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OFFICE OF MANAGEMENT AND BUDGET

CLIMATE RISK EXPOSURE:

AN ASSESSMENT OF THE FEDERAL GOVERNMENT'S FINANCIAL RISKS TO CLIMATE CHANGE

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Introduction

The climate crisis poses a serious threat to the United States economy and human welfare, with a narrowing timeframe to invest in opportunities to avoid the most catastrophic impacts. Extreme weather events can be exacerbated by climate change, disrupting supply chains, and flooding made worse by sea level rise can destroy critical infrastructure. As a smaller subset of these impacts, climate change threatens the Nation's fiscal health. The Fourth National Climate Assessment (NCA4) notes that:

> *Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth.*

The impacts of climate change on businesses and communities are broad; escalating costs, and lost revenue as a direct or indirect result of a changing climate is significant and varied. Across the United States, estimated damages from a subset of storms, floods, wildfires, and other extreme climate-related weather events have already grown to about $120 billion a year over the past five years (Smith, 2021). Some of the most severe harms from climate change will fall disproportionally upon socially vulnerable populations, including racial and ethnic minority communities (EPA, 2021). The Federal Government plays a critical role in helping American families, businesses, and communities recover from the impacts of extreme weather events – often acting as an insurer of last resort. Communities and businesses also face both immediate hazards, along with increasing risks over time, such as sea level rise. For instance, the Federal Government must ensure that Americans have access to housing and healthcare that is safe and affordable as well as access to critical transportation and communication infrastructure. Climate change increases the need for Federal support in these areas.

As broad economic damages from climate change grow, so does the impact of the climate crisis on the Federal budget. the Federal Government's budget is directly and substantially at risk from expected lost revenues and increasing expenditures due to climate change damages in coming decades, such as increasing costs from physical damages to our nation's infrastructure and healthcare expenditures, the instability of certain subsidized insurance programs, and accelerating instability that threatens global security.

To help address threats that climate change poses to the economy, President Biden signed the "Executive Order on Climate-Related Financial Risk" ("Executive Order") on May 20th, 2021. Section 6(b) of the Executive Order directs "[t]he Director of Office of Management and Budget and the Chair of the Council of Economic Advisors, in consultation with the Director of the National Economic Council, the National Climate Advisor, and the heads of other agencies as appropriate, [to] develop and publish annually, within the President's Budget, an assessment of the Federal Government's climate risk exposure." This paper assesses several areas where the Federal Government may experience significant climate change-associated risk and highlights some steps the Federal Government is taking to address those risks.

Although the presence of risk to the U.S. economy and to the Federal budget across these and other exposure points is clear (and supported by a large body of scientific evidence), we remain in the early stages of quantifying the total potential risk for American taxpayers and Federal programs. In several critical areas, quantitative projections of specific climate impacts are not yet available. Additionally, where climate impact measures do exist, estimating the impact on the Federal budget can be challenging due to the need to tie those risks to future decisions (e.g., estimating the extent to which the U.S. government will provide disaster aid or take on other liabilities). The report examines the Federal Government's climate risk exposure through six program-specific assessments that consider a handful of the out-year potential damages to these programs: crop insurance, coastal disasters, Federal healthcare, Federal wildland fire suppression, Federal facility flood risk, and flood insurance.[1] By reviewing the major impact categories in the NCA4 and examining data limitations of future risk for Federal programs, it is clear that significant climate risks are understood and apparent, but they are unable to be quantified at this time. The assessments included in this paper and projected risks that are quantified are helpful in approximating the order of magnitude of potential impacts of climate change on the Federal budget, in these six areas, but are subject to limitations and uncertainty.

A preliminary OMB/CEA report on this topic was published in 2016, which estimated that annual Federal expenditures could increase by $34-$112 billion per year by later century due to the impacts of climate change, along with significant potential for economic and Federal revenue losses (OMB, 2016). This assessment expands upon, and updates, that 2016 assessment.

Expenditure Impacts

Several limitations exist when projecting Federal expenditures. The horizon for most projections in Federal budgeting is 10 years; that horizon reflects a balance between the importance of considering both the current and future implications of budget decisions made today, and a practical limit on the construction of detailed budget projections for years in the future. Many impacts of climate change are expected to continue to worsen far beyond this 10-year horizon, and climate assessments (including those conducted in this paper) are often based on scenarios going to the mid- or late-century – well within the lifetimes of today's youngest Americans.

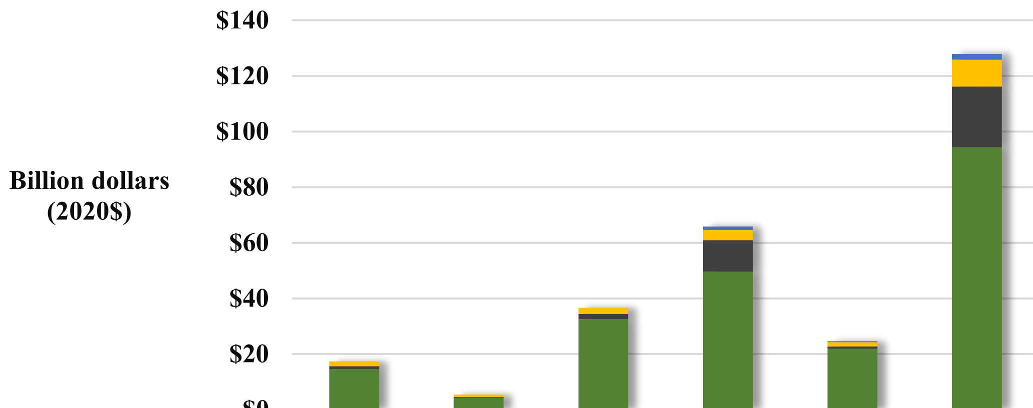
Nonetheless, it is informative to regularly model future conditions with the best available data to provide a relative scale of impact on future expenditures. The six individual assessments described in this paper reflect only a small portion of potential future financial risks to the Federal Government, but clearly illustrate that Federal financial risks will increase and create a demand for increased Federal expenditures.

