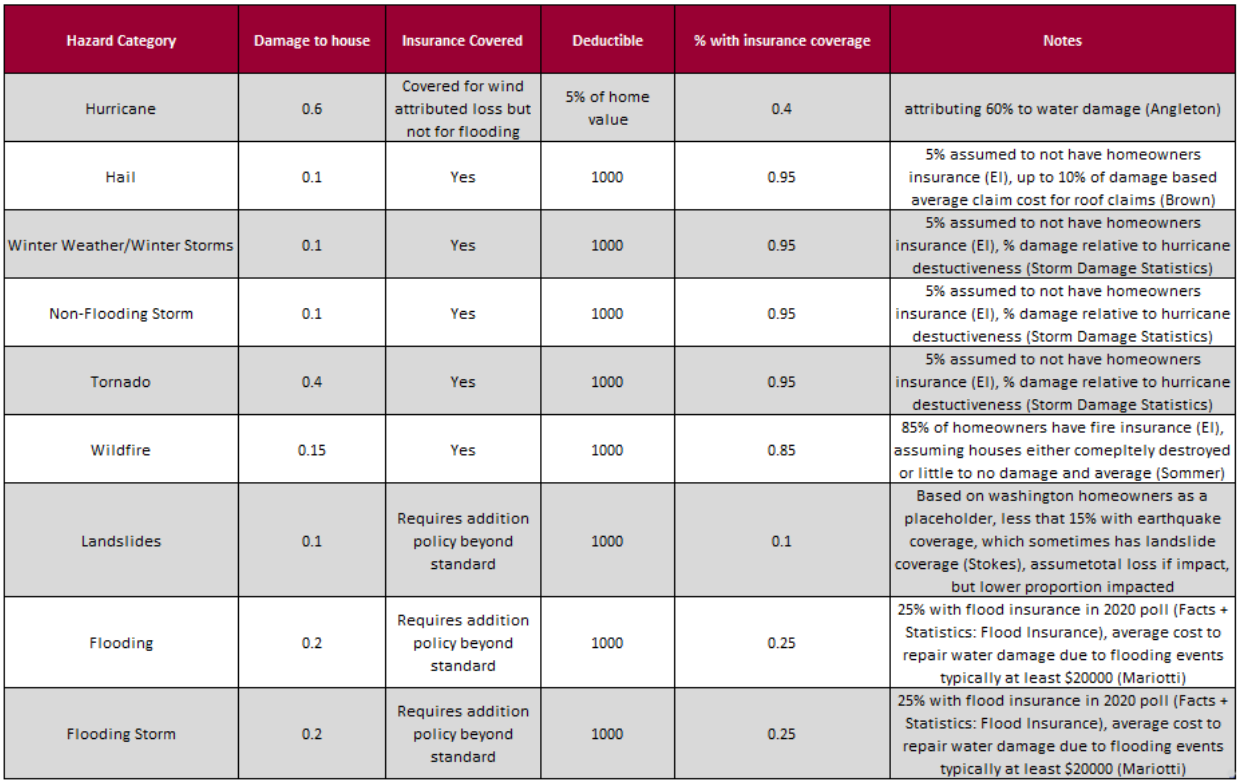
Appendix S: CRDP Projected Cost Values



Year	GDP	Program Cost (Mean)	Savings in Displacement Costs Due to Program (Mean)	Program Cost as Percent of GDP (Mean)	Budget (Percent of GDP)	With Program Mean Involuntary Displacement Costs	Without Program Mean Involuntary Displacement Costs
2025	1,692,628,368,768	22,070,909,975	8,154,664	1.304%	10%	2,877,700,986	2,885,855,650
2026	1,774,233,191,228	22,972,208,810	33,160,327	1.295%	10%	3,400,646,340	3,433,806,667
2027	1,858,967,340,211	23,192,745,677	41,028,125	1.248%	10%	3,239,127,275	3,280,155,400
2028	1,946,831,070,269	23,663,297,687	33,951,043	1.215%	10%	3,325,183,829	3,359,134,873
2029	2,037,824,126,851	24,108,910,581	39,695,441	1.183%	10%	3,383,624,587	3,423,320,028
2030	2,131,946,509,956	24,714,738,548	82,552,986	1.159%	10%	3,599,467,956	3,682,020,943
2031	2,229,198,474,136	25,411,029,445	56,748,459	1.140%	10%	3,902,989,188	3,959,737,647
2032	2,329,579,764,839	26,047,382,039	99,759,415	1.118%	10%	4,143,855,755	4,243,615,170
2033	2,433,090,509,342	26,516,790,549	79,026,280	1.090%	10%	4,215,116,927	4,294,143,207
