WHITE PAPER

OFFICE OF MANAGEMENT AND BUDGET

# ADDRESSING THE IMPACTS OF CLIMATE CHANGE:

# FEDERAL BUDGETARY RISKS, ADAPTATION PLANNING, AND THE CLIMATE BENEFITS OF FEDERAL INVESTMENTS

January 2025

# Table of Contents

# I. Summary

The effects of climate change involve numerous costs that are borne by society, including indirect effects on financial markets, budgets, trade, and employment, which are projected to be distributed unequally across communities, regions, and industries across the United States, from agriculture, finance, and tourism to healthcare, education, and real estate. Climate change impacts the economy through increases in temperature, rising sea levels, and more frequent and intense weather-related extreme events, which are estimated to generate substantial and increasing economic costs in many sectors (Hsiang et al., 2023).

Since 1980, the U.S. has sustained 403 weather and climate disasters where overall damages and costs reached or exceeded $1 billion (including Consumer Price Index [CPI] adjustment to 2024). The total cost of these 403 events exceeds $2.9 trillion (NOAA, 2024a). Evidence suggests that the frequency and intensity of weather and climate disasters are increasing. The annual average number of events between 1980 and 2024 was 9.0 events; the annual average for the most recent five years (2020-2024) is 23.0 events. These costs are being borne not only in the private sector, but also in the Federal Government.

As climate change intensifies, the climate effects are expected to impose substantial new costs across the U.S. economy and adversely affect the economic opportunities of most Americans (Hsiang et al., 2023). From unprecedented wildfires and extreme flooding to record-breaking hurricanes and drought, Americans across the country are feeling the devastating impacts of the climate crisis. In 2024, there were 27 confirmed weather and climate disaster events each with losses exceeding $1 billion in the United States. These events included 17 severe storm events, 5 tropical cyclone events, 1 wildfire event, and 2 winter storm events. Overall, these events directly resulted in the deaths of 568 people and had severe economic effects on the areas impacted. The indirect impacts of these events have as yet not been fully ascertained, but will be certain to increase both the total attributable mortality and the economic impacts associated with these events. Extreme events have also contributed to the human migration and the displacement of individuals, which can affect U.S. economic and national security interests (The White House, 2021).

The Federal Government's budget is directly and substantially at risk from expected lost revenues and increasing expenditures due to climate change in the coming decades. As directed by President Biden, agencies continue to build the technical and scientific capacity to assess the risks facing the Federal Government, and ultimately the American taxpayer, and to seek opportunities to use the best available information to implement measures to minimize that risk. This white paper captures these efforts by focusing on three objectives: (i) identify and assess climate financial risk for Federal programs, (ii) review Federal Agency plans for adaptation to climate change, and (iii) review and estimate the climate benefits of Federal investments in climate change mitigation. Below are some of the highlights from these three objectives.

1. **Federal Actions to Identify and Assess Climate Financial Risk.** This white paper provides insight on the growing threats of climate change on the Federal Government, in

particular risks of higher costs to Federal agencies, including programs that support farmers during disasters; risks to long-term Federal infrastructure; and risks to public health. The paper provides in-depth information on how the agencies arrived at cost estimates and the economic tools that are being developed to more accurately predict climate financial risks in the future. Some of the highlights include:

- *U.S. Department of Agriculture (USDA): Federal Crop Insurance Program's Pasture, Rangeland, and Forage Insurance Plan*

  The Pasture, Rangeland, and Forage insurance plan is a risk management tool for livestock producers to help mitigate financial losses from a decline in forage production during periods of decreased precipitation (such as from drought). Increasing drought could lead to an increase in participation in the plan, which may constitute a financial climate risk for the Federal Government. Under the full participation scenario, total net payments are projected to average $2.6 billion per year between 2024-2050, an increase of approximately $2.1 billion per year over the baseline scenario that assumes no change in participation from 2024 levels.
- *U.S. Department of State: Risks to Overseas Buildings and Operations*

  The Department of State has over 280 globally distributed diplomatic posts located in geographically diverse areas and exposed to a wide range of natural hazards, including earthquakes, extreme heat, extreme wind, flooding, landslides, tsunamis, water stress, and wildfire. Natural hazards have historically had substantial financial impacts on the Department's diplomatic infrastructure and operations. The Bureau of Overseas Buildings Operations Climate Security & Resilience Program has made significant strides in improving climate resilience at U.S. diplomatic missions.
- *U.S. Environmental Protection Agency (EPA) Facilities*

  The EPA Resiliency Assessment Program includes comprehensive climate resilience assessments of EPA's owned facilities to address future projected impacts from climate change site assessments, agency strategic goals related to resiliency, and commitments to implement high-priority projects to increase the Agency's resilience to impacts from climate change. Risks to five EPA facilities with completed climate resilience assessments are discussed. For the five facilities included in this paper, the total capital improvement costs through 2034 (undiscounted) are projected to equal $407 million, the total new construction cost is projected to be $876 million, and the total catastrophic rebuild cost is more than $1 billion.
- *U.S. Department of the Interior (Interior): Tools to Assess and Address Climate-Related Financial Risk to Buildings and Operations*

  Interior bureaus manage lands and resources that provide recreational opportunities to the public, supply water and hydropower in Western States, and are an important source of responsibly managed renewable and nonrenewable energy and mineral development. To meet these obligations, Interior maintains among its assets over 41,800 buildings—including visitor centers, schools, offices, museums, and housing. These buildings are distributed across the United States and its territories and are exposed to a wide range of potential hazards, including hazards related to climate change. The Department supports research and tools that can be used to assess the potential financial risks from climate change to these buildings and associated operations and help make informed decisions to address them.

- *U.S. Department of Transportation (DOT): Managing Climate Change and Financial Risk to the Transportation System*

  The National Transportation System moves passengers and freight across the Nation and provides connectivity to global transportation systems. Extreme weather events and climate change impacts can directly damage transportation infrastructure, requiring costly repairs and disrupting essential movement of goods and passengers. This paper presents the DOT frameworks and tools that support resilience assessments for transportation assets. The paper also includes descriptions of the system-wide climate hazard exposure tools, a summary of projected climate-related financial impacts on the transportation system, and DOT investments for resilience improvements.

2. **Federal Agency Climate Adaptation Planning and Implementation.** This white paper provides an overview of the evolution and progress made in development of Federal Climate Adaptation Plans as well as highlighting connections between reporting requirements for Agency Financial Reports and recent analyses by the U.S. Government Accountability Office related to adaptation and resilience activities and management of Federal fiscal risk. The paper provides recommendations on future focus areas for improvement, including technical expertise, enterprise risk management, scope planning, and action planning.

3. **Accounting for the Climate Benefits of Federal Investments.** Federal investments in reducing greenhouse gas emissions yield climate benefits that accrue to society. These benefits can be measured using estimates of the social cost of greenhouse gases. In particular, OMB examined the climate benefits of programs funded by the Inflation Reduction Act (IRA), which is the single largest piece of legislation to combat climate change in U.S. history. Using the social cost of greenhouse gases (EPA, 2023a), OMB estimates the projected economy-wide benefits from carbon dioxide emissions reductions for the modeled IRA provisions over the 12-year period range from $536 billion to $2.36 trillion, with the median projected benefits at $1.11 trillion.

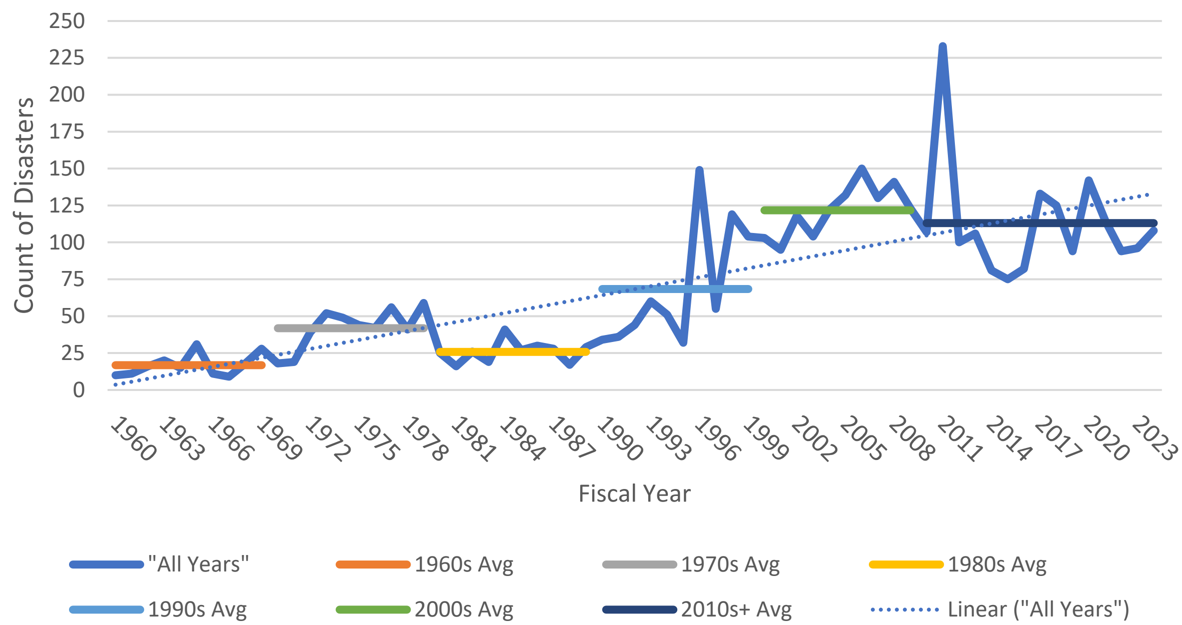
## II. Introduction

Extreme climate effects, often in the form of record temperatures, droughts, wildfires, and intensifying storms, are already imposing significant costs upon the public and the American economy. In addition to these acute risks, chronic risks such as sea level rise also inflict costs. The economic effects of climate change will depend on the extent of its physical effects, which are highly uncertain. This uncertainty of the physical effects of climate change implies a wide range of possible economic consequences, ranging from benign to catastrophic (CBO, 2024). The objective of this white paper is to help address the threat that climate change poses to the economy and to the budget of the Federal Government by highlighting risks to agency programs. Section 6(b) of Executive Order 14030 directs the Office of Management and Budget to work with Federal agencies to develop "an assessment of the Federal Government's climate risk exposure." The effects of climate change are expected to increase costs to public programs, including those provided by the Federal Government, posing additional challenges to public budgets that fail to account for the risks posed by climate change (Dolan et al., 2023; GAO, 2024).

It is clear that climate- and weather-related extreme events fueled by climate change pose an intensifying threat to the American economy—one that costs the U.S. close to $150 billion each year, a conservative estimate that does not account for loss of life, healthcare-related costs, or damages to ecosystem services (Jay et al., 2023). Natural disasters are becoming more frequent and destructive, with the average number of Presidentially declared disasters since 2010 approximately 65 percent greater than in the 1990s and over 250 percent greater than in the 1970s (see Figure 1). The United States now experiences a billion-dollar disaster approximately every three weeks on average, compared to once every four months during the 1980s (see Figure 2) (Jay et al., 2023). Ever-evolving economic tools and models continue to provide a better picture of increasing climate-related financial risks.

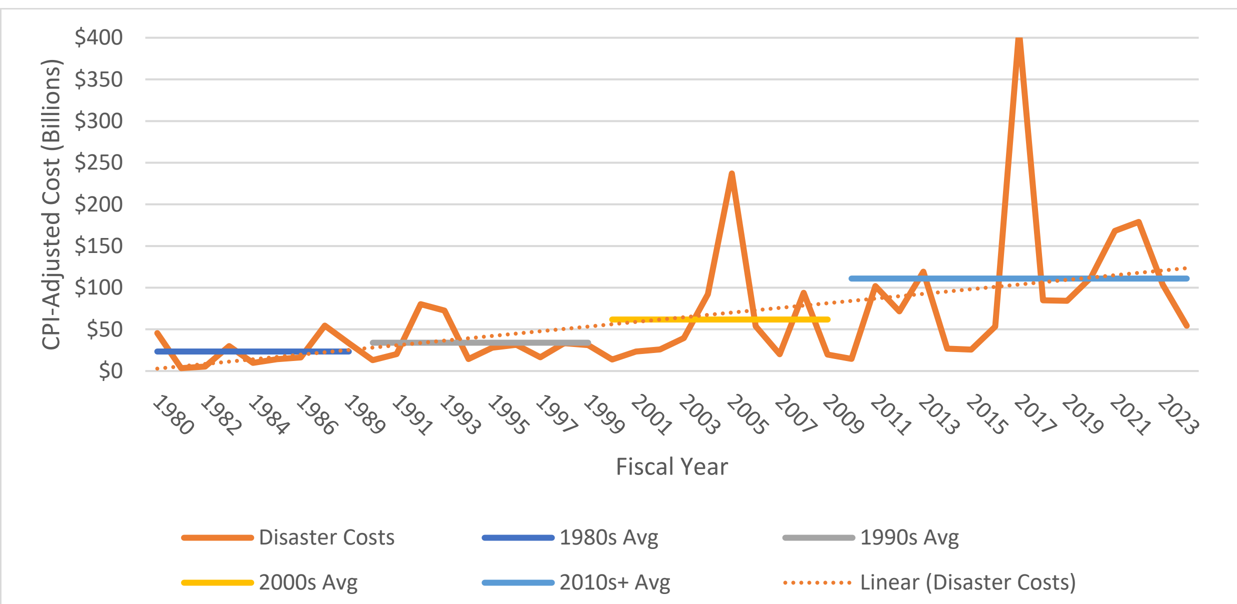
The increasing probability of multiple climate hazards occurring simultaneously or consecutively across the U.S. and across space or time, known as compound events, exacerbates the societal, ecological, and economic impacts of individual hazards and hinders the ability of communities to respond and cope, and continues to have growing direct and indirect effects on American financial markets, budgets, trade, and employment, along with non-market effects on social welfare. As an example, the compound effects of heat, drought, and wildfires can stress communities and ecosystems and amplify the economic damages caused by these hazards on their own. When combined, compound events have greater impacts than isolated hazards on ecosystems, water resources, public health, energy infrastructure, transportation, food systems, and interconnected societal networks, often straining disaster response (Singh et al., 2023). The economic effects of these disasters are being felt in households, businesses, and Federal, state, and local governments.

FIGURE 1: PRESIDENTIALLY DECLARED DISASTERS, 1960-PRESENT




Source: Federal Emergency Management Agency OpenFEMA dataset from https://www.fema.gov/openfema-data-page/disaster-declarations-summaries-v2

FIGURE 2: NOAA COST OF DISASTERS (BILLIONS OF 2024 DOLLARS), 1980-PRESENT




Source: National Oceanic and Atmospheric Administration (NOAA) data from https://www.ncei.noaa.gov/access/billions/events/US/1980-2024

According to the U.S. Government Accountability Office (GAO), the effects of climate change have cost the Federal Government billions of dollars, and these costs will likely increase in the future (GAO, 2024; NASEM, 2024). In the past five years (2020-2024), there have been notable climate-related financial impacts to the Federal Government due to extreme weather disasters, to include:

- The Federal Emergency Management Agency (FEMA) obligated $104.5 billion from the Disaster Relief Fund between 2020 and 2024 for weather- and climate-related natural disasters;
- The U.S. Department of Housing and Urban Development (HUD)'s Community Development Block Grant Disaster Recovery and Mitigation programs obligated $40.6 billion to support long-term housing, economic development, and infrastructure recovery needs due to climate-related events;
- The U.S. Army Corps of Engineers obligated $1.9 billion for its disaster response and recovery efforts from the funds appropriated to the Corps in those years due to climate-related events; and
- The U.S. Department of Defense (DOD) reported that climate change has the potential to disrupt operations, pose danger to assets and personnel, and require additional funding to support disaster response and recover efforts. In 2023, DOD reported spending $54.6 million in contingency preparedness that includes incorporating climate risk scenarios in war games and exercises, humanitarian assistance, and disaster relief and defense support to civil authorities' activities (U.S. Department of Defense, 2023a).

The costs to the American taxpayer are expected to go up, as the climate fiscal risks to the Federal Government—such as risks to insurance and lending programs, human health, and infrastructure—go up. Using the fiscal tools available, some Federal agencies are already projecting how much climate change will disrupt services and cause costs to balloon for certain programs. For example,

- The U.S. Department of Agriculture (USDA) Forest Service and Department of the Interior estimate that climate-fueled wildland fires could burn an additional 7.7 million acres of Federally-owned forests per year—an increase of 205 percent compared to today—by the end of the century, increasing expected suppression costs to $6.1 billion per year—compared to an average of $3.5 billion currently (2023 dollars) (Prestemon et al., 2024); and
- In a 2024 analysis, the USDA estimates that due to increased drought fueled by climate change, the Agency could see up to double the number of ranchers seeking assistance under the Livestock Forage Disaster Program by the end of the century compared to today. This corresponds to increases in Federal expenditures by more than $830 million more per year by the end of the century (2023 dollars) (Hrozencik et al., 2024).

Since 2021, the Office of Management and Budget (OMB) and agencies have annually worked to document progress toward better understanding and implementing actions to mitigate climate-related financial risk to Federal operations, programs, and facilities.[1] This white paper provides the fourth update from the OMB and agencies and focuses on key efforts, including a summary of

[1] President Biden signed Executive Order 14030, "Climate-Related Financial Risk" on May 20, 2021, to improve the Federal Government's capabilities to assess and reduce the risk that climate change poses to the Government and the economy.

the climate risk exposure of select Federal Government programs and an overview of Federal Agency Climate Adaptation Planning and Implementation.

# III. Federal Actions to Identify and Assess Climate Financial Risk

There are two categories of climate risks—physical risks and transition risks (EPA, 2024a). Physical risks are related to the physical impacts of climate change, and they may be event-driven (i.e., acute) or associated with longer-term shifts in climate patterns (i.e., chronic). Transition risks are those related to the transition to a lower-carbon economy. Climate risks vary in their timing and magnitude (NASEM, 2024). Table 1 presents a typology of climate risks in terms of their duration and economic variable.

TABLE 1: TYPOLOGY OF CLIMATE RISKS

| **Economic variable** | **Long-term (chronic)** | **Short-term (acute)** |
|---|---|---|
| Physical risks | • Lower average crop yields<br>• Lower productivity<br>• Sea level rise<br>• Adaptation costs | • Hurricanes<br>• Floods and fires<br>• Droughts<br>• Heat waves<br>• Grid failures and blackouts |
| Transition risks | • Green investment demand<br>• Shifts in types of jobs and skills<br>• Monetary policy decision<br>• Long-run productivity growth | • Energy price shocks<br>• Asset price shocks<br>• Transitional unemployment<br>• Policy transition shocks<br>• Policy uncertainty shocks<br>• Political risk<br>• Geopolitical risks<br>• Unknown unknowns |

Source: NASEM, 2024

This section provides a demonstration of the various approaches currently being employed to assess climate risks to agency programs, facilities, and services, including three analyses that provide quantitative estimates of financial risks. As such, this section is not intended to provide a comprehensive, whole-of-Government assessment of physical or transition risks of climate change. This section is organized into themes that relate to each assessment, including: (1) Risks to Insurance and Lending Programs, (2) Risks to Long-Term Infrastructure, (3) Risks to Human Health, and (4) Decision-Support Tools.

## A. Risks to Insurance and Lending Programs

More frequent and severe climate events such as droughts are projected with climate change, with implications for Federal credit programs, such as those that support the Nation's farmers and help everyday Americans buy a home, including crop insurance and housing mortgage lending programs. This section includes (i) an assessment of climate risks to the Federal Crop Insurance Program's Pasture, Rangeland, and Forage insurance plan, which is designed to help producers to mitigate financial losses from a lack of precipitation; and (ii) an overview of ongoing climate risk assessments of the Federal Housing Administration's commercial loan portfolio by the U.S. Department of Housing and Urban Development.

### (1) U.S. Department of Agriculture: Federal Crop Insurance Program's Pasture, Rangeland, and Forage Insurance Plan

**Introduction**

More frequent and severe climate events are projected as the climate changes, with implications for U.S. agricultural production and producers' incomes (Bolster et al., 2023). The agricultural sector is particularly vulnerable to the impacts of climate change, as crop yields, forage availability, and farm profits depend on evolving climatic conditions (Hsiang et al., 2017; Malikov et al., 2020). The Federal Government offers a variety of programs to help producers mitigate the financial impacts of adverse events (Tsiboe & Turner, 2023a; Turner et al., 2024), the largest of which is the Federal Crop Insurance Program (FCIP). Several of these programs aim specifically at mitigating risk within the livestock sector (MacLachlan et al., 2018). Such programs may constitute a financial climate risk for the Federal Government, as projections of climate in the U.S. suggest that drought conditions may become more frequent and intense for many regions in the future (Lehner et al., 2017; Leng & Hall, 2019; Zhao & Dai, 2017).

While previous studies have analyzed the potential impacts of climate change to FCIP outlays, most have focused on field crops (e.g., Beckman et al., 2024; Tack et al., 2018). A changing climate could also affect forage crops and livestock producers under scenarios where there is declining precipitation. Hrozencik et al. (2024) explored how climate change, through its effects on drought, could affect producer payments under the Livestock Forage Disaster Program (a standing disaster program administered by the Farm Service Agency that is not under FCIP). The FCIP Pasture, Rangeland, and Forage (PRF) insurance plan is another risk management tool for livestock producers that may help mitigate financial losses from a decline in forage production when rainfall falls below historical levels. To date, the financial climate risk to the Federal Government of this program is unknown (Turner et al., 2024).

PRF was introduced as a pilot product for the 2007 crop year (in six states: Pennsylvania, South Carolina, Texas, Colorado, North Dakota, and Idaho) to address some of the challenges associated with applying traditional crop insurance plans to perennial forage crops. For example, the same pasture or rangeland can be continuously grazed throughout the year, making it difficult to measure the productivity of the acreage for purposes of setting an insurance guarantee (as is needed for field crops under the FCIP). In contrast, PRF provides protection for producers when a loss of forage is experienced due to a lack of precipitation relative to a historical index. Because PRF utilizes a rainfall index for purposes of calculating losses, a measure of actual on-farm production or loss of production is not required. Moreover, traditional policies provide financial protection for the entire crop year, whereas ranchers may only have small windows during the year where livestock are grazing and after which insurance is not necessary.

PRF was expanded to all 48 contiguous States by 2016. Since then, participation in PRF has increased (Figure 3). Total insured FCIP acreage for the 2016 crop year was just under 300 million acres, of which 44 million acres were insured under PRF (approximately 15 percent of insured acreage). Total insured acreage has grown each year since 2016, with the relative share of PRF increasing as well. For the 2023 crop year, total insured FCIP acreage reached 538 million acres, with 278 million of those acres (approximately 52 percent of the total) insured under PRF. The 2023 crop year was the first time that acres insured under PRF represented the majority of total FCIP insured acres.[2,3] Figure 4 shows the average share of insured acres associated with the PRF insurance plan relative to all insured acreage in each county in 2016-2023. For many counties in the western and southern United States, PRF represents more than 75 percent of the insured acreage.

As the use of the PRF program becomes increasingly prevalent, it is important to understand how the program's financial risk to the United States government may change with a shifting climate. In this section, USDA uses projected precipitation estimates and estimates of biomass change to calculate potential future PRF net payments (indemnities, plus premium subsidies, minus total premiums). Depending on assumptions made on future PRF participation, net payments are projected to average between $495 million to $2.6 billion per year between 2024-2050. For reference, net payments have averaged approximately $603 million per year from 2020-2023, all in 2024 monetary terms.

**Data and Methods**

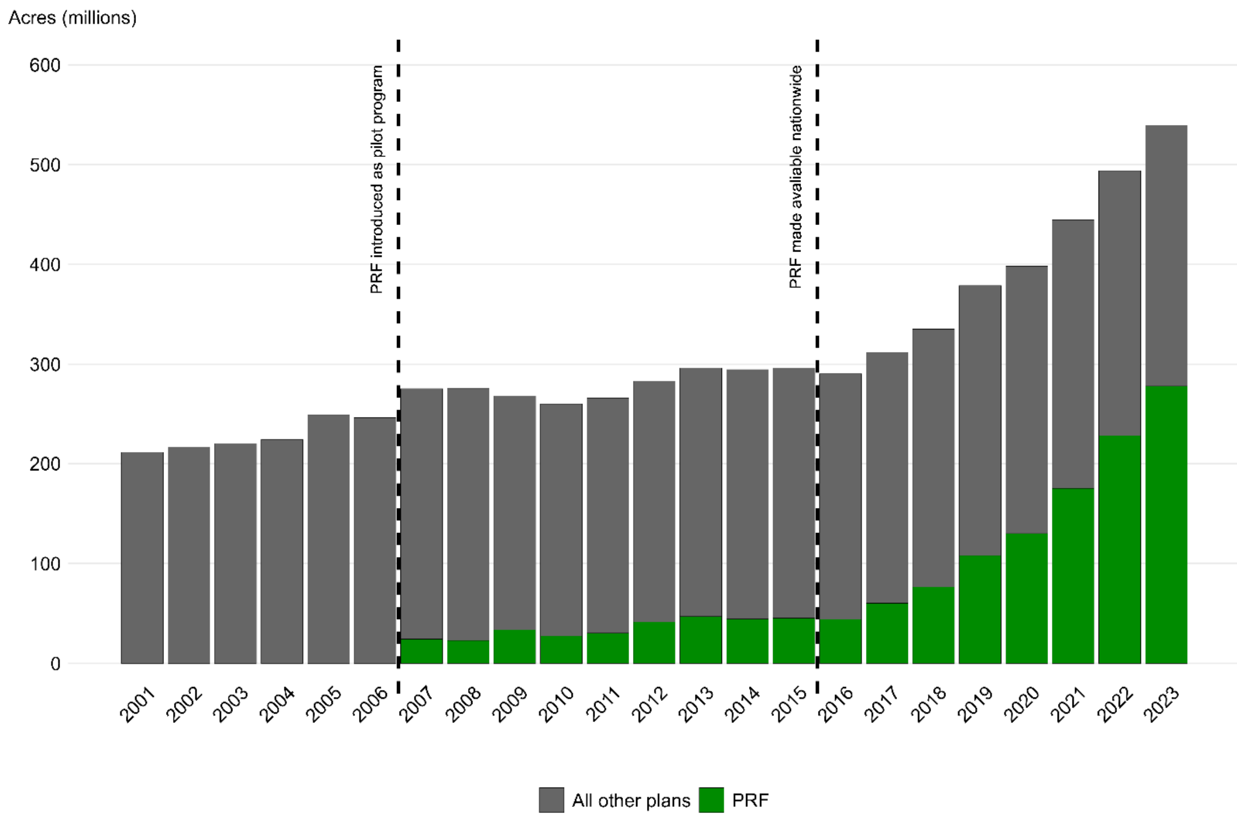
Estimation of future PRF payments requires three pieces of data:

1) Precipitation: grid-level estimates of future precipitation are required to calculate the grid-level precipitation indices and track when precipitation is projected to decline below the threshold necessary to trigger a PRF payment.
2) Biomass: grid-level estimates of future biomass availability are needed to calculate the value of the available forage in each grid. Available biomass directly influences the insured liability of a PRF policy and affects the magnitude of future payments when a payment is triggered by low precipitation.
3) Participation: county-level estimates of future participation are required to track the level and spatial distribution of insured forage under PRF so that the relevant precipitation and biomass values can be applied.

---

[2] Although several other insurance options have remained available for forages, more than 95 percent of all insured acreage for forage crops from 2016 to 2023 was enrolled in the PRF plan.
[3] USDA estimates that 21 percent of all land that could be used for pasture, rangeland, and forage in the contiguous U.S. is enrolled in PRF.

FIGURE 3: FCIP INSURED ACRES, 2001-2023




Note: Data in the chart represent USDA, Risk Management Agency's (RMA) Summary of Business files as of April 16, 2024.

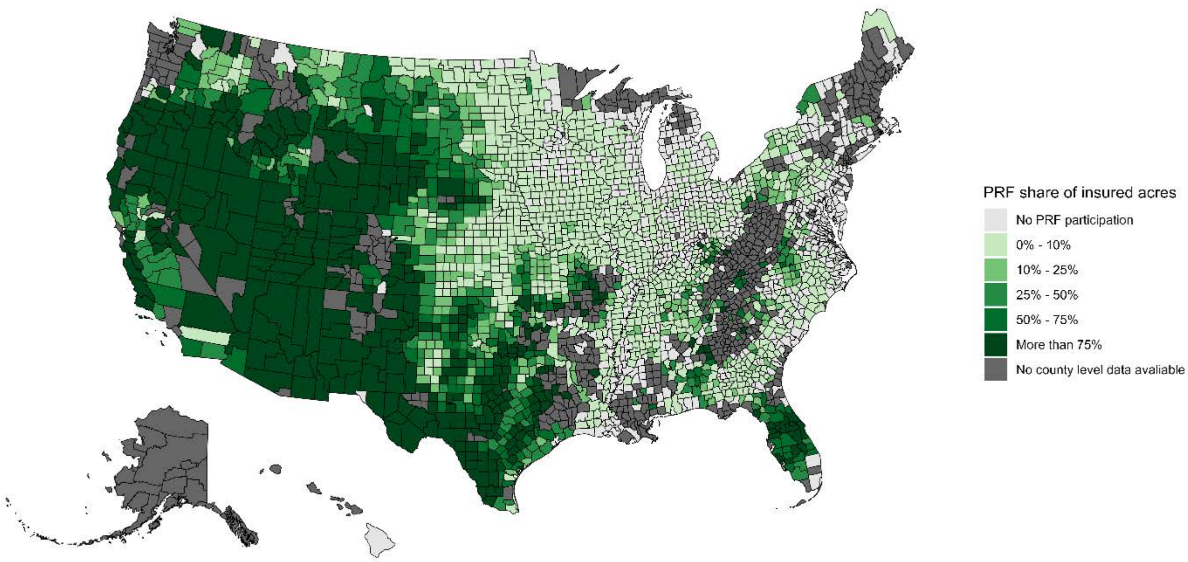
Source: USDA, Economic Research Service using data from USDA, Risk Management Agency.

Figure 5 describes the geographical and temporal patterns of precipitation, respectively, in the contiguous United States based on the modeling scenario described above. The geographical pattern indicates that areas of the contiguous United States may experience increases in precipitation as high as 22.51 percent and declines of up to -13.15 percent by 2050. While such changes are scattered throughout the country, differences in a few locations are worth highlighting. Particularly, under this climate scenario some Western regions of the U.S. would experience higher levels of precipitation by the middle of the century, which appear as blue clusters in the map. Some of these States (e.g., Nevada, Utah, Colorado, and Wyoming) also have the largest shares of pasture, range, and forage lands of the United States. The Midwestern Corn Belt,[4] where most of the U.S. corn and soybean production occurs, is expected to experience higher precipitation towards the middle of the century under this climate scenario. This region, however, has the lowest share of pasture, rangeland and forage land in the country. Future precipitation projections indicated several isolated areas of decreasing precipitation primarily located along the West and East coasts.

---

[4] The Midwestern Corn Belt includes states such as Indiana, Illinois, Iowa, Missouri, eastern Nebraska, and eastern Kansas.

FIGURE 4: AVERAGE PRF INSURED ACREAGE AS A SHARE OF TOTAL INSURED ACREAGE, 2016-2023




Note: USDA, Risk Management Agency's (RMA) Summary of Business files as of April 16, 2024. "No county-level data available" indicates that there was either no crop insurance participation or data was not disaggregated at the county level. "No PRF participation" indicates that some acreage in the county was enrolled in an FCIP policy, but no acreage was enrolled in PRF. PRF is not offered in Puerto Rico, Guam, or the U.S. Virgin Islands.

Source: USDA, Economic Research Service using data from USDA, Risk Management Agency.

The rest of this section discusses the process of estimating each of these data values.

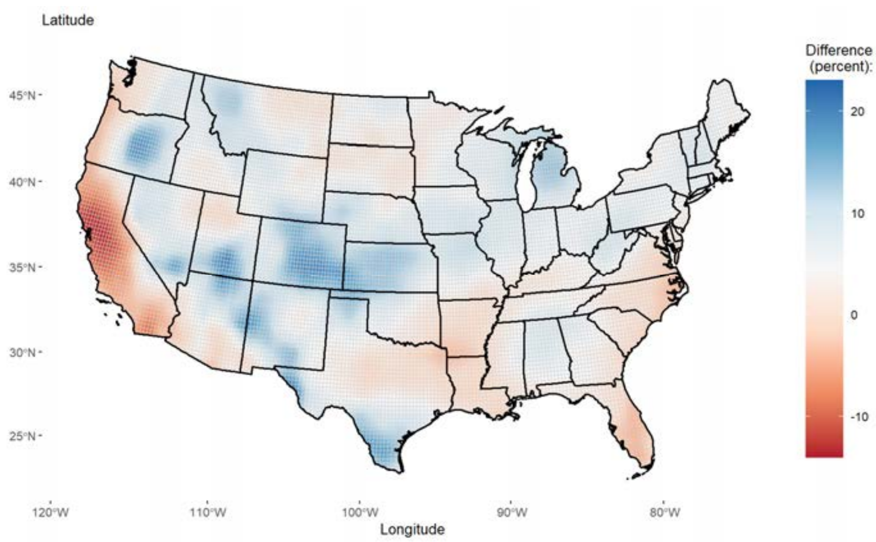
### *Future precipitation*

To estimate future precipitation and its impact on PRF payments, USDA uses the National Aeronautics and Space Agency (NASA)'s global climate projections, specifically, Shared Socioeconomic Pathway (SSP)5-Representative Concentration Pathway (RCP)-8.5. This climate scenario represents very high emissions for the impact of climate on future payments and has been the focus of recent Economics Research Service (ERS) reports (Beckman et al., 2024; Vaiknoras et al. 2024). USDA collects and processes climate change data from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) database based on the SSP5-8.5. The database is formed of simulation experiments performed by different scientific groups around the world, using general circulation models (GCMs). Thrasher et al. (2022) describes the simulation methodologies and database.

### *Future biomass*

Estimates of future quantities of available herbaceous biomass are obtained using a simulation program called G-Range. G-Range is a global, gridded ecosystem model of rangelands. Projected climate data from GCMs on monthly precipitation and temperatures (maximum and minimum) are input into G-Range to simulate changes to biomass on rangelands around the globe due to climate change (Boone et al., 2018). For each grid cell, plant growth and death, soil carbon levels, nutrient cycling and more are simulated by month based on changing precipitation and temperatures and the characteristics of the grid cell.

FIGURE 5: DIFFERENCE IN PROJECTED ANNUAL PRECIPITATION IN THE CONTIGUOUS UNITED STATES UNDER SSP5-8.5, 2020-2050




Note: Alaska and Hawaii were not included in the study as the Pasture, Rangeland, and Forage plan (PRF) was not available in those states in the past. Coverage was expanded to Hawaii in 2024.

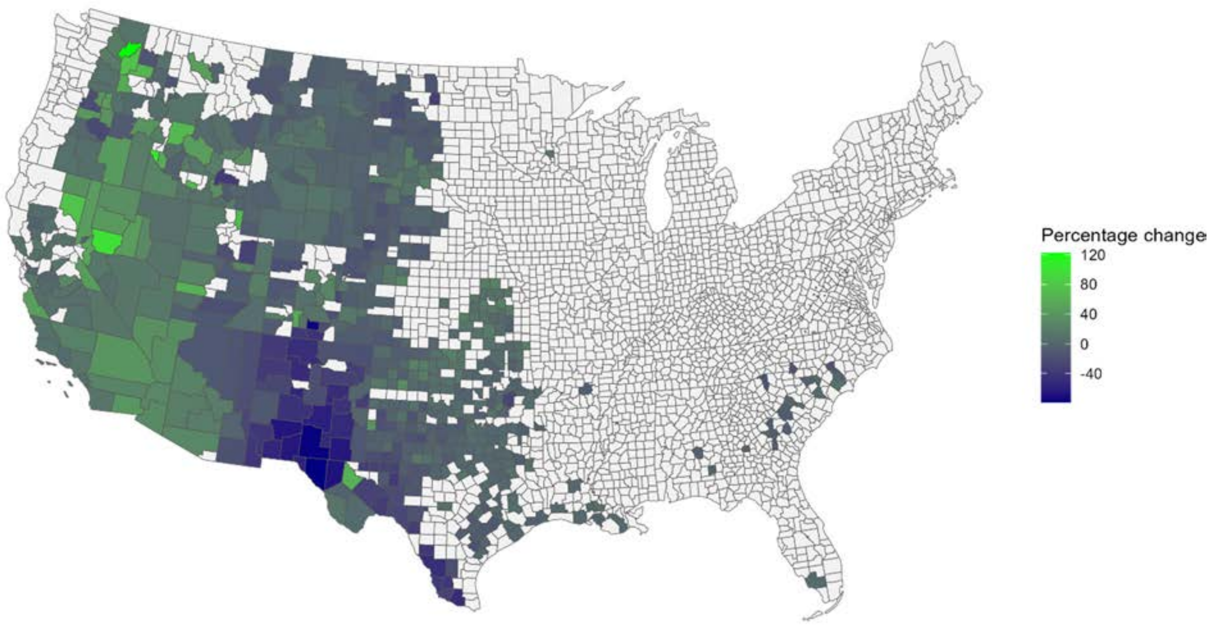
Source: USDA, Economic Research Service using data from the National Aeronautics and Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP). Models used are: HadGEM2.ES (Collins et al., 2011), IPSL-CM5A-LR (Dufresne et al., 2013), CSIRO-Mk3.6.0 (Collier et al., 2011), BCCCMS 1.1 (Wu, 2012), GFDL-CM3 (Donner et al., 2011), GISS-E2-R (Schmidt et al., 2006), and MIR-CGCM3 (Yukimoto et al., 2012).