Table 1 below shows estimates of recurring, annual expenditures (as impacted by climate change). The increased expenditures from these assessments total between an additional $25 billion to $128 billion per year by late century. These estimates represent only a narrow portion

[1] The Federal Government's exposure to climate risk is broader than the six assessments conducted for this paper. For further discussion of additional areas of Federal financial risks due to climate change, see the FY 2023 Analytical Perspectives chapter: *Federal Budget Exposure to Climate Risk*. https://www.whitehouse.gov/wp-content/uploads/2022/04/ap_21_climate_risk_fy2023.pdf

of the full financial risks of climate change to the Federal Government. Several impacts are not quantified in this report due to data limitations and other obstacles. For instance, impacts on national security; transportation, energy, and water infrastructure; ecosystem services; and some types of health impacts are not quantified due to the nascent nature of conducting these assessments. However, opportunities exist to expand expenditure assessments in future years to include additional topics and a broader set of modeling.

Table 1. Summary of Spending Increases for Quantified Climate Risk Exposure of Assessed Programs, in billion dollars (2020$)[a]



	Mid Century[e]			Late Century		
	Mean	Lower	Higher	Mean	Lower	Higher
Crop Insurance[b]		NA	NA	$1.2	$0.3	$2.1
Wildland fire Suppression[c]	$1.7	$0.8	$2.3	$3.7	$1.6	$9.6
Health Impacts	$1.0	$0.2	$1.8	$11.3	$0.8	$21.9
Coastal Disasters	$14.6	$4.4	$32.5	$49.6	$21.9	$94.3
Total[d]	$17.3	$5.4	$36.6	$65.8	$24.6	$127.9

[a]"Lower" estimates are largely based on assessments assuming Representative Concentration Pathway (RCP) 4.5, which the NCA4 framed in 2018 as a "lower" scenario with less warming - generally associated with lower population growth, more technological innovation, and lower carbon intensity. "Higher" estimates are largely based on assessments assuming RCP8.5, which the NCA4 frames as a "higher" scenario - generally associated with higher population growth, less technological innovation, and higher carbon intensity.
[b]The crop insurance analysis was only conducted for late century.
[c]The median of all wildland fire suppression simulations are used in the "Mean" column, so outliers in the "Higher" scenario are not overemphasized in the results.
[d]Several Federal financial risks are not included in this table due to the nascent ability to quantify future expenditures in this field. Some other future expenditures, such as flood insurance are not expected to increase because rate setting policies yield actuarially fair premiums with the ability to adjust as climate conditions change.
[e]The science of estimating Representative Concentration Pathways (e.g. RCP4.5 and RCP8.5) has evolved since NCA4 was released in 2018. RCP8.5, for instance has been viewed by some researchers as an extreme scenario. specific climate scenarios, and time periods can vary across this paper's assessments due to differences in available studies, datasets, and models. As a result, findings are comparable across risk assessments at an order-of-magnitude scale.

Estimated climate-related financial costs reach into the tens of billions per year by mid-century and grow into late-century. Climate-related costs in the assessed areas will also likely vary significantly from year to year, for instance the case of extreme weather events is expected to become more frequent and impactful in the years to come. This variation makes future planning and budgeting even more challenging and can create a reliance on supplemental appropriations outside of the annual budget process.

Revenue Impacts

Climate change is projected to reduce economic output in the United States and across the globe (Auffhammer, 2018). Because a large proportion of Federal revenue comes from labor and capital income taxes, and because lower output means lower aggregate labor and capital income, reduced output in the United States means lost revenue for the Federal Government under current tax policies. The Intergovernmental Panel on Climate Change (IPCC)'s most recent midrange projection under their very high greenhouse gas (GHG) emissions scenario suggests that warming of four and a half degrees Celsius over preindustrial levels could occur by 2100 if global emissions are allowed to continue unabated. However, climate commitments, from both governments and private industry, and technological advancements that have been implemented worldwide indicate that warming may be limited to just over three degrees Celsius under intermediate GHG emissions scenarios (IPCC, 2021; NGFS, 2021). One way economists have tried to estimate the economic damages from climate change is by estimating the correlation between macroeconomic activity and observed temperatures. Economists using this approach estimate that economic damages from warming between two and a half and four and a half degrees Celsius range from two to 23 percent of global gross domestic product (GDP) each year by 2100 (Kalkuhl and Wenz, 2020; NGFS, 2021; Newell, Prest and Sexton 2021; Burke et al. 2015). The distributions of these damage estimates are often not symmetric, with the same studies producing upper-end extreme outcomes at the 95^{th} percentile that range from 8.5 percent to over 50 percent of global GDP. One of the economic models places the estimate of annual damages from warming of three degrees Celsius at the 95^{th} percentile at about 10 percent of U.S. GDP by the end of the century (NGFS, 2021).

A number of factors affect the magnitude of such estimates, including the known uncertainties not captured. For example, the estimates do not account for important long-term factors that remain difficult to estimate using short-term variations in weather, both in terms of changes to the environment and monetarily, such as biodiversity loss, ocean acidification, and sea level rise (Dell, Jones, and Olken, 2014). Tipping points associated with non-linear changes in the climate and unprecedented events, like ice sheet disintegration and thawing permafrost, are also not captured in projections based on historical relationships between climate change and physical outcomes (Dietz et al., 2021). In addition, there is a lot of variation across current models that stem from uncertainty as to whether economic damages accrue to the level of GDP, the growth rate of GDP over time, or both. A small change in the growth rate can accumulate into large annual damages over a longer horizon, pushing the expected economic damages towards the top of the range of estimated impacts. For example, research suggesting that economic productivity is nonlinear relative to temperature changes—that there are significant negative temperature threshold effects on productivity in affected sectors—indicates that the estimates of climate change on economic growth rates would result in global GDP being reduced by over 20 percent in 2100 in the high emissions RCP 8.5 scenario (Burke et al., 2015). In contrast, Newell, Prest and Sexton (2021) assess the impact of climate change on GDP levels and show that in 2100, using the same high emissions scenario, global GDP is reduced by only 1 to 3 percent.