2034	2,539,730,580,369	26,551,381,143	152,429,760	1.045%	10%	3,848,948,319	4,001,378,079
2035	2,649,500,232,470	27,608,168,582	86,665,903	1.042%	10%	4,502,420,906	4,589,086,809
2036	2,762,399,211,095	28,200,283,087	77,714,136	1.021%	10%	4,688,721,704	4,766,435,841
2037	2,878,427,516,243	28,229,253,477	174,864,370	0.981%	10%	4,309,445,643	4,484,310,013
2038	2,997,585,402,467	28,748,341,247	198,383,043	0.959%	10%	4,417,916,611	4,616,299,653
2039	3,119,872,615,214	30,481,285,730	50,963,962	0.977%	10%	5,737,945,530	5,788,909,492
2040	3,245,289,281,760	30,158,933,409	191,091,169	0.929%	10%	5,000,436,306	5,191,527,475
2041	3,373,835,402,105	30,647,159,347	243,512,258	0.908%	10%	5,071,352,528	5,314,864,786
2042	3,505,510,848,974	31,412,631,507	234,131,919	0.896%	10%	5,417,430,361	5,651,562,280
2043	3,640,315,749,642	32,133,933,505	282,339,068	0.883%	10%	5,717,336,536	5,999,675,604
2044	3,778,250,104,110	32,367,323,152	288,278,090	0.857%	10%	5,527,417,811	5,815,695,900

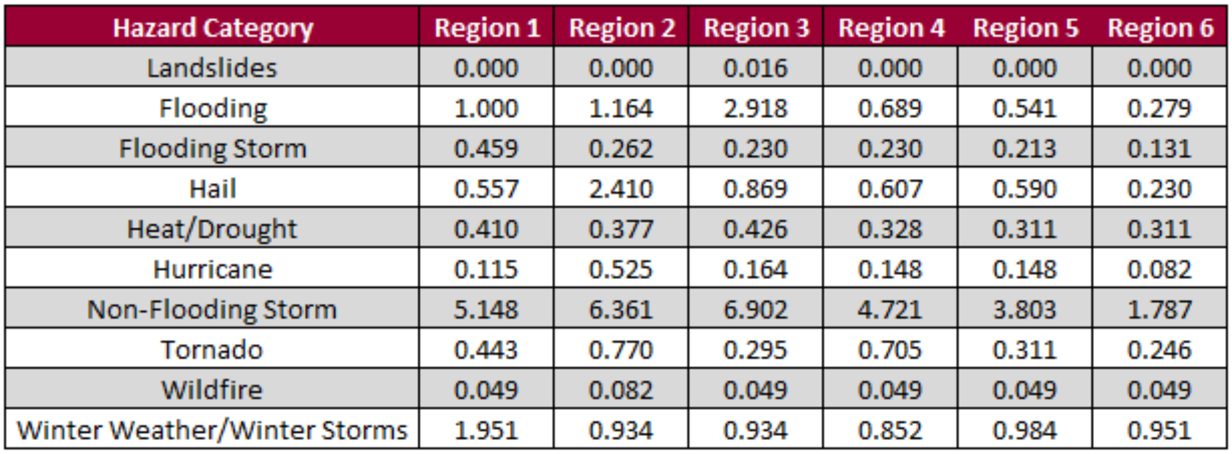
Appendix T: Voluntary Relocation Feature Resident Cost Analysis