Because G-Range only simulates rangeland areas, as defined by land cover type, some portions of the United States are not included.[5] Most rangelands are in the western half of the U.S., along with small areas of the southeastern United States. Between 2024 and 2050, it is estimated that the United States (excluding Alaska and Hawaii) will have a 1 percent gain in herbaceous biomass under the projected climate scenario. However, results vary by county and State (Figure 6). Some counties are predicted to lose over fifty percent of their herbaceous biomass by 2050; each of these counties are in either Texas, New Mexico, or Colorado. New Mexico in particular would experience large losses under SSP5-8.5: it has the largest percentage loss (35 percent) of any State,

[5] USDA determines potential areas for PRF adoption based on two sources of data. USDA's first source is Rangelands grided data from USDA-USFS, where USDA overlays the PRF grid surface with it to determine the share of each PRF grid that can be potentially enrolled in PRF. USDA supplements this with cropland data layer (CDL) grid data from 2008-2023, where USDA develops an indicator grid where this takes on the value of unity if the grid had alfalfa or pasture at least once over this period. Again, USDA overlays the PRF grid surface with this indicator surface to identify extra areas missed by Rangelands. For the counties that have PRF land but are not in G-Range USDA assumed that the growth in forage is zero. However, it is worth noting that the granular data from the G-Range model are particularly useful for the micro-level shocks which USDA uses for the macro-level projections at either the state or the national level. Practically, this means that USDA is putting more weights on the areas with G-Range model outcomes. USDA's estimate of land available for PRF is 1.3 billion acres, which is approximately 55 percent of all U.S. land, as noted by RMA (2024).

and all but one of its 30 rangeland counties are expected to lose herbaceous biomass. The State with the second greatest loss in herbaceous biomass is North Dakota, with a projected 13 percent decline in herbaceous biomass. By contrast, some counties would gain more than 50 percent herbaceous biomass; these counties are in Washington, Idaho, Nevada, California, Utah, and Colorado. At the State level, Washington has the greatest percentage increase (32 percent), followed by Nevada.

FIGURE 6: PERCENT CHANGE IN HERBACEOUS BIOMASS UNDER SSP5-8.5, 2024-2050




Note: Alaska and Hawaii were not included in the study as the Pasture, Rangeland, and Forage plan (PRF) was not available in those states in the past. Coverage was expanded to Hawaii in 2024.

Source: USDA, Economic Research Service using the G-Range simulation model with results averaged across seven general circulation models: HadGEM2.ES (Collins et al., 2011), IPSL-CM5A-LR (Dufresne et al., 2013), CSIRO-Mk3.6.0 (Collier et al., 2011), BCCCMS 1.1 (Wu, 2012), GFDL-CM3 (Donner et al., 2011), GISS-E2-R (Schmidt et al., 2006), and MIR-CGCM3 (Yukimoto et al., 2012).

### *Future participation*

With respect to enrollment, USDA generates estimates of future PRF participation using four distinct scenarios:

- A baseline scenario, in which insured acreage is held fixed at 2024 levels throughout the analysis.
- A non-negative trend-based growth scenario, in which future county-level PRF acreage is estimated by regressing past county-level PRF acreage on a trend variable using data from 2020 to 2023.
- A variable precipitation-driven growth scenario, in which county-level PRF participation is modeled as a function of historical monthly precipitation levels. Specifically, for each observation (defined by the unique combination of county, PRF coverage level, and index

interval), month-specific measures of precipitation were constructed based on the four-year moving average of grid-level precipitation for all grids in the county. PRF acreage was then regressed on these measures of precipitation along with an annual trend variable, indicators for farm bill periods (to control for distinct policy environments), and interactors between the annual trend and farm bill indicators. These regression results are then combined with projected changes in precipitation to get predicted rates of PRF enrollment for each year in the projection period.

- A full participation scenario, where all acreage that could potentially be used for rangeland, pasture, and forages is enrolled in the program.

#### *Calculating PRF net payments*

Estimations of future participation are combined with precipitation and biomass estimates to calculate insured liabilities. Projections for liability are based on anticipated changes in county base value (i.e., expected per acre value for PRF) and insured acreage. Here, the county base value is projected at the county level based on changes in biomass from the G-Range simulations (as discussed in the previous section). Finally, the base rate (used for premium calculation) and payment factors (used for indemnity calculations) for PRF are projected by applying RMA actuarial methodology (Coble et al., 2020; Tsiboe et al., 2023b) at the grid level based on estimated changes in precipitation (as previously described). These are then aggregated to the county level based on observed PRF participation patterns from 2018-2023 for counties with PRF coverage. The premium subsidy percentages are fixed at the levels established by legislation in 2024. The total future net payments are then calculated as the sum of total indemnity and premium subsidy minus total premium.[6]

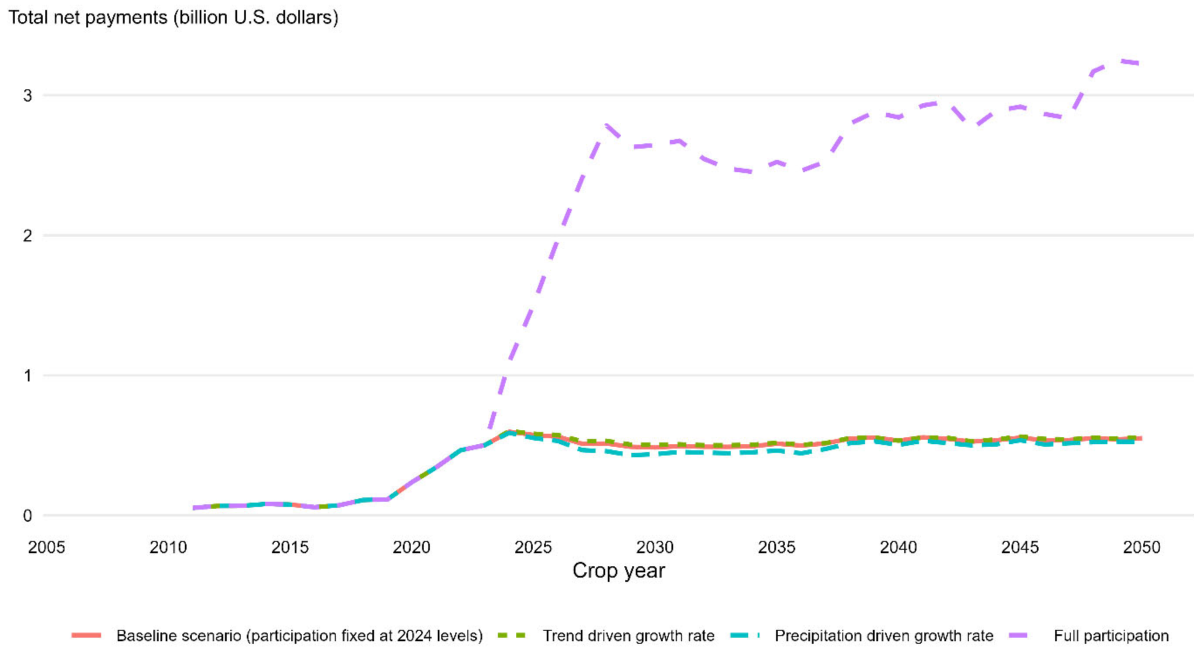
### The Financial Climate Risk of the Pasture, Rangeland, and Forage Insurance Plan

USDA uses the results from the precipitation and biomass models, along with estimates of future participation, to project 5-year moving averages of total net payments attributable to the PRF plan out to 2050. Payments are equivalent to the sum of indemnity payments and disbursed subsidies net of total premiums, as depicted in Figure 7 (all results are in 2024 dollars).

- Under the baseline scenario (participation fixed at 2024 levels), total net payments are projected to average $530 million per year between 2024-2050.
- Under a non-negative trend-based growth scenario, total net payments are projected to average $538 million per year between 2024-2050.
- Under the scenario allowing for a variable, precipitation-driven, growth rate in PRF participation, total net payments are projected to average $495 million per year.
- Finally, under the full participation scenario, total net payments are projected to average $2.63 billion per year between 2024-2050.

[6] The overall cost to the government is conditional on variations in: (A) total premiums, (B) premium subsidies provided to producers, (C) indemnities; (D) program delivery cost and subsidies, and (E) reinsurance (underwriting losses minus underwriting gains). Given the above cost items, the total cost is calculated as (A-B)-C-D+E. In this exercise, USDA only captures (A-B)-C.

FIGURE 7: PASTURE, RANGELAND, FORAGE RAINFALL PLAN 5-YEAR MOVING AVERAGE PROJECTED TOTAL NET PAYMENTS UNDER SSP5-8.5, 2011-2050

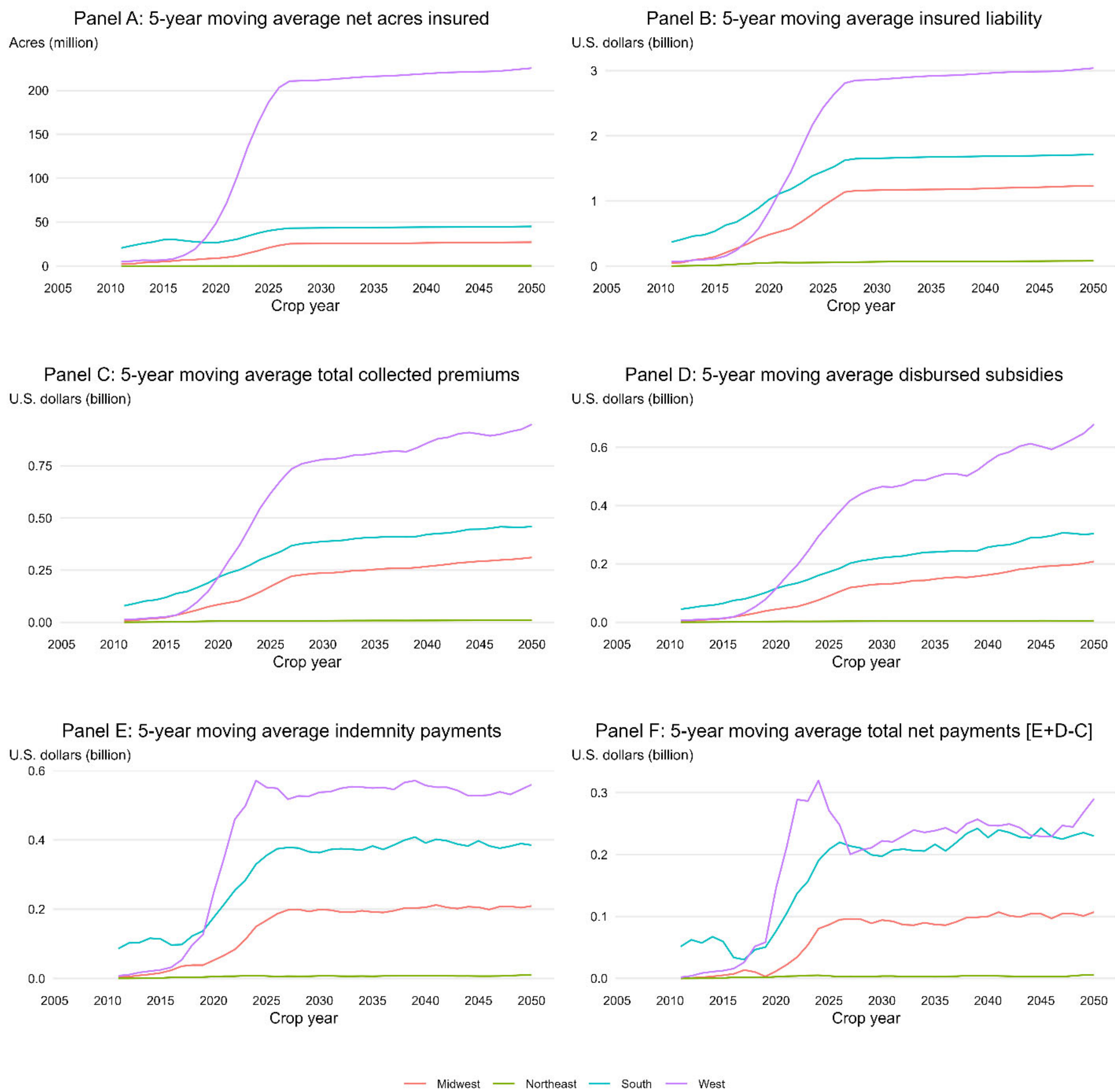



Note: All monetary values are in real 2024 dollars.

Source: USDA, Economic Research Service analysis of data from USDA, Risk Management Agency, National Aeronautics and Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), and the G-Range simulation model with results averaged across seven general circulation models: HadGEM2.ES (Collins et al., 2011), IPSL-CM5A-LR (Dufresne et al., 2013), CSIRO-Mk3.6.0 (Collier et al., 2011), BCCCMS 1.1 (Wu, 2012), GFDL-CM3 (Donner et al., 2011), GISS-E2-R (Schmidt et al., 2006), and MIR-CGCM3 (Yukimoto et al., 2012).

The results highlight that variation in payments can be significant even when holding participation fixed (either at 2024 levels or fixed at "full participation"). The change in payments at various points of time is driven by climatic variables – i.e., changes in precipitation and biomass. While a decline in precipitation relative to the rainfall index triggers PRF program payments, the magnitude of the payments is based on both precipitation and biomass. In practice, associating precipitation with participation, as was done with the "precipitation driven growth rate" assumption, is useful for letting growth rates be dynamic across regions of the U.S. with different precipitation levels. Figure 8 depicts program outcomes separately estimated for four regions of the U.S. Panel A shows that the majority of the recently observed growth in insured acres under PRF has been in the Western portion of the U.S.

FIGURE 8: PASTURE, RANGELAND, FORAGE PLAN BY REGION USING PRECIPITATION DRIVEN GROWTH RATE UNDER SSP5-8.5, 2011-2050




Notes: Midwest includes IL, IN, IA, LS. MI, MN, MO, NE, ND, OH, SD, WI. Northeast includes CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT. South includes AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA, WV. West includes AZ, CA, CO, HI, ID, MT, NV, NM, OR, UT, WA, WY.

Source: USDA, Economic Research Service based on analysis of data from USDA, Risk Management Agency, National Aeronautics and Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), and the G-Range simulation model with results averaged across seven general circulation models: HadGEM2.ES (Collins et al., 2011), IPSL-CM5A-LR (Dufresne et al., 2013), CSIRO-Mk3.6.0 (Collier et al., 2011), BCCCMS 1.1 (Wu, 2012), GFDL-CM3 (Donner et al., 2011), GISS-E2-R (Schmidt et al., 2006), and MIR-CGCM3 (Yukimoto et al., 2012).

Based on 5-year moving averages, growth in insured acreage in the West was estimated to increase by 38.3 percent from 163 million acres in 2024 (average insured acreage from 2020 to 2024) to 225 million acres by 2050 (average insured acreage from 2046-50) using results from the precipitation-driven growth rate scenario under SSP5-8.5. Percentage changes in enrolled acres were similarly estimated for the Midwest (56.1 percent), South (20.3 percent), and Northeast (52.3 percent). Other estimated outcomes (panels B-F of Figure 8) show a consistent relative ordering across regions with the West having the highest values followed by the South, Midwest, and Northeast. One exception is that estimated total net payments (panel F) for the South and West are comparable across the projection period despite the West having approximately 5 times the enrolled acreage. This is mostly explained by the higher productivity of acreage (as derived from the biomass analysis) in the South which results in relatively higher insured liabilities (panel B). For example, despite the West having approximately 5 times the enrolled acreage, insured liabilities are only about 1.75 times the liabilities of the South. Average annual net total payments for the four regions depicted in Figure 8 were $243 million (West), $220 million (South), $3.5 million (Northeast), and $96 million (Midwest).

It is important to note when interpreting the results depicted in Figure 8, that there is an implicit assumption that the correlations observed between precipitation and PRF enrollment trends to date will hold in the future. This may not be the case due to the number of factors that influence participation besides rainfall in addition to currently observed enrollment trends being heavily influenced by initial availability.[7]

## Conclusions

The Pasture, Rangeland, and Forage insurance program provides producers protection when a loss of forage is experienced due to a lack of precipitation. USDA uses projected precipitation estimates, along with estimates of biomass change, both due to climate change, to calculate potential future PRF net payments. USDA finds that grid-level estimates generally suggest increases in precipitation and biomass between 2024 and 2050 which result in total net PRF payments that are comparable to payment levels in recent years under a very high emissions climate scenario. Holding participation fixed at 2024 levels (i.e., the baseline scenario), estimating a trend-based growth rate, and estimating a precipitation-based growth rate all produce annual net payments that range from $429 million to $602 million.

These estimates are in a comparable range to the average annual net payments of $603 million per year observed from 2020-2023. However, upper bound estimates (assuming that enrollment rises to 100 percent of eligible acres) project that net payments would reach an average of $2.6 billion per year (with annual extremes of between $1.1 billion to $3.3 billion) over the projection period if all PRF eligible acreage was enrolled.

[7] Since PRF is a relatively new insurance product, much of the observed increases in demand to date are a result of the insurance product being made available for the first time in a producer's county. Thus, correlations between precipitation and changes in participation over this time period may not necessarily be indicative of a causal relationship.

USDA also found that variation in payments over time can be significant even when holding participation fixed (either at 2024 levels or fixed at "full participation"), indicating that a significant portion of the variance in program outcomes is driven by climatic variables—i.e., changes in precipitation and biomass. Although volatility in net payments is higher in absolute dollar terms under the full participation scenario, this is largely an artifact of scale. The coefficient of variation, which provides a measure of volatility that is normalized by the mean, in net payments across the projection period was between 0.05 and 0.18 for all four scenarios.

USDA simulates a range of scenarios as it is unknown how participation will change in the future. Although precipitation is expected to increase in the future based on the models used, there could also be an increase in drought (as shown in Hrozencik et al., 2024) if the precipitation events become heavier and less frequent. This could lead to an increase in participation, which may constitute a financial climate risk for the Federal Government. Note that not all land that could be used for pasture, rangeland, and forage in the contiguous United States is enrolled in FCIP/PRF, thus full participation is not likely.

### (2) U.S. Department of Housing and Urban Development: Federal Housing Administration and Risks to the Commercial Loan Portfolio

**Introduction**

The U.S. Department of Housing and Urban Development (HUD) continues to consider approaches to better integrate climate-related financial risk into underwriting standards, loan terms and conditions, and asset management and servicing procedures, as related to Federal lending policies and programs. HUD's Federal Housing Administration (FHA) insures single family and commercial portfolios of mortgages and seeks to proactively manage credit risk, including from current and future climate-fueled natural disasters. HUD FHA is assessing the financial impact of natural disasters and forecasted climate change risk on infrastructure and notably the commercial properties in FHA's insured multifamily and healthcare loan portfolios, and quantifying these values for the public. This includes managing the credit risk of FHA's multifamily and healthcare (collectively "commercial") loan portfolios, which, as of September 2024 month end, have approximately 15,000 loans totaling $167 billion in unpaid principal balances (UPB).[8]

**Background on FHA Programs**

FHA is a part of HUD and is one of the largest mortgage insurers in the world. FHA primarily operates from its self-generated income (fees and insurance premiums) and with the goal of increasing housing supply, access to credit and affordability. By design, FHA commercial programs are meant to complement, not supplant, private capital. FHA plays an important countercyclical role to support the housing market during economic downturns by providing access to mortgage credit when the private capital market retreats from or underserves markets. Unlike private mortgage insurers, FHA does not vary its insurance premiums by regions, creating an automatic regional stabilization policy. FHA's mortgage insurance also works to support

[8] Note, these multifamily and healthcare government loan programs are negative subsidy and therefore self-funded. Therefore, they do not require or receive annual appropriations from Congress.

affordable housing and other segments of the market that are underserved regardless of economic cycles.

FHA's Office of Risk Management and Regulatory Affairs regularly uses financial models to estimate the budgetary impacts of three commercial loan portfolios: 1) Multifamily Housing, 2) Nursing Homes, Assisted Living, Board and Care, and 3) Hospitals. For these calculations, FHA maintains financial models that forecast the probability of prepayment by the borrower, probability of insurance claim payment by FHA (due to borrower default), and probability of recovery on claimed loans/properties. These models allow FHA to produce reports for financial statements, audits, budgets, portfolio management, and ad hoc policy analyses.

These models undergo annual updates, which are approved by FHA's Model Risk Governance Board, overseen by the Office of Management and Budget (OMB), and audited by HUD's Office of Inspector General. Given the maturity and independent oversight of these models, FHA will use them as the starting point for the planned climate analyses.

**Literature Review**

In the United States, analyses of the financial impact of climate change are in early stages, especially for the Federal Government. Over the past four years, researchers have begun publishing studies with impacts on commercial mortgage portfolios, but results are still in the early stages, particularly in comparison to research on the residential mortgage market. Researchers Holtermans et al. (2023), state that

> *"an industry that is particularly exposed to climate risk is commercial and residential real estate. … But firms, as well as their investors and lenders, struggle with understanding the financial implications of climate risk on the value of assets, the future income stream of these buildings, and the impact climate risk may have on the ability of borrowers to make timely payments."*

For this reason, FHA reviewed a wide range of peer-reviewed literature and industry papers to understand how researchers and the financial services industry account for climate change with respect to mortgage portfolios. Unfortunately, several peer-reviewed research papers published in 2021, 2022, and 2023 state a finding akin to Holtermans et al. (2023): "…there are no existing papers that focus on the relationship between climate shocks and ex-post mortgage performance in the commercial real estate market." The body of literature is growing, but it is not yet as robust as for the single-family mortgages (which is also still in early stages). FHA's research into this subject focused on papers investigating commercial mortgages, but due to the limited availability of such research, also expanded to research on single-family mortgages and banking writ large. See Appendix A for a summary of key findings from the literature review.

**Description of Existing FHA Risk Model Methodology**

In the section on Background on FHA Programs, FHA discussed FHA's credit subsidy models, which FHA maintains in compliance with the Federal Credit Reform Act of 1990 (FCRA). Under FCRA, HUD must establish net present value budgeting for the cost of credit programs, explicitly recognizing the lifetime costs of loan programs upfront. FHA's credit subsidy models forecast a subsidy rate for each FHA loan program. For this purpose, the subsidy rate refers to the forecasted long-term cost to the government of a cohort of loans, calculated on a net present value basis and excluding administrative costs, as a percentage of total loan sizes insured. FHA's loan performance and cash flow forecasts that underly the credit subsidy models are mature, maintained annually, and subject to substantial review by internal and external parties.

The credit subsidy models forecast loan performance and cash flows. Insurance claims, post loan default, comprise the biggest losses paid out by HUD. In the case of prepayments, insurance premiums are no longer collected. FHA models these outcomes using binary logistic regression models. The two binary logistic regressions predict the probability of claim and prepayment given values taken by independent variables such as loan age, vacancy rates and debt service coverage ratio. The regressions are used to generate predicted claim and prepayment probabilities for each loan age. The model applies the conditional claim and prepayment probabilities separately to the insurance in force at the beginning of the period in each loan age.

FHA fits separate regression models for different loan products and asset classes. Many of the factors considered across these regressions are similar. Appendix B includes a list of variables used across the claim and prepayment models.

**Climate Analysis Methodologies**

As mentioned in the beginning of this section, the purpose of this study is to better understand the effect of climate change on FHA's multifamily and healthcare loan portfolios, and quantify these values for the public. Climate change poses several risks to FHA's commercial portfolio, most notably repetitive loss properties affected by coastal or riverine flooding, or acute damage from physical natural disasters. These properties may experience a reduction in the market value of the security or a loss of income that impacts their ability to pay debt service. When borrowers default, whether due to economic causes or physical disasters, HUD's recoveries on lender claims will be lower, increasing the costs of these loan programs. FHA's baseline credit subsidy models do not include any climate or natural disaster adjustments. Therefore, FHA designed the analyses below to evaluate and quantify the degree to which FHA's multifamily and healthcare portfolios are at risk of climate-related impacts.

FHA presents a summary of three approaches to analyze the budget impact of climate change, followed by a deeper discussion of each approach in Appendix C.

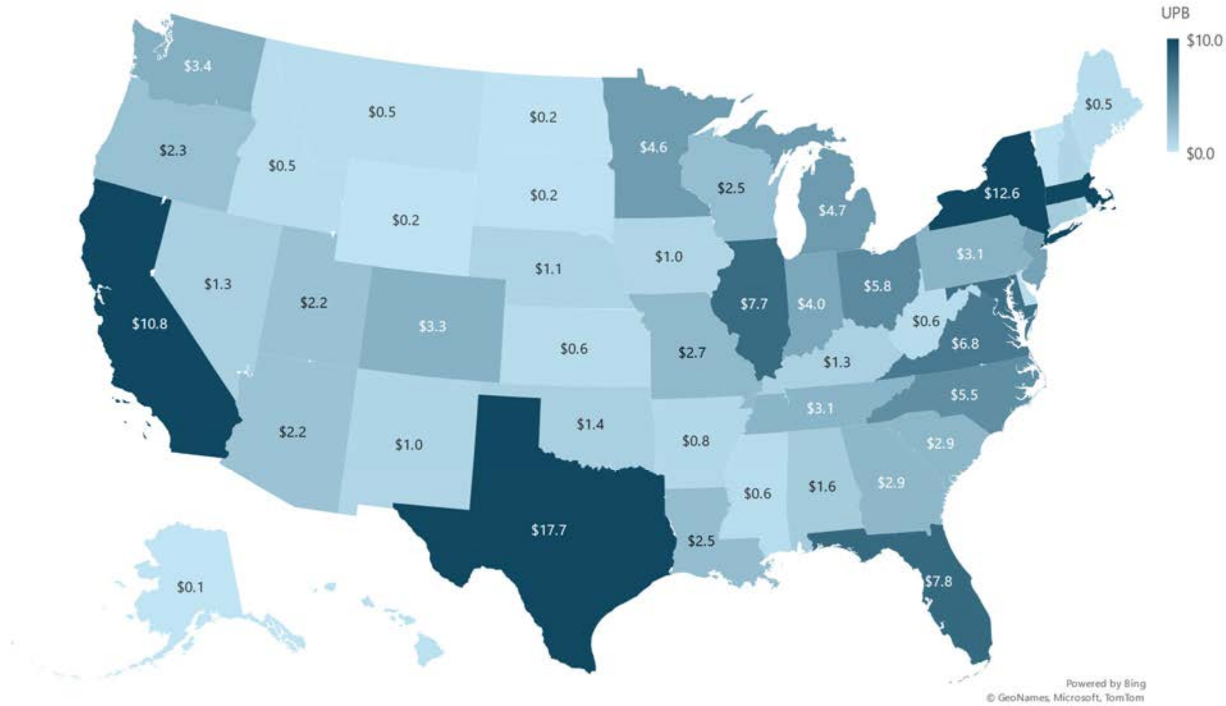
> **Approach 1, Simplified Natural Disaster Cost Calculation:** FHA incorporates current physical natural disaster hazards, via FEMA's National Risk Index (NRI), into the existing credit subsidy models and calculate the costs to the loan portfolios.
>
> **Approach 2, Transition Impacts of Climate Change:** FHA incorporates robust climate data regarding transitional risks into the existing credit subsidy forecasting models. This includes time-varying macroeconomic forecasts under varying greenhouse gas emissions scenarios.
>
> **Approach 3, Catastrophic Natural Disaster Impacts of Climate Change:** As an alternative to Approach 1, FHA incorporates robust climate data regarding catastrophic

physical disaster risks into the existing credit subsidy forecasting models. FHA applies zip code level climate risk data for the probability of natural disasters, such as hurricanes, floods, and wildfires, to quantify the impacts.

**Results of Climate Change Analyses**

In this section, FHA shows the results of applying the methodologies identified in the prior section to FHA’s multifamily and healthcare portfolios. First, for reference, Figures 9 and 10 include maps of the current portfolio of loans at state and county geographic levels and by UPB.

FIGURE 9: STATE MAP OF LOANS BY UPB (BILLIONS OF 2024 DOLLARS)




### *Approach 1: Simplified Natural Disaster Cost Calculation*

FHA starts with the results from incorporating the FEMA NRI loss rates into the credit subsidy model. In Table 2, FHA identifies the locations with the highest estimated loss rates and the corresponding UPBs of FHA loans. In Table 3, FHA identifies the locations with the largest UPBs and the corresponding estimated loss rates.

FIGURE 10: COUNTY MAP OF LOANS BY UPB, BILLIONS OF 2024 DOLLARS

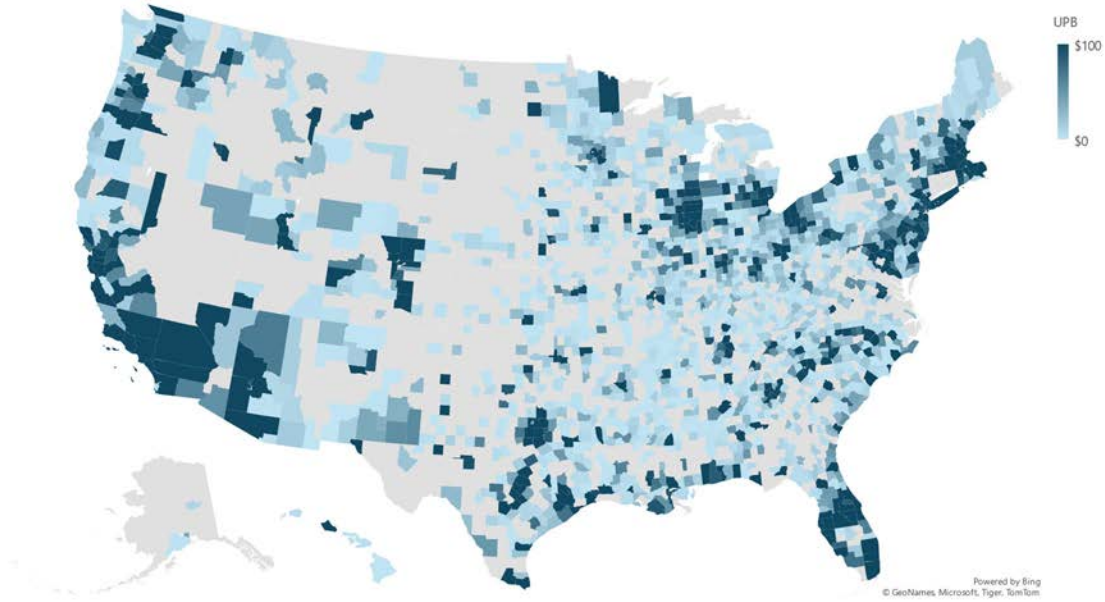



TABLE 2: LOCATIONS WITH HIGHEST LOSS RATES AND CORRESPONDING UPBS OF FHA LOANS

| Location | UPB as of September 2024 | One-Year Loss Rate | Ten-Year Loss Rate |
|---|---|---|---|
| Carteret County, North Carolina | $ 58,985,357 | 0.87% | 9% |
| Galveston County, Texas | $ 123,035,314 | 0.82% | 8% |
| Orange County, Texas | $ 93,424,818 | 0.70% | 7% |
| Georgetown County, South Carolina | $ 10,837,220 | 0.63% | 6% |
| Onslow County, North Carolina | $ 152,040,301 | 0.61% | 6% |
| Beaufort County, North Carolina | $ 45,948 | 0.61% | 6% |
| Craven County, North Carolina | $ 43,890,942 | 0.59% | 6% |
| Assumption Parish, Louisiana | $ 2,726,226 | 0.57% | 6% |
| Beaufort County, South Carolina | $ 51,348,223 | 0.54% | 5% |
| Jones County, North Carolina | $ 326,007 | 0.54% | 5% |

In Tables 4 and 5, FHA provides the results of the simplified natural disaster calculations for the estimated 2025 cohort, which is an estimated portfolio of loans starting in FY 2025, followed by FHA's existing portfolio for cohorts 1992-2023. As the 2024 cohort is not finalized, FHA skipped that cohort. FHA presents the 2025 cohort in addition to the existing portfolio to show the impact on the portfolio that will last the longest into the future. The following results are presented as the cost to FHA receipts, because that is one of the simplest metrics by which FHA can measure impact. However, FHA assumes no FEMA disaster assistance, other Federal disaster assistance, or private insurance support/recoveries. Therefore, it is appropriate to characterize the impacts as the cost to the public.

TABLE 3: LOCATIONS WITH HIGHEST FHA UPBS AND CORRESPONDING LOSS RATES

| Location | UPB as of September 2024 | One-Year Loss Rate | Ten-Year Loss Rate |
|---|---|---|---|
| New York City, New York | $6,507,051,437 | 0.03% | 0.30% |
| Cook County, Illinois | $3,962,052,919 | 0.02% | 0.17% |
| Los Angeles County, California | $2,545,557,681 | 0.18% | 1.83% |
| Denton County, Texas | $2,318,688,172 | 0.08% | 0.84% |
| Hennepin County, Minnesota | $1,975,713,531 | 0.02% | 0.22% |
| Bexar County, Texas | $1,865,602,113 | 0.02% | 0.24% |
| Montgomery County, Texas | $1,681,258,456 | 0.10% | 0.97% |
| Middlesex County, Massachusetts | $1,668,093,028 | 0.04% | 0.37% |
| Montgomery County, Maryland | $1,580,337,484 | 0.04% | 0.39% |
| Travis County, Texas | $1,496,774,207 | 0.03% | 0.31% |

TABLE 4: SIMPLIFIED NATURAL DISASTER ANALYSIS RESULTS, 2025 COHORT (MILLIONS OF 2024 DOLLARS)

| | Cohort 2025 (Baseline) | Cohort 2025 (FEMA Loss) | Difference (FEMA - Baseline) | Difference/ Baseline |
|---|---|---|---|---|
| Risk Category | Receipts ($ millions) | Receipts ($ millions) | Receipts ($ millions) | % Difference |
| Multifamily Programs | $220.2 | $208.4 | -$11.8 | -5.4% |
| Healthcare Programs | $147.7 | $144.0 | -$3.7 | -2.5% |
| Multifamily and Healthcare | $367.9 | $352.4 | -$15.5 | -4.2% |

Note: Differences may not always match due to rounding.

TABLE 5: SIMPLIFIED NATURAL DISASTER ANALYSIS RESULTS, 1992-2023 COHORTS (MILLIONS OF 2024 DOLLARS)

| | Cohorts 92-23 (Baseline) | Cohorts 92-23 (FEMA Loss) | Difference (FEMA - Baseline) | Difference/ Baseline |
|---|---|---|---|---|
| Risk Category | Receipts ($ millions) | Receipts ($ millions) | Receipts ($ millions) | % Difference |
| Multifamily Programs | $2,004.0 | $1,804.7 | -$199.3 | -9.9% |
| Healthcare Programs | $832.5,452,561 | $733.1 | -$99.4 | -11.9% |
| Multifamily and Healthcare | $2,836.4 | $2,538.0 | -$299.0 | -10.5% |

Note: Differences may not always match due to rounding.

Adding simplified natural disaster risk to the model reduces the 2025 cohort's net present value (NPV) of cash flow receipts by $15.5 million (4 percent) over the life of the loans. The 1992-2023 cohorts' NPV of cash flow receipts are reduced by $300 million (10.5 percent) over the remaining life of the loans. The greater estimated impact on historical loans is due to earlier loans being located in areas more prone to disasters than in recent years. Geographic location also explains other variations seen in Tables 4 and 5, such as multifamily housing loans being affected more than healthcare loans in the 2025 cohort, but less affected historically.

### *Approach 2: Transition Impacts of Climate Change*

In this second approach, FHA layers on the transition impacts of climate change policy to the baseline risk models. FHA assesses the economic impacts of climate change policy across three scenarios: 1) Current Policy, 2) Early Policy, and 3) Late Policy. These scenarios are intended to demonstrate the risk of economic impacts stemming from policies to curb fossil fuel emissions and climate change (e.g., job losses in areas of high fossil fuel production). FHA compares each of these scenarios to a status quo baseline scenario.

Ultimately the impact was minimal across all scenarios and cohorts. Total net present value of impacts moved in both upward (i.e., favorable) and downward (i.e., unfavorable) directions, were adjusted by at most 2 percent, and experienced an average impact of less than 1 percent. Depending on the climate scenario, impacts were unfavorable or favorable. As the late policies to address climate change occur so late in time, there are minimal early economic adjustments. In fact, there are fewer such adjustments than under current policies. As this methodology does not incorporate the natural disaster impacts, the downside risks of the late policy implementation are not calculated until Approach 3. Therefore, the late policy transition impact appears favorable in Approach 2, without the downside risk impact of this policy in Approach 3. The reason for the small magnitude is because the transitional impacts of climate change policy scenarios are on a longer time horizon than the loan portfolio. Most loan terms are 30 or 40 years, but the expected life of the loans is far shorter at eight years on average. Moreover, on an NPV basis, the earliest years of a loan's life are more impactful than later years, but the transition impacts occur later.