The uncertainty of economic damage projections is compounded when attempting to estimate the associated potential for lost U.S. Federal revenue. The exercise relies on difficult assumptions about the impact of economic losses on U.S. GDP and Federal revenue's sensitivity to U.S. GDP. For example, as discussed above, economic losses are commonly expressed as a percent of output and losses that occur in the form of non-market losses (e.g., premature mortality or biodiversity loss) do not directly translate into lost GDP—or Federal revenue.

In a scenario resulting in three degrees Celsius warming, the top end of the confidence interval (95th percentile) of GDP losses would result 7.1 percent lower Federal revenue by 2100 -- equivalent to approximately $2 trillion per year in today's dollars.[2] These estimates are the product of a simple extrapolation from leading economic loss projections and should be interpreted as one point in a range of possible revenue losses, rather than precise estimates.

Overview of assessments

Climate-related financial risks can affect the U.S. economy through two channels. The first involves physical risks, arising from damage to property, infrastructure, human health, and land. The second, transition risk, results from changes in policy, technology, and consumer and market preferences during the adjustment to a lower-carbon economy. Although the presence of risk to the U.S. economy and to the Federal budget across these and other exposure points is clear, and supported by a large body of scientific evidence, quantifying the total potential risk for American taxpayers and Federal programs remains in its early stages. Also, quantitative projections of specific climate impacts to related Federal program expenditures are not yet available in several critical areas, such as Federal financial infrastructure risks, national security risks, and risks to ecosystems. Additionally, where climate impact measures do exist, estimating the impact on the Federal budget can be challenging due to the need to tie those risks to future decisions (e.g., estimating the extent the U.S. government will provide disaster aid or take on other liabilities). The projections we do have are useful in approximating the order of magnitude of potential impacts of climate change on the Federal Budget but are still subject to significant limitations and uncertainty.

These assessments complement execution of the *Executive Order on Tackling the Climate Crisis at Home and Abroad*, as well as supporting budget priorities related to climate adaptation and resilience, by focusing on long-term risks to the United States' Federal ledger. Much of the work associated is also complemented by, and benefits from, the National Climate Assessment.

[2] The 95th percentile estimate used here is projected by NGFS under their Current Policies scenario. The NGFS Current Policies scenario assumes warming of over three degrees Celsius above pre-industrial averages. Economic damages for that amount of warming are estimated using the results from Kalkuhl and Wenz (2020) and are roughly 10 percent of GDP in 2100.

While a robust set of scientific studies and models of the global risks and impacts of climate change exist, our current understanding of the fiscal risks of climate change to the Federal Government is nascent, limited in scope, and subject to significant uncertainty. For instance, many models are based on known conditions, while the largest future climate impacts will be from previously low probability events that are now becoming normalized. Modeling these high-impact events can create wide ranges of potential cost impacts. However, the available evidence thus far indicates the fiscal risks to the Federal Government could be very significant over the course of this century without ambitious action to reduce GHGs and adapt our communities to a changing climate.

A preliminary, related OMB/CEA report, *Climate Change: The Fiscal Risks Facing the Federal Government*, was published in 2016, along with an Analytical Perspectives chapter in the FY 2017 Budget. The 2016 report concluded that annual Federal expenditures could increase by $34 to $112 billion per year by later this century due to the impacts of climate change, along with significant potential for economic and Federal revenue losses. The assessment noted limitations in producing these estimates and did not attempt to assess macroeconomic impacts of climate change.

This white paper builds on the work done for the 2016 report. In this white paper, prior assessments were either updated, expanded upon, or reworked using updated modeling assumptions. In many subject areas, more recent relevant Federal and academic modeling or analyses have been published, which have been utilized to advance and improve the assessments conducted for this white paper. OMB selected six key areas to conduct individual assessments in this white paper. These areas were chosen because each has strong links to the Federal Budget, are clearly vulnerable to the impacts of climate change, and are topics which have scientific or economic data available that can produce quantitative modeling of impacts. The six areas are: crop insurance, coastal disasters, Federal healthcare spending, Federal wildland fire suppression expenditures, Federal facility flood risks, and flood insurance. In each of these areas, OMB worked with experts across the Federal Government to leverage the best available quantitative modeling to estimate key potential effects of climate change and the associated financial risks to those Federal programs.

Each risk assessment draws either on findings from the best available scientific and economic literature or new analysis that uses existing models and datasets. The assessments generally compare current annual spending without further climate change to projected spending based on future scenarios utilized by the National Climate Assessment and International Panel on Climate Change. The assessments draw upon Representative Concentration Pathways, or RCPs, which are widely used in the climate research community to describe different climate futures and are based on the volume of greenhouse gases emitted. RCPs form the foundation for the majority of recent climate-related modeling efforts. The Fourth NCA largely focuses on RCP8.5 and RCP4.5 for framing purposes.[3] This paper attempts to follow the framing of the NCA by using data and modelling references from RCP4.5 and RCP8.5 when climate projection models and data are available. However, specific climate scenarios, and time periods can vary across this paper's

[3]RCP4.5 is framed as a "lower" scenario with less warming and is generally associated with lower population growth, more technological innovation, and lower carbon intensity. RCP8.5 is framed as a "higher" scenario and is generally associated with higher population growth, less technological innovation, and higher carbon intensity.

assessments due to differences in available studies, datasets, and models. As a result, findings are comparable across risk assessments only at the order-of-magnitude scale. Several of the assessments compare an unmitigated climate to different potential futures.

In addition, due to limitations in available models and the uncertainty inherent in projecting several decades into the future, the results of these assessments should be interpreted as indicative of the order of magnitude of potential impacts of climate change on Federal spending in the studied scenarios. Actual future impacts will vary depending on a wide range of factors such as population and income growth, policy changes, technological development, changing behavior—including adaptive responses—and the magnitude and pace of further climate change. Generally, the assessments do not attempt to fully represent the potential for adaptation or policy changes to attenuate fiscal impacts. For example, adaptation investments or assumptions are often not modeled or forecasted.