Insurance and Damage Assumptions



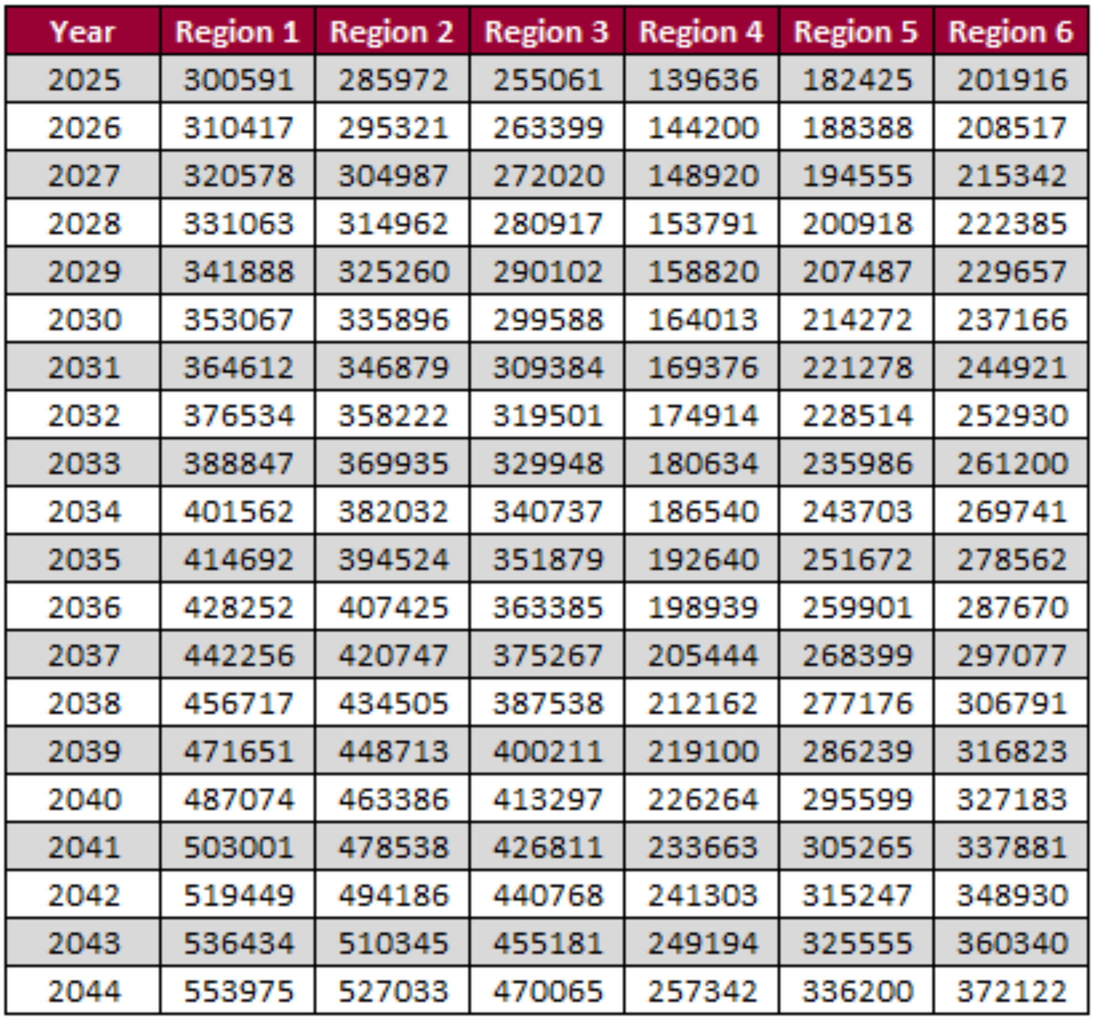
Hazard Category	Damage to house	Insurance Covered	Deductible	% with insurance coverage	Notes
Hurricane	0.6	Covered for wind attributed loss but not for flooding	5% of home value	0.4	attributing 60% to water damage (Angleton)
Hail	0.1	Yes	1000	0.95	5% assumed to not have homeowners insurance (EI), up to 10% of damage based average claim cost for roof claims (Brown)
Winter Weather/Winter Storms	0.1	Yes	1000	0.95	5% assumed to not have homeowners insurance (EI), % damage relative to hurricane destuctiveness (Storm Damage Statistics)
Non-Flooding Storm	0.1	Yes	1000	0.95	5% assumed to not have homeowners insurance (EI), % damage relative to hurricane destuctiveness (Storm Damage Statistics)
Tornado	0.4	Yes	1000	0.95	5% assumed to not have homeowners insurance (EI), % damage relative to hurricane destuctiveness (Storm Damage Statistics)
Wildfire	0.15	Yes	1000	0.85	85% of homeowners have fire insurance (EI), assuming houses either comepltely destroyed or little to no damage and average (Sommer)
Landslides	0.1	Requires addition policy beyond standard	1000	0.1	Based on washington homeowners as a placeholder, less that 15% with earthquake coverage, which sometimes has landslide coverage (Stokes), assumetotal loss if impact, but lower proportion impacted
Flooding	0.2	Requires addition policy beyond standard	1000	0.25	25% with flood insurance in 2020 poll (Facts + Statistics: Flood Insurance), average cost to repair water damage due to flooding events typically at least $20000 (Mariotti)
Flooding Storm	0.2	Requires addition policy beyond standard	1000	0.25	25% with flood insurance in 2020 poll (Facts + Statistics: Flood Insurance), average cost to repair water damage due to flooding events typically at least $20000 (Mariotti)