### *Approach 3: Catastrophic Natural Disaster Impacts of Climate Change*

Lastly, FHA layers dynamic catastrophic natural disaster modeling on top of the Current Policy scenario from the transition analyses in Approach 2 by testing two representative concentration pathways (RCPs), which represent different greenhouse gas concentrations in the atmosphere. Under the RCP 4.5 scenario, emissions remain around current levels until the middle of the century and then drop, while under the RCP 8.5 scenario, emissions roughly double from current levels by 2100. As noted in the analysis of the two scenarios in the methodology section, the probability of catastrophic natural disasters is the same in the 2020s. Over time, the probability of catastrophic natural disasters is projected to rise; for example, on average it increases by 0.1 percentage point through the 2050s under RCP 8.5. This small difference translates nearly dollar for dollar, with the NPV in RCP 8.5 scenarios at most 0.1 percent lower than RCP 4.5. For the 2025 cohort, this is approximately $300,000 across all loan programs. For this reason, FHA only shows the RCP 4.5 results in Table 6, which presents the results from the transition and catastrophic natural disaster analysis of the 2025 cohort. Akin to the Approach 1 results, the following Approach 3 results are presented as the cost to FHA receipts. However, it is more appropriate to characterize the impacts as the cost to the public.

When comparing the catastrophic natural disasters to the baseline transition scenario, the disasters reduce the 2025 estimated NPV of receipts by $46 million dollars, or 11.4 percent. Similar to the FEMA NRI scenarios, multifamily housing loans are estimated to be impacted more substantially than healthcare loans at roughly 15 percent and 6 percent respectively.

Table 7 presents the results from the analysis of the 1992-2023 cohorts. For the existing 1992-2023 book of business, there is a larger impact. When comparing the catastrophic natural disasters to the baseline transition scenario, the disasters reduce the estimated NPV of receipts by $838 million dollars, or 26.2 percent. Unlike the FEMA NRI scenarios, multifamily housing loans are estimated to be impacted more substantially than healthcare loans at roughly 29 percent and 20 percent respectively.

TABLE 6: TRANSITION AND CATASTROPHIC NATURAL DISASTER ANALYSIS RESULTS, 2025 COHORT (MILLIONS OF 2024 DOLLARS)

| | $ Impact of Approach 1 | % Impact of Approach 1 | $ Impact of Approach 3 | % Impact of Approach 3 | $ Impact of Climate Change (Approach 3- 1) | % Impact of Climate Change (Approach 3- 1) |
|---|---|---|---|---|---|---|
| Risk Category | $ millions | % | $ millions | % | $ millions | % |
| Multifamily Programs | -$11.8 | -5.4% | -$36.0 | -14.9% | -$24.3 | -9.5% |
| Healthcare Programs | -$3.7 | -2.5% | -$10.1 | -6.1% | -$6.4 | -3.6% |
| Multifamily and Healthcare | -$15.5 | -4.2% | -$46.1 | -11.4% | -$30.6 | -7.2% |

Note: Differences may not always match due to rounding.

TABLE 7: TRANSITION AND CATASTROPHIC NATURAL DISASTER ANALYSIS RESULTS, 1992-2023 COHORTS (MILLIONS OF 2024 DOLLARS)

| | Impact of Approach 1 | % Impact of Approach 1 | Impact of Approach 3 | % Impact of Approach 3 | $ Impact of Climate Change (Approach 3- 1) | % Impact of Climate Change (Approach 3- 1) |
|---|---|---|---|---|---|---|
| Risk Category | $ millions | % | $ millions | % | $ millions | % |
| Multifamily Programs | -$199.3 | -9.9% | -$627.9 | -29.0% | -$428.7 | -19.1% |
| Healthcare Programs | -$99.4 | -11.9% | -$209.7 | -20.4% | -$110.3 | -8.5% |
| Multifamily and Healthcare | -$299.0 | -10.5% | -$837.6 | -26.2% | -$539.0 | -15.7% |

Note: Differences may not always match due to rounding.

An important finding, when comparing the climate change impacted natural disaster losses to the FEMA current natural disaster rates, is that the climate change scenarios result in losses that are three times larger ($46 million vs. $15 million for the 2025 cohort and $837 million vs $299 million for 1992-2023 cohorts). This suggests that climate change will increase losses for the 2025 cohort by $30 million dollars (7 percent of the NPV) and for the 1992-2023 cohorts by $539 million (16 percent of the NPV).

**Conclusions**

This section examines the financial impacts of natural disasters and climate change on FHA's multifamily housing and healthcare loan guarantee portfolio and quantifies costs to the public. First, FHA incorporated physical natural disaster risks into its credit subsidy models. Second, FHA assessed the economic impact of climate transition policies. Lastly, FHA analyzed the effects of climate-adjusted natural disaster forecasts. As a reminder, the following results represent the cost to the public, since FEMA disaster assistance, other Federal disaster assistance, and private insurance recoveries were not considered in the analysis. FHA assumes the impact on FHA receipts would be lower when Federal disaster assistance and private insurance are factored in. However, the broader approach of the analysis allows the reader to understand the entire costs that natural disaster and climate change pose. Baseline natural disaster risks reduced forecasted FHA receipts by 4.2 percent for the 2025 cohort and 10.5 percent for the existing 1992-2023 cohorts. Transition-related risks were mixed, depending on the scenario, but ultimately had a minimal impact on projections ranging between -0.8 percent to 2.2 percent. Climate-adjusted natural disasters reduced projected receipts by 11.4 percent for the 2025 cohort and 26.2 percent for the existing 1992-2023 cohorts. Comparing these results to the baseline natural disaster risk suggests a future climate change impact of 7.2 percent and 15.7 percent, on top of current natural disaster risk and the economic impact of transition policies.

At the onset of this research plan, FHA considered several alternative scenarios FHA aimed to incorporate. Given time and resources, FHA was not able to complete all of them for this analysis. In the future, FHA anticipates continuing to build out analyses for future publications. Future scenarios for analysis could include the following:

1. Forecast estimates for future FY cohorts (e.g., FY 2030, FY 2050, or later);
2. Account for FEMA, other Federal disaster assistance, and/or private insurance payouts to separate public and insurance market costs from FHA-specific impacts;
3. Adjust the cohort composition of new loans with greater climate exposure risk, due to adverse selection described in the literature;
4. Identify the historical impact of natural disasters on FHA loans and adjust natural disaster forecasts based on experience;
5. Apply scenarios with varying increases in sea level; and
6. Adjust electricity usage/costs using the debt service coverage ratio calculations described in the literature.

## B. Risks to Long-Term Infrastructure

The Federal portfolio of physical assets—buildings, infrastructure, and other fixed capital—are threatened by drastic changes in their local environment as a result of climate change. Importantly, the Federal Government is financially responsible for any damages from natural disasters that occur to its own assets. Many Federal Government assets are climate-sensitive, such as dams, irrigation infrastructure, and levees, where risk can come in the form of service reductions (e.g., flood mitigation) due to deviations away from the climate for which they were designed (e.g., increased frequency and intensity of natural disasters) (Financial Stability Oversight Council, 2021). Adding to the exposure of these physical assets is the fact that the built environment itself can be a major driver of climate change (Chu et al., 2023). For example, urban development patterns can exacerbate climate impacts, such as increases in heat capture and retention, and increases in the severity of flooding from overloaded stormwater infrastructure. An additional concern is that many of these risks are unevenly distributed across populations—often falling on already overburdened and historically marginalized communities (EPA, 2021a). Recognizing this, the Federal Government is taking action to assess these risks and their impact on Federal fiscal responsibilities. This section provides additional details on two such efforts: (i) an overview of climate risks to overseas buildings and operations by the U.S. Department of State, and (ii) an assessment of exposure to climate risks at facilities operated by the U.S. Environmental Protection Agency.

### (1) U.S. Department of State: Risks to Overseas Buildings and Operations

**Introduction**

Natural hazards present significant threats to the stability and functionality of essential infrastructure, which in turn can impact international diplomacy. Given that many of these natural hazards are increasing in frequency and severity with the changing global climate, proactively addressing related risks is crucial for safeguarding the Nation's interests and ensuring the effectiveness of U.S. diplomatic missions abroad. As of May 2024, the Department of State (State) has over 280 globally distributed diplomatic posts (e.g., Embassies and Consulates) located in geographically diverse areas and exposed to a wide range of natural hazards (earthquake, extreme heat, extreme wind, flood, landslide, tsunami, water stress, wildfire, and volcanic eruption). The ability of these posts to be present with their host nation in the wake of a natural hazard event, combined with the challenges associated with State's own ability to recover from that event in a foreign place, are two factors unique to the U.S. diplomatic mission that make it essential to seek resilience in diplomatic facilities abroad. Therefore, the Department needs to be aware of and prepared for all possible natural hazards, their potential impacts, and how the changing climate will increase these impacts.

The Department of State's Bureau of Overseas Buildings Operations (OBO) is central to this effort. OBO's mission is to provide the most effective facilities for United States diplomacy abroad. The typical estimated lifespan of a building is approximately 50 years, so it is imperative that natural hazards, especially those exacerbated by climate change, be considered throughout the lifecycle and portfolio management process.

Within this framework, OBO's Climate Security & Resilience (CS&R) Program addresses the challenges posed by natural hazards and climate change. The vision of the CS&R Program is for all State diplomatic missions to be aware of and resilient to natural hazards. By aligning resilience efforts across the Department, the CS&R Program supports building a more secure and resilient portfolio through achieving its mission of preparing and adapting U.S. diplomatic missions for potential disruptions caused by natural hazards.

**Planning, Assessment, and Analysis**

CS&R's strategic directives and policies have evolved since their inception, guided most recently by Executive Order 14008, the State Department's 2021 and 2024 Climate Adaptation and Resilience Plans (CARPs) and highlighted in the Government Accountability Office (GAO) reports (GAO, 2022; GAO, 2023). The CARPs emphasize the importance of enhancing natural hazard awareness and resilience as a priority for the State Department, setting goals to strengthen the resilience of its overseas facilities. The 2023 GAO reports reviewed the Department of State's efforts to account and prepare for the effects of climate change in the design, construction, operations, and maintenance of its overseas real property assets. It further highlighted that the CS&R Program's effectiveness depends on adequate staffing and resource allocation, emphasizing the need for strategic workforce planning to align with the program's mission and goals.

Natural hazards have historically had substantial financial impacts on the Department's diplomatic infrastructure and operations. For example, the magnitude 7.0 earthquake in Port-au-Prince, Haiti (2010) inflicted severe damage on both the Deputy Chief of Mission's residence as well as other mission residences and new housing had to be acquired. This event provided a reminder of the need for awareness at foreign posts of the heightened vulnerability inherent with relying on local housing markets and building standards. Another example, Hurricane Irma (2017) caused extensive damage in Havana, Cuba including the main embassy compound. Extreme winds and storm surge displaced large shipping containers that damaged the perimeter wall and façade. This resulted in complicated repair needs to ensure the continued security of the U.S. embassy. As a final example, in Manila, Philippines, despite the protection offered by a sea wall, the waterfront embassy often suffers from flooding during heavy rains severely limiting the effectiveness of this important diplomatic platform, going back more than 10 years. This and other factors, including substantial due diligence, have led to the potential need to relocate the mission further inland to avoid future flooding damage and other natural hazard-related disruptions. Diplomatic posts have also had operational responses to a variety of other natural hazards such as wildfire smoke, lack of potable water, and volcanic ash fall. The calculation of costs related to the above hazard events is complicated as it involves both tangible (repairs) and intangible (down time, due diligence, and market research costs).

The CS&R Program's goals focus on proactively improving resilience in numerous ways, such as by integrating natural hazard assessment and risk management tools into OBO's portfolio management processes. This involves creating natural hazard-based risk scores for each diplomatic post. Scores are based on the exposure of each property to potential natural hazard events, as well as measures of severity and vulnerability. Exposure is the measure of likelihood that a hazard will occur. Severity and vulnerability are measures of the magnitude of the possible impacts and susceptibility to increased levels of risk associated with occurrence of a hazard event. These risk scores help prioritize the global portfolio of diplomatic missions, allowing OBO to incorporate natural hazard risks into capital project prioritization and facility management. In its capital planning process, all OBO properties eligible for a capital improvement or replacement project are scored with respect to defined thresholds for several factors, one of which is natural hazards. The properties identified with the greatest potential deficiencies are further vetted through a collaborative stakeholder input process to prioritize and define capital project requirements and related cost estimates.

Additionally, the CS&R Program has recently developed Natural Hazard/Climate Adaptation Assessments for detailed post level reviews of hazard resilience. CS&R's 2023 pilot assessments have led to the recent development of the CS&R Construct of Building Resilience Adaptation Strategies (CoBRAS) platform. CoBRAS contains over 150 specific criteria to help facilitate the assessment of site-specific natural hazard risks using pointed questions to evaluate a post's preparedness and resilience at regional, site, and building levels. It also includes financial considerations, providing indications of relative rough order of magnitude (ROM) cost estimates for recommended adaptation strategies, which helps prioritize and implement resilience measures effectively. Future goals for the CS&R Program include expanding the CoBRAS platform to include more detailed cost evaluation capabilities, allowing for a more detailed assessment of resilience investments. Previous studies from both the U.S. Chamber of Commerce (2024) and the National Institute of Building Sciences (2019) highlight the economic benefits of investing in climate resilience, underscoring that proactive measures can yield significant returns compared to the costs of post-disaster repairs and recovery efforts.

**Conclusion**

The CS&R Program aims to enhance diplomatic mission preparedness through continued program growth, expert expansion, and state-of-the-art scientific methods. The CS&R Program is already exploring innovative solutions to enhance resilience. For instance, remote slope monitoring using satellite technology, in collaboration with the Italian Space Agency, could reduce the need for onsite slope inspections and improve monitoring of unstable slopes near U.S. diplomatic assets. This approach could significantly enhance the ability of diplomatic missions to anticipate and respond to dangerous ground shifts. Another innovative pilot project involves real-time earthquake structural monitoring of an embassy office building where the building is directly instrumented. After an earthquake, this suite of instruments can quickly assess structural response against pre-defined performance thresholds to assess the building's level of damage and potential for occupant safety concerns. This will be beneficial to OBO facility managers and engineers who can more quickly and confidently assess the viability of re-occupying a building and continuing operations.

In addition to internal projects, collaborative efforts with Federal agencies and private sector partners are essential for enhancing resilience. As CS&R is not part of a science mission-oriented agency, it is important to leverage interagency partners to ensure that the most accurate and cutting-edge data and techniques are being used. The CS&R Program has established relationships with the Department of Defense (DoD), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). These current partnerships focus on developing seismic hazard parameters and tsunami modeling, improving data availability and accuracy for enhancing resilience throughout all aspects of OBO's work in managing a global portfolio. Data from these partnerships are used in informing world-wide project prioritization, advising on real estate acquisitions, informing design standards for new projects, and in enhancing emergency preparedness.

The CS&R Program has made significant strides in improving climate resilience at U.S. diplomatic missions. Ongoing challenges include overcoming reactive biases and enhancing proactive planning. Sustained investment in natural hazard resilience is vital for national security and the safety of diplomats. By prioritizing proactive measures and strategic planning, the CS&R Program aims to ensure that diplomatic missions are well-prepared for future natural hazard events.

### (2) U.S. Environmental Protection Agency: Risks to EPA Facilities

**Introduction**

Since 2021, EPA has been working to meet the goals set forth in Executive Orders (EOs) 14008, 14030, and 14057, and the Disaster Resiliency Planning Act (Public Law 117-221), including to:

- Understand the agency's climate vulnerabilities and develop strategies for how the agency intends to manage such impacts or incorporate risk mitigation into facility master plans;
- Build technical capacity to assess climate-related financial risk to EPA programs, assets, and liabilities to increase the long-term stability of EPA's operations; and,
- Reduce the emissions impact and increase the climate resilience of Federal facilities, fleets, and operations.

EPA's Office of Mission Support (OMS) established a Resiliency Assessment Program to meet the requirements of Executive Order 14008 and respond to the Biden-Harris administration's focus on climate adaptation, resilience and disaster planning in the Federal Government (EPA, 2024b). The program includes comprehensive climate resilience assessments of EPA's owned facilities to address future projected impacts from climate change site assessments, agency strategic goals related to resiliency, and commitments to implement high-priority projects to increase the agency's resilience to impacts from climate change. The risk assessments, developed in 2022, have been systematically conducted to analyze each laboratory's likelihood of exposure to 18 climate and other hazards, level of vulnerability to impacts from climate change, and magnitude of consequence, as well as to inform asset management. Vulnerability and consequence are assessed through four lenses: impacts to EPA's mission, workforce, physical assets, and transportation and utilities systems the agency relies on. EPA began conducting climate resilience assessments at facilities in March 2022, and has since completed 11 onsite visits through FY 2024. The agency intends to conduct the seven remaining assessments by FY 2026. These site assessments are one example of how EPA is tangibly implementing measures to protect its own workforce, facilities, critical infrastructure, and supply chains from the risks posed by climate change.

EPA has developed this section in order to:

- Describe the methodology and potential outcomes for climate resilience assessments at EPA facilities;

- Quantify the agency's risk to owned facilities and account for future related expenses resulting from intensified climate and natural hazards;
- Provide rationale to address and prioritize required facility maintenance projects that also improve resilience; and,
- Communicate how the agency is incorporating natural disaster resiliency into real property asset management.

EPA expanded on existing Federal resilience toolkits to create a comprehensive five-step resilience framework to assess owned facilities. Figure 11 summarizes the five steps, which are described in detail below.

FIGURE 11: EPA'S FIVE-STEP CLIMATE RESILIENCE ASSESSMENT FRAMEWORK


First, based on the assessment scope, identify relevant hazards. OMS identified 18 hazards that are considered in the assessments (Table 8). Climate and hazard historical data and projections used in the assessments come from local and state hazard mitigation plans and climate assessments and Federal resources (including the National Oceanic and Atmospheric Administration, U.S. National Climate Assessment, Federal Emergency Management Agency, and U.S. Geological Survey) over a 30-year time horizon, which is a mid-century timeframe (the 2050s) that is used in many of the data source projections. Where available, the assessment team reviews both the Representative Concentration Pathway 4.5 and 8.5 scenarios from the Intergovernmental Panel on Climate Change.

TABLE 8: LIST OF HAZARDS ADDRESSED

| | | |
|---|---|---|
| 1. Coastal flooding, including: | 3. Hurricanes | 12. Extreme cold |
| a. Sea level rise | 4. Tornadoes | 13. Winter storms |
| b. High-tide flooding | 5. Straight-line/high winds | 14. Warming surface waters |
| c. FEMA coastal flood zones | 6. Hail | a. Freshwater |
| d. Tsunami | 7. Lightning | b. Sea water |
| e. Storm surge | 8. Drought | 15. Nor'easters |
| 2. Inland flooding, including: | 9. Wildfire | 16. Landslides |
| a. Extreme precipitation | 10. Earthquake/seismicity | 17. Erosion |
| b. FEMA inland flood zones | 11. Extreme heat | 18. Volcanoes |

Second, for each owned facility, a vulnerability and risk assessment is conducted to identify critical assets and services, and to categorize the consequences of damage, disruption, or loss of each asset and service. This includes preliminary research into the hazard exposure and site and research characteristics, hosting pre-site visit virtual meetings, and a comprehensive site visit as well as onsite interviews. The team meets with staff across all functions at the facility (e.g., operations and maintenance, facilities management, delivery and receiving, security, information technology (IT), applied science and research, and external partners, if applicable). Topics of discussion include priority assets, consequences if work is disrupted, redundancy in transportation and deliveries, requirements for onsite work, reliance on utility services, experiences with past hazards, and general issues and priorities. After the site visit, the assessment team identifies which of the site's assets are most at-risk to those hazards over the next 30 years based on their likelihood of exposure to each hazard; vulnerability of the assets if exposed; and consequence of damage, disruption, or loss caused by the hazard occurring to four categories: mission, physical assets, workforce, and utilities/infrastructure/services. For this analysis, the assessment team uses a five-choice rating scale for each (very low, low, medium, high or very high) to assign a rating to likelihood, vulnerability, and consequence.

Third, the assessment team develops project recommendations to address assets and services that are either most at-risk from exposure to climate hazards, and/or those which have a lower likelihood of occurring but the highest consequences if damaged, disrupted, or lost. Consequences are assessed via four categories: mission continuity, physical assets, workforce safety and ability to carry out duties; and disruptions to the delivery of utilities, infrastructure, and goods and services. Project recommendations are categorized as planning, policies and procedures; new construction; operations and maintenance; retrofit; lifecycle; removal and remediation; or relocation.

Fourth, near-term actions and future adaptation measures are suggested to address the identified risks and consequences. As part of the recommendation development, the assessment team determines relative costs and general timing for each project. Project timelines were assigned on the following scale to align with EPA's facility master planning methodology: within 12 months, 1 to 5 years, 6 to 10 years, 11 to 15 years, and 16+ years. The project recommendations and suggested timelines from steps three and four are then added to a prioritization schema for a workgroup made of EPA leadership and site representatives, to rank the criticality of the project. At the end of the scoring process, EPA has a consensus-based list of very high and high prioritized projects, based on their technical and cost feasibility, and its impact to the facility's exposure and mission.

Fifth, implementation and monitoring occur for the projects and actions, accounting for the intensity, duration, area exposed, and frequency of climate and other hazards increasing in the future. The project recommendations are intended to provide a comprehensive roadmap to improve each facility's climate and hazard resilience as budget and time allow in the immediate to extended term, including initiating planning projects, and incorporating climate adaptation into existing processes and efforts.

**Assessment Results and Budget Analysis**

Risks to five EPA facilities with completed climate resilience assessments are discussed in this section. They include (i) Gulf Breeze, Florida, (ii and iii) Ada and Gaar Corner, Oklahoma, (iv) Edison, New Jersey, and (v) Montgomery, Alabama. These five facilities have 60 building and structure assets in total. The assessments identified that these assets have 304 exposures across the five likelihood levels to various hazards; 198 of these exposures were rated as "very high" (65 percent). The left pie chart in Figure 12 displays the 304 hazard exposures and the percentage breakdown of each exposure from very low to very high. The right pie chart in Figure 12 displays the breakdown of only the very high exposures associated with each of the five facilities. All five facilities assessed have assets on their campuses with very high likelihood of exposure to at least one hazard. However, most of the assets with very high exposure to the 18 climate and other natural hazards are located at EPA's Gulf Breeze laboratory in Florida, due to its location and large number of assets.

FIGURE 12: TOTAL HAZARD EXPOSURE BY CATEGORY AND THE CAMPUS BREAKDOWN OF VERY HIGH EXPOSURE

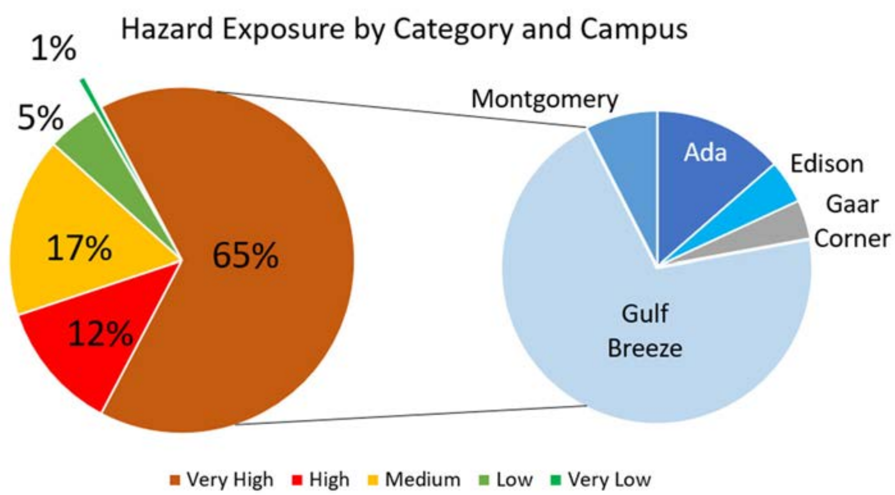



Figure 13 displays cost estimates projected to implement facility master plan projects and resiliency recommendations over the next 10 years, with accounting for expected inflation during the implementation year. The average facility master plan inflation rate across the 10-year time frame is about 1.16 percent and does not include any additional escalation for shortages in labor, goods or services due to climactic or natural hazard events. The "Total Buildings and Facilities (B&F) and Resiliency Projects" line displays the total for all projects beginning in 2023, as the climate change resiliency assessment program began in 2022.

After developing the baseline of internal constructions costs, shown in Figure 13, EPA conducted a preliminary analysis of the construction pricing across the country (Cumming Group, 2023; Döhrmann, et al., 2021; Ghorbani, 2023; Ungles et al., 2023). This helped EPA develop an estimated cost comparison of each campus and their capital improvement costs, which is the total of operations and maintenance, resiliency and master plan projects, and the new construction prices for their respective market, shown in Figure 14. The capital improvement and new construction costs are escalated. A ‘catastrophic rebuild’ category was also included to begin accounting for additional and unknown expenses incurred from potential supply chain disruptions and labor shortages as a result of climate change impacts.

FIGURE 13: PLANNED EPA CONSTRUCTION COSTS AND PROJECTED ESCALATION AT FIVE EPA FACILITIES

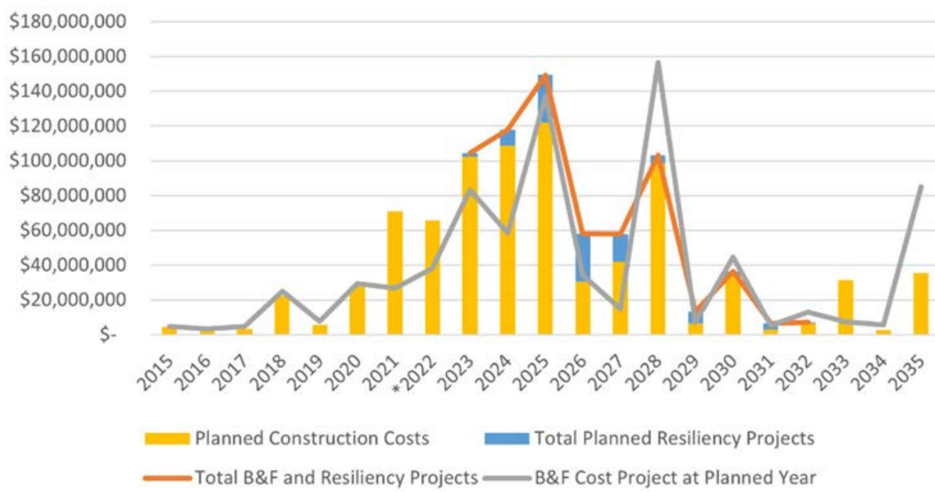
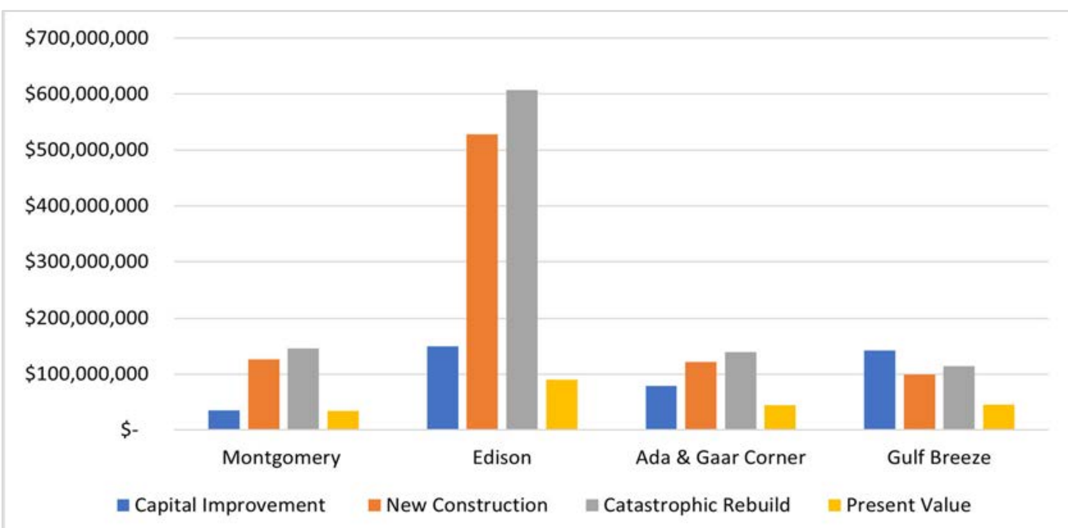



FIGURE 14: EPA’S COMPARATIVE FACILITY VALUES AND CONSTRUCTION SCENARIOS. THIS IS A GRAPHIC REPRESENTATION OF THE VALUES IN TABLE 9




For the five facilities included in this section, the total capital improvement costs through 2034 (nominal, undiscounted) are projected to equal $407 million, the total new construction cost is projected to be $876 million, and the total catastrophic rebuild cost is more than $1 billion, shown in Table 9. The catastrophic rebuild cost estimates currently do not include the cost of any specialized research equipment; however, equipment is documented in EPA’s agencywide property management database and may include replacement costs on a site-by-site basis. The specific facilities that were prioritized for this analysis are representative of a variety of climatic and natural hazards to address and have an existing need for critical repairs. By selecting the facilities included in this paper, the EPA can address the most pressing projects that will not only improve the facilities' overall condition but improve their resilience to compounding hazard impacts.

TABLE 9: CONSTRUCTION COST SCENARIOS BY EPA FACILITY (MILLIONS OF 2024 DOLLARS)

| Cost Category | Gulf Breeze | Ada & Gaar Corner | Edison | Montgomery | Total |
|---|---|---|---|---|---|
| Estimated Value in 2034 | $45.0 | $44.3 | $90.3 | $33.9 | $213.5 |
| Capital Improvement Cost Through 2034 | $142.6 | $79.2 | $149.7 | $35.5 | $407.1 |
| New Construction Cost 2024 | $99.6 | $121.4 | $528.5 | $126.9 | $876.4 |
| Catastrophic Rebuild | $114.6 | $139.6 | $607.8 | $145.9 | $1,007.8 |

EPA has identified four priority projects across facilities discussed in this paper that are included within the total capital improvement costs through 2034 shown in Table 10 for the following reasons:

- EPA has identified projects that are critical to protecting internal assets, which is why most of the projects are roof replacements and building envelope related. The approach used to identify these near-term projects prioritizes foundational needs for facilities (e.g., fixing leaking roofs and deteriorating building envelopes). These projects are a necessary first step to make the agency's physical assets and workforce more resilient to hazard impacts.
- EPA has prioritized these four project locations from climate resiliency assessments already completed to maintain flexible, adaptable, and achievable goals that account for future availability of resources specifically to support capital improvement activities. Once these critical project needs are addressed, the agency intends to invest in additional projects that will further enhance the labs' resilience. The exception is the project at EPA's Gulf Breeze laboratory, which is a climate adaptation effort to maintain facility access via the only vehicular road to the island where the lab is located. Other EPA facilities also have project needs, but EPA has not yet conducted climate resiliency assessments at these sites, and therefore does not know the likelihood of exposure to climate hazards and the extent of other issues at the site.
- Relocation planning and projects for very high-risk or low-lying facilities can be a complex and lengthy process, and EPA is still in the early stages of developing a formal disinvestment process. Rather than solely focusing adaptation efforts on coastal facilities, EPA will instead address critical infrastructure needs proposed across the country with

each of the four projects. By addressing the critical infrastructure needs first, the agency will additionally increase the amount of quality and usable space within the owned portfolio and allow the agency to have more feasible options available for potential relocation projects in the future.

TABLE 10: PRIORITIZED IMPROVEMENT PROJECTS INITIAL COST ESTIMATES AND COSTS PROJECTED AT IMPLEMENTATION YEAR

| Cost Category | Project | Estimated Cost | Escalated Costs |
|---|---|---|---|
| Gulf Breeze | Causeway Riprap Upgrade and Repair | $5,000,000 | $6,500,000 |
| Ada & Gaar Corner | Roof Replacement and Tuckpoint Repair | $2,500,000 | $3,250,000 |
| Edison | Campus Roof Repair (Buildings 10, 205, 209, and 210) | $6,000,000 | $7,800,000 |
| Montgomery | Roof Replacement and Tuckpoint Repair | $7,000,000 | $9,100,000 |

The cost estimates included for each project listed in Table 10 are taken from EPA master planning efforts in coordination with the climate resiliency assessments. EPA updates master plans for each facility on a five-year cycle. The master plans for several of the locations in this paper are three to five years old, so the “Estimated Cost” does not account for recent inflation and construction cost escalation. The estimates have not been verified by an independent third-party and therefore have a wide range of potential costs. Additionally, recent costs for similar projects in progress or completed at other EPA laboratories have greatly exceeded the original cost estimates. To account for this, an escalation of 30 percent has been applied to the “Estimated Cost” to account for price inflation and labor and supply shortages that are more common in post-climate disaster recovery. Actual escalation figures may vary by region and availability at the year of implementation. Each facility profile below includes a description of the EPA facility’s mission, location characteristics, likelihood of hazard exposure and the recommended project.

### *Gulf Breeze, Florida*

The Gulf Ecosystem Management and Modeling Division (GEMMD) is a division within the EPA Office of Research and Development’s Center for Environmental Measurement and Modeling (CEMM). CEMM divisions conduct research on environmental contaminants to provide fundamental methods and models that inform and evaluate environmental management practices and policies. GEMMD’s specific mission is to lead specialized research in marine, estuarine, and watershed ecology and ecotoxicology to predict and assess the impacts of human-generated stressors on aquatic life in the Gulf of Mexico

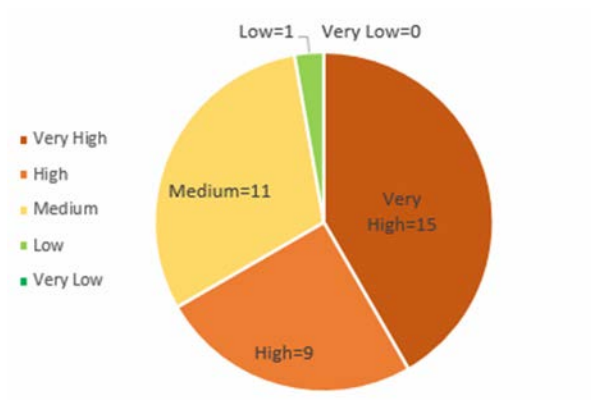



FIGURE 15: NUMBER OF EPA BUILDINGS AT RISK IN THE GULF BREEZE, FL CAMPUS

and across the United States.[9] The number of EPA buildings at risk in the Gulf Breeze, FL campus is presented in Figure 15. EPA's Criminal Investigation Division (CID) and the National Oceanic and Atmospheric Administration also occupy buildings on the island.

GEMMD is located on the Gulf Coast on the manmade, 16.5-acre Sabine Island, in the Santa Rosa Sound within Escambia County. The island served many functions before becoming home to an environmental research laboratory in 1970. The campus's primary assets are 26 occupied buildings, including two main laboratories, as well as many office buildings and small out-buildings. GEMMD's other assets include the causeway, shoreline, a boat house with lifts, and four piers.

Given its climate zone and specific site characteristics, the Gulf Breeze campus has very high exposure to many climate hazards: sea level rise, straight-line high winds, warming seawater temperatures, lightning, storm surge, hurricanes, and extreme heat.[10] As a result of the climate resiliency assessment, EPA began design of a shoreline and causeway riprap upgrade and repair project to protect Sabine Island from wave and water erosion. This project is critical, as the causeway is the only vehicular entryway onto the island.

### *Ada and Gaar Corner, Oklahoma*

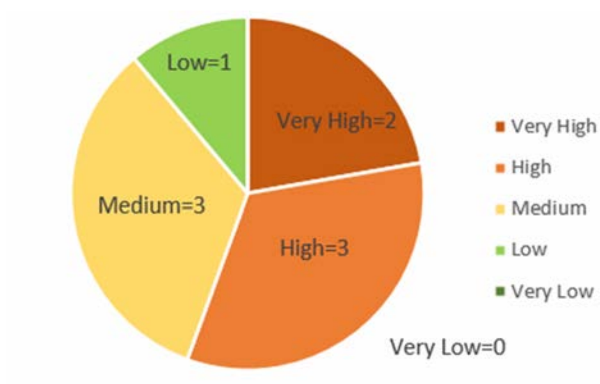



FIGURE 16: NUMBER OF EPA BUILDINGS AT RISK IN THE ADA AND GAAR CORNER, OK CAMPUSES

The Robert S. Kerr Environmental Research Center (RSKERC) and Gaar Corner are EPA Office of Research and Development laboratory facilities.[11] RSKERC staff plan and conduct fieldwork across the U.S. to protect and restore groundwater through data collection and tool, model and strategy development. The Groundwater Characterization and Remediation Division (GCRD) studies physical, chemical and biological processes that influence movement of water, chemicals or microorganisms in subsurface environments and provides special analytical services. GCRD also conducts applied site-specific studies to determine the effectiveness of pollutant removal practices and pollution avoidance. The division works with the EPA regions, program offices and others on specific issues as needed. EPA's Region 6 Laboratory is currently consolidating into RSKERC and analyzes contaminants in air, drinking water, non-potable water, solid and chemical materials. EPA's Region 6 Laboratory manages the region's contract laboratory program; provides technical expertise to the region and Federal, state, tribal and local entities; performs technical audits of environmental monitoring and

---

[9] EPA (Environmental Protection Agency). (2023). Gulf Ecosystem Measurement and Modeling Division (GEMMD) Master Plan Report. Real Property Services Division Internal.
[10] EPA (Environmental Protection Agency). (2022). Facility Climate Resilience Assessment Report: Gulf Breeze. Sustainable and Transportation Solutions Branch Internal.
[11] EPA (Environmental Protection Agency). (2020). Robert S. Kerr Environmental Research Center (RSKERC) Master Plan, Fourth Draft. Real Property Services Division Internal.

public water supply laboratories; and provides expert witness support for civil and criminal enforcement cases. The number of EPA buildings at risk in the Ada and Gaar Corner, OK campuses is presented in Figure 16.