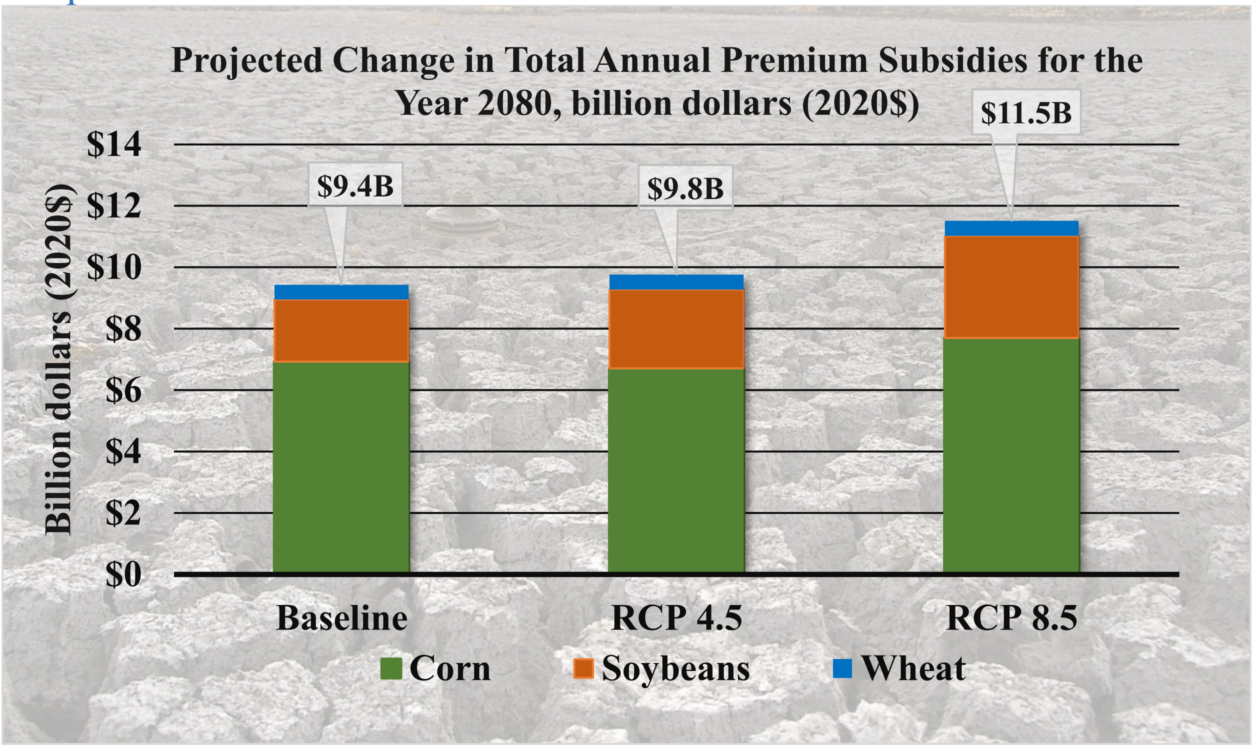
Along those lines, the overall scope of the paper is not comprehensive. Substantial financial risks to national security, transportation and water infrastructure, ecosystem services, and several other climate impacts are not assessed in this paper. Also, the breadth of each individual assessment offers a fraction of the potential quantified risks within that topic. For instance, morbidity estimates are modeled for only a handful of the health risks caused by climate change in the healthcare assessment. It is highly plausible that the actual climate-related financial risks to the Federal Government are much larger than those that are presented in this paper.

Future opportunities to better understand financial risks

As academic literature on climate science and economics continue to advance, further collaboration between OMB, CEA, and other key Federal agencies will be necessary to ensure that the understanding of climate change risks facing the Federal Budget becomes more comprehensive. The "Executive Order on Climate-Related Financial Risk" calls for an annual assessment of the Federal Government's climate risk exposure. By more regularly and consistently incorporating climate-related financial risk planning into the budget process, the executive branch will be better suited to assess risks.

The FY 2023 President's Budget and agencies' Congressional Justifications highlight several budgetary requests that will help reduce the Federal Government's long-term fiscal exposure to climate-related financial risk. Near-term Federal investments to both mitigate greenhouse gas emissions and adapt to future climate scenarios can help reduce the future costs identified in this paper but will require both Congressional appropriations and Federal implementation. Several near-term investments to reduce future climate risks are presented in the FY 2023 President's Budget. While investments are expected to reduce the Federal Government's exposure to future climate-related financial risks, more work is needed to identify and quantify the impact of factors that can mitigate or compound climate change fiscal risk. Investments in adaptation, for instance, can significantly reduce future risk exposure. At times, higher up-front adaptation costs will save taxpayers and the Federal Government in the long-term. On the other hand, business as usual investments that are more prone to the risks from climate change could further exacerbate future risks. Better understanding and attempting to quantify factors like these as they relate to Federal budget formulation is important for taking steps to mitigate the broad and urgent financial crises the Federal Government could face.

Crop Insurance



USDA found that Federal expenditures on crop insurance premium subsidies are expected to increase 3.5 to 22 percent due to climate change-induced crop losses by the late-century Under RCP 4.5, the subsidies for crop insurance premiums would be about 3.5 percent higher compared to a climate similar to that of the recent past—an increase of roughly $330 million/year in 2020 dollars by the late century. Under RCP 8.5, the projected increase in crop insurance premium subsidies is 22 percent—an approximate increase of $2.1 billion per year (2020$) by the late-century.

As mentioned in NCA4, climate change is anticipated to shift agricultural production regions (USGCRP, 2018). Average crop yields for most major commodities are projected to decline due to higher temperatures, as well as climate-change induced drought intensification and increasingly frequent natural disasters such as flooding. Particularly, crops which are planted in the spring—such as corn, soybeans, and sorghum—are more likely to experience declines in productivity due to excessive heat and dryness during summer (Gowda et. al, 2018). Crops vary in their ability to handle high temperatures and drought. For example, soybeans are more sensitive to extreme heat relative to corn; therefore, soybeans are projected to experience larger declines in crop productivity from climate change compared to corn (Crane-Droesch et al., 2019). However, crops, such as winter wheat and barley, may experience increased yields from higher temperatures in the spring since these crops are planted in the fall and harvested in early summer. In the Western part of the United States, where wildfire frequency and intensity are anticipated to increase, wine grape production may experience losses directly from fire and indirectly from smoke taint[4] (Krstic, Johnson, and Herderich, 2015). While there could be some benefits to climate change, models overall project a negative impact on crop production. Previous research has estimated that county-level temperature trends caused 19% of the national-level Federal crop insurance gross indemnities from 1991 to 2017 (Diffenbaugh et al., 2021).