Expected Number of Occurrences per Hazard Category per Year



Hazard Category	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Landslides	0.000	0.000	0.016	0.000	0.000	0.000
Flooding	1.000	1.164	2.918	0.689	0.541	0.279
Flooding Storm	0.459	0.262	0.230	0.230	0.213	0.131
Hail	0.557	2.410	0.869	0.607	0.590	0.230
Heat/Drought	0.410	0.377	0.426	0.328	0.311	0.311
Hurricane	0.115	0.525	0.164	0.148	0.148	0.082
Non-Flooding Storm	5.148	6.361	6.902	4.721	3.803	1.787
Tornado	0.443	0.770	0.295	0.705	0.311	0.246
Wildfire	0.049	0.082	0.049	0.049	0.049	0.049
Winter Weather/Winter Storms	1.951	0.934	0.934	0.852	0.984	0.951

Inflation-Adjusted Property Values by Region (Ψ)



Year	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
2025	300591	285972	255061	139636	182425	201916
2026	310417	295321	263399	144200	188388	208517
2027	320578	304987	272020	148920	194555	215342
2028	331063	314962	280917	153791	200918	222385
2029	341888	325260	290102	158820	207487	229657
2030	353067	335896	299588	164013	214272	237166
2031	364612	346879	309384	169376	221278	244921
2032	376534	358222	319501	174914	228514	252930
2033	388847	369935	329948	180634	235986	261200
2034	401562	382032	340737	186540	243703	269741
2035	414692	394524	351879	192640	251672	278562
2036	428252	407425	363385	198939	259901	287670
2037	442256	420747	375267	205444	268399	297077
2038	456717	434505	387538	212162	277176	306791
2039	471651	448713	400211	219100	286239	316823
2040	487074	463386	413297	226264	295599	327183
2041	503001	478538	426811	233663	305265	337881
2042	519449	494186	440768	241303	315247	348930
2043	536434	510345	455181	249194	325555	360340
2044	553975	527033	470065	257342	336200	372122

The expected property damage excess of homeowners insurance was calculated by region as follows.

$$\sum_{Hazard} Frequency \times (\min(Damage\ \% \times Median\ House\ Price, Deductible) \times \\ P(HO\ Insurance) + \left(1 - P(HO\ Insurance)\right) \times Damage\ \% \times Median\ House\ Price) +$$