RSKERC and Gaar Corner have very high likelihood of exposure to extreme heat, tornadoes, straight-line high winds, and hail, as well as high likelihood of exposure to lightning and wildfires.[12] While they do not have a very high likelihood of exposure to extreme precipitation, when there are storms with heavy precipitation, the roof leaks and puts sensitive and expensive laboratory equipment at risk. To address the highest likelihood and most consequential hazards, EPA proposes to conduct roof and building envelope repair and replacement at the RSKERC Main Laboratory Building. The proposed project includes removing the existing roof that is leaking and replacing it with a new roof that includes a 30-year warranty. The project also includes building envelope grouting and tuck pointing to prevent future water intrusion.

### *Edison, New Jersey*

The Edison Environmental Center (EEC) provides comprehensive data to support enforcement, compliance and monitoring of Superfund sites, coastal waters, several Brownfield sites and three nationally recognized estuaries.[13] It supports Superfund remediation actions, pesticide and toxic substances enforcement, laboratory data quality assurance and quality control, field monitoring and sampling, and stormwater research. The location is also a valuable resource for environmental emergency response operations and counter-terrorism efforts in the New York City metropolitan area, across EPA Region 2 and nationally. Recently, the EEC adopted additional functions as one of the agency's National Digitization Centers. The number of EPA buildings at risk in the Edison, NJ campus is presented in Figure 17.

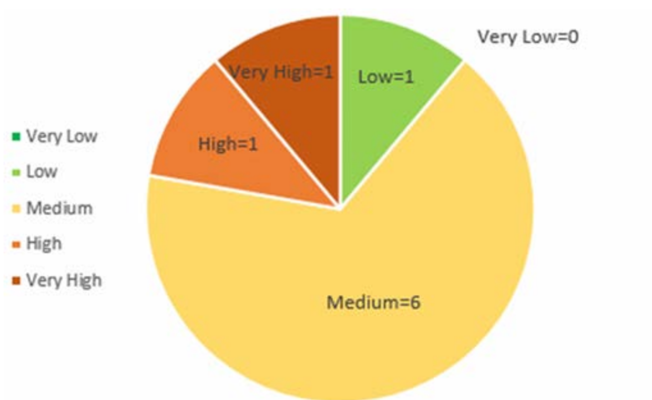



FIGURE 17: NUMBER OF EPA BUILDINGS AT RISK IN THE EDISON, NJ CAMPUS

Other Federal agencies on the campus include the U.S. Army Corps of Engineers, Agency for Toxic Substances and Disease Registry, Public Health Service and the General Services Administration. The EEC is exposed to extreme heat and extreme precipitation. This, coupled with increased humidity, has led to water intrusion and mold growth in buildings on the campus with roofs and building envelopes in poor condition.[14] Additionally, new and increasing operational functions expand the range of requirements on campus and increase the demand for energy and

---

[12] EPA (Environmental Protection Agency). (2023). Facility Climate Resilience Assessment Report: Ada and Gaar Corner. Sustainable and Transportation Solutions Branch Internal.

[13] EPA (Environmental Protection Agency). (2020). Edison Environmental Center (EEC) Office Master Plan Study Final Report. Real Property Services Division Internal.

[14] EPA (Environmental Protection Agency). (2024). Facility Climate Resilience Assessment Report: Edison. Sustainable and Transportation Solutions Branch Internal.

indoor moisture control. EPA proposes to remove existing roofs that are leaking on Buildings 10, 205, 209, and 210 and replace them with new roofing that includes a 30-year warranty. The proposed project also includes building envelope grouting and tuckpointing to prevent future water intrusion.

### *Montgomery, Alabama*

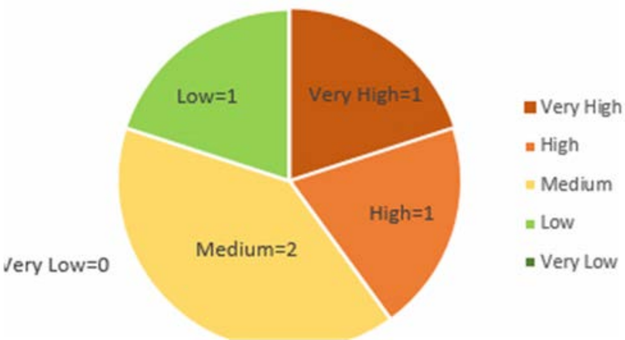



FIGURE 18: NUMBER OF EPA BUILDINGS AT RISK IN THE MONTGOMERY, AL CAMPUS

The National Analytical Radiation Environmental Laboratory (NAREL) is part of EPA's Office of Air and Radiation and is responsible for managing and publishing near real-time data from the nationwide environmental radiation monitoring system (RadNet), analysis of a variety of materials for radiation contamination, and emergency response activities for radiological events.[15] Sample analysis occurs in the Counting Room, which is one of the largest of its kind in the country and is one of NAREL's most critical assets. NAREL collaborates with other EPA offices, such as the Office of Land and Emergency Management and the Office of Water, as well as other Federal agencies including the Department of Energy and Department of Homeland Security, states, and tribes. The number of EPA buildings at risk in the Montgomery, AL campus is presented in Figure 18.

The hazards with a very high likelihood to impact Montgomery include tornadoes, straight-line/high winds and extreme heat, and hazards with high likelihood to impact the facility include hurricanes/tropical storms and lightning.[16] To increase the facility's resilience to these very high and high likelihood hazards, EPA proposes to remove existing roofs that are leaking and replace them with new roofing that includes a 30-year warranty. The proposed project also includes building envelope grouting and tuckpointing to prevent future water intrusion.

## Ongoing Planning and Future Analysis

To incorporate climate-related financial risk into future asset management, EPA performed an initial correlation analysis to identify any relationships between the condition of agency assets, their likelihood of exposure to climate hazards, and the potential impact to operational costs of the facility. The results of this analysis were non-conclusive and preliminary. EPA will continue to improve the quality of the underlying data and the associated analysis to help inform its long-term approach for prioritizing projects and investments in its facilities. Specifically, this analysis may help the agency determine how to compare facilities that have high replacement cost but a lower

[15] EPA (Environmental Protection Agency). (2024). National Analytical Radiation Environmental Laboratory (NAREL) Master Plan Report. Real Property Services Division Internal.
[16] EPA (Environmental Protection Agency). (2023). Facility Climate Resilience Assessment Report: Montgomery. Sustainable and Transportation Solutions Branch Internal.

number of buildings with likely hazard exposure to facilities that have a lower replacement cost but a higher portion of buildings with likely hazard exposure.

EPA is also working to put together a stakeholder group, led by an executive level (Senior Executive Service) committee, to determine the decision tree to make the necessary investment and disinvestment decisions based on the results of the climate resiliency assessments.

## C. Risks to Human Health

Rising temperatures, increases in the frequency and severity of extreme weather and wildfires, vector-borne diseases, food insecurity, and knowledge of the threat of climate change itself have all been linked to declines in Americans' physical and mental health (Carleton et al., 2022; Wen & Burke, 2022; Hayden et al., 2023). This section of the white paper provides (i) an overview of the U.S. Department of Health and Human Services and its efforts to manage climate risks to its operations; and (ii) highlights from the U.S. Environmental Protection Agency and the efforts by the Office of Land and Emergency Management to manage physical risks at Superfund sites.

### (1) U.S. Department of Health and Human Services: Framing Climate Financial Risks

**Introduction**

For the Department of Health and Human Services (HHS), it is clear that physical hazards associated with climate change have impacts on human health, health systems, and health sector supply chains, ranging from acute impacts of natural disasters and heat waves to long-term impacts of slow-moving climate change effects like prolonged drought and sea level rise (Marvel et al., 2023). Transition risks are associated with decarbonization efforts, including the energy transition away from fossil fuels and other greenhouse gas-generating activities. Examples of categories of transition risk include disruption in labor markets, energy costs, and costly changes in industrial processes. The extent of health-specific transition risks, such as increased costs associated with transition to new low-carbon biomedical technologies is unclear. However, as the health sector is one of the largest and most distributed economic sectors in the country, it is highly plausible that the health sector broadly, and HHS more specifically, will encounter financial risks associated with the climate transition including incurring short-term costs for decarbonization and retraining staff. Though it is important to consider transition risks that may arise due to climate change mitigation strategies, the bulk of the information currently available focuses on the financial risks of climate change itself. Therefore, this document primarily focuses on the financial risks due to climate change and not transition risks.

For this high-level assessment of HHS climate financial risks, HHS has aimed to identify where health and agency operational risks associated with climate change may amplify existing health disparities, requiring enhanced and targeted resilience efforts and financial safeguards to support communities at increased risk of these compounded impacts.

In a white paper published March 2023, the Office of Management and Budget laid out their approach to a common framework for assessing climate-related financial risk for the Federal budget (OMB, 2023a). The paper divides physical risks into three categories:

- Physical Asset Risks
- Mission and Operational Risks (i.e., risks to an organization's ability to achieve its mission and conduct its day-to-day operations)
- Changes in Expenditures of Federal Programs

This section focuses on these categories of physical risks and identifies examples in each of them for HHS Operating Divisions.  These examples are meant to be illustrative of the variety of ways in which climate change may affect the physical assets, mission, and financial expenditures of the Department, and not a comprehensive assessment of the Department's exposure to climate-related financial risk.

**Physical Asset Risk**

HHS has many physical assets that may be impacted by extreme weather and other climate-related events such as floods, hurricanes, and rising sea levels (Jay et al., 2023; Hayden et al., 2023). HHS identifies potential risks HHS clinical and biomedical research facilities but does not quantify the associated financial costs (U.S. Department of Health and Human Services, 2024a). The following are selected examples of physical asset risk to health-related structures.

*National Institutes of Health (NIH):* NIH operates the Clinical Center with 200 inpatient beds and dozens of outpatient clinics that saw over 81,000 patients in 2023. This facility is in Bethesda, MD, and is potentially vulnerable to hurricane risk according to FEMA's National Risk Index. If a significant climate disaster were to occur, these patients would likely require relocation and there may be an impact on outpatient clinical care.

Further, costs may be associated with rebuilding damaged or destroyed research facility infrastructure either at NIH or for grantees (NASEM, 2017). For example, in 2013, NIH was allocated $149 million from the Public Health and Social Services Emergency Fund as part of a supplemental appropriation[17] in the Disaster Relief Appropriations Act of 2013 (Public Law 113-2), including money to the NIH to restore grantee labs damaged by Superstorm Sandy (Disaster Relief Appropriations Act, 2013; NIH, 2013).

*Indian Health Service (IHS)*: IHS is responsible for providing Federal health services to American Indians and Alaska Natives. To this end, IHS operates a network of over 600 hospitals, clinics, and health stations on or near Indian reservations around the country (IHS Physicians; IHS Locations). Many of these hospitals are located in areas that experience greater risk from climate change including in areas at risk from extreme heat (e.g., Phoenix, AZ), drought (e.g., Albuquerque, NM), and areas at risk for flooding or sea level rise (e.g., Mashpee, MA).

*Centers for Disease Control and Prevention (CDC)*: CDC operates 20 port health stations at major ports of entry in the U.S. as well as an Emergency Operations Center in Atlanta, GA, global regional offices, and many research laboratories. These facilities may be vulnerable to coastal flooding, and other climate-related events (Jay et al., 2023; Marvel et al., 2023; FEMA, 2024; NOAA, 2024b).

**Mission and Operational Risks**

Most HHS Divisions face climate-related risks to their missions (e.g., providing social services to low-income families and individuals, or protecting people living in the United States from

[17] Making supplemental appropriations for the fiscal year ending September 30, 2013, to improve and streamline disaster assistance for Hurricane Sandy, and for other purposes (2014).

emerging disease) and risks to operations (e.g., providing clinical services or conducting emergency responses to weather-related disasters).

*Administration for Children and Families (ACF)*: The Low-Income Home Energy Assistance Program (LIHEAP), through grants to states, territories, and tribes, provides financial assistance to low-income households to reduce the costs associated with home energy bills, energy crises, weatherization, and minor energy-related home repairs. In 2024, LIHEAP was appropriated $4.115 billion in grant funding to provide this energy assistance.[18]

Cooling days (days that require air conditioning or other cooling) are anticipated to increase by 65 percent by the end of the current century. Such an increase in cooling needs would likely increase demand for LIHEAP assistance, making it more difficult to meet the energy security needs of all eligible low-income households (OMB, 2023a).

Additionally, the Head Start Environmental Exposure Mapping Tool highlights the risks to children and pregnant women enrolled in the program associated with exposures to climate-related hazards including excess heat, wildfire smoke, flooding, and ozone air pollution. Head Start preschool and Early Head Start programs cumulatively served more than 800,000 children birth through age five and pregnant women during the 2021-2022 program year (ACF, 2023). These risks to Head Start and Early Head Start program sites may increase the need for the comprehensive services that are part of the Head Start model to ensure young children from low-income families are prepared for school success. Climate-related hazards also pose a threat to continuity of operations of program sites. Together, these climate-related hazards pose mission risk by reducing the availability of services to meet the needs of enrollees within the constraints of current funding.

Reporting demonstrates a direct correlation between the consequences of natural disasters and an increased risk of human trafficking and other forms of exploitation (Fuller et al., 2022). Natural disasters often compound vulnerabilities that individuals, families, and communities may already be experiencing. Disasters can cause people to lose their homes, jobs, and transportation and disrupt support systems that are in place to keep them safe. Traffickers can exploit these conditions by promising food, shelter, and other resources. Disasters can also create new markets for cheap labor, incentivizing traffickers to recruit people who lost their job or migrant workers through fraudulent offers, promising employment and/or residency before using other tactics to maintain control. These risks may increase the need for housing, comprehensive case management services, and other assistance funded by the Administration for Children and Families (Chon & Grant, 2022).

*Centers for Medicare & Medicaid Services (CMS):* Emergency Preparedness & Response Operations (EPRO), which monitors and disseminates information, training and coordinates real-time emergency regulatory relief on behalf of CMS, along with the Centers and Offices that support the processes, may need to allocate more resources to address climate-related extreme weather events (CMS, 2024a). CMS provides numerous flexibilities and waivers (e.g., waivers under Section 1135 of the Social Security Act) to address urgent medical and financial needs in

[18] LIHEAP was appropriated $4.025 billion in FY 2024, $4.015 billion of which was for the base grant funding. LIHEAP also received $100 million in Bipartisan Infrastructure Law funding (ACF, 2024).

affected communities, including in communities impacted by events such as hurricanes and tropical storms (CMS, 2024b). Since 2021, there have been 15 natural disasters (e.g., a winter storm, a severe storm, a flood, wildfires, and hurricanes), impacting 13 separate states or territories, that have resulted in public health emergency determinations (ASPR, 2024). The cost associated with reviewing and administering waivers will increase across CMS components and State Survey Agency partners as these occur with greater frequency.

CMS/Center for Medicare and Medicaid Innovation (CMMI) models sometimes require policy changes in response to climate change-driven events such as hurricanes or spread of infectious disease. These are often referenced in model documents as “extreme and uncontrollable circumstances”, and, in these scenarios, CMS/CMMI may make policy accommodations for affected providers that may drive higher expenditures for the Center, Medicare and/or Medicaid.

*Indian Health Service (IHS):* Non-Hispanic American Indian and Alaskan Native populations are at far greater risk of adverse health outcomes from climate-related threats than their non-Hispanic White counterparts, including 7.34 times higher odds of dying following a natural disaster (Sharpe & Wolkin, 2022) and a 3-fold higher risk of heat-related mortality (Vaidyanathan et al., 2020). As many American Indian and Alaska Native populations live in areas at high risk of extreme heat, wildfire smoke, flooding, and other climate-related threats, the IHS facilities serving them may face both mission and operational risks as both the populations and facilities themselves are affected. This could potentially worsen the existing disparities in adverse health outcomes experienced by these populations.

*Substance Abuse and Mental Health Services Administration (SAMHSA):* SAMHSA’s FY2024 enacted budget amount for disaster response was $1.953 million (U.S. Department of Health and Human Services, 2024b). More frequent natural disasters lead to increased stress, trauma, and substance use issues among affected populations (Heanoy & Brown, 2024). For example, recent hurricanes, wildfires and floods increased the need for mental health services. Mental health symptoms may increase following emergencies and disasters, such as hurricanes (Schoenbaum et al., 2009; Bevilacqua et al., 2020). With increasingly severe hurricane seasons and other climate-related disasters, SAMHSA is predicted to experience a surge in demand for disaster response screening, assessment, treatment, and care coordination (Lawrence et al., 2020; Miller et al., 2021a; U.S. Department of Health and Human Services, 2024c).

*Administration for Strategic Preparedness and Response* (*ASPR*): ASPR leads the nation's medical and public health preparedness for, response to, and recovery from disasters and public health emergencies. As extreme weather events are increasing in frequency and geographic range, ASPR, with their partners, will support by providing key medical resources and personnel. Since 2021, there have been 15 unique extreme weather events that have led to 27 declared Federal public health emergencies, and requests for ASPR’s support to the states will likely increase (ASPR, 2024). The increase in demand may challenge ASPR’s ability to fully meet emergency response needs and may divert resources from other important ASPR mission areas.

*The Food and Drug Administration (FDA)*: FDA regulates medical products, the supply chains of which may be at risk from climate-related disruptions (Lawrence et al., 2020), creating drug or device shortages or exacerbating existing shortage issues (FDA, 2024). Pharmaceutical and other medical product supply chains are becoming increasingly vulnerable in part due to globalization and the projected impact of climate change internationally (Miller et al., 2021a; Sherman et al., 2023). Further, a substantial percentage of drug and device manufacturing facilities in the U.S. are located in areas at-risk for extreme weather events (U.S. Department of Health and Human Services, 2024b), including coastal and riverine flooding, tornadoes, and extreme heat, further suggesting supply chain risk. Additionally, there may be an increased demand for certain drugs (e.g., asthma medication) (Abir et al., 2024), due to changes in climate (e.g., more frequent heat waves, more frequent wildfire smoke polluting air quality, extended allergy seasons, and flooding-induced mold) that are associated with greater rates of asthma and other disease processes putting pressure on the supply chain due to increased demand.

FDA is also responsible for protecting the nation's food supply. Climate change has and is anticipated to further increase the risk of some food-borne illnesses, including those caused by Salmonella and *Vibrio* bacteria species (Levy, 2015; Froelich & Daines, 2020; Morgado et al., 2020; Billah & Rahman, 2024), which may put increased demands on FDA to monitor for and respond to these illnesses. Additionally, FDA is integrally involved with its HHS partners in responding to an increasing number of emerging pathogens by helping to facilitate the development of diagnostic tools and medical countermeasures and may also need resources for increased review of new vaccines as new products come online in response to the impacts of climate change.

*Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR):* Climate change poses a threat to CDC/ATSDR missions and operations due to increased risk of infectious disease and increased frequency and need for emergency disease surveillance and response activities, both domestically and abroad. Distribution of insect vectors is also broadening in the United States, suggesting heightened risk for vector borne disease outbreaks (such as ticks carrying Lyme Disease in the United States, for example) (Couper et al., 2021). CDC/ATSDR also plays a role in response to wildfires (CDC, 2024a) and other natural disasters (CDC, 2024b; CDC, 2024c). These climate-related factors may create a mission and operational risk to the CDC/ATSDR, as the burden of emergency responses involving data collection, information dissemination, and treatment increases over time within the United States.

CDC/ATSDR also responds to disease outbreaks abroad by providing disease surveillance and supports to on-the-ground health workers. Outbreaks are increasing due to changes in precipitation, heat, and other climate-related factors. For example, CDC/ATSDR engages in international surveillance of emerging and ongoing epidemics, including focusing on ecological changes leading to disease outbreaks (CDC, 2024d). CDC/ATSDR also works directly with the World Health Organization to respond to emerging threats and outbreaks related to vector-borne diseases (CDC, 2024e). This raises the potential of increased demand for CDC resources to be used abroad to identify diseases, create surveillance tools, and contain outbreaks.

*Health Resources and Services Administration (HRSA)*: HRSA funds health centers which serve as health safety nets (Lewis et al., 2021) and provide essential primary care to rural and low-income populations (Miller et al., 2021b). In addition to health centers, HRSA oversees the Ryan

White HIV/AIDS Program and grant opportunities open to rural health clinics and rural hospitals. Services provided by health centers have been shown to reduce emergency room visits by uninsured individuals (Nath et al., 2019), thereby helping mitigate patient demand for hospitals in surge situations, and increasing the resilience of regional health systems. Health centers also provide important care after climate-related disasters (Paek et al., 2018). HRSA provides program guidance and administrative flexibilities to health centers to mitigate the impacts of disaster events (HRSA, 2022). Reports in the gray literature document that health centers are working to address climate-related events through infrastructure resilience (Hostetter & Klein, 2022), as well as supporting health professionals in climate action due to the recognition of the impacts on climate change on the people who health centers serve (Rehr & Perkowitz, 2019).

**Changes in Expenditures of Federal Programs**

Expenditure risk result from increases in financial outlays due to the impact of climate and extreme weather events on programs with mandatory spending requirements.

*Centers for Medicare & Medicaid Services (CMS):* Several studies have examined the magnitude of increases in health care expenditures for Medicare and Medicaid as a result of climate change-related health impacts. Examples of these climate change-related health impacts include the impacts of hurricanes, extreme heat, wildfire, and exposure to vectors such as ticks that carry Lyme disease on patient morbidity and mortality (Lay et al., 2018; Limaye et al., 2019; Liu et al., 2019).

In a 2022 report, using the EPA's Framework for Evaluating Damages and Impacts (FrEDI), the Office of Management and Budget (OMB) estimated that climate-related cost for Medicare and Medicaid could increase between "$824 million and $22 billion (2020$) dollars by the end of the century" based on estimated air quality impacts and an OMB morbidity impact assessments for valley fever, southwest dust, and wildfires. This climate-related cost would add approximately 1 percent of additional national health expenditures. (OMB, 2022a). It is important to note that while the FrEDI and OMB estimates consider the most common risks from climate change, there may be other variables not included in these estimates that could impact the financial cost.

Lay et al. (2018) completed a study focusing on hyperthermia (overheating) and predicted that emergency room visits related to ambient temperatures in individuals 64 and younger in the U.S. will cost an additional $6 to $52 million by 2050. In a similar study, focusing on the impact of extreme temperature in Minneapolis/St Paul, results also suggested a significant financial burden of extreme temperature (Liu et al., 2019). Limaye et al. (2019) calculated the cost associated with 10 distinct episodes of climate change-related events from 2012 alone with data from the Health Care Utilization Project (HCUP), with each event estimated to have between $4.9 million (Heat Wave in Wisconsin) and $544 million (Hurricane Sandy) in morbidity costs in 2018 dollars. These studies highlight the need to understand the impact of temperature and extreme weather on anticipated Medicaid and Medicare spending.

**Conclusion**

This qualitative exploration of climate-related financial risks to the Department of Health and Human Services builds upon previous analyses that have focused primarily on the financial risks to CMS due to increased climate-related disease burden in Medicare and Medicaid beneficiaries. While the studies demonstrate that CMS is facing financial expenditure risk from increased climate-related burden of disease, many Operating Divisions face increasing mission and operational risks from diversion of resources to emergency responses and other programs. Long-term predictive modeling of climate-related health impacts and high-consequence extreme weather events is currently limited, which limits the ability to provide more quantitative estimates of financial risk that accompany the physical and mission-related risks that were the focus of this document. Nonetheless, scoping and bounding estimates that describe the likely financial impacts of the risks listed here should be the next steps in the ongoing effort to approximate, disclose, and mitigate climate-related financial risks and assure the long-term stability of Health and Human Services programs.

### (2) U.S. Environmental Protection Agency: Managing Physical Risk at Superfund Sites

**Introduction**

EPA's Office of Land and Emergency Management (OLEM) proactively manages current and anticipated impacts of climate change on hazardous waste site remediation programs.

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986, EPA achieves its mission to protect human health and the environment by responding to releases of hazardous substances, pollutants or contaminants.[19] CERCLA, informally called Superfund, allows EPA to clean up contaminated sites where hazardous waste has been dumped, left out in the open, or otherwise improperly managed. The Superfund Program focuses on making a visible and lasting difference in communities through its mission of protecting public health and the environment.

The EPA Office of Land and Emergency Management (OLEM) is taking action to address known physical risks posed by climate change across its national programs. These risks may include, but are not limited to, damages from wildfire in drought-stricken areas, hurricane force winds and flooding, and even operational impacts due to limited access or loss of electricity or communications. These risks and adaptation measures are described in nine site profiles, further described below. OLEM has emphasized integrating adaptation efforts across the site cleanup and waste management programs, including the Superfund remedial program within the Office of Superfund Remediation and Technology Innovation (OSRTI). Consistent with CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP)[20] as well as agency policy and guidance documents, OSRTI has integrated climate resilience into the Superfund cleanup process. The Superfund remedial program routinely considers the potential impacts from climate change and extreme weather events during remedy selection, design, implementation and operation and maintenance. Climate hazards such as increased frequency of natural disasters, increased flood risk, increased drought risk, or other climate-related changes in site conditions may affect short- and long-term remedy protectiveness. In 2017, after an active hurricane season, the

[19] 42 USC §9604(a)(1)
[20] 40 CFR Part 300

Superfund program completed a study (EPA, 2019) to document the impacts from these extreme weather events on and evaluate the remedy resilience for sites located in EPA Regions 2, 4, and 6, which cover the U.S. Southeast and the Caribbean regions which are exceptionally vulnerable to sea level rise, extreme heat events, and hurricanes per the U.S. Global Change Research Program. The study found that 16 sites across the three regions were impacted by the storms and sustained minor damage, but no sites reported an impairment to remedy protectiveness.

Since 2021, OLEM has made significant progress in assessing site and remedy vulnerabilities and anticipating the impact of climate change to Superfund hazardous waste sites. This progress is illustrated in the following excerpts from two site profiles that describe the climate risk exposure:

- The Rocky Mountain Arsenal site (RMA) in Commerce City, Colorado is vulnerable to wildfires and the threats they pose to the site's existing infrastructure and buildings for system maintenance and groundwater treatment. In December 2021, a wildfire quickly spread across more than 6,000 acres within 17 miles of the site due to an unusually high amount of dry grass, a low amount of recent snowfall, and wind gusts exceeding 100 miles per hour. To adapt to these risky conditions, the site undergoes periodic prescribed burns conducted to expend potential wildfire fuels in a controlled manner. This practice also generates co-benefits by helping maintain the desired perennial grasses providing habitat for native and migratory wildlife, preventing onsite growth of invasive plant species, and fostering local biodiversity.
- The Port Hadlock site borders Port Townsend Bay, a marine inlet in the Olympic Peninsula in Washington State. Due to its coastal location, the covered landfill is vulnerable to erosion associated with tidal action and storm surge. Site inspections and remedy reviews allow for improved precision in repairs to the landfill cap and armor rock replacement. These resilience measures allow for shellfish rebound, help to control costs, and are sustainable in the long term. Institutional controls involving restricted site access and land use remain in place.

Further details from seven more case studies of climate adaptation at remediation sites are provided at: https://www.epa.gov/superfund/superfund-climate-resilience.

To improve management of risks from climate change to remedy protectiveness at Superfund sites, in 2021 OSRTI published a national program guidance (OLEM, 2021) on considering climate resilience in Superfund site management, OLEM Directive No. 9355.1-120, *Consideration of Climate Resilience in the Superfund Cleanup Process for Non-Federal National Priorities List Sites*. This guidance established consistent policy that encourages regional site cleanup teams to consider potential impacts of extreme weather events and changing climate conditions at Superfund sites to ensure the protection of human health, welfare, and the environment. In 2024, this memorandum was superseded by OLEM Directive No 9355.1-121, *Consideration of Climate Resilience in the Superfund Cleanup Process for Non-Federal and Federal National Priorities List Sites*, which expanded upon the 2021 memo to include Federal National Priorities List (NPL) sites and references to enforcement authorities.

As stated in the 2024 Directive, project managers should generally assess the vulnerability of a remedial action's components, including its associated site infrastructure, and evaluate whether the long-term integrity of a selected remedy may be impaired by adverse effects of climate change. The assessment may lead to a site-specific analysis of the remedial action in light of current, forward-looking information on local or regional climate and weather regimes.

Based on any potential vulnerabilities identified, project managers should evaluate resilience measures that increase the system's resilience to a changing climate and ensure continued protectiveness of human health, welfare, and the environment. Multiple resilience measures may be appropriate, and if so, the site team should set priorities to maximize return on limited resources, based on best professional judgment regarding factors such as cost and impact on site operations.

To further refine and monetize the estimates of climate financial impacts, the Superfund remedial program is undertaking an analysis over the next year. The focus will be on quantifying potential financial liabilities at sites that have remedies selected, in consideration of the following available data:

- Remedy types (e.g., landfill cap, pump and treat system),
- Most anticipated vulnerabilities by remedy type and location,
- Remedy implementation cost data (non-Federal, fund-lead sites only), and
- Hands-on experience of climate contacts and project managers in each regional office.

As context, in 2019, the Government Accountability Office (GAO) found that 60 percent of the non-Federal sites on the NPL are vulnerable to climate risks (flood, storm surge, wildfire) (GAO, 2019a).

**Methods**

To develop estimates of financial liability at Superfund sites due to climate change, EPA will develop quantitative projections of financial liabilities for specific remedy types located in areas, with an initial focus on impacts due to changes in precipitation and flooding as this data was the most available and reliable immediately. By leveraging work conducted for the Climate Adaptation Plans and internal facility assessments in EPA's Office of Mission Support's climate resilience assessment at laboratory facilities, this effort will fit into the broader agency efforts to address financial risks of climate impacts.

Based on EPA's prior research, groundwater pump and treat (P&T) systems can be highly vulnerable to climate change. OSRTI identified 18 sites where P&T was selected as the sole containment/treatment remedy between 2013 and 2023, with an anticipated median capital construction cost of over $15 million per remedy in 2023 at the time of the respective Record of Decision. While EPA does not model an expected rate of destruction due to increased risks of floods at these sites, assuming a 50 percent rate of destruction at these sites during a flood event, the potential liability is estimated to be $135 million based on initial construction estimates.

To develop a more precise estimate, OLEM's analytical activities are ongoing and expected to continue into 2025. The team will:

- Conduct a screening analysis to establish which sites have suitable data for inclusion (suitable data may include remedy construction date, remedy operational status, baseline costs and the cost element structure [i.e., capital costs, operation and maintenance costs, and periodic costs]);
- Estimate financial liability of capital costs for repair and/or replacement;
- Develop assumptions for minor and major impacts to remedies due to climate change and severity of damage expected due to those impacts; and
- Quantify the financial liabilities for the selected sites in high-, medium-, and low-cost estimates based on severity of the potential vulnerability.

**Preliminary Results from Rocky Mountain Arsenal**

While the Rocky Mountain Arsenal (RMA) is a Federal facility and would not be included in an estimate of EPA's potential financial risk, it provides insight on the scale of costs that could be encountered at Superfund sites with multiple operable units with separate areas of land with cleanup activities underway. EPA offers these partial estimates of the range of liabilities facing the program as a preview of, not a substitute for, the more detailed analysis underway now.

This site operates five pump and treatment (P&T) systems treating approximately 657 million gallons annually (Navarro Research and Engineering, Inc., 2024). The site is located in Commerce City, Colorado where climate projections, under Representative Concentration Pathways (RCP) 4.5 emission scenario, indicate an increase in extreme daily precipitation between 7-9 percent between 2040-2060 (Colorado Water Conservation Board, 2024). Increase in extreme daily precipitation under future climate scenarios may suggest an increased flooding risk; indeed since 1864, Colorado has been experiencing a major flood disaster roughly once every five years with a 19 percent probability that a major flood disaster will occur in any given year (Colorado Department of Public Safety, 2018). The potential liability of operating the RMA P&T systems under an increased flooding risk is estimated by assuming five major floods by mid-century with damage from each flood requiring 50 percent capital replacement costs for two to all five P&T systems based on initial construction estimates. Given these assumptions, the estimated mid-century present value of the potential liability from flooding related damages to P&T systems ranges from $49 million to $121 million higher than the estimated baseline costs (i.e., no flooding) to operate the remedy.

**Timeline and Objectives**

The current focus is on setting the analytical scope, gathering data, and developing screening criteria to ensure accuracy of the monetized estimates of impact. This study will also identify data gaps and next steps to implement the approach for a broader set of Superfund sites that may be subject to additional vulnerabilities, such as wildfire or drought, and for potential applicability to other EPA programs with investments at risk from climate impacts (e.g., Resource Conservation Recovery Act (RCRA) hazardous waste and Leaking Underground Storage Tank (LUST) cleanup programs).

## D. Decision Support Tools

As demonstrated in each of the prior sections' assessments and program highlights, each Federal agency required the use of or developed customized analytical capabilities that provided spatially relevant projections of physical climate change impacts. These same analytical capabilities are needed by a range of stakeholders; for example, by architects and engineers that are designing built environment projects to account for future climate change and extreme weather impacts, farmers and ranchers adjusting operations and incorporating climate-smart agriculture practices, and municipal government officials that are incorporating climate risks in updates to their general plans.

This section highlights efforts by two Federal agencies to manage the physical risks of climate change and inform decision making to respond to those risks, including (i) the U.S. Department of the Interior's implementation of tools to assess and address climate risks to buildings and operations, and (ii) efforts by the U.S. Department of Transportation to manage climate risks to the transportation system.

### (1) U.S. Department of the Interior: Tools to Assess and Address Climate-Related Financial Risk to Buildings and Operations

**Introduction**

The Department of the Interior (the Department, Interior) has significant responsibilities, including managing 20 percent of the Nation's lands and the natural and cultural resources found there. Interior bureaus manage lands and resources that provide recreational opportunities to the public, supply water and hydropower in Western States, and are an important source of responsibly managed renewable and nonrenewable energy and mineral development. The Department fulfills trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated island communities. As part of its ongoing commitment to these responsibilities, Interior produces extensive science and information to support its bureaus, partners, and the public.

Interior's assets include buildings[21] distributed across the United States and its territories, which exposes them to a wide range of potential hazards, including hazards related to climate change. For example, in June 2022 Yellowstone National Park experienced a 500-year flood event, in which park regions received 7.5-9.5 inches of rain and snowmelt in a 24-hour period. The flooding destroyed several key sections of road, triggered major evacuation operations, and damaged wastewater infrastructure leading to a 1-year closure of Mammoth Hot Springs Hotel—impacts

[21] Interior's Office of Property Acquisition and Management provided these key definitions:

- *Buildings* typically have four walls and a roof;
- *Structures* are all constructed assets that are not buildings;
- *Facilities* is inclusive of both buildings and structures;
- *Assets* is inclusive of buildings, structures, and administrative land (does not include stewardship land); and
- *Infrastructure* tends to refer to large-scale structures (e.g., dams, highways, bridges, etc.).

that have required significant resources to address.[22] In September 2024, Hurricane Helene affected the Southeastern United States, bringing over 30 inches of precipitation to the region traversed by the Blue Ridge Parkway, washing out bridges and causing slope failures that continue to limit access to the scenic road.[23]

The Department supports research and tools to help managers account for these exposures and manage for risk, which generate a value of information (VOI) to decision makers. This case study focuses on the development of a VOI framework that could be used in future applications to assess the potential financial risk from climate change to over 41,800 Interior-owned or managed buildings—including visitor centers, schools, offices, museums, housing, and restaurants—and associated operations. The framework is illustrated through a case study using outputs from the Strategic Hazard Identification and Risk Assessment (SHIRA) Project on flood risk to inform the siting of a visitor center. Experts from the SHIRA Project and Interior's Office of Property Acquisition and Management guided the development of the case study.

**Background**

In June 2024, the Department issued its 2024 Climate Adaptation Plan (the Plan) (U.S. Department of the Interior, 2024), which includes an assessment of exposures to climate hazards, and associated risks[24] to the Department's mission, operations, and services. This includes quantitative assessments of exposure to climate-related hazards across the portfolio of Interior-owned or managed buildings. The Plan also includes an implementation plan that lays out priority actions the Department will take through 2027 to reduce its exposure to climate risks.

The assessment of exposure and risk in the Plan is based on projections in two spatially explicit tools. The first is the Federal Mapping App developed for all agencies by the White House Council on Environmental Quality (CEQ) and the National Oceanic and Atmospheric Administration. The second is the SHIRA Project, a platform developed by the U.S. Geological Survey (USGS) and Interior's Office of Emergency Management (OEM) for internal use by Interior staff.