The Federal Crop Insurance Program (FCIP) provides subsidized insurance for losses from unexpected decreases in crop yields or revenue caused by natural perils. The program operates through a public-private partnership between the Federal Crop Insurance Corporation (FCIC)—the Federal Government entity—and Approved Insurance Providers (AIPs)—the private sector entities. The Risk Management Agency (RMA) of the U.S. Department of Agriculture (USDA) oversees operation of the FCIP, as directed by the FCIC Board of Directors (7 U.S.C. § 1508). The FCIP is subsidized through insurance premium subsidies and, for the private sector implementation, subsidies for administrative and overhead expenses (7 U.S.C. § 1508(e)). Premium subsidy is based on a percentage of the total insurance premium, such that the total premium is the sum of the premium subsidy and the "farmer-paid" premium (Rosch, 2021). Additionally, the program requires that producers cannot be excluded from the program on the basis of risk, assuming the producer is using good farming practices for producing their crop. In 2021, farmers paid 37% of the total crop insurance premium, with the remaining 63% being subsidized by the Federal Government (Risk Management Agency, 2021). Also, the FCIC provides reinsurance— insurance for insurance providers when catastrophic events result in high indemnities paid to insurance policyholders—to the AIPs through the *Standard Reinsurance Agreement* (SRA), which provides the terms and conditions under which FCIC and the AIPs share in premiums and losses. When the FCIC's share of losses exceeds its share of premiums per the terms of the SRA, there is an additional cost to the Federal Government in the form of "underwriting losses" (Rosch, 2021).

While the Federal crop insurance program existed in pilot form from the 1930s through the 1970s, the permanent Federal crop insurance program was established by the Federal Crop Insurance Act of 1980. The program did not gain traction until after the 1994 Crop Insurance Reform Act (Risk Management Agency, 2013), which significantly increased premium subsidies and introduced the catastrophic level of coverage. As premium subsidies increased, participation expanded, and underwriting was refined, the program's actuarial performance improved. Since the expansion of the program, the FCIP portfolio has grown in diversity in crops and geographic location. Over 100 agricultural commodities had crop insurance policies available and the liability for the program totaled $136.6 billion with premium subsidies totaling $8.6 billion in 2021. (Risk Management Agency, 2021). By expanding to include a greater diversity of locations and crops, the FCIP is able to maintain actuarial soundness, which means, on average, that unsubsidized (total) insurance premiums will equal gross insurance indemnities[5]. In other words, risk is accurately reflected in insurance premiums. However, maintaining actuarial soundness does not mean that the program costs will be constant. For example, climate change could impact the costs of the program.

[4] Smoke taint causes crops to become unpalatable due to an "ash-y" flavor. The issue is particularly notable in wine grapes.

[5] Gross indemnities are equal to the indemnities that farmers receive from the insurance policy in the event of a crop loss. Net indemnities are equal to the gross indemnities minus the farmer-paid insurance premium. Note the definition of "actuarially sound" excludes administrative costs.

To examine how the program cost could change over time, researchers from USDA's Economic Research Service (ERS) developed a series of models to project the increase in Federal Government outlays associated with crop insurance premium subsidies towards the end of this century (Crane-Droesch et al., 2019). While the Federal Government subsidizes premiums, administrative costs, and underwriting losses, the majority of the outlays for FCIP are associated with the premium subsidies. For example, for crop year 2019, 76.5% of the program costs were from premium subsidies (Risk Management Agency, 2021).

Risk Assessment

To develop projected costs of the FCIP, there are several modeling components. The modeling assumes that the policy variables, such as the design of the crop insurance program and the current subsidy rates, remain constant. The potential changes in costs stem from changes in the total premiums, which are dependent on acreage, average yields, average prices, yield risk, and price risk. Since premium subsidies are a percentage of the total premiums, increases or decreases in the total premiums will result in the premium subsidies increasing or decreasing as well. Given that the majority of crop insurance liability[6] (and the most robust data) is for row crops, the researchers focused on the three most widely grown crops in the United States: corn, soybeans, and wheat (Crane-Droesch et al. 2019). These three crops account for 60% of total crop insurance liability (Risk Management Agency, 2021).

The model components are as follows:

- **Yields:** The researchers established historical relationships between crop yield (crop production per acre) and weather variables, such as air temperature, precipitation and growing degree days[7]. The models, utilizing the historical data, are then used to project yields out to the end of the century with input from five commonly-used General Circulation Models (GCMs), which represent a wide range of outcomes. GCMs use information relating to greenhouse gas emissions from RCPs to generate projections of climate variables.

  The researchers examined two different warming scenarios, one that is a high-emissions "worse-case" scenario (RCP8.5) and another that projects lower warming (RCP4.5). For the time period examined, the researchers compare the total expected insurance premiums in 2080 under each scenario to a baseline climate (1981-2013) scenario using a forty-year period in the GCM output (2060-2099) to capture yield risk.

- **Economic:** The projected average yields are then entered in ERS's Regional Environment and Agriculture Programming Model (REAP), which is an economic model that simulates producers' crop choice, planted acres, and crop prices under the various yields produced by the different climate scenarios.

[6] Liability is defined by a percentage selected by the producer (typically between 50%-85%) multiplied by the crop price, expected yield, and acreage insured.
[7] Growing degree days are an agronomic measure of how many days are suitable for plant growth based on whether the temperature exceeds a certain base threshold.

- **Policy:** From the crop price and yield distributions that are outputted from REAP, the researchers project the crop insurance premiums and subsidies. The FCIP has multiple types of crop insurance, most of which either insures the producer for a certain level of yield per acre or crop revenue per acre. The researchers' calculations assume the most popular form of crop insurance for corn, soybeans, and wheat, called Revenue Protection (RP), for all insured acreage in the projections. RP provides farmers with a guaranteed percent of their anticipated revenue (Risk Management Agency, n.d.). The anticipated revenue is based on historical yields of the producer and the greater of the projected price at the beginning of planting season or the price during harvest time (Crane-Droesch et al. 2019). In 2020, 90.5% of FCIP liability for corn, wheat, and soybeans was RP (Risk Management Agency, 2021).