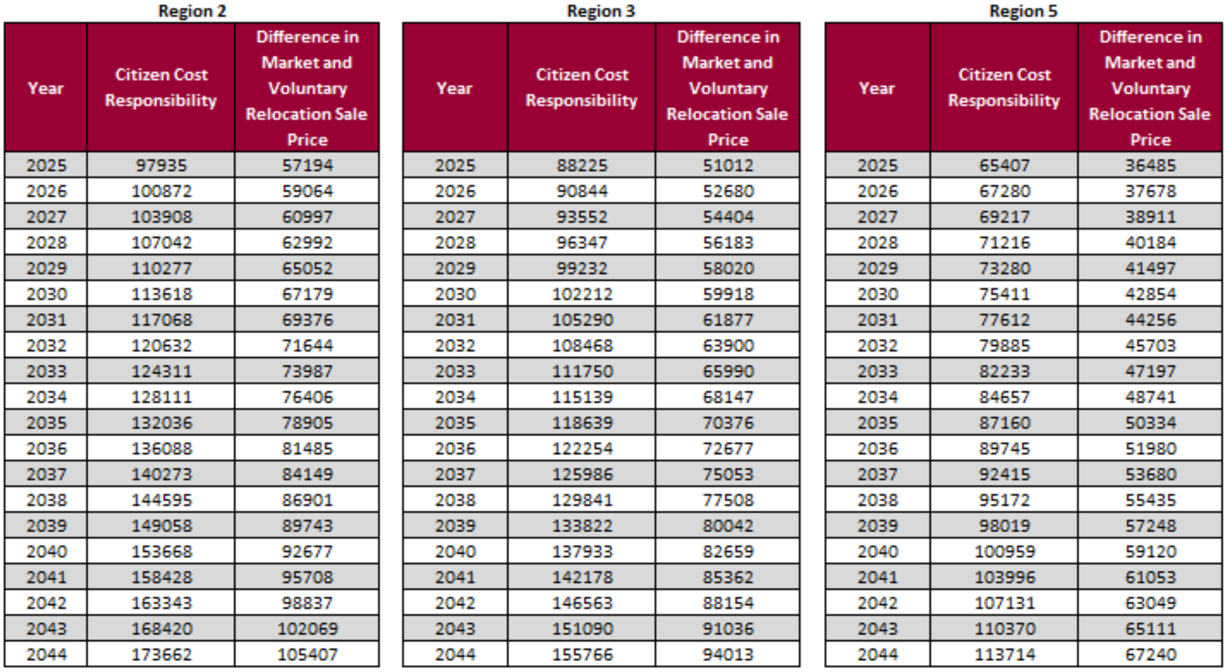
- P(HO Insurance) – the probability of having homeowners insurance coverage for the hazard category
- Damage % – The assumed percent of damage to the house by hazard category
- Median House Price – the median house price within the specific region adjusted for inflation
- Deductible – assumed deductible for the homeowners insurance policy
- Frequency – the expected number of occurrences of the hazard category per year within the specified region

This was compared with the financial impact of participating in the voluntary relocation feature. Under this program, consumers receive the assessed value of their house, which is assumed to be 80% of market value, thus, returning a negative financial impact of 20% of the house value.

This was calculated by multiplying the inflation-adjusted median house value by 0.2.

The final comparison of the voluntary program's financial impacts and total expected property damage excess of homeowners insurance in pecunias, separated by regions in which the voluntary relocation feature applies is shown below.