Section 3A1 of the Plan (Addressing Climate Risks Affecting Interior Buildings) outlines several Department- and Bureau-level actions to reduce exposure to climate risks, including:

- Updating Department policy to address risks in future actions;

[22] Funding for recovery is coming from a variety of sources; Yellowstone National Park State of the Park 2023 includes an overview. Notably, the Disaster Relief Supplemental Appropriations Act, 2023 (Division N, Title VII) made $1.5 billion available to support recovery from natural disasters at several national park units. A substantial portion of that amount was authorized for the long-term flood recovery efforts in Yellowstone.
[23] As of October 2024, the National Park Service (NPS) has reported impacts to multiple parks ranging from Florida to Virginia. Beginning September 30, over 400 NPS employees from 37 states and the District of Columbia and Puerto Rico, representing 64 parks and offices across the NPS, have been deployed to assist with recovery efforts.
[24] Here DOI uses definitions of exposure and risk from the Fifth National Climate Assessment.

- *Exposure*: The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by climate change.
- *Risk*: Threats to life, health and safety, the environment, economic well-being, and other things of value. Risks are evaluated in terms of how likely they are to occur (probability) and the damages that would result if they did happen (consequences).

- Adding climate change-related hazards to decision support tools; and
- Improving the resilience of Department buildings by evaluating site-specific vulnerabilities and following best practices in new construction, repair, and modernization.

The Department has begun to implement these actions—updating Departmental policy to comply with OMB Memorandum M-24-03, "Advancing Climate Resilience through Climate-Smart Infrastructure Investments and Implementation Guidance for the Disaster Resiliency Planning Act," and extending the capabilities of decision support tools to include climate-related hazards and better support climate change adaptation. During the development of the Plan, the Department also released several updated Departmental Manual (DM) chapters that clarify policy on climate adaptation, including 523 DM 1, "Climate Change Policy." This policy directs the Department to address climate change impacts on Department mission, operations, and services, including using best available science and established approaches to manage for uncertainty such as vulnerability assessments, scenario planning, and adaptive management. Interior has developed and is continually refining a risk register, which will enable enterprise risk management across programs and bureaus for strategic, operational, reporting, and compliance risks to the Department's mission.

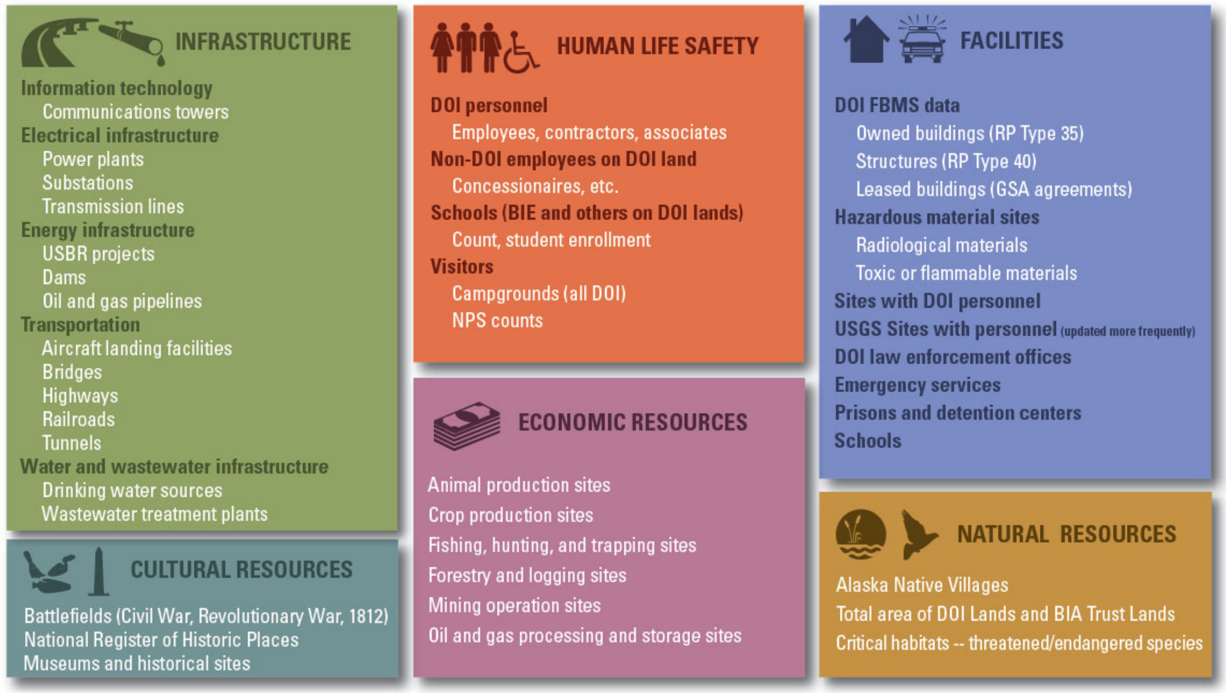
**Incorporating Climate Projections into Hazard Assessment to Better Understand Risk Exposure**

The SHIRA Project was launched in 2018, as part of Interior's Integrated Approach to becoming disaster resilient. It works toward several goals, including to:

- Improve understanding of hazard-related risks posed to Department assets, resources, and people;
- Determine the Department's data and tool needs to enable effective risk planning;
- Identify realistic Departmental threats and commonalities to enable multi-hazard planning;
- Curate and deliver the best available hazards and asset data;
- Characterize and effectively communicate the hazard exposure of Interior's assets;
- Develop tools to support Departmental unit, regional, and national risk planning; and
- Build a Departmental risk community of practice to share best practices and to leverage limited resources.

The project hosts several tools in a secure cloud environment that support short-term and long-term planning by visualizing and quantifying exposure to a wide range of hazards across a suite of Interior assets that include buildings, employees, and natural and cultural resources (see Figures 19 and 20). Hazard exposure data can be used to inform facility management, employee training, infrastructure planning, public outreach, and spending priorities, among other uses. Hazards were initially organized into six categories: geophysical, ecosystem health, human health, technological, weather, and wildfire. In June 2024, a seventh category that includes climate-related hazards was added (see Table 11 and Figure 19), which provides the new information being evaluated in the case study.

FIGURE 19: GRAPHIC OF DEPARTMENT ASSET LAYERS INCLUDED IN SHIRA PROJECT TOOLS




## The Role of a Value of Information (VOI) Framework to Assess the Impact of Decision Support Tools on Risk Reduction

Information is the foundation of evidence-based decision-making and action. Producing and sharing information with decision makers, including impacts on financial risk exposure through planning and investment decisions, has value, in part because it helps manage costs. For example, the SHIRA Project includes climate projection layers that indicate exposure[25] to climate hazards and can be used to assess potential climate-related financial risk (also reported in the 2024 Climate Adaptation Plan, see Text Box 1). Importantly, this value is not always evident immediately. In some cases, the impacts of decisions persist for decades (e.g., through the lifespan of facilities and other infrastructure). The fact that the VOI may not be immediately evident can lead to underinvestment in information products (a common situation for public goods like the SHIRA Project) and potentially lead to un- or underinformed decision making.

A framework to assess VOI helps describe the benefits of information for Department actions and operations to decision makers. To better assess the potential VOI in climate-related decision-making, the Department will draw on work conducted by the USGS on their scientific research programs. The methods draw on the theory of information to help make decisions and improve outcomes. Through a number of case studies, the USGS has demonstrated a Bayesian analysis decision-tree approach is particularly useful to assess changes in outcomes and associated benefits

[25] Indication of exposure varies by hazard, in some instances exposure is a binary measure (e.g., an asset within an area susceptible to sinkholes) while for other variables the magnitude of exposure is also provided (e.g., the number of additional days above 95 degrees F that an asset is exposed to under a given future climate scenario).

in response to information (Pindilli et al., 2023; Pindilli and Loftin, 2022; Pearlman et al., 2019). In these case studies, decision pathways and assumptions are identified for actions taken "with" and "without" the information. Decision scenarios with next-best information ("without" the information products being assessed) are typically referred to as counterfactuals. The measurement of the effect of the additional information relative to a counterfactual is an estimate of the societal benefits from the reduced uncertainty due to the information.

FIGURE 20: GRAPHIC OF HAZARD LAYERS INCLUDED IN SHIRA PROJECT TOOLS[26]


### Process to Develop a VOI Framework to Evaluate Changes in Climate-Related Financial Risk

To determine whether a VOI case study can be developed, the first step is to identify the information product (i.e., the SHIRA Project) and scope out who uses the information, how the information is used, and the expected benefits from incorporating the information into decision-making (see Table 12). This effort to assess the information product should *only* be viewed as a scoping exercise to better understand the product and to help determine the potential viability of a case study. This information product inventory helps identify which application (use case) can lead to development of a scenario with a decision point related to the information and some narrative on what could have happened before this information became available (see Figure 21). The scenario is then elaborated as a series of potential outcomes from different alternatives resulting from the decision point (see Figure 22 in the following section for an example). Assigning probabilities and monetizing the outcomes are consistently the most challenging components of

[26] Hazards in italics cannot be mapped.

this approach. Once the scenario is described, it helps to work backwards on the decision tree to determine whether a case study will be viable.

TABLE 11: CLIMATE-RELATED HAZARDS INCLUDED IN SHIRA TOOLS, WITH ASSOCIATED SCENARIOS, TIMESCALES, AND GEOGRAPHIC EXTENTS

| **Climate-related Hazard (* - denotes 2024 addition)** | **Scenarios** | **Timescales** | **Geographic Coverage** |
|---|---|---|---|
| Number of Days Above 95˚ F* | RCP 4.5 and RCP 8.5 | Historic, mid-century and late-century | CONUS |
| Number of Heating Degree Days* | RCP 4.5 and RCP 8.5 | Historic, mid-century and late-century | CONUS |
| Number of Cooling Degree Days* | RCP 4.5 and RCP 8.5 | Historic, mid-century and late-century | CONUS |
| Precipitation Events Exceeding 2 Inches* | RCP 4.5 and RCP 8.5 | Historic, mid-century and late-century | CONUS |
| Sea Level Rise | 1-foot increments (one to five feet) | Can be crosswalked with emissions reports | CONUS, HI, and territories |
| | Intermediate and Intermediate-High | 2050 and 2090 | CONUS, HI, and territories |
| Wildfire Risk | Burn probability | Current and 2053 | All 50 states |
| | Flame length | Current and 2053 | All 50 states |
| | Wildfire hazard potential<br>Risk to potential structures | Current conditions | All 50 states |
| | | Current conditions | All 50 states |
| Riverine Flooding | 100-year and 500-year storms (National Flood Hazard Layer) | Current conditions | All 50 states and Puerto Rico |
| | Combinations of storms (100-year, 500-year) and climate scenarios (SSP 4.5 and 8.5) | 2023 and 2053 | All 50 states and Puerto Rico |
| Permafrost | Presence | Current conditions | AK and CONUS |
| Sinkhole susceptibility | Landscape conditions | Current and 2079 | CONUS |

TEXT BOX 1: DEPARTMENT BUILDINGS ARE EXPOSED TO A WIDE RANGE OF CLIMATE HAZARDS, WITH IMPLICATIONS FOR CLIMATE-RELATED FINANCIAL RISK

The addition of climate hazard projections into SHIRA Project tools enables Interior staff to easily overlay climate projections on maps of Department buildings, management units (e.g., parks, refuges, etc.), employee duty stations, or other features (see Figure 19). This information helps identify potential risks and opportunities for corrective actions. Similar high-level exposure analyses were included in the Department's 2024 Climate Adaptation Plan, providing insights regarding future climate exposures and implications for climate-related financial risk, including:

- *Extreme Heat*. Nearly every Interior-owned or managed building will experience more frequent temperatures exceeding historical maximums under each climate scenario evaluated using SHIRA. This is projected to be accompanied by increases in the number of cooling degree days and decreases in the number of heating degree days, which have implications for operations and maintenance.
- *Extreme Precipitation*. Precipitation events in excess of two inches are, on average, expected to increase by 20-29 percent by mid-century and 30-51 percent by late century, depending on the climate scenario. This has implications for operations and maintenance, and potentially for employee safety.
- *Sea Level Rise*. Depending on the climate scenario, 533-1167 Interior-owned or managed buildings are projected to be inundated by sea level rise by 2090. Conservative estimates of replacement value for these buildings—which do not include associated structures, assets, or infrastructure (see footnote 25)—are just under $1 billion.
- *Wildfire*. Approximately 25 percent of Interior-owned or managed buildings, including more than 2,500 housing structures, nearly 500 office buildings, and over 90 visitor centers—a portfolio with a replacement value of more than $49 billion—are in areas where wildfire currently presents a high-to-extreme risk to structures.
- *Flooding*. Approximately 27 percent of Interior-owned or managed buildings are currently in an area with a one percent annual exceedance probability (AEP) of flood, with an additional 6 percent in an area with a 0.2 percent AEP flood. The overall estimated replacement value of these buildings is estimated to be just under $15 billion. Data from the First Street Foundation projecting floodplain extents in 2052, included in the SHIRA Project's tools, indicates that roughly an additional 300 buildings will be within areas with an AEP of at least 0.2 percent by mid-century.

Following the release of the CAP and the addition of new climate-related capabilities to the SHIRA Project, Department staff have started to socialize these exposure assessment approaches with internal stakeholders. Monitoring changes in Interior building and infrastructure damage reports going forward will help refining accounting for the costs of these hazards in the future.

Interior has identified three primary types of decision makers using climate-related hazards risk information: (1) Asset managers, (2) Unit and Human Resource managers, and (3) Senior Leadership. The SHIRA Project identified the following potential use cases for the Department:

- Hazardous materials management
- Climate adaptation
- Emergency management
- Visitor protection
- Staff protection
- Cultural resources protection
- Interpretation and Outreach
- Conservation management
- Facilities and Infrastructure
- Natural resource extraction
- Enterprise risk management
- Physical Security
- Policy Analysis
- Planning

The users and use cases are crosswalked to help identify the relevant climate-related applications using the new/improved information. The users identify the expected categories of benefits from the new/improved information in the climate-related application, if possible. Benefits can include new improvements and enhancements (e.g., improvements to a baseline condition), which can affect non-quantified advancements in mission and goals (e.g., enhancing staff and visitor experience; advancing sustainability, environmental justice); avoided losses/cost avoidance/operational efficiency (e.g., savings achieved through targeted investments to prevent a loss); cost savings (e.g., increasing the efficiency of decision-making by right-sizing investments); and reduced opportunity/implicit costs (e.g., budgeting more accurately to help limit real-time funding cuts with potentially costly tradeoffs).

**Framework for a VOI Case Study on Climate-Related Financial Risk to Interior's Buildings and Operations**

The Department evaluated the information product inventory for the SHIRA Project (see Table 12) to determine the viability of a scenario for development of a VOI case study. This included consideration of the interactions between various hazards and users/applications. While the exposure of Departmental assets and operations to climate hazards increases financial risk to the Department, the nature of these risks varies by hazard. For example, sea level rise presents risks of total loss to facilities due to inundation, but also stochastic risks due to changing exposure to storm surges, tidal flooding, and saltwater intrusion. Extreme heat does not present the risk of total loss of a building but does affect the operations that rely on the structure (e.g., visitor services, education, office work), and negatively affects Interior personnel working outside.

TABLE 12: SHIRA PROJECT INFORMATION PRODUCT INVENTORY: IDENTIFYING THE USERS, USES, AND EXPECTED BENEFITS OFR CLIMATE HAZARD INFORMATION IN THE DEPARTMENT

| Developer | User | Climate-Related Application | Benefit |
|---|---|---|---|
| Office of Emergency Management (OEM) and the U.S. Geological Survey (USGS) | Asset managers (Incorporate hazards in plans or projects (e.g., mitigation, capital investments, land use, economic development)) | Facilities management:<br>• Building/Infrastructure siting<br>• Building/Infrastructure modernization<br>• Infrastructure lifecycle investments-recapitalization vs. divestiture<br>• Incorporation of nature-based solutions | • More resilient capital investments (ensure mission delivery and support; avoided loss of investment)<br>• Targeted mitigation in design (avoid over/under design)<br>• Better recognize course of action decisions (minimize sunk costs/ commitment bias). Recognize opportunities for managed retreat (cost savings). |
| | | Budget planning | • Address expected increases in utilities (lower opportunity costs)<br>• Incorporate incremental costs of climate hazard mitigation measures into project cost estimates (lower opportunity costs) |
| | Unit managers, Human Resource managers (Integrate multi-hazard plans into existing comprehensive conservation/management plans to protect employees and visitors, as well as to minimize future damage to or loss of natural, economic, capital and cultural resources) | Procedural changes to operations and services (including visitor and staff protection) | • Targeted changes to procedures for cooling (cost savings; avoided health care costs, loss of life; fulfill mission through enhanced visitor and staff experience)<br>• Improved hazardous materials management (avoided cleanup costs, health care costs, loss of life)<br>• Reduced threat of disease outbreaks (avoided health care costs, loss of life) |

| Developer | User | Climate-Related Application | Benefit |
|---|---|---|---|
| | | Conservation management | • Reduced threat of invasive species (avoided loss)<br>• Reduced threat of wildlife disease outbreaks (avoided loss)<br>• Climate-optimized conservation and restoration of natural resources (creation, enhancement, protection; enhancement, cost savings, avoided loss)<br>• Improved restoration and reduced loss of irreplaceable cultural resources (avoided loss of collections and/or cultural sites and resources) |
| | Senior Leadership (Develop policies and guidance to reduce hazard impacts across the Department) | Policies and guidance on cross-cutting programs | • Wildfire risk management (cost savings, avoided loss, lower opportunity costs)<br>• Invasive species management (cost savings, avoided loss, lower opportunity costs)<br>• Water quality and quantity management (avoided losses, lower opportunity costs due to drought) |

FIGURE 21: PROCESS TO DEVELOP VOI FRAMEWORK


Consideration was also given to the types of applications in the information product inventory that could be informed by SHIRA tools. For example, Interior staff noted difficulty in assessing operations and maintenance (O&M) impacts due to variability in material and energy costs over time, consumption, and technological changes. Gathering O&M costs with a reasonable degree of confidence for such an analysis would prove a challenge across Interior's bureaus. The relatively small size and remote nature of individual facilities within the Department's portfolio, combined with extremely limited site staffing capacity, continues to challenge O&M capture at the asset level, thus making O&M forecasting unreliable at the time of writing. Other discussions included how some data are difficult to map using SHIRA tools due to the destructive but ephemeral nature of some hazards (e.g., harmful algal blooms), the lack of nationally consistent data (e.g., power grid failures), or the time-sensitivity of the data (e.g., susceptibility to disease of wildlife populations) (Wood et al., 2019). Staff also noted that some current hazards, such as landslides, may be exacerbated or altered by climate change (e.g., through changing frequencies of heavy precipitation events) but national-scale research to identify where and how changes were likely to occur under different scenarios has not yet been conducted. These issues limit Interior's ability to do further analyses for certain applications in the SHIRA Project product inventory.

Interior determined a case study could likely be developed for climate-related financial risk to Interior's real property assets and operations, especially for buildings (see footnote 25). Given the complexities mentioned above, the Department chose a narrow focus on climate-related risk to siting Interior's larger owned and managed buildings to start.

Because Interior is still preparing to use SHIRA to inform large investments like siting of buildings, a stylized scenario is presented here. That is, the hypothetical details of this case study are based on realistic information to help pilot VOI analysis. To streamline the approach, the decision point is a choice between two locations for a replacement visitor center that are within the same area (i.e., labor and materials costs, utility rates, etc., are constant). A single building design and operations plan is assumed for both locations. The baseline construction cost for this building is estimated at approximately $25 million, which is above the threshold that triggers a Departmental review of an Interior Bureau construction project (i.e., a "large" investment necessitating a higher level of assessment).[27]

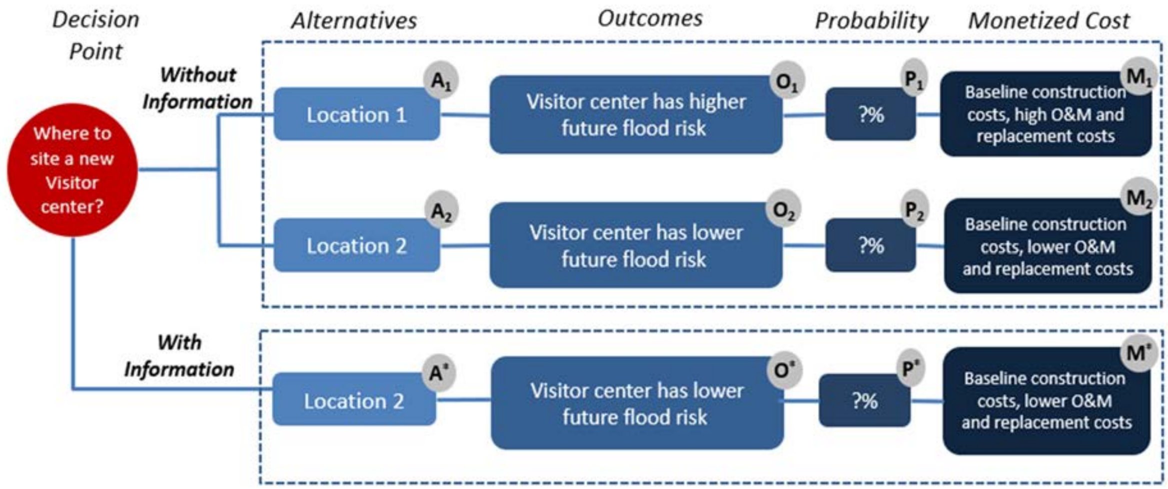
The Federal Flood Risk Management Standard directs Federal agencies to not build in the floodplain unless there is no other alternative (E.O. 13690; 520 DM 2). One of the SHIRA tools available to Interior staff—the Risk Mapper—enables asset managers to evaluate potential facility locations for the hazards identified in Figure 20, including riverine flooding. While Location 1 is not in the 500-year floodplain at the moment, the new information in SHIRA shows it may be in the 500-year floodplain in the year 2053. At Location 2, SHIRA confirms the higher elevation is consistently outside of the 500-year floodplain under different climate change scenarios.

The framework depicts a highly simplified hypothetical VOI case study on climate-related financial risk to the siting of a hypothetical visitor center (see Figure 22). The goal is to help familiarize decision makers with the process of VOI assessment to allow for more realistic, robust analysis in the future. Alternatives (A) and expected outcomes (O) are identified for decision pathways with and without the new SHIRA information, with the assumption that pathway has an associated probability of selection (P) and suite of expected costs (M). The "without" information decision scenario is expected to include additional pathways as the absence of information removes restrictions on the decision space for planners.

A template is developed to help guide initial thinking about baseline costs and the relative financial effects of climate-related hazards when siting a building (see Table 13). Decisions on actual locations would likely have a complex mix of effects on the baseline estimate, including higher costs (+), lower costs (–), no effects (N = baseline), and unknown/uncertain effects (?), which could affect the universe of alternatives and outcomes. For the purpose of this simplified case study, both Location 1 and Location 2 have baseline construction and management costs, but SHIRA information identifies a higher risk of inundation (i.e., higher potential losses, O&M costs) for Location 1, leading to a projected increase in certain costs.

[27] Department policy requires that all projects are reviewed by Bureau Investment Review Boards for compliance with Interior's Lifecycle Investment Planning Guidance; projects over $20 million are also reviewed for compliance by the Department.

FIGURE 22: FRAMEWORK FOR THE VOI OF SHIRA PROJECT INFORMATION IN SITING A NEW INTERIOR VISITOR CENTER




Adapted from Pearlman et al., 2019

TABLE 13: PRELIMINARY ASSESSMENT OF CLIMATE-RELATED FINANCIAL EFFECTS FOR TWO HYPOTHETICAL LOCATIONS TO SITE A NEW INTERIOR VISITOR CENTER

| **Categories Affecting Baseline* Estimate of Construction and Operating Costs** | **Relative Effects on Baseline Cost (+ = higher; – = lower; N= no effect (baseline); ? = unknown/uncertain)** | |
|---|---|---|
| | **Location 1** | **Location 2** |
| Connectivity to other Interior-owned and managed facilities | N | N |
| Access to existing utilities | N | N |
| Quality of travel routes | N | N |
| Effects of SHIRA Flood Risk-Related Projections | | |
| • Operations & Maintenance | + | N |
| • Need for future mitigation | + | N |
| • Effects on staff and visitors | + | N |
| • Effects on facilities, including natural resource and cultural collections | + | N |
| Modification of original building design | + | N |

* The starting building design and operations plans under consideration are the same for both locations, i.e., baseline cost estimates.

In this hypothetical example, the monetized costs are assumed to be the same except for the long-term costs incurred by siting the visitor center in a future floodplain at Location 1. This may not be the case in a real-world decision, and modifications to the baseline could affect both locations, including benefit-cost effects from:

1. Known costs savings or increased costs due to connectivity to other Interior-owned and managed facilities.
2. Access to existing utilities (power, water, sewage, telephone/internet), or costs associated with new connections. For example, if investment in new water infrastructure is needed, additional assessment may be required to determine whether the financial threshold is triggered for application of the Principles, Requirements, and Guidelines, for Water and Land Related Resources Implementation Studies (PR&G; 707 DM 1).
3. Quality of travel routes for visitors, which could involve construction of roads, sidewalks, parking lots and/or alternative transportation.
4. Effects on staff and visitors, e.g., cost savings or increased costs associated with time/convenience, and safety management.
5. Potential changes to the building design, e.g., structural changes to justify siting.
6. Other impacts on mission delivery, e.g., for sustainability goals (expected building lifespans, etc.), or for natural and cultural resource protection (risks to natural and cultural resources).

**Next Steps**

To complete the pilot VOI framework, Interior's next steps involve identifying the probabilities of each outcome and monetizing the expected costs for the highly simplified approach. When probabilities and expected costs have been identified, the VOI can be calculated as the difference between the expected monetized costs in the "with" information decision scenario and the expected monetized costs in the "without" information decision scenario. The inclusion of new information allows for an explicit comparison of costs and identification of an optimal decision. Once the Department has completed this initial pilot, additional consideration will be made about assessing a more realistic scenario encountered by Interior's decision makers. A robust framework, refined through case studies, is expected to help the Department quantify the economic value of continued investments in information to help reduce the climate-related financial risk to real property assets and operations.

### (2) U.S. Department of Transportation: Managing Climate Change and Financial Risk to the Transportation System

**Introduction**

The National Transportation System (NTS) serves to move passengers and freight throughout the nation and provides connectivity to global transportation systems. Extreme weather events and climate change impacts can directly damage transportation infrastructure, requiring costly repairs and disrupting essential movement of goods and passengers (U.S. Department of Transportation, 2023). Extreme weather events—including heat waves, wildfires, tropical storms, high winds, storm surges, and heavy downpours—are becoming more frequent and severe as the climate changes. In 2023, there were 28 weather and climate disasters costing at least $1 billion with a total price tag of at least $92.9 billion (Smith, 2023).

The impacts on the NTS from exposure to climate hazards include damage to airport runways, roadways, bridges, railways, ports, and pipelines from riverine and coastal flooding, extreme heat and thawing permafrost, soil subsidence, and landslides. The United States Department of Transportation's (U.S. DOT or DOT) operational assets such as office buildings, data centers, research facilities, ship and vehicle fleets, safety test tracks, air traffic control facilities and equipment, and communication assets are also impacted by exposure to climate hazards.

The U.S. DOT is actively working to reduce the impacts of climate hazards on transportation infrastructure by incorporating climate risk and resilience into its decision-making processes. DOT has released several frameworks and tools that can help organizations conduct local or regional climate hazard exposure and vulnerability assessments of transportation assets. These tools can be customized to address specific climate hazards, identify which assets should be protected, and determine solutions to enhance climate resilience.

DOT has also prioritized building climate resilience for Federally owned facilities, assets, and operations. To support these priorities, DOT has developed new decision support tools that provide system-wide climate exposure information to assess the vulnerability of assets or facilities using consistent methods. Facility managers utilize this multi-hazard exposure information to rate asset vulnerability and criticality which can then be combined into system-level summaries. This approach provides regional and national managers with information to prioritize actions across distributed assets and facilities.

This section summarizes select DOT frameworks and tools that support resilience assessments for transportation assets. It also includes detailed descriptions of the system-wide climate hazard exposure tools, a summary of projected climate-related financial impacts on the transportation system, and DOT investments for resilience improvements. Building on the strong foundation of resilience tools, DOT plans to extend the system-wide hazard exposure methods and quantify the financial risk climate change poses to select portions of the nation's transportation system.

**DOT Tools for Resilience Assessments**

The DOT frameworks and tools for resilience assessments are based on established best practices that combine the exposure of assets to climate hazards with their sensitivity and adaptive capacity to determine asset vulnerability. Measures of asset vulnerability and criticality can support risk ratings and tactical interventions to avoid future losses in functionality. These approaches are consistent with other Federal tools developed by the U.S. Geological Survey (USGS), the Department of Defense (DOD), and the U.S. Department of Housing and Urban Development (HUD). DOT has created climate resilience resources and tools that provide decision support for various transportation infrastructure and operational system applications (Table 14).

**DOT System-Wide Climate Hazard Exposure and Resilience Assessments**

The DOT system-wide decision support tools integrate Federal climate data resources to provide consistent hazard exposure information for facilities and other operational assets with verified locations. This section describes additional tools and methodologies developed by DOT to assess climate impacts and build resilience across the nation's transportation infrastructure, emphasizing their practical application in real-world scenarios.

TABLE 14: EXAMPLES OF DOT TOOLS AND FRAMEWORKS FOR ASSESSING VULNERABILITY AND INFORMING RESILIENCE IMPROVEMENT DECISIONS

| Tool | Application |
|---|---|
| Resilience and Disaster Recovery (RDR) Tool Suite (U.S. DOT Volpe National Transportation Systems Center, 2024 and Office of the Assistant Secretary for Research and Technology) | Supports Federal, state, and local governments in selecting and prioritizing infrastructure construction and roadway improvement projects by assessing the return on investment (ROI) for resilience specific to various assets. The tool suite includes components for assessing disruption due to hazard exposure, calculating net benefits of resilience investments across future scenarios, and evaluating changes in travel performance metrics due to resilience investments. RDR is a multi-modal model that encompasses freight and passenger travel on roads and transit systems, allowing agencies to incorporate the cost and benefits of resilience into the transportation planning decision-making process to make informed decisions on future infrastructure investments. |
| Vulnerability Assessment and Adaptation Framework (FHWA, 2017a) | Enables transportation agencies to assess their infrastructure's vulnerability to extreme weather and climate impacts. The framework provides an in-depth and structured process for conducting a vulnerability assessment including: defining the study scope, obtaining asset and climate data, assessing vulnerability, identifying and prioritizing adaptation strategies, and utilizing assessments to inform asset planning as well as operations and maintenance. |
| Vulnerability Assessment Scoring Tool (VAST) (FHWA, 2017b) | An Excel-based resource that assists transportation agencies with conducting an indicator-based vulnerability assessment of their transportation assets. VAST is designed to address asset types including rail, airports and heliports, oil and gas pipelines, bridges, roads and highways. Users can leverage this tool to conduct context-specific vulnerability assessments, selecting appropriate climate stressors, indicators, and data sources to formulate asset vulnerability scores. Once the assessment process is complete, transportation agencies can use these vulnerability scores to prioritize projects and effectively allocate resources. |
| Transit Resilience Guidebook (FTA) | A guidebook to aid local government officials, Metropolitan Planning Organizations (MPOs), and other entities with resilience planning, funding, operating, or coordinating with transit agencies. It includes recommendations and examples of how to identify and address climate vulnerabilities and risks and how to build resilience into transit assets throughout their life-cycle process. The Guidebook presents a resilience planning framework overlaid onto agency processes using six resilience phases: "Assess," "Plan," "Design and Construct," "Manage," "Maintain," and "Monitor" (Filosa et al., 2024). |

Note: These tools all include guidance on accessing climate hazard exposure data.

### *Climate Hazard Exposure and Risk (CHER) Tool*

The U.S. DOT Volpe Center, in collaboration with the Office of the Assistant Secretary for Administration, developed the Climate Hazard Exposure and Risk (CHER) tool for internal assessments of Federal buildings' operational resilience (U.S. Department of Transportation, 2024a). The CHER tool applies a risk-based framework that combines facility manager ratings of the vulnerability of critical systems to each climate hazard (based on sensitivity and adaptive capacity) with exposure metrics to score each mission-critical asset. The risk assessments in turn inform high-priority resilience strategies for project planning and development.

The CHER tool sources historical climate hazard information from the Federal Emergency Management Agency (FEMA) National Risk Index (NRI) (FEMA, 2024) and includes annualized occurrence frequencies of fourteen climate-related hazards: coastal flooding, cold wave, drought, hail, heat wave, hurricane, ice storm, landslide, lightning, riverine flooding, strong wind, tornado, wildfire, and winter weather. An additional eight climate hazards are derived from data in the World Climate Research Program's (WCRP) phase 5 Coupled Model Intercomparison Project (CMIP5) (WCRP, 2024). The CHER tool uses climate projection data for Representative Concentration Pathway (RCP) 8.5[28] centered on the year 2050 (WorldClim, 2024) and considers temperatures in the hottest and coldest months, and precipitation in the wettest and driest months. Finally, the tool includes estimates of inundation due to sea level rise (SLR) on top of mean higher high water (MHHW) from the National Oceanic and Atmospheric Administration (NOAA, 2017).

DOT used the CHER tool to support system-wide analysis of climate exposure for DOT operational assets, including 1,411 DOT facilities flagged as mission-critical. The analysis determined that 1,049 DOT facilities are projected to have more than a five-degree Fahrenheit increase in the maximum temperature by 2050. More than 83 facilities are projected to experience an increase of 1 inch or more in maximum precipitation, while 288 facilities are expected to experience a decrease in maximum precipitation by 2050. A comprehensive dashboard provides insight into climate hazard exposure across mission-critical facilities. When combined with the multi-hazard vulnerability assessments that facility managers are completing, the information will help DOT prioritize resilience investments.

#### *Climate Hazard Exposure of the National Plan of Integrated Airport Systems (NPIAS)*

Natural and climate hazards, such as the unprecedented and disruptive wildfires in the western U.S. and intense rainfall events in the eastern U.S., threaten airport operations in numerous ways (FAA, 2021; EPA, 2023b; U.S. Department of Transportation, 2024b). Some coastal airport regions are experiencing chronic "sunny day," or tidal flooding. Rising sea levels threaten the viability of coastal airports from the continental U.S. to Micronesia (Yesudian & Dawson, 2021). Permafrost collapse in Alaska has led to an airport relocation (Alaska Department of Transportation, 2021).

In response to these threats, the Federal Aviation Administration (FAA) is taking action to bolster adaptation and increase the resilience of airport facilities and the National Airspace System (NAS) to protect continuity of operations, performance, and infrastructure investments (FAA, 2021). The U.S. DOT Volpe Center is collaborating with FAA to develop an Airport Resilience Assessment Framework (ARAF) to better incorporate resilience analysis and prioritization into airport project planning and funding processes. The ARAF provides location-specific exposure information that has been specifically tailored for evaluating potential climate impacts to critical airside infrastructure at airports; other elements of the framework provide a common approach to conducting vulnerability and resilience assessments of the infrastructure elements, as well as offering examples of solutions to reduce specific climate impacts. This information can support master planning and project development activities along with applications for Federal, state, and local funding of projects that improve resilience.

[28] Climate projections under RCP 4.5 are not included as there are minimal differences from RCP 8.5 through 2050.

Exposure to many different climate hazards can pose a risk to airports, and analysis of the probability of current and future hazards is a necessary component of a resilience assessment. FAA is developing a climate exposure dashboard tool as part of the ARAF to complete a system-wide analysis of the 3,287 existing, public-use airports published as the 2023-2027 NPIAS. The team evaluated location-specific NPIAS airport exposure to several priority climate hazards relevant to airport operations at present and in the year 2050 (where available, under two emissions scenarios). The analysis draws from a wide array of national, authoritative datasets, including those published by the EPA, FEMA, NOAA, the Department of Agriculture (USDA), and the U.S. Geological Survey (USGS)[29].

To facilitate comparison across the NPIAS, the ARAF tools will provide standardized, directly comparable, and actionable estimates of hazard and climate change exposure for all NPIAS airports. The ARAF addresses seven priority hazard categories: coastal flooding, riverine flooding, precipitation and storms, high temperatures, wind, wildfires, and land stability. Multiple indicators of historic, current and/or projected exposure inform each hazard category. Some indicators of high temperature are the average maximum daily temperature of the hottest month, the number of days above 95 degrees, the number of days above 105 degrees, and the number of days above the threshold of the historical 99$^{th}$ percentile.

Rising temperatures can pose numerous challenges for airports, especially in regions, like the Southwest, with historically high temperatures that will likely continue to experience rising yearly average temperatures.

For each climate indicator, the analysis will classify each airport's exposure level on a 5-point scale from very low to very high. Expert knowledge and analysis of historical data informed the exposure level thresholds, which also align with existing FAA and design standards wherever possible. Table 15 summarizes the number of NPIAS airports expected to experience select climate hazard thresholds.

Individual airports will be able to prioritize attention to climate hazards showing high or very high exposure at their location. While some airports are more exposed to some hazards than others, airports need to consider their multi-hazard risk landscape to adequately safeguard passengers, personnel, and facilities against the potential impacts of climate change. Airport operators will be able to utilize the climate exposure information provided by the ARAF tools to inform their own vulnerability assessments and obtain a comprehensive understanding of where and how to plan the most impactful hazard mitigation investments.