  The analysis assumes that the FCIP will maintain actuarial soundness in the future; this assumption is supported by recent historical data (Crane-Droesch et al. 2019). Over the last 20 years, the national average loss ratio[8] has stayed close to 1. A loss ratio of 1 indicates that an insurance program is actuarially sound (Risk Management Agency, 2021).

The research shows there is a great amount of uncertainty under the different warming scenarios and GCMs; however, there are general trends that can be expected. The analysis shows that generally crop yields will decrease under the warming scenarios. To provide context for the changes in the cost of the program, we first observe how yields and planted acreage are anticipated to change near the end of the century.

Due to climate change, overall, acreage is anticipated to decline. Decreases in non-irrigated acreage more than offset increases in irrigated acreage. Dryland (non-irrigated) corn planted acreage is expected to decline throughout the Midwest with the largest declines in southern Nebraska and northern Kansas. Irrigated acres of corn in the Midwest, particularly eastern Nebraska and western Iowa are anticipated to increase. The trends in soybeans are similar to the trends in corn. In particular, a higher fraction of soybean acreage in the Delta region[9] will be irrigated. Wheat acreage is less concentrated in the Midwest compared to corn and soybeans: A sizable portion of wheat production occurs in the western United States, especially in Washington, Oregon, Idaho, and Montana. Large declines in dryland wheat acreage are anticipated in Washington and Kansas. The increases in irrigated wheat acreage are primarily projected in Oregon and Washington through the Dakotas and the Delta region. As an exception, as the climate changes in northeastern North Dakota, dryland acreage for wheat is projected to increase there.

Generally, these projections show declining yields caused by climate change. The largest declines in non-irrigated yields, in terms of percentages, are projected in the southeastern United States. There are expected increases for irrigated corn yields in Montana, Wyoming, and

[8] The loss ratio is equal to gross indemnities divided by unsubsidized insurance premiums.
[9] The Delta region is composed of Arkansas, Mississippi, and Louisiana. This region is as defined by the Economic Research Service Farm Production Regions.

Colorado; however, these increases are not anticipated to be substantial. Likewise, there are some projected increases for irrigated soybeans in southwestern North Dakota. The changes to wheat are more variable. Both dryland and irrigated wheat yields are projected to increase in the Dakotas and Montana, while substantial yield declines are anticipated in Arizona and New Mexico.

In addition to the change in production—the product of yield and acreage—both yield risk and price risk are projected to change due to climate change. The authors at the ERS report risk using a measure called the "coefficient of variation" (CV), which is the variability (standard deviation) divided by the average (mean). This provides an appropriate measure for looking at percentage changes under different scenarios and GCMs since CV is normalized for average local yields or average local revenue and is therefore a strong proxy for insurance premiums. In addition to the change in yield risk, price risk is expected to change. This is an important component of insurance premiums under Revenue Protection policies and a pathway through which changes in yield risk in one region of the country can impact crop insurance premiums for all areas of the country. Both corn and wheat price risk are expected to moderately decrease in the future, due to the price level increase being greater than the increase in price variability. However, the price risk of soybeans is anticipated to increase significantly, in part due to soybean yield variability being higher than that of corn and wheat, which could cause supply shocks, and thus even greater price variability.

Unlike the yields and planted acreage, the authors did not separate the change in premiums for each crop by dryland and irrigated. For corn, the largest increases in premiums are projected to occur in Kansas and Eastern Colorado with premiums generally increasing throughout the country. In some areas where corn is not a primary crop, such as the Central Valley of California, the decline in price risks outweighs increases in yield risks, causing premiums to be slightly lower in the future. Given the substantial increase in yield risks and price risks for soybeans across multiple soybean-growing regions, premiums for soybeans are expected to increase for the majority of producers. The impact of climate change on crop insurance premiums is more varied for wheat compared to corn and soybeans, given the greater variability of regions where wheat is planted.

Table 2 shows the impact of climate change nationally on FCIP premium subsidies for the year 2080, accounting for adaptation through shifts in acreage planted and increased irrigation. The changes to the cost of the program from corn and wheat are minimal, excluding the high emission warming scenario (RCP8.5) for corn. However, the cost-increase for soybeans is particularly notable with a projected 27 percent increase in cost under the lower warming scenario (RCP4.5) and a 65 percent increase in the cost of the program under the high emission "worst case" scenario (RCP 8.5). Cost increase is tied to soybeans greater vulnerability to heat and drought compared to corn and wheat. Under the lower warming scenario, the cost of today's FCIP would be about 3.5 percent higher than under a future with a climate similar to that of the recent past. Under the high emissions scenario, this cost increase is 22 percent (Crane-Droesch et al. 2019).

Table 2. Projected Costs of the Crop Insurance Premium Subsidies, 2080

Crop	Emission scenario	Premium Subsidies in 2020$ (millions per year)	Percentage Change for the Baseline
Corn	Baseline	6,933	-
	RCP 4.5	6,711	-3.2%
	RCP 8.5	7,704	11.1%
Soybeans	Baseline	2,016	-
	RCP 4.5	2,568	27.4%
	RCP 8.5	3,323	64.8%
Wheat	Baseline	485	-
	RCP4.5	485	0.0%
	RCP 8.5	488	0.0%
Total	Baseline	9,434	-
	RCP4.5	9,764	3.5%
	RCP 8.5	11,516	22.1%
Difference	Baseline		
	RCP4.5	330	
	RCP 8.5	2,082	

Source: Crane-Droesch and others (2019); Office of Management and Budget for the GDP-chain deflator (2021)

Key Limitations and Uncertainties

Given the high-level of uncertainty, there are several caveats to the analysis. There is evidence that producers choose their insurance coverage level within a budget constraint, where the constraint is equal to a percentage of crop revenue (Bulut, 2018). This could translate to producers purchasing lower levels of coverage and liability decreasing if farmer-paid premiums increase proportionately more than crop revenue. However, lower Federal outlays for Federal crop insurance may not directly translate to lower costs for the Federal Government overall, as crop insurance may be supplemented by ad-hoc disaster programs, as has been the case in recent years. Additionally, if the costs of climate change take the form of higher food prices, this impact could have repercussions for the Federal Government's expenditures for feeding programs.