Final Comparison of Voluntary Relocation Feature Resident Costs



Region 2

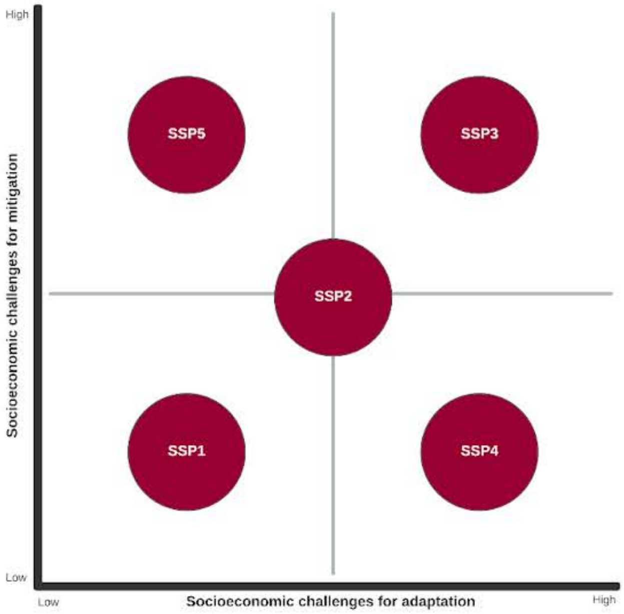
Year	Citizen Cost Responsibility	Difference in Market and Voluntary Relocation Sale Price
2025	97935	57194
2026	100872	59064
2027	103908	60997
2028	107042	62992
2029	110277	65052
2030	113618	67179
2031	117068	69376
2032	120632	71644
2033	124311	73987
2034	128111	76406
2035	132036	78905
2036	136088	81485
2037	140273	84149
2038	144595	86901
2039	149058	89743
2040	153668	92677
2041	158428	95708
2042	163343	98837
2043	168420	102069
2044	173662	105407

Region 3

Year	Citizen Cost Responsibility	Difference in Market and Voluntary Relocation Sale Price
2025	88225	51012
2026	90844	52680
2027	93552	54404
2028	96347	56183
2029	99232	58020
2030	102212	59918
2031	105290	61877
2032	108468	63900
2033	111750	65990
2034	115139	68147
2035	118639	70376
2036	122254	72677
2037	125986	75053
2038	129841	77508
2039	133822	80042
2040	137933	82659
2041	142178	85362
2042	146563	88154
2043	151090	91036
2044	155766	94013

Region 5

Year	Citizen Cost Responsibility	Difference in Market and Voluntary Relocation Sale Price
2025	65407	36485
2026	67280	37678
2027	69217	38911
2028	71216	40184
2029	73280	41497
2030	75411	42854
2031	77612	44256
2032	79885	45703
2033	82233	47197
2034	84657	48741
2035	87160	50334
2036	89745	51980
2037	92415	53680
2038	95172	55435
2039	98019	57248
2040	100959	59120
2041	103996	61053
2042	107131	63049
2043	110370	65111
2044	113714	67240



Each SSP has differing assumptions surrounding socioeconomic and technological development. The socioeconomic and technological factors considered in each SSP are, population and economic growth, urbanization, trade, energy, and agricultural systems. Each SSP results in a different climate future, due to the greenhouse gasses that will be emitted under each set of assumptions (Riahi et al.).