At the regional and system level, FAA will be able to screen across the NPIAS to identify airports, airport types, and regions that have the highest climate exposures and that could especially benefit from evaluation, planning, and investment towards climate resilience. For example, the Northwest Mountain Region was noted as a historically high-exposure region for wildfires, winter weather, and coastal flooding. Taken together, the exposure information and the airport resilience

[29] Federal data sets included in the analysis include FEMA NRI variables, LOCA, BIOCLIM, FEMA flood hazard zones, and NOAA sea level rise.

assessments of the ARAF form a baseline that FAA can use to identify high-priority resilience needs at all airports in the NPIAS.

TABLE 15: NUMBER OF NPIAS AIRPORTS WITH HIGH OR VERY HIGH EXPOSURE TO SELECT CLIMATE HAZARDS BY 2050 UNDER RCP 4.5 AND RCP 8.5

| | | | **Number of NPIAS Airports** | | |
|---|---|---|---|---|---|
| **Climate Hazard** | **Data Source** | **Threshold** | **Historic** | **2050, RCP 4.5** | **2050, RCP 8.5** |
| Mean Max Temp of the Hottest Month | WorldClim | **Temp > 105°F** | 31 | 45 | 49 |
| Mean Max Temp of the Hottest Month | WorldClim | Temp > 100°F | 17 | 220 | 349 |
| Days Above 105F | LOCA | **> 10 days/year** | 52 | 399 | 511 |
| Days Above 105F | LOCA | >7 days/year | 13 | 151 | 182 |
| Annual Hurricanes | FEMA NRI | **>1 per 2 years** | 26 | na | na |
| Annual Hurricanes | FEMA NRI | >3 per 10 years | 63 | na | na |
| Change in Rainfall of the Wettest Month | WorldClim | **>2-inch increase** | na | 9 | 13 |
| Change in Rainfall of the Wettest Month | WorldClim | >1.5-inch increase | na | 9 | 14 |

Note: Very high exposure is indicated in **bold**; high (which excludes very high) exposure otherwise.

### Climate-Related Transportation System Costs

The resilience frameworks and tools developed by DOT, combined with Federal climate hazard exposure information, provide the necessary foundation and resources to support an analysis of climate-related financial impacts for select transportation modes. Records of past climate-related financial impacts on the transportation system, including direct damages and loss of operations, provide a basis for projected costs under changing climate conditions (Table 16).

TABLE 16: CLIMATE-RELATED FINANCIAL DAMAGES TO THE TRANSPORTATION SYSTEM

| Mode/Coverage | Year | Events | Scope (Direct damage, losses from operations) | Cost Impacts ($, year) | Source |
|---|---|---|---|---|---|
| Infrastructure | 2020 | Hurricane Laura | Economic losses, direct damages | 13 billion (2020$) | NASEM, 2021a |
| U.S. ports | 2018 | Hurricane Florence | Direct damages | 46 million (2018$) | Van Houtven et al., 2022 |
| U.S. ports | 2005 | Hurricane Katrina | Direct damages | 2.2 billion (2005$) | Van Houtven et al., 2022 |
| U.S. export networks | 2019 | Mississippi River Flooding | Economic losses and delays | 1 billion (2019$) | Van Houtven et al., 2022 |
| U.S. airports | 2015 | Power Outages | Economic losses | 150 billion (2015$) | NASEM, 2021a |

Several studies have estimated the future costs of changes in climate conditions and increased severity of recent climate-related natural disasters on the U.S. transportation system (Table 17).

The benefits from resilience investments may or may not be realized in the immediate or midterm future (NASEM, 2021b). However, investment in climate resilience has been shown to reduce the costs of repairing damaged infrastructure and to avoid financial impacts of loss of operational capacity (National Institute of Building Sciences, 2019). Funded by HUD, FEMA, and others, the National Institute of Building Science (NIBS) estimated a 6:1 benefit-to-cost ratio when building projects adopt code requirements to elevate structures one foot above the base flood elevation (National Institute of Building Sciences, 2019).

TABLE 17: CLIMATE-RELATED FINANCIAL DAMAGES PROJECTED FOR CLIMATE CHANGE IMPACTS ON THE TRANSPORTATION SYSTEM

| Mode/Coverage | Projected Timeframe | IPCC RCP | Scope (Direct damage, losses from operations) | Cost Impacts[30] ($year) | Source |
|---|---|---|---|---|---|
| U.S. paved roads | 2090 | 8.5 | Direct damages from temperature and precipitation | 20 billion per year (2015$) | Gomez, 2022 |
| U.S. paved roads | 2100 | 4.5 and 8.5 | Direct damages from temperature, precipitation, and freeze-thaw cycles | 230 billion (2015$) | NASEM, 2021b |
| U.S. railroad | 2100 | 4.5 | Delays, loss of operations | 40 billion (2015$) | EPA, 2017 |
| U.S. railroad | 2100 | 8.5 | Delays, loss of operations | 50 billion (2015$) | EPA, 2017 |
| Contiguous U.S. pavement | 2040 | 4.5 | Direct costs | 19 billion (2017$) | Underwood et al., 2017 |
| Contiguous U.S. pavement | 2100 | 4.5 | Direct costs | 21.8 billion (2017$) | Underwood et al., 2017 |
| Shipping industry | 2100 | 4.5 | Direct damages and disruptions | 25 billion per year (2022$) | Van Houtven et al., 2022 |
| U.S. bridges | 2050 | 4.5 | Maintenance and direct damages | 1.5 billion per year (2015$) | |
| U.S. bridges | 2090 | 4.5 | Maintenance and direct damages | 510 million per year (2015$) | EPA, 2017 |
| U.S. bridges | 2050 | 8.5 | Maintenance and direct damages | 1.7 billion (2015$) | EPA, 2017 |
| U.S. bridges | 2090 | 8.5 | Maintenance and direct damages | 1 billion (2015$) | EPA, 2017 |
| Alaska infrastructure | 2100 | 4.5 | Adaptation costs | 3.7 billion (2015$) | EPA, 2017 |
| Alaska infrastructure | 2100 | 8.5 | Adaptation costs | 4.5 billion (2015$) | EPA, 2017 |

A 2021 study of climate change impacts to railroads, roads, and coastal property considered the effects of a "no adaptation" approach to infrastructure management and quantified costs in scenarios where adaptive measures are taken in response to climate change impacts ("reactive" adaptation) and in advance of impacts ("proactive" adaptation). The study estimated that by 2050 under a medium greenhouse gas emission scenario (RCP 4.5), costs for roads are over 6 times higher without adaptation compared to reactive adaptation, and over 12 times higher than proactive adaptation (Neumann et al., 2021). For rail, there is a small reduction in cost for reactive adaptation strategies, but a nearly 15-fold decrease in costs for proactive adaptation (Table 18).

[30] Cost Impacts are cumulative from the study year through the projected timeframe, or per year by the projected time frame where indicated as "per year", in the dollar-years provided by the study authors.

Direct costs to infrastructure associated with climate change and selected indirect costs to users, such as delay and vehicle operating costs, were also considered. The findings emphasize the potential for remarkable cost savings through proactive investment in adaptation.

TABLE 18: AVERAGE ANNUAL CHANGE IN COSTS RELATIVE TO THE BASELINE, 1986-2005 (5-GCM AVERAGE, BILLIONS OF 2018 DOLLARS, UNDISCOUNTED).

| Infrastructure Sector and Scenario | 2050 | |
|---|---|---|
| | RCP 8.5 | RCP 4.5 |
| Roads | | |
| No Adaptation | $158.6 | $100.4 |
| Reactive Adaptation | $19.0 | $13.1 |
| Proactive Adaptation | $9.0 | $8.3 |
| Rail | | |
| No Adaptation | $11.3 | $5.8 |
| Reactive Adaptation | $10.2 | $5.4 |
| Proactive Adaptation | $0.9 | $0.4 |

Note: Only the costs of climate change above those incurred for historic climate are included (Neumann et al., 2021).

**DOT Investments for Resilience Improvements**

DOT is investing in resilience improvements to agency assets and the U.S. transportation system through capital improvements to DOT infrastructure, technical assistance for state, MPO, local, and tribal communities, Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program formula funding and discretionary grant awards, and emergency relief funding. The projected damages to transportation systems (Table 17) far exceed the magnitude of funding that has been appropriated for DOT resilience grant programs or for emergency funding programs. DOT is working to maximize the ROI of Federal investments by developing tools such as benefit-cost analysis (BCA) requirements and guidance for the PROTECT program and the RDR tool suite. More broadly, DOT has incorporated climate resilience considerations into criteria for discretionary grant funding across the Department, as appropriate and consistent with statute.

*FHWA: PROTECT Program*

DOT launched the Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program with a total of $9.1 billion available as formula funding ($7.3 billion) and discretionary grants ($1.8 billion) over five years. PROTECT is the first dedicated Federal transportation grant program to help make surface transportation more resilient through funding for planning activities, resilience improvements, community resilience, and evacuation routes. PROTECT requires that recipients measure the performance of resilience projects. This effort to define and develop resilience metrics will be leveraged to support a DOT-wide effort to document the measurable outcomes of resilience projects. By funding projects that improve resilience to natural hazards and climate change impacts, the PROTECT Discretionary Grant Program aims to reduce damage and disruption to the transportation system, improve the safety of the traveling public, and improve equity by addressing the needs of disadvantaged communities that are often the most vulnerable to hazards (FHWA, 2024a).

### *FTA: Climate Resilience and Adaptation Competitive Grants*

FTA's Bus Exportable Power Systems (BEPS) program enables public transportation agencies, communities, and states to access resilient and flexible power options through hybrid, electric and fuel cell bus fleet vehicles during major power disruptions. This program builds on BEPS technologies, developed under FTA's previous research grants, to develop national standards for bus-to-building battery power transfer. The BEPS integrated systems can ensure community energy assurance after natural disasters by transforming hybrid, electric and fuel cell buses into mobile power generators.

### *DOT Emergency Relief Funding*

DOT emergency relief funding from FTA and FHWA (implemented through different statutes and regulations) supports reactive adaptation strategies to improve the resilience of systems and assets after they have been damaged by natural disaster.

The FTA Emergency Relief (ER) program provides assistance to public transit operators in the aftermath of an emergency or major disaster (FTA, 2024). This aid pays for protecting, repairing, and replacing equipment and facilities that may suffer or have suffered serious damage as a result of an emergency, including natural disasters such as floods, hurricanes, and tornadoes. FTA encourages recipients to include cost-effective resilience features in repair and rebuilding projects. When provided with funding to do so, FTA may also fund stand-alone resilience projects to help prevent future damage and public transportation service disruptions. The program can also fund the operating costs of evacuation, rescue operations, temporary public transportation service, or reestablishing, expanding, or relocating service before, during or after an emergency. FTA provided over $102.3 million in ER funding in FY 2023 to 17 transit agencies, cities, and planning councils in eight states and territories and nearly $110 million to eight transit agencies and state DOTs in six states and one territory in FY 2024.

The FHWA Emergency Relief (ER) program supports the repair and reconstruction of Federal-Aid Highways and Federally Owned Roads that are severely damaged over a wide area by a natural disaster or catastrophic failure from an external cause. The Bipartisan Infrastructure Law (BIL) emphasized ER eligibilities to include wildfires and economically-justifiable improvements that will mitigate the risk of recurring damage or the cost of future repair from extreme weather, flooding, and other natural disasters (Kalla & Shepherd, 2019).[31] Protective features include: raising roadway grades, relocating roadways in a floodplain to higher ground above projected flood elevation levels or away from slide-prone areas, stabilizing slide areas, stabilizing slopes, lengthening or raising bridges to increase waterway openings, increasing the size or number of drainage structures, upsizing culverts or replacing culverts with bridges, installing seismic retrofits on bridges, adding scour protection at bridges, installing riprap, or adding other scour, stream stability, coastal or other hydraulic countermeasures, including spur dikes, and the use of natural infrastructure.

The BIL required FHWA to develop best practices for State Departments of Transportation for improving the use of resilience in the ER program and other emergency relief, released in 2024

[31] Per 23 U.S.C. 125(d)(2)(A)(ii); eligibility for wildfires was added to language in 23 U.S.C. 125(a)(1k).

(FHWA, 2024b). The resilience betterments are anticipated to decrease costs to the ER program over time by reducing future damages from similar events (FHWA, 2024b). FHWA allocated over $1 billion in ER funds in FY 2024 for the repair or reconstruction of Federal-aid highways and Federally owned roadways damaged by natural disasters or catastrophic failures. The ER program allocates funding by emergency event to each ER applicant, and ER allocation records can provide historic cost information that can inform projected climate-related financial impacts on the highway system including increased expenditures under the ER program.

**Knowledge Sharing and Capacity Building**

DOT is working to leverage the system-wide, transportation-focused climate exposure data processing methodology developed for specific projects to provide resources and tools across the organization. The U.S. DOT Climate Change Center is the focal point for policy and action on climate change within the Department. The regular meetings include technical climate and resilience presentations, discussion of how climate resilience or mitigation can be incorporated into DOT activities, and coordination between DOT Operating Administrations on policy updates, climate challenges, and other priority activities.

The Transportation Vulnerability and Resilience Data Program (TVRDP) is a new Bureau of Transportation Statistics (BTS) initiative to fill data gaps and provide access to data, statistics, analyses, and tools needed to measure the vulnerability of transportation systems to the direct and indirect disruptions caused by natural, manufactured, and cyber events. Evaluation of the ability of the national transportation system to recover from those disruptions will support DOT efforts to meet local decision-maker needs for community resilience to extreme weather required by the BIL. BTS will prepare a climate data services and metrics web hub (platform) by 2025 and produce a state of practice report.

For DOT grant applicants, a checklist is available on DOT Navigator to help develop strong Climate Change Mitigation, Adaptation and Resilience Grant components. Through these efforts, the Department is building a transportation system that is resilient to the impacts of climate change while advancing climate and environmental justice.

**Next Steps: Financial Risk of Climate Change to Transportation Systems**

The DOT resilience assessment frameworks and decision support tools will provide the foundation for an assessment of climate financial risk exposure to the U.S. transportation system and DOT operational assets. DOT plans to establish an interdisciplinary team of resilience experts from department modal administrations. Building on FHWA resilience tools, FTA research, and the BTS TVAR activities, the team will extend the climate hazard exposure analysis approach used for ARAF, RDR, and other tools. Using a combination of literature review, internal DOT data, and damage functions developed for the RDR tool suite, the team will develop a case study to estimate climate-related financial impacts for select transportation modes (e.g., airports, highways, transit, rail, waterways, or pipelines). The analysis will include the costs of direct repairs due to climate change impacts and costs due to operational losses. For the NPIAS airports, the team will use the completed climate exposure analysis and consider financial impacts for different scenarios such as the impacts of heat or sea level rise on the lifespan of runways and other airport assets, and airport relocation requirements.

**Summary**

Communities across the country are facing increasingly extreme and sometimes deadly weather events that destroy homes and livelihoods, along with transportation and other critical infrastructure. Recovery costs are only projected to increase as extreme temperatures and precipitation, SLR, inland water level rise or fall, and storm surge increasingly impact all modes of transportation infrastructure (Jay et al., 2023). DOT is building on a long history of considering climate hazard impacts on the NTS with new programs, technical resources, and decision support tools to ensure that Federal transportation investments incorporate evidence-based measures to improve resilience and manage climate-related financial risk. The tools and resources will also support ongoing DOT assessments of climate-related financial risks to the transportation system and provide information to reduce risk exposure.

# IV. Federal Agency Climate Adaptation Planning and Implementation

Section 211 of Executive Order 14008, “Climate Action Plans and Data and Information Products to Improve Adaptation and Increase Resilience”, directs each Federal agency to submit a draft action plan “that describes steps the agency can take with regard to its facilities and operations to bolster adaptation and increase resilience to the impacts of climate change”. These plans are meant to, among other things, describe the Agency’s climate vulnerabilities and plan to use the power of procurement to increase the energy and water efficiency of United States Government installations, buildings, and facilities and ensure they are climate-ready. Effective adaptation efforts will strengthen national preparedness.

Federal fiscal exposure to climate change can be limited by enhancing climate resilience—that is, taking actions to reduce potential future losses by planning and preparing for potential climate hazards (GAO, 2024). Identifying the most significant climate-related risks and vulnerabilities to agency operations and missions, and identifying actions to manage those risks and vulnerabilities, is essential to inform decision-making around Federal investments and uninterrupted delivery of services to the public. Recent considerations of climate-related financial risk and climate adaptation together are seen in three key places:

1. Federal Climate Adaptation Plans;
2. Agency Financial Reports; and
3. Government Accountability Office (GAO) Reports.

**Federal Climate Adaptation Plans**

In June 2024, 24 Federal agencies released updated 2024-2027 Climate Adaptation Plans (CAPs). These most recent plans reflect a growing maturity across Federal agencies in climate adaptation planning and implementation, and demonstrate greater integration of climate risk into agency mission delivery, operations, and asset management (CEQ, 2024a). Agencies for the first time applied a data-driven approach to assessing the climate risks to their facilities and employees (CEQ, 2024b). Agencies were also asked to assess the climate risks to their missions, operations, and services, and develop actions to account for climate risk in their planning and decision-making, budget formulation, policies and programs, supply chains and procurement, and funding to external parties. The instructions for development of the CAPs explicitly linked to the objectives of OMB Memorandum M-24-03, including implementation of the Disaster Resiliency Planning Act (Public Law 117-221) and best practices for advancing climate-smart infrastructure. This guidance complements existing requirements for risk management and consideration of natural hazard and climate risk described in OMB Circular No. A-11, *Capital Programming Guide*. For the first time, agencies also provided evaluations of their implementation via a common set of indicators and metrics (CEQ, 2024c).

In the 2024-2027 CAPs, agencies were asked to describe assessments of their agency’s climate-related financial risk exposure and if, and how, these assessments are being used to inform budget formulation. Agencies were also asked to report on their technical capacities to assess risk to their programs, including through agency-wide enterprise risk management (ERM).

Table 19 identifies analyses of Federal climate-related financial risk published between 2021 and 2024 and their relevance to Federal agencies who have produced CAPs (OMB, 2022a; OMB, 2022b; OMB, 2023a; OMB, 2023b; OMB, 2024a; OMB, 2024b).

TABLE 19: ASSESSMENTS OF CLIMATE-RELATED FINANCIAL RISK RELEVANT TO AGENCIES WITH CLIMATE ADAPTATION PLANS

| Assessment Topic | Relevant CAP Agencies |
|---|---|
| General or cross-agency analyses | |
| Federal facilities | GSA, DOD, DOE, all |
| Federal healthcare spending | HHS, EPA, VA |
| Federal wildland fire suppression expenditures | USDA, DOI |
| Federally financed housing portfolio | HUD, VA, USDA |
| Coastal disaster response | Commerce, USACE, DHS |
| Program-specific analyses | |
| National Flood Insurance Program | DHS |
| Crop insurance | USDA |
| Livestock Forage Disaster Program | USDA |
| Low Income Home Energy Assistance Program | HHS |
| Multifamily and healthcare (“commercial”) loans | HUD |
| Superfund sites | EPA |

The majority of the agencies that prepared updated CAPs described ongoing efforts to integrate climate risk, including climate-related financial risk, into their budget formulation and related processes. While this section provides a high-level summary of common themes identified across agency CAPs, individual CAPs should be referred to for greater detail relevant to each agency’s unique authorities.

While some of the agencies highlighted the assessments included in Table 23, the CAPs do not demonstrate if and how agencies are using these analyses to directly inform program delivery or budget formulation. Rather, many agencies, including Department of Commerce, Department of Energy (DOE), Department of Labor, the General Services Administration (GSA), the National Aeronautics and Space Administration (NASA), the Tennessee Valley Authority (TVA), and the U.S. Department of Agriculture (USDA), describe how they are integrating consideration of climate-related risks into their enterprise risk management processes in accordance with OMB Circular No. A-123, *Management's Responsibility for Enterprise Risk Management and Internal Control*. For example,

> “[DOE does this] …by producing an agency Risk Profile as part of the implementation of an Enterprise Risk Management (ERM) capability coordinated with strategic planning, strategic review, and internal control processes. Climate change is included as a risk in the DOE Risk Profile, to ensure that climate risks are included in budget formulation.”

Similarly, USDA states:

> "Through the ERM process, Mission Areas, Agencies, and Staff Offices identify risks that may impede achievement of Agency objectives and Departmental strategic objectives. As part of the guidance, [the Office of Budget and Program Analysis] will direct Mission Areas/Agencies to explicitly consider the climate risk exposure assessments in their ERM risk assessment process. Then, during the budget planning and formulation process, Mission Areas, Agencies, and Staff Offices are required to identify their top enterprise risks and integrate discussion of these risks into their budget justifications."

Some agencies, like the Environmental Protection Agency (EPA) and NASA, draw direct lines between their agency's strategic plans and the budget formulation process. For example, EPA established three Long-Term Performance Goals associated with a climate adaptation and resilience objective of the EPA FY 2022-2026 Strategic Plan, the fulfillment of which are connected to annual budget formulation.

Other agencies, like the Department of Defense (DOD), the Department of Health and Human Services (HHS), and the Department of Justice (DOJ), have developed specific guidance to address climate adaptation and resilience priorities during budget formulation. Most clearly, DOD described specific investments to mitigate climate risks via subsets of annual budget requests in the FY 2023 report, *Meeting the Climate Challenge* (U.S. Department of Defense, 2022) and the FY 2024 report, *Enhancing Climate Capability – Mitigating Climate Risk* (U.S. Department of Defense, 2023b).

One challenge in understanding how agencies consider climate-related financial risk is that many of the CAPs focus primarily on climate risks to facilities and assets, rather than the entirety of agency missions and operations. However, the significant advancements many agencies have made to consider climate risks and the financial implications to their facilities are of great value. Incorporating natural hazard and climate risk information in real property asset management includes identifying information about current and future (projected) natural hazard and climate risks over the expected service life of an asset or portfolio of assets and considering how critical an asset is for an agency's mission or programs. Advancements in this area are due to the development and improvement of facility risk assessment tools, for example by the Department of the Interior and the Department of Transportation (DOT), and the need to adhere to requirements of the Disaster Resiliency Planning Act.

Finally, as described in the following two sections, agencies for the first time drew connections between reporting requirements for Agency Financial Reports (AFRs) and recent analyses by GAO related to adaptation and resilience activities and management of Federal fiscal risk.

**Agency Financial Reports**

Since 2022, Federal agencies have been asked to report details related to climate risk management, including climate-related financial risk, in their Agency Financial Reports (AFRs). OMB Circular No. A-136, *Financial Reporting Requirements* directs agencies to include this information in two sections of their AFRs: Section II.2.5. Forward-Looking Information and Section II.4.10 Climate-

Related Financial Risk for Certain CFO Act agencies. In the Forward-Looking Information section:

> "Significant entities should summarize any efforts taken or planned to assess, measure, and mitigate any significant climate-related risks that could affect the entity's performance, financial position, or financial condition. The risks include risks to assets (such as property, plant, and equipment (PP&E), and loan portfolios), liabilities (including loan guarantee liabilities), contingent liabilities, and program costs."

In the section on Climate-Related Financial Risk for Certain CFO Act agencies, agencies are required to provide links to agency outputs on climate-related risk and climate-related financial risk. Agencies are encouraged to report on budget authority or outlays related to reducing the Federal Government's exposure to climate-related financial risk as well as information about agency governance, strategy, risk management, and metrics of climate-related financial risk.

In the 2024-2027 CAPs, several agencies, including DOD, DOJ, DOT, and GSA, specifically highlighted the links between the CAPs and the reporting requirements of the AFRs. As agencies strengthen their internal coordination on climate adaption, responses to these annual reporting requests may become increasingly robust. For example, in the FY 2022 (USDA, 2022) and FY 2023 (USDA, 2023) AFRs, USDA reported only the required information, whereas USDA was able to provide greater detail in the FY 2024 AFR (USDA, 2024), reflecting the progress made in developing its 2024-2027 CAP.

**Government Accountability Office (GAO) Reports**

Since 2013, GAO has included "Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks" on its High-Risk List (GAO, 2024). GAO has conducted a number of recent engagements on fiscal risk to the Federal Government and how adaptation and resilience actions can mitigate these risks, many with agencies who also produce CAPs (Table 20) (GAO, 2019b). Many of these reports build on GAO's Disaster Resilience and Enterprise Risk Management Frameworks to identify and develop recommended actions.

In its 2024-2027 CAP, GSA refers to the GAO High-Risk List when describing recent climate change-related impacts on the agency's revenue, expenditures and balance sheets. For TVA and USDA, their 2024-2027 CAPs were key documents to provide evidence of implementation of GAO's recommendations within their agencies. GAO's recommendations for TVA included developing a plan to identify and prioritize resilience measures and conducting an inventory of assets and operations vulnerable to climate change, both of which TVA's recent CAP was able to achieve. USDA included an appendix to its 2024-2027 CAP to assess 13 potential options posed by GAO to enhance the resilience of farmers via USDA's Farm Production and Conservation agencies and USDA's Climate Hubs.

While climate change impacts to Federal risk remain a fixture on GAO's High-Risk List, GAO assessments will continue to be helpful to agencies in identifying areas for strengthening their adaptation and resilience efforts and concurrently managing fiscal risk to their organizations.

TABLE 20: RECENT GAO ASSESSMENTS OF CLIMATE RESILIENCE AND CLIMATE-RELATED FISCAL RISK RELEVANT TO AGENCIES THAT PRODUCE CLIMATE ADAPTATION PLANS

| Assessment Topic | Relevant CAP Agencies | Year |
|---|---|---|
| Climate Change: Options to Enhance the Resilience of Federally Funded Flood Risk Management Infrastructure | U.S. Army Corps of Engineers | 2024 |
| Climate Change: Options to Enhance the Resilience of Agricultural Producers and Reduce Federal Fiscal Exposure | USDA | 2023 |
| Climate Change: Improved Federal Coordination Could Facilitate Use of Forward-Looking Climate Information in Design Standards, Building Codes, and Certifications | Commerce | 2016 |
| Climate Resilience: DOD Needs to Assess Risk and Provide Guidance on Use of Climate Projections in Installation Master Plans and Facilities Design | DOD | 2019 |
| Climate Resilience: Actions Needed to Ensure DOD Considers Climate Change Risks to Contractors as Part of Acquisition, Supply, and Risk Assessment | DOD | 2020 |
| Climate Resilience: DOD Coordinates with Communities, but Needs to Assess the Performance of Related Grant Programs | DOD | 2020 |
| Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes | DOE | 2021 |
| Electricity Grid: Climate Change is Expected to have Far-reaching Effects and DOE and FERC Should Take Actions | DOE | 2021 |
| Electricity Grid: DOE Should Address Lessons Learned from Previous Disasters to Enhance Resilience | DOE | 2022 |
| Overseas Real Property: State has not Aligned Natural Hazard Resilience Plans to Staffing Levels | State | 2023 |
| Climate Resilience: Options to Enhance the Resilience of Federally Funded Roads and Reduce Fiscal Exposure | DOT | 2021 |
| Superfund: EPA Should Take Additional Actions to Manage Risks from Climate Change | EPA | 2019 |
| Water Infrastructure: Technical Assistance and Climate Resilience Planning Could Help Utilities Prepare for Potential Climate Change Impacts | EPA | 2020 |
| Flood Mitigation: Actions Needed to Improve Use of FEMA Property Acquisitions | DHS | 2022 |
| Tennessee Valley Authority: Additional Steps Are Needed to Better Manage Climate-Related Risks | TVA | 2022 |

### Conclusions and Lessons Learned

Out of necessity given the impact of increased disasters on mission execution, agencies have made significant progress in identifying their exposure and developing plans to minimize their future risk. However, there remain opportunities to strengthen links between adaptation actions and management of climate-related financial risk to Federal agencies:

- **Technical Expertise.** Agencies require technical expertise to effectively assess their exposure and to maintain and develop new assessments of climate-related financial risk. In addition, building a general understanding of climate change and a more specific understanding of its impact to an organization's mission-delivery and operations, including amongst budget and planning staff, will improve the management of fiscal risk to the Federal Government.

- **Enterprise Risk Management (ERM).** Many agencies are already taking steps to consider climate-related risks as part of their ERM efforts. Leveraging climate adaptation expertise within the agency to assess programmatic, financial, or operational climate risks, in some cases, will enable agencies to ensure that climate risks are appropriately elevated with relative priority given their comparative fiscal risk to the enterprise in ERM assessments.

- **Scope Planning.** Many of the CAPs limited their discussion of climate risk and budget formulation to climate risk to Federal facilities. Through improved coordination, planning, and progress reporting, agencies can consider how to broaden this scope to include climate risks to both mission-delivery and operations.

- **Action Planning.** There remains a communications gap between agency personnel responsible for the development of assessments of climate-related financial risk and those responsible for program delivery and budget formulation. Better linking the technical experts who develop the assessments to program managers and budget officers will ensure that relevant and high-priority assessments are considered in program design and delivery.

# V. Accounting for the Climate Benefits of Federal Investments

Federal investments in reducing greenhouse gas emissions yield climate benefits that accrue to society. OMB examined the climate benefits of programs funded by the Inflation Reduction Act (Public Law 117-169), which is the single largest piece of legislation to combat climate change in U.S. history (EPA, 2023c). This section is divided into the following subsections:

1) Monetizing climate benefits from changes in greenhouse gas (GHG) emissions using the social cost of greenhouse gases (SC-GHG),
2) Estimated benefits of carbon dioxide emission reductions as a result of the investment from the Inflation Reduction Act (IRA), and
3) Conclusions.

**Monetizing Climate Benefits Using the Social Cost of Greenhouse Gases**

The SC-GHG is a metric that puts the effects of climate change into monetary terms to help policymakers and the public understand the benefits of reducing climate pollution—that is, by estimating the costs society faces from unabated emissions that are contributing to impacts on human health and the environment. Specifically, the SC-GHG is the monetary value of the net economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere, or the benefit of avoiding that increase. The SC-GHG differs by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs.

In principle, the SC-GHG is a comprehensive metric that includes the value of all future climate change impacts (both negative and positive), including changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, reflects the societal value of reducing GHG emissions by one metric ton and is the theoretically appropriate value to use to monetize the social impacts of policies that affect GHG emissions. In practice, data and modeling limitations restrain the ability of SC-GHG estimates to include all physical, ecological, and economic impacts of climate change, implicitly assigning a value of zero to the omitted climate damages. All existing estimates of the SC-GHG are, therefore, necessarily a partial accounting of climate change impacts and likely underestimate the marginal benefits of abatement. Federal agencies have used estimates of the SC-GHG to monetize the value of changes in greenhouse gas emissions in relevant analytical contexts for more than fifteen years.

In this section, OMB estimates the climate benefits of IRA investments using an updated set of SC-GHG estimates published by the EPA in 2023. These estimates reflect recent and substantial advances in the scientific literature on climate change and its economic impacts and incorporate recommendations made by the National Academies of Science, Engineering, and Medicine. A detailed explanation of each input and the modeling process is provided in EPA's November 2023 *Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (EPA, 2023a). The Report, which was subject to public comment and an external expert peer review, also discusses the modeling limitations and the many categories of climate impacts and associated damages that are only partially or not yet reflected in the SC-GHG estimates.

OMB has reviewed relevant scientific developments and determined that EPA's 2023 estimates currently reflect the best available evidence on monetizing the value of changes in greenhouse gas emissions. OMB is thus applying these estimates in this paper. The *FY 2023 Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance with the Unfunded Mandates Reform Act*, published by OMB's Office of Information and Regulatory Affairs, provides additional detail on the history of SC-GHG and OMB's assessment of the SC-GHG estimates developed by EPA. The EPA estimates can be found in Table 21.

TABLE 21: ANNUAL SOCIAL COST OF GREENHOUSE GASES, 2020-2050

| | SC-$CO_2$ (2020 dollars per metric ton of $CO_2$) with near-term discount rate | | | SC-$CH_4$ (2020 dollars per metric ton of $CH_4$) with near-term discount rate | | | SC-$N_2O$ (2020 dollars per metric ton of $N_2O$) with near-term discount rate | | |
|---|---|---|---|---|---|---|---|---|---|
| Emission Year | 2.5% | 2.0% | 1.5% | 2.5% | 2.0% | 1.5% | 2.5% | 2.0% | 1.5% |
| 2020 | 120 | 190 | 340 | 1,300 | 1,600 | 2,300 | 35,000 | 54,000 | 87,000 |
| 2025 | 130 | 210 | 360 | 1,600 | 2,000 | 2,700 | 40,000 | 60,000 | 95,000 |
| 2030 | 140 | 230 | 380 | 1,900 | 2,400 | 3,200 | 45,000 | 66,000 | 100,000 |
| 2035 | 160 | 250 | 410 | 2,300 | 2,800 | 3,700 | 50,000 | 73,000 | 110,000 |
| 2040 | 170 | 270 | 430 | 2,700 | 3,300 | 4,200 | 55,000 | 79,000 | 120,000 |
| 2045 | 190 | 290 | 460 | 3,100 | 3,800 | 4,700 | 60,000 | 86,000 | 130,000 |
| 2050 | 210 | 310 | 480 | 3,500 | 4,200 | 5,300 | 66,000 | 93,000 | 140,000 |

Note: Values of SC-$CO_2$, SC-$CH_4$, and SC-$N_2O$ are rounded to two significant figures. The annual unrounded estimates are available in Appendix A.5 of *EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (EPA, 2023a).

**Estimated Benefits of Carbon Dioxide Emission Reductions as a Result of the Investment from the Inflation Reduction Act**

The IRA is the largest piece of legislation to reduce GHG emissions ever enacted in the United States (EPA, 2023c) and funds clean energy technologies like solar, wind, and clean hydrogen. This legislation, along with the American Rescue Plan Act (Public Law 117-2), the Infrastructure Investment and Jobs Act (Public Law 117–58), the CHIPS and Science Act (Public Law 117-167), contributed to private companies announcing commitments to invest a total of $1 trillion, including private investments in electric vehicles and batteries ($182 billion), clean energy manufacturing and infrastructure ($91 billion), and clean power ($188 billion) (The White House, 2024). Furthermore, the IRA sets out to lower energy costs for households.

The average American household saves $500 a year in utility bills when using a heat pump relative to other forms of heating, and IRA offers consumers a tax credit of up to $2,000 for the cost of a heat pump. Other clean energy tax credits for American households include 30 percent tax credits for rooftop solar and EV chargers (up to $1,000) and up to $7,500 in tax credits for electric vehicle purchases.

The analysis presented below provides an update to the OMB analysis estimating the climate benefits of the IRA, published in 2022 (Office of Management and Budget, 2022OMB, 2022c). This updated analysis uses projections of GHG emission reductions that were not available in 2022 and estimates of the SC-GHG developed by EPA that incorporate findings of recent scientific literature.

### *Method*

The monetized benefits of carbon dioxide ($CO_2$) reductions resulting from the IRA are calculated using the social cost of carbon (SC- $CO_2$) estimates developed by EPA (2023f) and the projections of $CO_2$ emission reductions due to implementing provisions within the IRA from EPA (2023e) and Bistline et al. (2023). To calculate the present value of the monetized benefits of $CO_2$ emission reductions, we use a near-term discount rate of 2 percent[32], set the "present value year" to 2023 and report dollars inflation-adjusted to 2023[33]. The EPA report (2023e) includes projections from ten independent economy-wide models and four independent electricity sector models over the time period 2024 through 2035. Of the six models used by Bistline et al. (2023) to project the economy-wide $CO_2$ reductions from investments in the IRA, projections out to 2050 are provided for four of the models in the supplemental data to the article.[34] Since Bistline et al. (2023) report the annual $CO_2$ reductions for every five years from 2025 to 2050 for these economy-wide models within the supplementary material, we linearly interpolate the annual reductions for years not included in the results.[35] The models operate under different assumptions and were developed by researchers in academia, Federal Government, and the private sector.

### *Caveats and Limitations*

Like the previous OMB analysis, only benefits pertaining to $CO_2$ emission reductions are reported. Other benefits of the IRA programs, such as improved air or water quality or the reduction of GHGs other than $CO_2$, are not accounted for in the analysis. For example, the Methane Emission Reduction Program—authorized by IRA—has several components, including $1.36 billion in financial and technical assistance to mitigate emissions of methane and other GHGs in the oil and gas sector, waste emission charges (WEC) to oil and gas facilities, and improving reporting of methane from the oil and gas sector. The climate benefits calculated in the regulatory impact analysis for the final rule on WEC, estimated at $2.40 billion[36] in 2019 dollars ($2.8 billion in 2023 dollars) for 2024-2035, are not included in the analysis below (EPA, 2024c). The benefits of reducing emissions of hydrofluorocarbons (HFCs) from the IRA funded programs, such as HFC

---

[32] The discount rate of 2 percent is chosen since 2 percent is the central near-term discount rate presented in the *EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (EPA, 2023a). Also, 2 percent is the real social discount rate recommended by OMB when benefits or costs reflect certainty-equivalent valuations (OMB, 2023c).

[33] 2023 is the most recent full year available with actual data at the time of this analysis.

[34] The analysis uses the projections from Bistline and colleagues (2023) found in the file "IRA Comparison—Emissions" found at https://zenodo.org/records/7879732. The four models included in this analysis are EPS-EI, MARKAL-NETL, REGEN-EPRI, and RIO-REPEAT.

[35] While linear interpolation is used here for ease and transparency, linear interpolation may not be reflected in the models' exact behavior in between the five-year intervals reported in the supplementary data but will reflect the general trend of the projections in between the reported 5 years.