The analysis is unable to precisely predict technological change that can increase crop resiliency to drought or other natural disasters. Given the history of significant technological improvements in a variety of areas including seed traits, precision irrigation and fertilization, it is unclear whether the assumption of no additional technological adaptation is appropriate and additional modeling would be beneficial in this area. An often-cited example for the impact of technological change within crop production is the effect of the 1988 drought versus the 2012 drought on corn yields in the Midwest. Using the 1988 drought as a comparison point, scientists claim that yield losses in the 2012 drought would have been severely worse if not for the technological advancements in seed and management (Elliot et al., 2018).

As mentioned earlier, while corn, soybeans, and wheat currently compose approximately 60 percent of the liability of the Federal Crop Insurance Program; that leaves roughly 40 percent of the liability not included due to the lack of data availability. This includes specialty crops in the southeastern United States, which are susceptible to hurricanes, and crops like wine grapes in California which are vulnerable to not only drought but wildfires (Risk Management Agency, 2021). Finally, as the researchers note "*Foreign supply or demand changes that are driven by climate change would mitigate or exacerbate this effect, though this analysis does not model production in the rest of the world*" (Crane-Droesch et al., 2019). Therefore, while the impact of climate change on agriculture is evident, there is a large range of possible outcomes.

Notable Agency Actions to Mitigate Identified Risks

The Federal Crop Insurance Program is already taking several actions to adapt to climate effects and support and adjust as producers undertake working lands conservation and climate-smart agriculture[10]. A fundamental part of the program helps ensure this adaptation since the program is constantly updated with the most recent data to present actuarially fair offers. This includes reducing the window of historical experience to 20 years, as opposed to almost 40 years previously used, to properly account for current climate conditions. RMA also regularly reviews yields, program dates, growing regions, and high-risk areas (such as flood-prone land).

RMA also has brought multiple climate-smart programs to market to support farmers who are adapting to climate change or other working lands conservation benefits. In many cases, a proactive approach may have economic benefits for the producer and other conservation benefits such as reduced nutrient runoff in addition to the climate benefits. For example, the Post Application Coverage Endorsement (PACE) is a new insurance product that provides coverage for producers who apply nitrogen in-season—known as "post-applying"—and are at risk of being unable to do the application, due to poor weather conditions (Risk Management Agency, 2022). Post-applying nitrogen reduces overall nitrogen use, run-off, and cost, in comparison to applying all nitrogen fertilizer prior to planting the crop.

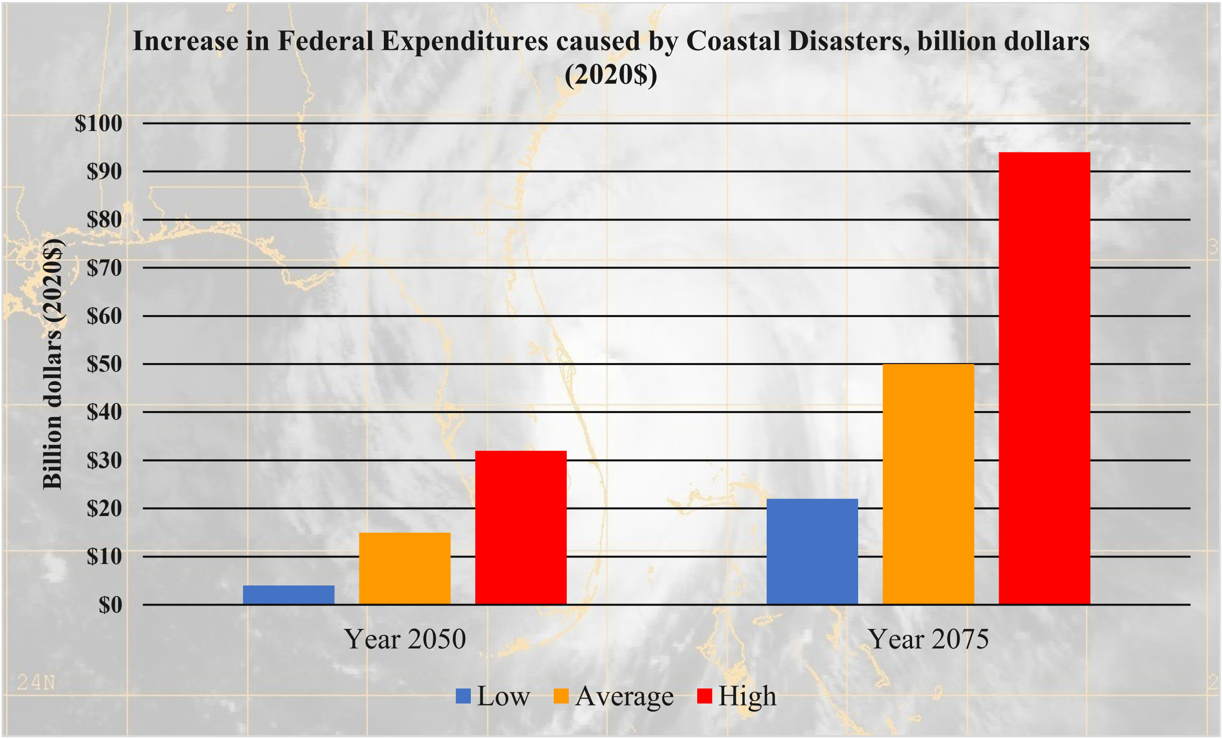
RMA also is supporting cover crops by explicitly identifying it as a good farming practice and ensuring termination guidelines are up to date, reflect the best available science, and are flexible for new regions and practices. RMA also is supporting research efforts, both within the USDA and with universities on the effects of cover crops on yield and risk. This effort includes a pilot data sharing arrangement with external parties. Lastly, RMA has provided additional premium subsidies on insured crops that were preceded by a cover crop. This program started as state partnerships to targeted producers but has expanded to include a national footprint to support farmers that maintained cover crops despite the financial hardships of the pandemic. The program saw unprecedented interest with over 12 million acres of cover crops reported, up from the 2-3 million acres historically reported. A second year of the program was announced in February 2022 (Risk Management Agency, 2022a).