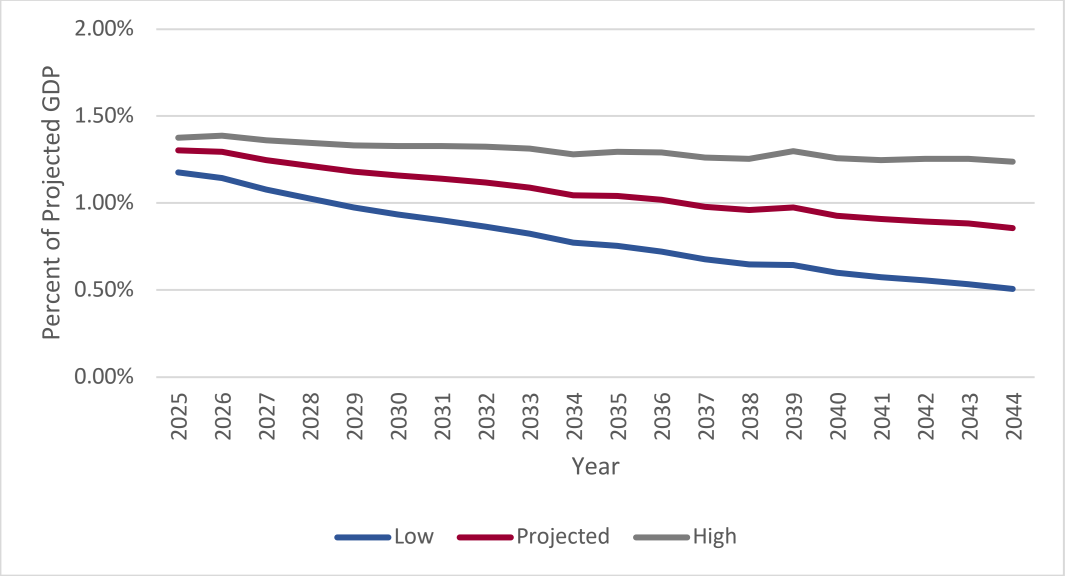
1. To determine the relationship between the atmospheric concentration of carbon dioxide and the property damage resulting from hazard events, annual data was required. However, the IPCC's SSP database only includes the atmospheric concentration of carbon dioxide by decade. Therefore, annual atmospheric concentration of carbon dioxide data was sourced from the NOAA (Tans and Keeling).
2. Annual atmospheric concentration of carbon dioxide data and Storslysia's historical property damage in years 1962-2020 were compared to determine their relationship. Storslysia's property damage was inflation-adjusted prior to the analysis.
3. As the atmospheric concentration of carbon dioxide increases, global surface temperature increases, and the frequency and intensity of weather events will increase (Acevedo and Novta). Therefore, a model was constructed to capture the positive trend.
4. Storslysia's property damage was logarithmically transformed. Then, a linear model was constructed. While the model is not a perfect fit, it attempts to capture the complex relationship between the atmospheric concentration of carbon dioxide and hazard events.
5. Before applying the model to the atmospheric concentration of carbon dioxide values by SSP, the intermediate values were found in a similar manner as was completed for worldwide GDP and population.
6. With annual atmospheric concentration of carbon dioxide data for each SSP, the linear model could be applied to predict the logarithmically-transformed property damage.
7. With the predicted logarithmically-transformed property damage by year, the RAFs were computed to capture the relationship between SSP1–2.6, SSP2–3.4, and SSP3–6.0 to the baseline, SSP5. To do so, all of the logarithmically-transformed property damage predictions were divided by those of the baseline, SSP5.

Final RAFs

Year	SSP1–2.6	SSP2–3.4	SSP3–6.0	SSP5–Baseline
2025	0.994	0.994	1.000	1.000
2026	0.992	0.993	0.999	1.000
2027	0.990	0.992	0.998	1.000
2028	0.988	0.990	0.997	1.000
2029	0.987	0.989	0.996	1.000
2030	0.984	0.987	0.995	1.000
2031	0.982	0.986	0.994	1.000
2032	0.980	0.984	0.993	1.000
2033	0.977	0.982	0.992	1.000
2034	0.975	0.980	0.991	1.000
2035	0.972	0.978	0.989	1.000
2036	0.970	0.976	0.988	1.000
2037	0.967	0.974	0.986	1.000
2038	0.964	0.972	0.985	1.000
2039	0.961	0.969	0.983	1.000
2040	0.957	0.967	0.982	1.000
2041	0.954	0.964	0.980	1.000
2042	0.951	0.962	0.978	1.000
2043	0.947	0.959	0.976	1.000
2044	0.944	0.956	0.974	1.000
2045	0.940	0.954	0.972	1.000