[36] The estimated climate benefits for methane reductions are calculated using a discount rate of 2 percent and present value year of 2023.

Reclaim and Innovative Destruction Grants, are also not accounted for in this analysis.[37] Additionally, the analysis does not include non-environmental benefits related to the IRA, such as increasing private investment (CEA, 2024).

While complex, the models for $CO_2$ emissions rely on simplified versions of the world and require assumptions. For example, one simplification made is that not all the IRA provisions are included in each model. While the models generally include the components of IRA that are anticipated to have the largest impact on energy consumption and $CO_2$ emissions, certain programs are left out of all or most models, such as funding for the Department of Energy (DOE) Loan Program Office or electric loans for renewable energy. Each of the models also require a series of assumptions regarding, for example the representation of economic sectors, technology costs and constraints, how the IRA funding is implemented, fossil energy prices, and economic growth.

As noted above and discussed in the *EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (EPA, 2023a), the current EPA SC-GHG estimates reflect a partial accounting of climate change impacts from changes in GHG emissions. In addition to the other benefits excluded from this analysis, the use of partial estimates leads to conservative estimates of monetized benefits.

#### *Results*

Table 26 shows a range of estimates for monetized benefits for $CO_2$ emission reductions based on the results included in Appendix A of the EPA report (2023c) for the years 2024-2035. While the table does show an economy-wide estimate for the monetized benefits, the individual sectors—electric, building, transportation, and industry—cannot be added together to equal the benefits of the economy-wide estimate. The results across sectors are not mutually exclusive because electricity is used within the building, transportation, and industry sectors, causing indirect emissions from electricity in those respective sectors. The projected economy-wide benefits for the modeled IRA provisions over the 12-year period range from $536 billion to $2.36 trillion, with the median projected benefits at $1.11 trillion. In addition to capturing provisions within the IRA that are targeted at specific sectors, the economy-wide projections also account for emission-reducing provisions that cut across different sectors, like the tax credits for carbon oxide sequestration, the clean hydrogen production tax credit, and the Greenhouse Gas Reduction Fund.

Of the four sectors reported in the EPA report, the greatest benefits of reduced $CO_2$ are projected from the electric sector, which range from $352 billion to $1.78 trillion, with a median of $899 billion. In 2022, the electric sector was the sector with the second-highest source of emissions in the United States, accounting for approximately a quarter of emissions (EPA, 2023c). These estimated benefits are due to a wide range of provisions within the IRA that focus on investment in clean energy—including but not limited to: the production tax credit (PTC) and investment tax credit (ITC) for electricity from wind and solar; the zero-emission nuclear power PTC; the tax credit for carbon oxide sequestration; and the PTC and ITC for new clean electricity.

[37] Reductions in HFCs could result in large climate benefits, see EPA (2021b) and Tan et al. (2024) for social cost of hydrofluorocarbon estimates and the climate benefits from similar policies.

The IRA incentivizes energy efficiency in buildings through provisions like the energy efficient home improvement tax credit, the new energy efficient homes credit, and energy efficient commercial buildings deduction. The benefits estimated from the modeled IRA provisions impacting the building sector are estimated to range between $316 billion and $1.38 trillion, with a median of $655 billion.

The estimated monetized benefits of $CO_2$ emission reductions for the transportation sector due to modeled provisions of the IRA range from $25 billion to $324 billion. All the economy-wide models used in the EPA report account for the clean vehicle tax credit and most models account for tax credits for biodiesel and renewable fuels production; however, only one model includes the tax credit for previously owned clean vehicles. Transportation is the sector that generates the most emissions in the United States (EPA, 2023c), accounting for roughly 28 percent of U.S. emissions. As with all the modeling of emission reductions due to the IRA, whether or not provisions are modeled and how the provisions are modeled impact the estimates presented in Table 22.

TABLE 22: MONETIZED BENEFITS OF CARBON DIOXIDE EMISSIONS REDUCTIONS, 2024-2035 (BILLIONS OF 2023 DOLLARS)

| Sectors* | # of Models | Minimum | Median | Maximum |
|---|---|---|---|---|
| Economy-wide | 10 | $536 | $1,109 | $2,361 |
| Electric Sector | 14 | $352 | $899 | $1,782 |
| Building Sector | 10 | $316 | $655 | $1,380 |
| Transportation Sector | 10 | $25 | $106 | $324 |
| Industry Sector | 10 | $95 | $312 | $759 |

* Sectors are non-additive.

The last sector modeled in the EPA report is the industry sector, in which the benefits of the modeled IRA provisions for the sector range from $95 billion to $759 billion, with a median of $312 billion. The IRA provisions impacting the industry sector, include the advanced energy project credit and the tax credit for carbon oxide sequestration. Coverage of the IRA provisions concerning industry within the modeling is limited relative to other sectors. For example, while the building, transportation, and electric sector results had provisions that were included in all models, with the exception of the tax credit for carbon oxide sequestration, no single IRA provision concerning only the industrial sector is included in all 10 of the economy-wide models.

For calculating the economy-wide benefits of $CO_2$ reductions out to 2050, we use the results of four economy-wide models from Bistline et. al. (2023). The present value of $CO_2$ benefits with a 2 percent discount rate and a present value year of 2023 has a median of $3.932 trillion (inflation-adjusted to 2023 dollars) for the period 2025-2050, with the lowest estimate of the four models being $3.535 trillion and the highest estimate of the four models being $5.340 trillion.

**Conclusions**

Recent scientific advancements have aided society's understanding of the cost of GHG emissions to society. The SC-GHG helps us understand that the benefits generated through the $CO_2$ reduction investments alone in the IRA can greatly outweigh the cost. While the full scope of societal harm caused by GHG emissions is not yet fully captured in the SC-GHG, current values allow us to demonstrate the benefits that Federal investments will have long into the future.

# VI. Conclusion

The risks of climate change are threatening both the Federal Government's budget and the economic prosperity of everyday Americans. Physical risks refer to the harm to people and property arising from acute climate-related events, such as hurricanes, wildfires, floods, and heatwaves, and chronic shifts in climate, including higher average temperatures, changes in precipitation patterns, and sea level rise (Federal Reserve, 2023). Federal agencies continue to build capacity to conduct assessments of the financial risk of these physical climate risks, develop plans for how best to adapt to a changing climate, and review and estimate the benefits of Federal investments in climate change mitigation.

This paper includes examples of the approaches used by Federal agencies to estimate the financial costs of climate change, and the economic tools that are being developed to more accurately predict climate fiscal risks in the future. The highlights of projected climate fiscal risks that threaten the Federal Government provided in this paper include:

- USDA's Federal Crop Insurance Program, and risks to the Pasture, Rangeland, and Forage insurance plan;
- Risks to the HUD's commercial lending portfolio;
- State and risks to overseas buildings and operations;
- Risks to EPA facilities;
- Framing climate financial risks to HHS operations;
- EPA and managing climate risks at Superfund sites;
- Tools to assess and address climate financial risks to Interior buildings and operations; and
- Climate financial risks to DOT and the U.S. transportation system.

This paper provides an overview of the advancements in the development of Federal Climate Adaptation Plans and opportunities for further work needed to maximize the utility of those plans. This paper also provides an overview of the benefits of Federal investments in reducing greenhouse gas emissions that contribute to climate change and a discussion of how those benefits can be measured using estimates of the social cost of greenhouse gases. As an example of those benefits, the paper provides estimates of the economic benefits of investments in the Inflation Reduction Act, where the median projected benefits from carbon dioxide emissions reductions through 2035 are approximately $1.1 trillion.

These are just a few examples of how OMB and Federal agencies are working to improve the accounting of climate-related Federal expenditures, reduce the Federal Government's long-term exposure to climate-related financial risk, and provide the best available information to support decision-making. All of these efforts are being undertaken in order to minimize the financial risk to taxpayer dollars and Federal programs, projects, and activities.

# VII. References


Abir, M., Vardavas, R., Hasan Tariq, Z., Hock, E., Lawson, E., & Cortner, S. (2024). Impact of Climate Change on Health and Drug Demand. Santa Monica, CA: RAND Corporation. https://www.rand.org/t/RRA3425-1.

ACF (Administration for Children & Families). (2023). Head Start Program Facts: Fiscal Year 2023. https://headstart.gov/program-data/article/head-start-program-facts-fiscal-year-2023.

ASPR (Administration for Strategic Preparedness & Response). (2024a). Declarations of a Public Health Emergency. https://aspr.hhs.gov/legal/PHE/Pages/default.aspx.

Beckman, J., Dong, F., Ivanic, M., & Villoria, N. (2024). Climate-induced yield changes and TFP: How much R&D is necessary to maintain food supply? ERR-333, Economic Research Service, United States Department of Agriculture. https://www.ers.usda.gov/publications/pub-details?pubid=109476.

Bevilacqua, K., Rasul, R., Schneider, S., Guzman, M., Nepal, V., Banerjee, D., Schulte, J., & Schwartz, R.M. (2020). Understanding associations between Hurricane Harvey exposure and mental health symptoms among greater Houston-Area residents. *Disaster Medicine Public Health Preparedness*, *14*(1)103-110. https://doi.org/10.1017/dmp.2019.141.

Billah, M., & Rahman, M. (2024). Salmonella in the environment: A review on ecology, antimicrobial resistance, seafood contaminations, and human health implications. *Journal of Hazardous Materials Advances*, *13*,100407. https://doi.org/10.1016/j.hazadv.2024.100407.

Bolster, C.H., Mitchell, R., Kitts, A., Campbell, A., Cosh, M., Farrigan, T., Franzluebbers, A., Hoover, D., Jin, V., Peck, D., Schmer, M., & Smith, M. (2023). Ch. 11. Agriculture, food systems, and rural communities. In: *Fifth National Climate Assessment*. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA.

Boone, R.B., Conant, R.T., Sircely, J., Thornton, P.K., & Herrero, M. (2018). Climate change impacts on selected global rangeland ecosystem services. *Global Climate Change Biology*, *24*, 1382-1393. https://doi.org/10.1111/gcb.13995.

Bistline, J., Blanford, G., Brown, M., Burtraw, D., Domeshek, M., Farbes, J., Fawcett, A., Hamilton, A., Jenkins, J., Jones, R., King, B., Kolus, H., Larsen, J., Levin, A., Mahajan, M., Marcy, C., Mayfield, E., McFarland, J., McJeon, H., Orvis, R., Patankar, N., Rennert, K., Roney, C., Roy, N., Schivley, G., Steinberg, D., Victor, N., Wenzel, S., Weyant, J., Wiser, R., Yuan, M., & Zhao, A. (2023). Emissions and energy impacts of the Inflation Reduction Act. *Science*, *380*(6652),1324-1327. https://doi.org/10.1126/science.adg3781.

Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R.E., McCusker, K.E., Nath, I., Rising, J., Rode, A., Seo, H.K., Viaene, A., Yuan, J., & Zhang, A.T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics, 137*(4), 2037–2105. https://doi.org/10.1093/qje/qjac020.

CBO (Congressional Budget Office). (2024). The Risks of Climate Change to the United States in the 21st Century. https://www.cbo.gov/publication/60845.

CDC (Centers for Disease Control and Prevention). (2024a). Wildfires. https://www.cdc.gov/wildfires/about/index.html.

CDC (Centers for Disease Control and Prevention). (2024b). Emergency Preparedness and Response. https://www.cdc.gov/emergency/index.html.

CDC (Centers for Disease Control and Prevention). (2024c). Natural Disasters and Severe Weather. https://www.cdc.gov/natural-disasters/index.html.

CDC (Centers for Disease Control and Prevention). (2024d). South America Regional Office. https://www.cdc.gov/global-health/regional/south-america.html.

CDC (Centers for Disease Control and Prevention). (2024e). What CDC Is Doing. https://www.cdc.gov/vector-borne-diseases/what-cdc-is-doing/index.html.

CEA (Council of Economic Advisers). (2024). GDP Issue Brief. October 2024. https://www.whitehouse.gov/cea/written-materials/2024/10/30/gdp-issue-brief/.

CEQ (Council on Environmental Quality). (2024a). Federal Progress, Plans, and Performance. https://www.sustainability.gov/progress.html.

CEQ (Council on Environmental Quality). (2024b). Federal Climate Adaptation Plan Maps. 2024-2027 Climate Adaptation Plans: Climate Hazard Exposure Assessment. https://storymaps.arcgis.com/stories/72c397b30930442ebf4b71027e932135.

CEQ (Council on Environmental Quality). (2024c). *Assessing the Progress and Impact of Federal Climate Adaptation: Developing Climate Resilience Indicators and Metrics*. https://www.sustainability.gov/pdfs/indicatorsmetrics-2024-cap.pdf.

Chon, K., & Grant, N. (2022). Preventing and addressing human trafficking in the wake of disasters. The Family Room Blog, Administration for Children & Families. https://www.acf.hhs.gov/blog/2022/09/preventing-and-addressing-human-trafficking-wake-disasters.

Chu, E.K., Fry, M.M., Chakraborty, J., Cheong, S.-M., Clavin, C., Coffman, M., Hondula, D.M., Hsu, D., Jennings, V.L., Keenan, J.M., Kosmal, A., Muñoz-Erickson, T.A., & Jelks, N.T.O. (2023). Ch. 12. Built environment, urban systems, and cities. In: *Fifth National Climate Assessment*. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH12.

CMS (Centers for Medicare & Medicaid Services). (2024a). How we can help. https://www.cms.gov/about-cms/what-we-do/emergency-response/how-can-we-help.

CMS (Centers for Medicare & Medicaid Services). (2024b). Hurricanes & tropical storms. https://www.cms.gov/about-cms/what-we-do/emergency-response/past-emergencies/hurricanes-tropical-storms.

Coble, K., Goodwin, B., Miller, M. F., Rejesus, R., Harri, A., & Linton, D. (2020). *Review of the Pasture, Rangeland, Forage Rainfall Index Crop Insurance Program Indexing and Rating Methodology Final Report*. Report to RMA by Sigma Agricultural Risk and Actuarial Services, LLC.

Collier, M. A., Jeffrey, S. J., Rotstayn, L. D., Wong, K. K., Dravitzki, S. M., Moseneder, C., ... & Atif, M. (2011, December). The CSIRO-Mk3. 6.0 Atmosphere-Ocean GCM: participation in CMIP5 and data publication. In *International congress on modelling and simulation–MODSIM* (pp. 2691-2697). https://doi.org/10.36334/modsim.2011.f5.collier.

Collins, W. J., Bellouin, N., Doutriaux-Boucher, M., Gedney, N., Halloran, P., Hinton, T., Hughes, J., Jones, C. D., Joshi, M. , Liddicoat, S., Martin, G., O'Connor, F., Rae, J., Senior, C., Sitch, S., Totterdell, I., Wiltshire, A. and Woodward, S. (2011) Development and evaluation of an Earth-System model – HadGEM2. *Geoscientific Model Development*, *4*(4). pp. 1051-1075. ISSN 1991-959X

Couper, L., MacDonald, A., & Merdecai, E. (2021). Impact of prior and projected climate change on US Lyme disease incidence. *Global Change Biology*, *27*(4), 738-54. https://doi.org/10.1111/gcb.15435.

Colorado Department of Public Safety. (2018). 2018-2023 Colorado Hazard Mitigation Plan. https://climate.colorado.gov/2018-2023-colorado-hazard-mitigation-plan.

Colorado Water Conservation Board. (2024). Colorado Hazard Mapping and Risk MAP Portal. Retrieved on October 31, 2024, https://coloradohazardmapping.com/climate2.

Cumming Group. (2023). 2023 Construction Market Analysis. https://insights.cumming-group.com/.

Döhrmann, D., Gürtler, M., Hibbeln, M., & Metzler, R. (2021). Arising from the Ruins: The impact of natural disasters on reconstruction labor wages. (2021). *International Journal of Disaster Risk Reduction*, *59*, 102210. https://doi.org/10.1016/j.ijdrr.2021.102210.

Dolan, F., Price, C.C., Lempert, R.J., Patel, K.V., Sytsma, T., Park, H.M., De Leon, F., Bond, C.A., Miro, M.E., & Lauland, A. (2023). The budgetary effects of climate change and their potential influence on legislation: Recommendations for a model of the Federal budget. RAND Corporation Research Report. Santa Monica, CA: RAND Corporation. http://www.rand.org/pubs/research_reports/RRA2614-1.html.

Donner, L. J., Wyman, B. L., Hemler, R. S., Horowitz, L. W., Ming, Y., Zhao, M., ... & Zeng, F. (2011). The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3. *Journal of Climate*, *24*(13), 3484-3519. https://doi.org/10.1175/2011JCLI3955.1.

Dufresne, J.L., Foujols, M.A., Denvil, S., Caubel, A., Marti, O., Aumont, O., Balkanski, Y., Bekki, S., Bellenger, H., Benshila, R., Bony, S., Bopp, L., Braconnot, P., Brockmann, P., Cadule, P., Cheruy, F., Codron, F., Cozic, A., Cugnet, D., de Noblet, N. … Vulchard, N. (2013). Climate change projections using the IPSL-CM5 Earth System Model: From CMIP3 to CMIP5. *Climate Dynamics*, *40*, 2123–2165. https://doi.org/10.1007/s00382-012-1636-1.

EPA (Environmental Protection Agency). (2017). Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430-R-17-001. Washington, D.C.: U.S. Environmental Protection Agency. https://www.epa.gov/cira/multi-model-framework-quantitative-sectoral-impacts-analysis.

EPA (Environmental Protection Agency). (2021a). Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003. https://www.epa.gov/cira/social-vulnerability-report.

EPA(Environmental Protection Agency). (2021b). *Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs)*. https://www.epa.gov/system/files/documents/2021-09/ria-w-works-cited-for-docket.pdf.

EPA (Environmental Protection Agency). (2023a). Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. U.S. Environmental Protection Agency, EPA-HQ-OAR-2021-0317. https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf.

EPA (Environmental Protection Agency). (2023b). Climate Change Indicators in the United States. Retrieved from https://www.epa.gov/climate-indicators/.

EPA (Environmental Protection Agency). (2023c). Electricity Sector Emissions Impacts of the Inflation Reduction Act: Assessment of projected $CO_2$ emission reductions from changes in electricity generation and use. U.S. Environmental Protection Agency, EPA 430-R-23-004.

EPA (Environmental Protection Agency). (2024a). Climate risks and opportunities defined. EPA Center for Corporate Climate Leadership. https://www.epa.gov/climateleadership/climate-risks-and-opportunities-defined.

EPA (Environmental Protection Agency). (2024b). U.S. Environmental Protection Agency 2024-2027 Federal Climate Adaptation Plan. Retrieved June 2024, https://www.epa.gov/system/files/documents/2024-06/epas-2024-2027-climate-adaptation-plan-508-compliant.pdf.

EPA (Environmental Protection Agency). (2024c). Regulatory Impact Analysis of the Proposed Waste Emissions Charge. U.S. Environmental Protection agency, EPA-430/R-23-005.

FAA (Federal Aviation Administration). (2021). United States Aviation Climate Action Plan. Retrieved from https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.

FDA (Food & Drug Administration). (2024). Drug shortages. https://www.fda.gov/drugs/drug-safety-and-availability/drug-shortages.

Federal Reserve. (2023). *Principles for Climate-Related Financial Risk Management for Large Financial Institutions*. October 2023. https://www.federalreserve.gov/supervisionreg/srletters/SR2309a1.pdf.

FEMA (Federal Emergency Management Association). (2024). National Risk Index for Natural Hazards. Retrieved from FEMA Products and Tools: https://www.fema.gov/flood-maps/products-tools/national-risk-index.

FHWA (Federal Highway Administration). (2017a). Vulnerability Assessment and Adaptation Framework, Third Edition Washington, D.C.: Federal Highway Administration. FHWA-HEP-18-020. https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/.

FHWA (Federal Highway Administration). (2017b). U.S. DOT Vulnerability Assessment Scoring Tool (VAST). U.S. Climate Resilience Toolkit. https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/scoring_tools_guide/page00.cfm.

FHWA (Federal Highway Administration). (2024a). Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation Discretionary Program Metrics. 89 FR 20290. Retrieved from https://www.federalregister.gov/documents/2024/03/21/2024-05934/promoting-resilient-operations-for-transformative-efficient-and-cost-saving-transportation.

FHWA (Federal Highway Administration). (2024b). Emergency Relief Program. Retrieved from Federal-aid Programs and Special Funding: https://www.fhwa.dot.gov/programadmin/erelief.cfm.

Filosa, G., Gilman, S., Hossfeld, D., Kim, Y., & Wingo, K. (2024). Transit Resilience Guidebook. Federal Transit Authority, Washington, D.C. Retrieved from https://www.transit.dot.gov/sites/fta.dot.gov/files/2024-05/TPE-FTA-Resilience-Guidebook-05-29-2024.pdf

Financial Stability Oversight Council. (2021). Report on Climate-related Risks. https://home.treasury.gov/system/files/261/f-Climate-Report.pdf.

Froelich, B.A., & Daines, D.A. (2020). In hot water: Effects of climate change on Vibrio-human interactions. *Environmental Microbiology*, *22*(10), 4101-4111. https://doi.org/10.1111/1462-2920.14967.

FTA Office of Program Management. (2024). Emergency Relief Program. Retrieved from Federal Transit Authority: https://www.transit.dot.gov/funding/grant-programs/emergency-relief-program.

Fuller, M., Cavanaugh, N., Green, S., & Dunderstadt, K. (2022). Climate change and state of the science for children's health and environmental health equity. *Journal of Pediatric Health Care*, *36*(1), 20-6.

GAO (Government Accountability Office). (2019a). SUPERFUND: EPA Should Take Additional Actions to Manage Risks from Climate Change. October 2019. GAO-20-73. https://www.gao.gov/assets/gao-20-73.pdf.

GAO (Government Accountability Office). (2019b). CLIMATE CHANGE: Opportunities to Reduce Federal Fiscal Exposure. June 2019. GAO-19-625T. https://www.gao.gov/assets/gao-19-625t.pdf.

GAO (Government Accountability Office). (2022). Overseas Real Property: State's Initial Assessment of Natural Hazard Risks Faced by its Posts. October 2022. https://www.gao.gov/assets/gao-23-105452.pdf.

GAO (Government Accountability Office). (2023). Overseas Real Property: State Has Not Aligned Natural Hazard Resilience Plans to Staffing Levels. June 2023. https://www.gao.gov/products/gao-23-105887.

GAO (Government Accountability Office). (2024). Congressional Action Needed to Enhance Economics Information and to Limit Federal Fiscal Risk. GAO Highlights. August 14, 2024. GAO-24-106937. https://www.gao.gov/products/gao-24-106937.

Ghorbani, S. (2023). How Cost Contingency is Calculated. Project Control Academy. Retrieved September 17, 2024, https://www.projectcontrolacademy.com/cost-contingency-calculation/.

Gomez, J.A. (2022). Climate Resilience: Options to Enhance the Resilience of Federally Funded Roads and Reduce Fiscal Exposure. GAO-21-436. https://www.gao.gov/assets/gao-21-436.pdf.

Hayden, M.H., Schramm, P.J., Beard, C.B., Bell, J.E., Bernstein, A.S., Bieniek-Tobasco, A., Cooley, N., Diuk-Wasser, M., Dorsey, M.K., Ebi, K.L., Ernst, K.C., Gorris, M. E., Howe, P. D., Khan, A.S., Lefthand-Begay, C., Maldonado, J., Saha, S., Shafiei, F., Vaidyanathan, A., & Wilhelmi, O.V. (2023). Ch. 15. Human health. In: *Fifth National Climate Assessment*. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH15.

Heanoy, E., & Brown, N. (2024). Impact of natural disasters on mental health: Evidence and implications. *Healthcare*, *12*(18), 1812. https://doi.org/10.3390/healthcare12181812.

Hino, M., & Burke, M. (2020). *Does Information About Climate Risk Affect Property Values?* [White paper]. National Bureau of Economic Research.

Holtermans, R., Kahn, M.E., & Kok, N. (2023). Climate risk and commercial mortgage delinquency. MIT Center for Real Estate Research Paper No. 23/08. http://dx.doi.org/10.2139/ssrn.4066875.

Hostetter, M, & S. Klein. (2022). How health care organizations are preparing for climate shocks and protecting vulnerable patients. The Commonwealth Fund. Available from: https://www.commonwealthfund.org/publications/2022/oct/how-health-care-organizations-are-preparing-for-climate-shocks.

Hrozencik, R.A., Perez-Quesada, G., & Bocinsky, K. (2024). The stocking impact and financial-climate risk of the Livestock Forage Disaster Program (Report No. ERR-329). U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details?pubid=108371.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., & Houser, T. (2017). Estimating economic damage from climate change in the United States. *Science*, *356*(6345), 1362-1369. https://doi.org/10.1126/science.aal4369.

Hsiang, S., Greenhill, S., Martinich, J., Grasso, M., Schuster, R.M., Barrage, L., Diaz, D.B., Hong, H., Kousky, C., Phan, T., Sarofim, M.C., Schlenker, W., Simon, B., & Sneeringer, S.E. (2023). Ch. 19. Economics. In: *Fifth National Climate Assessment*. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH19.

IPCC (Intergovernmental Panel on Climate Change). (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32. https://doi.org/10.1017/9781009157896.001.

Jay, A.K., Crimmins, A.R., Avery, C.W., Dahl, T.A, Dodder, .R.S., Hamlington, B.D., Lustig, A., Marvel, K., Méndez-Lazaro, P.A., Osler, M.S., Terando, A., Weeks, E.S., & Zycherman, A. (2023). Ch. 1. Overview: Understanding risks, impacts, and responses. In: Fifth National Climate Assessment. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH1.

Kalla, H., & Shepherd, G. (2019). Memorandum: Integration of Resilient Infrastructure in the Emergency Relief Program. Washington, D.C.: FHWA. Retrieved October 11, 2024, https://www.fhwa.dot.gov/specialfunding/er/191011.cfm.

Keenan, J.M., & Bradt, J.T. (2020). Underwaterwriting: from theory to empiricism in regional mortgage markets in the U.S. *Climatic Change*, *162*, 2043–2067. https://doi.org/10.1007/s10584-020-02734-1/.

Lawrence, J., Ibne Hossain, N.U., Jaradat, R., & Hamilton, M. (2020). Leveraging a Bayesian network approach to model and analyze supplier vulnerability to severe weather risk: A case study of the U.S. pharmaceutical supply chain following Hurricane Maria *International Journal of Disaster Risk Reduction*, *49*, 101607. https://doi.org/10.1016/j.ijdrr.2020.101607.

Lay, C., Mills, D., Belova, A., Sarofirm, M., Kinney, P., Vaidyanathan, A., Jones, R., Hall, R., & Saha, S. (2018). Emergency department visits and ambient temperature: Evaluating the connection and projecting future outcomes. *GeoHealth*, *2*,182-94. https://doi.org/10.1002/2018GH000129.

Lehner, F., Coats, S., Stocker, T. F., Pendergrass, A. G., Sanderson, B. M., Raible, C. C., & Smerdon, J. E. (2017). Projected drought risk in 1.5 C and 2 C warmer climates.

*Geophysical Research Letters*, *44*(14), 7419-7428. https://doi.org/10.1002/2017GL074117.

Leng, G., & Hall, J. (2019). Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. *Science of the Total Environment*, *654*, 811-821.

Levy, S. (2015). Warming trend: How climate chapes vibrio ecology. *Environmental Health Perspectives*, *123*(4), A82-A9. https://doi.org/10.1289/ehp.123-A8.

Lewis, V., Spivack, S., Murray, G., & Rodriquez, H. (2021). FQHC designation and safety net patient revenue associated with primary care practice capabilities for access and quality. *Journal of General Internal Medicine*, *36*(10), 2922–2928. https://doi.org/10.1007/s11606-021-06746-0.

Limaye, V.S., Max, W., Constible, J., & Knowlton, K. (2019). Estimating the health-related costs of 10 climate-sensitive events during 2012. *GeoHealth*, *3*, 245-65. https://doi.org/10.1029/2019GH000202.

Liu, Y., Saha, S., Hoppe, B., & Convertino, M. (2019). Degrees and dollars-Health costs associated with suboptimal ambient temperature exposure. *Science of the Total Environment*, *678*, 702-17. https://doi.org/10.1016/j.scitotenv.2019.04.398.

MacLachlan, M., Ramos, S., Hungerford, A., & Edwards, S. (2018). Federal natural disaster assistance programs for livestock producers, 2008-16. USDA Economic Research Service Economic Information Bulletin No. 187. January 2018. https://www.ers.usda.gov/publications/pub-details?pubid=86989.

Malikov, E., Miao, R., & Zhang, J. (2020). Distributional and temporal heterogeneity in the climate change effects on US agriculture. *Journal of Environmental Economics and Management*, *104*, 102386. https://doi.org/10.1016/j.jeem.2020.102386.

Marvel, K., Su, W., Delgado, R., Aarons, S., Chatterjee, A., Garcia, M.E., Hausfather, Z., Hayhoe, K., Hence, D.A., Jewett, E.B., Robel, A., Singh, D., Tripati, A., & Vose, R.S. (2023). Ch. 2. Climate trends. In: *Fifth National Climate Assessment*. Crimmins, A.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Stewart, B.C., & Maycock, T.K., Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH2.

Miller, F., Young, S., Dobrow, M., & Shojania, K. (2021a). Vulnerability of the medical product supply chain: the wake-up call of COVID-19. *BMJ Quality and Safety*, *30*(4), 331-335. https://doi.org/10.1136/bmjqs-2020-012133.

Miller, K., Miller, K., Knocke, K., Pink, G., Holmes, G., & Kaufman, B. (2021b). Access to outpatient services in rural communities changes after hospital closure. *Health Services Research*, *56*, 788-801. https://doi.org/10.1111/1475-6773.13694.

Morgado, M.E., Jiang, C., Zambrana, J., Romeo Upperman, C., Mitchell, C., Boyle, M., Sapkota, A.R., & Sapkota, A. (2021). Climate change, extreme events, and increased risk of salmonellosis: foodborne diseases active surveillance network (FoodNet), 2004-2014. *Environmental Health*, *20*(105). https://doi.org/10.1186/s12940-021-00787-y.

Nath, J., Costigan, S., Lin, F., Vittinghoff, E., & Hsia, R. (2019). Access to Federally Qualified Health Centers and Emergency Department Use Among Uninsured and Medicaid-insured Adults: California, 2005-2013. *Society for Academic Emergency Medicine*, 26, 129-139. https://doi.org/10.1111/acem.13494.

NASEM (National Academies of Sciences, Engineering, and Medicine). (2017). The Essential Role of Research Sponsors. In: *Strengthening the Disaster Resilience of the Academic Biomedical Research Community: Protecting the Nation's Investment*. Carlin, E., Brown, L., & Benjamin, G.C., Eds. Washington, DC: National Academies Press.

NASEM (National Academies of Sciences, Engineering, and Medicine). (2021a). Investing in Transportation Resilience: A Framework for Informed Choices. The National Academies Press. https://doi.org/10.17226/26292.

NASEM (National Academies of Sciences, Engineering, and Medicine). (2021b). ACRP Research Report 228: Airport Microgrid Implementation Toolkit. Washington, DC. https://doi.org/10.17226/26165.

NASEM (National Academies of Sciences, Engineering, and Medicine). (2024). Incorporating Climate Change and Climate Policy into Macroeconomic Modeling: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/27447.

National Institute of Building Sciences. (2019). Natural Hazard Mitigation Saves: 2019 Report. https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf.

Navarro Research and Engineering, Inc. (2024). Rocky Mountain Arsenal: Fiscal Year 2022 Annual Summary Report for Groundwater and Surface Water, October 1, 2021 – September 30, 2022. https://home.army.mil/carson/2617/0613/1616/fiscal-year-2022-annual-summary-report-for-groundwater-surface-water-main-text-and-tables.pdf.

Neumann, J. E., Chinowsky, P., Helman, J., Black, M., Fant, C., Strzepek, K., & Martinich, J. (2021). Climate effects on US infrastructure: The economics of adaptation for rail, roads, and coastal development. *Climatic Change*, *167*(44). https://doi.org/10.1007/s10584-021-03179-w.

NOAA (National Oceanic and Atmospheric Administration). (2017). Detailed Method for Mapping Sea Level Rise Inundation. NOAA Office for Coastal Management.

NOAA (National Oceanic and Atmospheric Administration). (2024a). Billion-Dollar Weather and Climate Disasters. NOAA National Center for Environmental Information. https://www.ncei.noaa.gov/access/billions/.

NOAA (National Oceanic Atmospheric Administration). (2024b). Sea level rise a---map viewer 2024. https://www.climate.gov/maps-data/dataset/sea-level-rise-map-viewer.

OMB (Office of Management and Budget). (2022a). Federal budget exposure to climate risk. https://www.whitehouse.gov/wp-content/uploads/2022/04/ap_21_climate_risk_fy2023.pdf.

OMB (Office of Management and Budget). (2022b). Climate risk exposure: An assessment of the Federal Government's financial risks to climate change. https://www.whitehouse.gov/wp-content/uploads/2022/04/OMB_Climate_Risk_Exposure_2022.pdf.

OMB (Office of Management and Budget). (2022c). OMB Analysis: The Social Benefits of the Inflation Reduction Act's Greenhouse Gas Emission Reductions. https://www.whitehouse.gov/wp-content/uploads/2022/08/OMB-Analysis-Inflation-Reduction-Act.pdf.

OMB (Office of Management and Budget). (2023a). Budget exposure to increased costs and lost revenue due to climate change: a preliminary assessment and proposed framework for future assessments. https://www.whitehouse.gov/wp-content/uploads/2023/03/climate_budget_exposure_fy2024.pdf.

OMB (Office of Management and Budget). (2023b). Budget exposure to increased costs and lost revenue due to climate change. https://www.whitehouse.gov/wp-content/uploads/2023/03/ap_10_climate_change_fy2024.pdf.

OMB (Office of Management and Budget). (2023c). OMB Circular No. A-94, Appendix D: Discount Rates for Benefit-Cost Analysis. https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-94AppendixD.pdf.

OMB (Office of Management and Budget). (2024a). Analysis of Federal climate financial risk exposure. https://www.whitehouse.gov/wp-content/uploads/2024/03/ap_11_climate_risk_fy2025.pdf.

OMB (Office of Management and Budget). (2024b). Climate financial risk: The Federal Government's budget exposure to financial risk due to climate change. https://www.whitehouse.gov/wp-content/uploads/2024/03/climate_budget_exposure_fy2025.pdf.

Paek, H., Niess, M., Padilla, B., & Olson, D. (2018). A community health center blueprint for responding to the needs of the displaced after a natural disaster: The Hurricane Maria experience. *Journal of Health Care for the Poor and Underserved*, *29*(2). https://dx.doi.org/10.1353/hpu.2018.0040.

Pearlman, F., Lawrence, C.B., Pindilli, E.J., Geppi, D., Shapiro, C.D., Grasso, M., Pearlman, J., Adkins, J., Sawyer, G., & Tassa, A. (2019). Demonstrating the value of Earth observations—Methods, practical applications, and solutions—Group on Earth Observations side event proceedings: U.S. Geological Survey Open-File Report 2019–1033, 33 pages. https://doi.org/10.3133/ofr20191033.

Pindilli, E.J., & Loftin, K. (2022). What's it worth? Estimating the potential value of early warnings of cyanobacterial harmful algal blooms for managing freshwater reservoirs in Kansas, United States. *Frontiers in Environmental Science*, *10*, 805165. https://doi.org/10.3389/fenvs.2022.805165.

Pindilli, E.J., Chiavacci, S.J., & Straub, C.L. (2023). The value of scientific information—An overview. U.S. Geological Survey Open-File Report 2023-1011. https://doi.org/10.3133/ofr20231011.

Prestemon, J.P., E. Belval, J. Costanza, S. Kay, J. Morisette, K. Riley, K. Short, B.K. daSilva. (2024). U.S. Department of Agriculture Forest Service and U.S. Department of the Interior: Update on projected wildland fire suppression costs due to climate change impacts. Pages 17-53, 96-131 in: White House, Office of Management and Budget, "Climate financial risk; The Federal Government's budget exposure to financial risk due to climate change." March 2024, Washington, DC. 131 pages. https://www.whitehouse.gov/wp-content/uploads/2024/03/climate_budget_exposure_fy2025.pdf.

Rehr, R., & Perkowitz, R. (2019). Moving Forward: A Guide for Health Professionals to Build Momentum on Climate Action. Washington, DC: ecoAmerica. https://ecoamerica.org/wp-content/uploads/2023/01/CFHMFG-web.pdf.

Risk Management Agency (RMA), USDA. Pasture, Rangeland, Forage. https://legacy.rma.usda.gov/policies/pasturerangeforage/.

Schmidt, G. A., Ruedy, R., Hansen, J. E., Aleinov, I., Bell, N., Bauer, M., ... & Yao, M. S. (2006). Present-day atmospheric simulations using GISS ModelE: Comparison to in situ, satellite, and reanalysis data. *Journal of Climate*, *19*(2), 153-192. https://doi.org/10.1175/JCLI3612.1.

Schoenbaum, M., Butler, B., Katoaka, S., Norquist, G., Springgate, B., Sullivan, F., Duan, N., Kessler, R., & Wells, K. (2009). Promoting mental health recovery after Hurricanes Katrina and Rita: What could we have done at what cost? *Archives of General Psychiatry*, *66*(8):906-14. http://doi.org10.1001/archgenpsychiatry.2009.77.