Appendix W: Inflation Sensitivity Testing

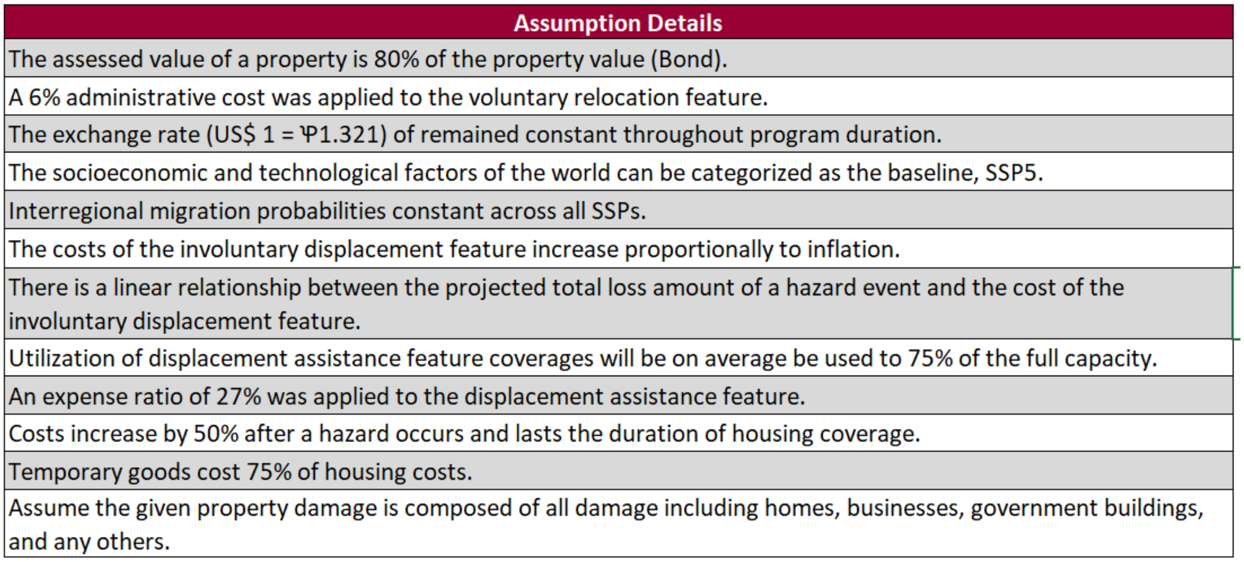
Projected CRDP Costs (% of Storslysia GDP) under Low, Projected, and High Inflation



Projected CRDP Costs (% of Storslysia GDP) under Low, Projected, and High Inflation

Year	Low	Projected	High
2025	1.177%	1.304%	1.375%
2026	1.143%	1.295%	1.388%
2027	1.077%	1.248%	1.360%
2028	1.026%	1.215%	1.347%
2029	0.977%	1.183%	1.333%
2030	0.936%	1.159%	1.328%
2031	0.901%	1.140%	1.328%
2032	0.864%	1.118%	1.324%
2033	0.824%	1.090%	1.313%
2034	0.773%	1.045%	1.280%
2035	0.753%	1.042%	1.297%
2036	0.722%	1.021%	1.292%
2037	0.678%	0.981%	1.262%
2038	0.648%	0.959%	1.255%
2039	0.646%	0.977%	1.300%
2040	0.601%	0.929%	1.257%
2041	0.575%	0.908%	1.249%
2042	0.554%	0.896%	1.253%
2043	0.534%	0.883%	1.255%
2044	0.507%	0.857%	1.239%

Appendix X: Assumption Details



Assumption Details
The assessed value of a property is 80% of the property value (Bond).
A 6% administrative cost was applied to the voluntary relocation feature.
The exchange rate (US$ 1 = Ꝑ1.321) of remained constant throughout program duration.
The socioeconomic and technological factors of the world can be categorized as the baseline, SSP5.
Interregional migration probabilities constant across all SSPs.
The costs of the involuntary displacement feature increase proportionally to inflation.
There is a linear relationship between the projected total loss amount of a hazard event and the cost of the involuntary displacement feature.
Utilization of displacement assistance feature coverages will be on average be used to 75% of the full capacity.
An expense ratio of 27% was applied to the displacement assistance feature.
Costs increase by 50% after a hazard occurs and lasts the duration of housing coverage.
Temporary goods cost 75% of housing costs.
Assume the given property damage is composed of all damage including homes, businesses, government buildings, and any others.

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