Sharpe, J., & Wolkin, A. (2022). The epidemiology and geographic patterns of natural disaster and extreme weather mortality by race and ethnicity, United States, 1999- 2018. *Public Health Reports, 137*(6):1118-1125. https://doi.org/10.1177/00333549211047235.

Sherman, J., MacNeill, A., Biddinger, P., Ergun, O., Salas, R., & Eckelman, M. (2023). Sustainable and resilient health care in the face of a changing climate. *Annual Review of Public Health*, *44*, 255-277. https://doi.org/10.1146/annurev-publhealth-071421-051937.

Smith, A. B. (2023, January 4). 2023: A historic year of U.S. billion-dollar weather and climate disasters. National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/blogs/beyond-data/2023-historic-year-us-billion-dollar-weather-and-climate-disasters.

Singh, D., A.R. Crimmins, J.M. Pflug, P.L. Barnard, J.F. Helgeson, A. Hoell, F.H. Jacobs, M.G. Jacox, A. Jerolleman, & M.F. Wehner. (2023). Focus on compound events. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.F1.

Tack, J., Coble, K., & Barnett, B. (2018). Warming temperatures will likely induce higher premium rates and government outlays for the U.S. crop insurance program. *Agricultural Economics 49(5)*: 635-647. https://doi.org/10.1111/agec.12448.

Tan, T., Rennels, L. & Parthum, B. (2024). The social costs of hydrofluorocarbons and the benefits from their expedited phase-down. *Nature Climate Change*, *14*, 55–60. https://doi.org/10.1038/s41558-023-01898-9.

The White House. (2021). Report on the impact of climate change on migration. October 2021. https://www.whitehouse.gov/wp-content/uploads/2021/10/report-on-the-impact-of-climate-change-on-migration.pdf.

The White House. (2024). Investing in America. https://web.archive.org/web/20250101234129/https:/www.whitehouse.gov/invest/.

Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., & Nemani, R. (2022). NASA global daily downscaled projections, CMIP6. *Scientific Data*, *9*(1), 262. https://doi.org/10.1038/s41597-022-01393-4.

Tsiboe, F., & Turner, D. (2023a). The Crop Insurance Demand Response to Premium Subsidies: Evidence from U.S. Agriculture. *Food Policy, 119*, 102505. https://doi.org/10.1016/j.foodpol.2023.102505.

Tsiboe, F., Tack, J., & Yu, J. (2023b). Farm-level evaluation of area- and agroclimatic-based index insurance. *Journal of the Agricultural and Applied Economics Association*, *2*(4), 616-633. https://doi.org/10.1002/jaa2.77.

Turner, F., Baldwin, K., Beckman, J., Nava, N.J., Tsiboe, F., & Vaiknoras, K. (2024). Potential Budgetary Impacts of Climate Change on the Pasture, Rangeland, and Forage Insurance Plan, EB-38. Economic Research Service, U.S. Department of Agriculture. https://www.ers.usda.gov/publications/pub-details?pubid=110544.

Underwood, B. S., Guido, Z., Gudipudi, P., & Feinberg, Y. (2017). Increased costs to US pavement infrastructure from future temperature rise. *Nature Climate Change*, *7*(10), 704–707. https://doi.org/10.1038/nclimate3390/.

Ungles, B., D'Orlando, J., Romero, S., & Tribble, E. (2023). Life Sciences Fit Out Costs Guide. Cushman & Wakefield. Retrieved September 17, 2024, https://www.cushmanwakefield.com/en/united-states/insights/life-sciences-fit-out-cost-guide.

United Nations. (2016). The Paris outcome on loss and damage. Article 8 of Paris Agreement and Decision. United Nations Framework Convention on Climate Change. https://unfccc.int/files/adaptation/groups_committees/loss_and_damage_executive_committee/application/pdf/ref_8_decision_xcp.21.pdf.

U.S. Chamber of Commerce. (2024). The Preparedness Payoff: The Economic Benefits of Investing in Climate Resilience: 2024 Climate Resiliency Report. https://www.uschamber.com/assets/documents/USChamber_AllState-2024-Climate-Resiliency-Report.pdf.

USDA (U.S. Department of Agriculture). (2022). *2022 Agency Financial Report*. https://www.usda.gov/sites/default/files/documents/fy-2022-agency-financial-report.pdf.

USDA (U.S. Department of Agriculture). (2023). *2023 Agency Financial Report*. https://www.usda.gov/sites/default/files/documents/fy-2023-agency-financial-report.pdf.

USDA (U.S. Department of Agriculture). (2024). *2024 Agency Financial Report*. https://www.usda.gov/sites/default/files/documents/fy-2024-agency-financial-report.pdf.

U.S. Department of Defense. (2022). *Meeting the Climate Challenge*. April 2022. https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Meeting_the_Climate_Challenge_J-book.pdf.

U.S. Department of Defense. (2023a). *U.S. Department of Defense Agency Financial Report: Fiscal Year 2023*. https://comptroller.defense.gov/Portals/45/Documents/afr/fy2023/DoD_FY23_Agency_Financial_Report.pdf.

U.S. Department of Defense. (2023b). *Enhancing Combat Capability: Mitigating Climate Risk*. March 2023. https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2024/PB_FY2024_ECC-Mitigating_Combat_Capability.pdf.

U.S. Department of Health and Human Services. (2024a). *U.S. Department of Health & Human Services 2024 - 2027 Climate Adaptation Plan*. https://www.sustainability.gov/pdfs/hhs-2024-cap.pdf.

U.S. Department of Health and Human Services. (2024b). *Justification for Estimations for Appropriations Committees. Substance Abuse and Mental Health Services Administration*. https://www.samhsa.gov/sites/default/files/samhsa-fy-2024-cj.pdf.

U.S. Department of Health and Human Services. (2024c). Linking Medical Product Manufacturing Locations with Natural Hazard Risk: Implications for the Medical Product Supply Chain. Assistant Secretary for Planning and Evaluation: Office of Science & Data Policy. https://aspe.hhs.gov/reports/medical-product-manufacturing-locations-natural-hazard-risk.

U.S. Department of the Interior. (2024). *Department of the Interior Climate Adaptation Plan 2024*. https://www.sustainability.gov/pdfs/doi-2024-cap.pdf.

U.S. Department of Transportation. (2023). *Transportation Statistics Annual Report 2023*. Washington, DC. https://doi.org/10.21949/1529944.

U.S. Department of Transportation. (2024a). *U.S. Department of Transportation 2024 - 2027 Climate Adaptation Plan*. Washington, D.C. https://www.sustainability.gov/pdfs/dot-2024-cap.pdf.

U.S. Department of Transportation. (2024b). United States Aviation Climate Action Plan. https://www.transportation.gov/sites/dot.gov/files/2024-12/US%20Aviation%20State%20Action%20Plan%202024%20-%20Final.pdf.

U.S. DOT Volpe National Transportation Systems Center. (2024). Resilience and Disaster Recovery (RDR) Tool Suite: User Guide Version 2024.1. Retrieved from https://github.com/VolpeUSDOT/RDR-Public/blob/main/documentation/RDR_UserGuide_final.pdf.

U.S. Department of the Treasury. (2023). *Insurance Supervision and Regulation of Climate-Related Risks*. June 2023. https://home.treasury.gov/system/files/136/FIO-June-2023-Insurance-Supervision-and-Regulation-of-Climate-Related-Risks.pdf.

Vaidyanathan A., Malilay, J., Schramm, P., Saha, S. (2020). Heat-Related Deaths — United States, 2004–2018. *Morbidity and Mortality Weekly Report, 69*, 729–734. http://dx.doi.org/10.15585/mmwr.mm6924a1.

Vaiknoras, K., Kiker, G., Nkonya, E., Morgan, S., Beckman, J., Johnson, M., & Maros, I. (2024). The effect of climate change on herbaceous biomass and implications for global cattle production. (Report No. ERR-339). U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details?pubid=110039.

Van Houtven, G., Gallaher, M., Woollacott, J., & Decker, E. (2022). Act Now or Pay Later: The Costs of Climate Inaction for Ports and Shipping. RTI International. Retrieved from https://www.edf.org/sites/default/files/press-releases/RTI-EDF%20Act%20Now%20or%20Pay%20Later%20Climate%20Impact%20Shipping.pdf.

WCRP (World Climate Research Program). (2024). Coupled Model Intercomparison Project (CMIP). https://www.wcrp-climate.org/wgcm-cmip.

Wen, J., & Burke, M. (2022). Lower test scores from wildfire smoke exposure. *Nature Sustainability*, *5*(11), 947–955. https://doi.org/10.1038/s41893-022-00956-y.

Wood, N., Pennaz, A., Ludwig, K., Jones, J., Henry, K., Sherba, J., Ng, P., Marineau, J., & Juskie, J. (2019). Assessing Hazards and Risks at the Department of the Interior—A Workshop Report. U.S. Geological Survey Circular 1453, 42 pages. https://doi.org/10.3133/cir1453.

WorldClim. (2024). Downscaled CMIP5 data, 5 minute spatial resolution. Retrieved from WorldClim: https://www.worldclim.org/data/v1.4/cmip5.html.

Wu, T. (2012). A mass-flux cumulus parameterization scheme for large-scale models: description and test with observations. *Climate Dynamics*, *38*, 725–744. https://doi.org/10.1007/s00382-011-0995-3.

Yesudian, A.N., & Dawson, R.J. (2021). Global analysis of sea level rise risk to airports. *Climate Risk Management*, *31*, 100266. https://doi.org/10.1016/j.crm.2020.100266.

Yukimoto, S., Adachi, Y., Hosaka, M., Sakami, T., Yoshimura, H., Hirabara, M., ... & Kitoh, A. (2012). A new global climate model of the Meteorological Research Institute: MRI-CGCM3—Model description and basic performance—. *Journal of the Meteorological Society of Japan. Ser. II*, *90*(0), 23-64. https://doi.org/10.2151/jmsj.2012-A02.

Zhao, T., & Dai, A. (2017). Uncertainties in historical changes and future projections of drought. Part II: model-simulated historical and future drought changes. *Climatic Change*, *144*, 535-548. https://doi.org/10.1007/s10584-016-1742-x.

# Appendix A: Literature Review (HUD Federal Housing Administration, section III.A.2)

**Impacts of Disasters on Mortgage Loans**

Holtermans et al. (2023) investigate the impact of climate shocks on commercial real estate mortgage payment behavior. They find that Hurricanes Harvey (2017) and Sandy (2012) led to a 281 percent and 18 percent increase on multifamily delinquencies, respectively compared to the two-year period prior to the hurricanes making landfall. Whether these are 'typical' or 'climate-induced' natural disasters, they provide evidence that natural disasters contribute to delinquencies and losses and justify consideration in HUD's analyses.

Hino and Burke (2020) conducted a nationwide evaluation of the effect of floodplain presence on single family property values, finding that full pricing of presence in the floodplain lowers property values by 5 percent to 11 percent. Additionally, they conclude that 3.8 million U.S. floodplain homes are over-valued and markets with better-informed buyers exhibit stronger responses to new information about flood risk. These concepts suggest that government loss rates could increase if agencies do not account for this risk during underwriting and budget formulation.

Holtermans et al. (2023) also performed analyses on floodplain properties for commercial loans affected by natural disasters. They find that delinquency rates are not higher in Federal Emergency Management Agency's (FEMA's) designated flood plain zones after landfall of a hurricane, and state "This finding suggests that perceived flood risk, in the form of FEMA's 100-year floodplain, is incorporated at the time of underwriting." They rationalize that proper underwriting in these floodplains accounts for why mortgages in FEMA's 100-year floodplain maintain their existing delinquency rate in the face of natural disasters, while delinquencies rise in non-floodplain areas with a larger share of damaged homes. While this may conflict with Hino and Burke (2020), both papers are important to consider in tandem. Hino and Burke (2020) suggest single family floodplain properties are overvalued, but Holtermans et al. (2023) find that lenders proactively account for this risk during underwriting. HUD's takeaway from these studies is that lenders that adequately account for weather-induced risks are more likely to be adversely affected by the consequences of these risks. However, lenders, including HUD, may overvalue these properties if they do not sufficiently account for future climate-induced weather risks over the life of the loan.

**Adverse Selection**

Another risk for HUD is the adverse selection of properties brought for insurance. Keenan and Bradt (2020) test the hypothesis that single family lenders with locally concentrated portfolios accept and retain fewer mortgage assets in climate affected areas. The logic is that locally concentrated lenders have a keen understanding of local climate risk and take steps to mitigate them. The authors conclude that climate exposure and local concentration reduce lenders' loan acceptance and retention.[38] Lenders avoid retention of these riskier loans by transferring the risk of these properties to the Federal Government (e.g., Fannie Mae and Freddie Mac). This adverse selection makes the Government Sponsored Enterprises' (GSEs') portfolios riskier. While current

[38] An important limitation is that the findings were not statistically significant outside the southeast and Gulf coast.

research focuses on single family housing loans being transferred to the GSEs, this risk could apply to multifamily loans as well. All else equal, this suggests HUD's mortgage portfolios could be more costly, if lenders require HUD's guarantee to originate these loans and bring more of this business to HUD. If lenders take these actions, loans at greater risk for climate impacts may make up a larger share of HUD's portfolio in the future. This finding paradoxically suggests HUD should also accept fewer of these high climate-risky mortgages, but it may increase the demand for the agency to do so if lenders will not lend to certain areas without government backing.

## Appendix B: Variables Used in Claim and Prepayment Models (HUD Federal Housing Administration, section III.A.2)

1. Program and subprogram types
2. Duration variables such as loan age, construction period, and lock-out periods
3. Vintage Indicators
4. Original Loan Size
5. Servicer Size
6. Seasonality Indicators
7. HUD Assistance Contract Expiration Indicator
8. Physical Inspection (PASS) Score
9. Facility Type Indicator
10. Number of Cured Defaults in Past 2 Years
11. Indicator for Previous Interest Rate Loan Modifications
12. Debt Service Coverage Ratio (DSCR)
13. Economic Vacancy Rate
14. Quick Ratio
15. Reserves Per Unit (RPU)
16. Negative Equity Indicator
17. Average Payment Period
18. Debt Yield
19. Debt-to-Assets Ratio
20. Missing or Delayed AFS Submission Indicator
21. Market Vacancy Rate
22. Median Household Income
23. Interest Rate Spread
24. Population Age 65+

# Appendix C: Detailed Descriptions of Climate Analysis Methodologies (HUD Federal Housing Administration, section III.A.2)

**Approach 1: Simplified Natural Disaster Cost Calculation**

This approach incorporates FEMA physical natural disaster hazards into FHA's loan forecasting models and calculates the costs to FHA's commercial loan portfolios. FEMA's "National Risk Index [NRI] is a dataset and online tool to help illustrate the United States communities most at risk for 18 natural hazards. It was designed and built by FEMA in close collaboration with various stakeholders and partners in academia; local, state and Federal Government; and private industry. The Risk Index leverages available source data for natural hazard and community risk factors to develop a baseline risk measurement for each United States county and Census tract."[39] These data represent current hazard risk and, as of the publication of this paper, do not account for future risk based on modeling of various climate scenarios.

For the purposes of this paper, we apply the NRI expected annual loss rates for buildings for all available disasters: 1) Avalanche, 2) Coastal Flooding, 3) Cold Wave, 4) Drought, 5) Earthquake, 6) Hail, 7) Heat Wave, 8) Hurricane, 9) Ice Storm, 10) Landslide, 11) Lightning, 12) Riverine Flooding, 13) Strong Wind, 14) Tornado, 15) Tsunami, 16) Volcanic Activity, 17) Wildfire, and 18) Winter Weather.

These annual loss rates represent the probability a building will experience a natural disaster. Figure C-1 is a map that illustrates the annual loss rate throughout the country, with all disaster types combined. It is also important to note that these are point-in-time for each geographic location. This means that they represent disasters and loss rates affecting the country today, in the early 2020s. These rates are not adjusted for changes in the future or climate impacts. Other forecasts, such as the forecasts described in the next subsection, anticipate conditions for catastrophic natural disasters will worsen in the coming decades. As FEMA's NRI is not a forecast, it does not reflect that. Nevertheless, this data allows us to calculate the costs of current natural hazards with a vetted public dataset.

To incorporate FEMA physical hazard data, we layer on the probabilistic losses stemming from natural disasters using the FEMA NRI as follows. For each year, we take the UPB at risk and calculate natural disaster losses by applying FEMA's annual loss rate of buildings in the census tract where each loan is located. After calculating building damage risk at the loan level, we aggregate the results to the portfolio level. The remaining UPB is available for default and claim stemming from market/financial causes. In other words, natural disaster loss and market/financial losses must be mutually exclusive.

The FEMA NRI loss rate serves as a combined default/claim/recovery rate; it identifies the probability of losses annually and is considered an 'all-in' loss rate. This methodology was confirmed with FEMA to ensure proper treatment of NRI estimates. In Table C-1, we provide a

[39] https://hazards.fema.gov/nri/learn-more

simplified formula that applies the NRI loss rate into the existing credit subsidy model methodology.

FIGURE C-1: FEMA NRI ANNUAL LOSS RATE FOR BUILDINGS, ALL DISASTERS

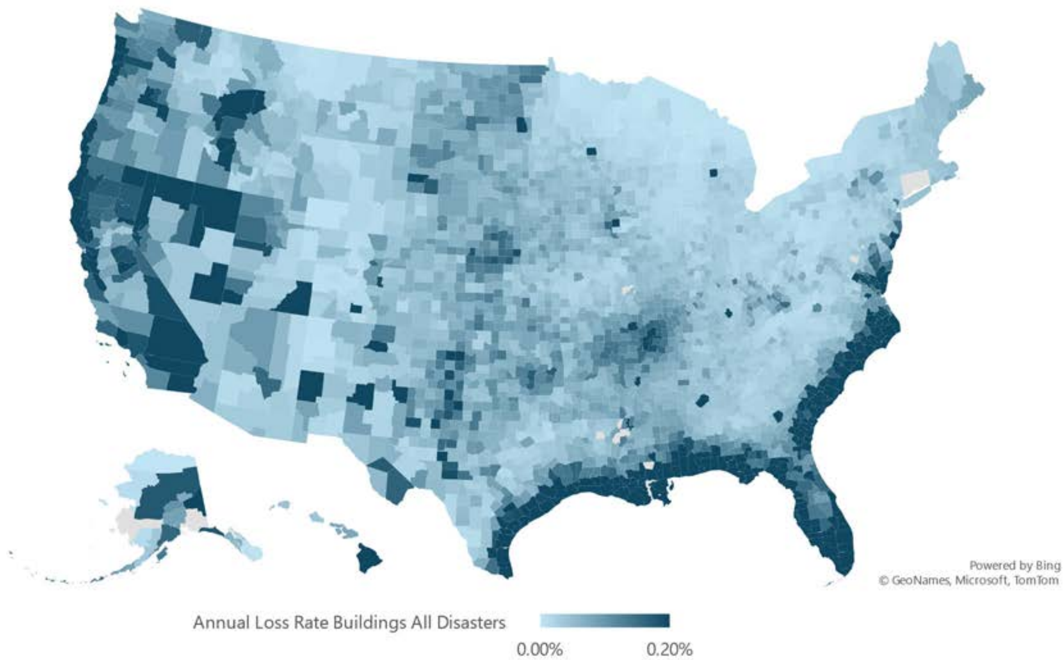



TABLE C-1: SAMPLE CALCULATION INCORPORATING FEMA NRI INTO LOAN MODELING USING EXAMPLE NUMBERS

| | |
|---|---|
| $10,000,000 | Starting Period Loan UPB |
| 1% | Example FEMA Annual Loss Rate |
| $100,000 | Disaster caused loss amount ($10M * 1% = $100K) |
| $9,900,000 | UPB available for market /financial caused default ($10M – $100K = $9.9M) |
| 10% | Probability of Default |
| $990,000 | Defaulted UPB ($9.9M * 10% = $990K) |
| 5% | Probability of Claim after a Default |
| $49,500 | Claim Amount ($990K * 5% = $49.5K) |
| 39% | Loss Rate Post Asset Sale (after Claim) |
| $ 19,305 | Market/Finance Loss Amount ($49.5K * 39% = $19.31K) |
| $ 119,305 | Total Loss Given Default/Claim ($100K + $19.31K = $119.31K) |

It is important to note that total loss estimates reflect the total loss to the Federal Government, not the loss to HUD through reduced receipts. We assume no recoveries on catastrophic natural disaster impacted properties. There are three main reasons for this: 1) We want to explicitly identify the full public impact of natural disaster risk, 2) Weak hazard insurance market in most vulnerable areas may limit recoveries, and 3) Limitations in data availability. First, one of the goals of this paper is to identify the full public dollar impact of natural disaster risk. While FEMA or other disaster recovery funding, including HUD's Community Development Block Grant Disaster Recovery funds, may cover some property losses, the source of funds still comes from taxpayer dollars. While hazard insurance could cover losses, in many locations, hazard insurance is not sufficient and insurers are pulling out of these the hazard insurance market or refusing to insure certain locations (U.S. Department of the Treasury, 2023). Florida is a prominent example of this phenomenon. This leaves borrowers supported by state insurers that use taxpayer dollars. 3) Lastly, we plan to incorporate property-level hazard insurance data in the future. However, we were unable to obtain and prepare the data in time for this submission. In the future, we hope to explicitly identify the potential property damage and segment the amount of losses covered by sources such as hazard insurance.

### Approach 2: Transition Impacts of Climate Change

FEMA's NRI has many advantages, including: (1) there is no cost to HUD to obtain the data, (2) data are widely accessible, and (3) data are easy to incorporate into FHA's existing models. However, there are several disadvantages, including: (1) the values do not reflect climate-induced risks, (2) the data are static, point-in-time values, limiting forecasting accuracy, and (3) NRI does not include economic scenarios accounting for different climate changes policies (often referred to as transition impacts of climate change). For this reason, FHA procured services that provide property-level climate risk data for probability of acute natural disasters, such as hurricanes, floods, and wildfires. These data also include time-varying macroeconomic forecasts on the transitional risks related to climate change.

Transition-related climate risks refer to the potential economic impacts of policies that reduce fossil fuel emissions and mitigate climate change. For example, climate policies may shift employment patterns, which could subsequently shift population between different cities or states. Such changes in migration could affect vacancy rates and thereby net operating income and property values. Approach 2 seeks to account for these impacts on loan performance and cash flow forecasts. To evaluate these transition-related economic impacts of climate change, we apply three specific policy scenarios, described below: 1) Current Policy, 2) Early Policy/Net Zero 2050, and 3) Late Policy/Delayed Transition.

#### *Current Policy*

The Current Policy scenario is based on the Network for Greening the Financial System (NGFS) Current Policy scenario of the same name. This scenario assumes governments across the world only implement current policies to address climate change. While many countries are implementing policies to tackle climate change, they are not enough to meet current commitments under the Paris Climate Accords to limit warming to well below 2ºC above preindustrial levels. Under this scenario, emissions continue to grow until 2080. Temperatures breach the Paris target of 2ºC above preindustrial levels by 2050 and rise more than 3ºC by 2100. Global warming at this level leads to nonlinear increases in severe and irreversible physical impacts. The shock develops slowly throughout the forecast horizon. Physical damages take time to materialize, as carbon emissions lead to higher temperatures and economic dislocation only over the long term.

#### *Early Policy / Net Zero 2050*

Under this scenario, policymakers immediately act to mitigate climate change and curtail carbon emissions, achieving global net-zero carbon emissions by 2050 and a global temperature increase of 1.5ºC from preindustrial levels.

*Late Policy / Delayed Transition*

Under this scenario, globally policymakers put off action to curtail climate change and abate carbon emissions until 2031. As in the Early Policy/Net Zero 2050 scenario, countries with current commitments to reach net-zero emissions by 2050 meet their goals. Unlike the Net Zero 2050 scenario, the Delayed Transition scenario does not assume that those countries without commitments reach net-zero emissions. The emissions trajectory is therefore higher than in the Early Policy / Net Zero 2050 scenario and global warming by 2050 reaches 1.8ºC above preindustrial levels.

**Approach 3: Catastrophic Natural Disaster Impacts of Climate Change**

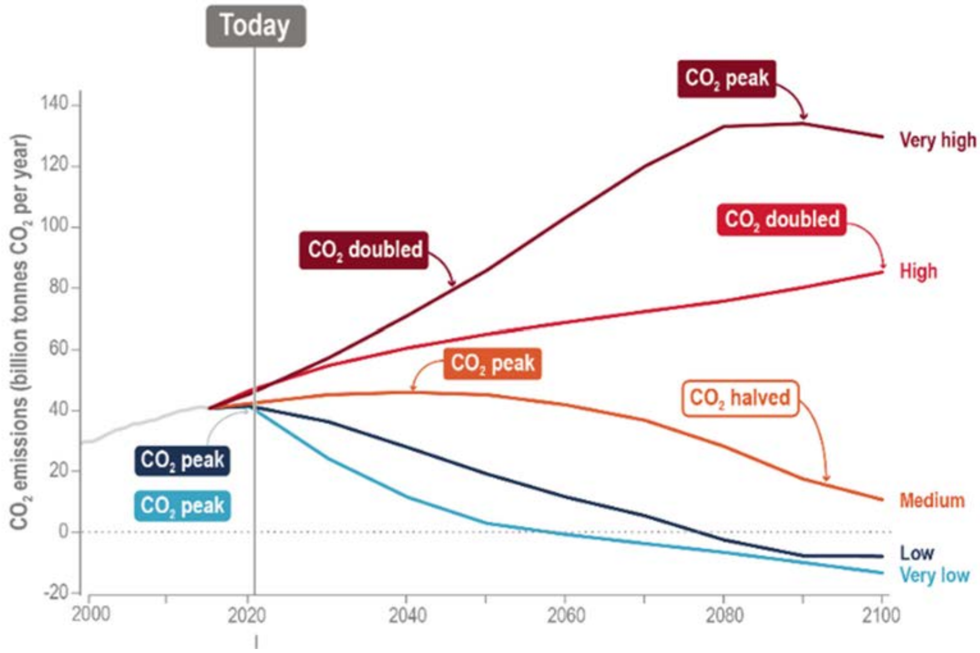
Lastly, we layer dynamic catastrophic natural disaster modeling on top of the current policy scenario from the transition analyses. We obtained the probability of building loss from natural disasters at the zip code level. The losses are forecast for each location in decade segments (e.g., 2020-2029, 2030-2039, etc.). Climate forecasts are run under several greenhouse gas (GHG) emissions scenarios that represent different possible futures. The following representative concentration pathways (RCPs) represent different GHG concentrations in the atmosphere.

RCP 4.5 is an intermediate GHG emissions scenario, under which emissions remain around current levels until the middle of the century and then drop (IPCC, 2021). It involves a range of strategies and technologies to reduce greenhouse gas emissions, including using more renewable energy and nuclear power, and implementing energy efficiency measures.

RCP 8.5 is a very high emissions scenario, under which emissions roughly double from current levels by 2100. This results in a temperature increase of around 4.3°C by 2100, compared to pre-industrial temperatures (IPCC, 2021). RCP 8.5 highlights the potential consequences of insufficient action on climate change. It includes unsustainable consumption rates and energy consumption, increased reliance on fossil fuels, and significant ecological challenges. Figure C-2 contains a graphic from the Intergovernmental Panel on Climate Change (IPCC), which depicts emissions under varying GHG emissions scenarios.[40] The RCP 4.5 is the 'Medium' line in the chart, and RCP 8.5 is the 'Very high' line in the chart.

[40] Infographic TS.1 in IPCC, 2021: Technical Summary. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 147–286 https://www.ipcc.ch/report/ar6/wg1/figures/technical-summary/ts-infographics-figure-1.

FIGURE C-2: IPCC GRAPHIC ON GHG EMISSIONS SCENARIOS




Source: Infographic TS.1 in IPCC, 2021: Technical Summary. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 147–286 https://www.ipcc.ch/report/ar6/wg1/figures/technical-summary/ts-infographics-figure-1.

To assess the impact of these scenarios on FHA loans, we obtained natural disaster loss rates for the following seven stressors: 1) Wildfires, 2) Floods, 3) Hurricanes, 4) Sea Level Rise, 5) Water Stress, 6) Heat Stress, and 7) Earthquakes. While earthquakes are not climate related, given the availability of the data, and that FHA's pre-existing model does not account for earthquake risk, we incorporate the loss rates for this disaster.

When analyzing the loss rates for RCP 4.5 and RCP 8.5, we found the forecasts are identical in the 2020s and on average RCP 8.5 is 1 basis point larger than RCP 4.5 in the 2050s. This can be explained as GHG forecasts diverge more significantly after 2050 (IPCC, 2021). Figures C-3 and C-4 include maps of the composite loss scores across all disasters for RCP 4.5 in the 2020s and 2050s.

FIGURE C-3: MAP OF COMPOSITE LOSS RATES IN THE 2020s FOR RCP 4.5 SCENARIO

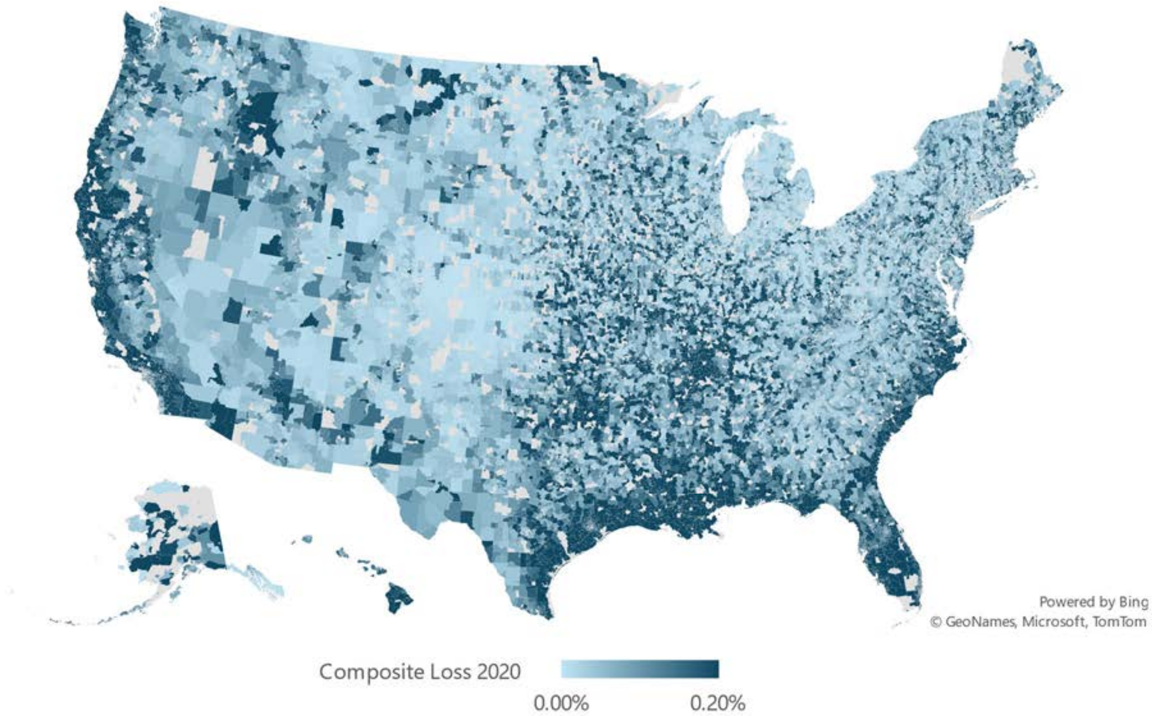
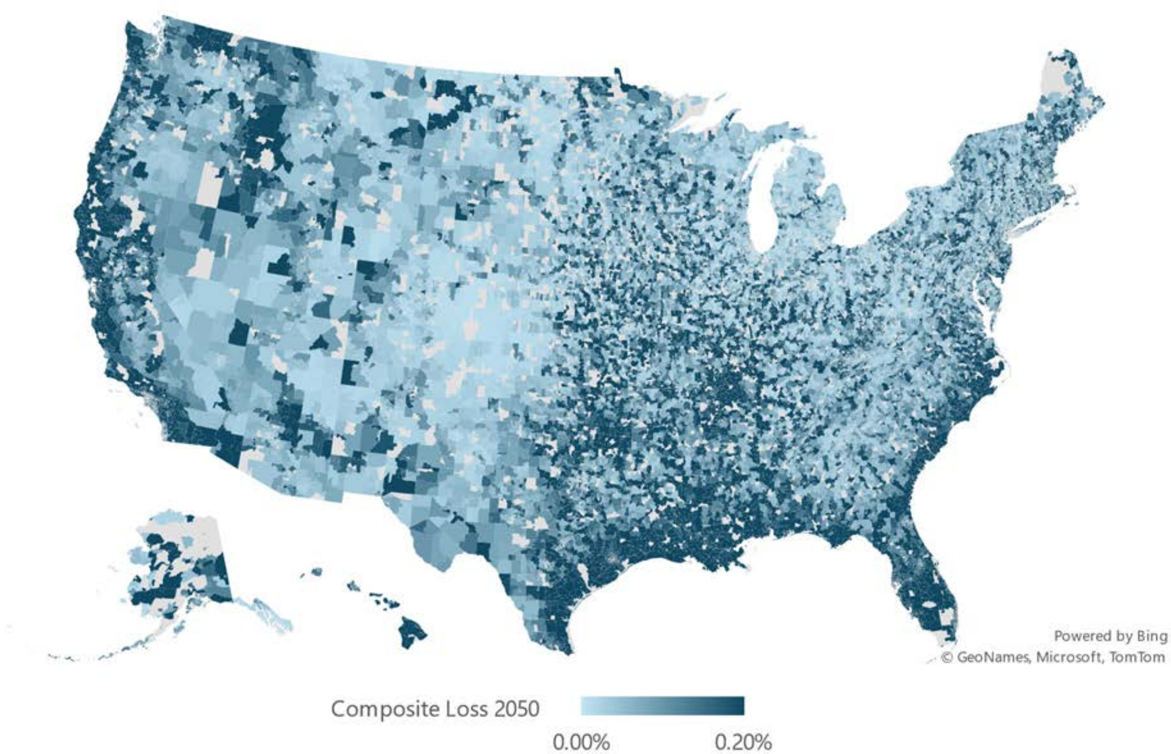



FIGURE C-4: MAP OF COMPOSITE LOSS RATES IN THE 2050s FOR RCP 4.5 SCENARIO



Additionally, Table C-2 includes a list of the locations of zip codes with the highest RCP 4.5 loss rates in 2020s and 2050s, and the forecasted increase over that time.

TABLE C-2: ZIP CODES WITH THE HIGHEST CATASTROPHIC NATURAL DISASTER LOSS RATES, 2050s VS. 2020s

| Zip code | 2020s Loss Rate | 2050s Loss Rate | Difference (2050s-2020s) |
|---|---|---|---|
| Kobuk, Alaska | 8.20% | 12.65% | 4.45%-pts |
| Shageluk, Alaska | 4.23% | 6.52% | 2.30%-pts |
| Buras, Louisiana | 5.05% | 6.48% | 1.43%-pts |
| Braithwaite, Louisiana | 4.43% | 5.86% | 1.43%-pts |
| Chatham County, Georgia | 4.55% | 5.96% | 1.41%-pts |
| Boothville, Louisiana | 4.42% | 5.82% | 1.39%-pts |
| Everglades, Florida | 3.27% | 4.57% | 1.30%-pts |
| Buras, Louisiana | 3.77% | 5.03% | 1.25%-pts |
| Chokoloskee, Florida | 3.08% | 4.32% | 1.24%-pts |
| Braithwaite, Louisiana | 3.09% | 4.16% | 1.07%-pts |
| Shungnak, Alaska | 1.95% | 3.00% | 1.05%-pts |
| Combs, Kentucky | 4.23% | 5.26% | 1.03%-pts |
| Sunshine, Louisiana | 8.48% | 9.49% | 1.01%-pts |
| Pearlington, Mississippi | 3.11% | 4.10% | 0.99%-pts |
| Savannah, Georgia | 3.34% | 4.29% | 0.95%-pts |

Akin to Approach 1 it is important to note that we assume no recoveries on properties impacted by catastrophic natural disasters for the purpose of this analysis.[41]

Lastly, we must acknowledge the limitations of this approach. First, the catastrophic natural disaster data are provided at the zip code level. For commercial properties, the most accurate assessments will occur at the property level. Aggregated numbers do not account for building level mitigation measures and any site-specific differences within a zip code. Property level data would be most accurate, and even data aggregated to the Census Block or Census Block Group level would provide greater granularity and accuracy than zip code data, with greater feasibility than property specific metrics. Second, there are many different climate models available and FHA's selected source reflects only one model. One reason FHA's selected source was most preferred was its ability to differentiate across property types (e.g., single family vs. multifamily vs. healthcare). Nevertheless, the technology across sources improves every year and there is no consensus around which models are most accurate. FHA selected the best option for its purposes based on its market research.

[41] The rationale follows that discussed under Approach 1. While the government may cover some losses through disaster assistance programs, such payments are still paid by taxpayers. It is also possible that hazard insurance could cover losses. However, in many locations, hazard insurance is not sufficient and insurers are pulling out of the hazard insurance market. This leaves borrowers supported by state insurers that use taxpayer dollars. The interagency working group suggested avoiding including these recoveries to show the full extent of possible losses.