[10] More information climate-smart agriculture can be found at https://www.farmers.gov/conservation/climate-smart

RMA has also modified existing programs to support climate-smart practices. For example, recent changes allow rice producers who use alternate wet-dry irrigation (also known as intermittent irrigation) and furrow irrigation to obtain irrigated insurance. Those practices dramatically save water (and costs) for producers (Risk Management Agency, 2021a). Additionally, a review of the data showed producers maintained the same yields and overall risk levels as regular flood irrigation, therefore extending insurability to those producers was both actuarially sound and in support of climate-smart agriculture.

Beyond the Federal crop insurance program, USDA is taking a number of actions to address the rising costs associated with climate change. Most notably, USDA is advancing a Partnership for Climate-Smart Commodities initiative that is incentivizing farmers to deploy practices that sequester carbon and reduce greenhouse gas emissions from their operations, while developing new markets for agricultural commodities produced with climate smart practices. Under this initiative, USDA has explicitly identified a suite of farming practices—such as the use of cover crops, low or no tillage, agroforestry, and the like—and is applying measurement, monitoring and verification techniques to confirm the climate benefits associated with such practices (U.S. Department of Agriculture, 2022).

Coastal Disasters



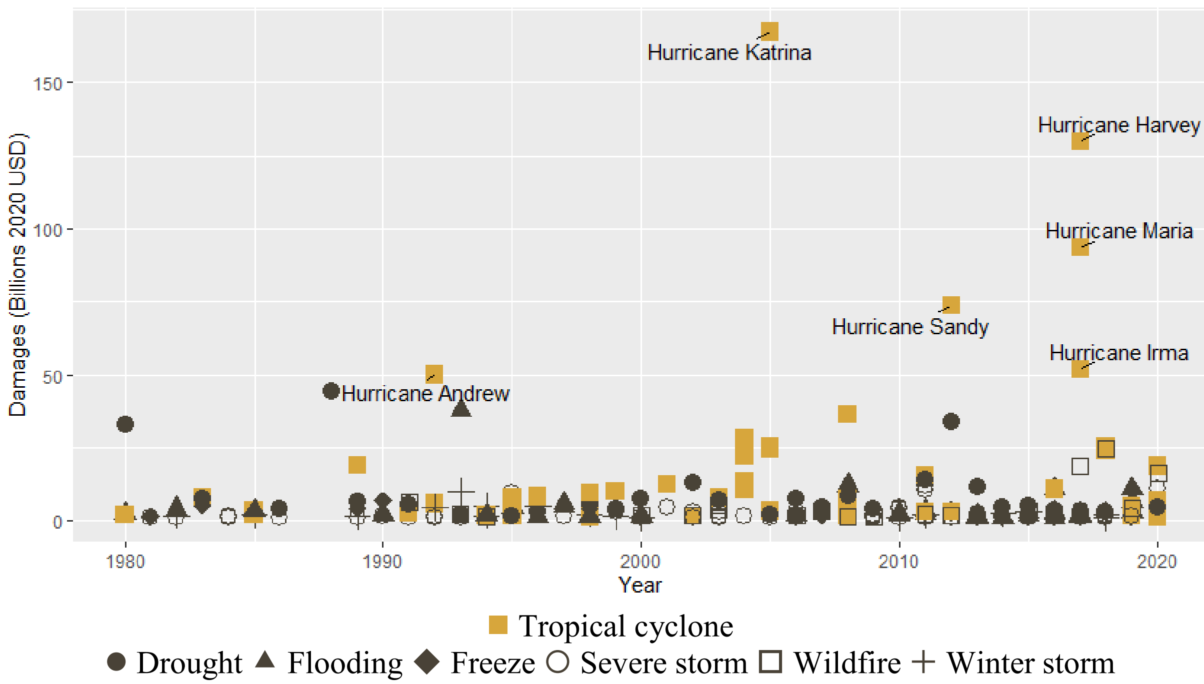
Based on updates to results from CBO (2016), OMB estimates that annual Federal spending increases on coastal disaster response are projected to range from $4-$32 billion annually in 2020 dollars, with a mean of $15 billion, in 2050. By 2075 these annual increases due to projected hurricane frequency reach $22-$94 billion (2020$), with a mean increase of $50 billion.

According to the Office for Coastal Management, 40 percent of Americans live in counties on the coast. For these Americans, climate change will lead to increased exposure to disaster losses. Additionally, critical economic activities are at risk from coastal disasters, including fisheries, energy production, and commerce at ports. While all coastal disasters have an acute impact on those affected, as will be shown in this section, *strong Atlantic hurricanes that hit large metropolitan areas* have comparatively larger overall losses.

The National Oceanic and Atmospheric Administration (NOAA) tracks disasters with large-dollar damages in its Billion-Dollar Weather and Climate Disasters Database, which contains disasters with total losses over one billion current dollars. In addition, they update the database with both (a) new billion-dollar disasters and (b) in line with the title of the database, past disasters for current dollar damages, as inflation increases the nominal value of old disaster damages. The dataset begins in 1980. While this database tracks total losses and not Federal expenditures, this data emphasizes the increased relative magnitude of damages from tropical cyclones[11] vis-à-vis other disasters. Using the NOAA National Centers for Environmental Information Storm Event damages database could give a perspective on aggregate smaller events, e.g. nuisance events. Being more numerous, these smaller events in aggregate could cause comparable or greater damages.

Figure 1 plots data from the NOAA Billion-Dollar Weather and Climate Disasters database. The time series plot shows total U.S. losses for disasters over $1 billion by year, including only disasters from 1980-2020.[12] Light, square points are tropical cyclones; and dark, other shapes are other disasters.

Figure 1. Damages of Billion Dollar Disasters from 1980-2020, Cost in Dollars



Source: NOAA Billion-Dollar Weather and Climate Disasters database (2021); Consumer-Price Index for all Urban Consumers (CPI-U) from the Bureau of Labor Statistics.

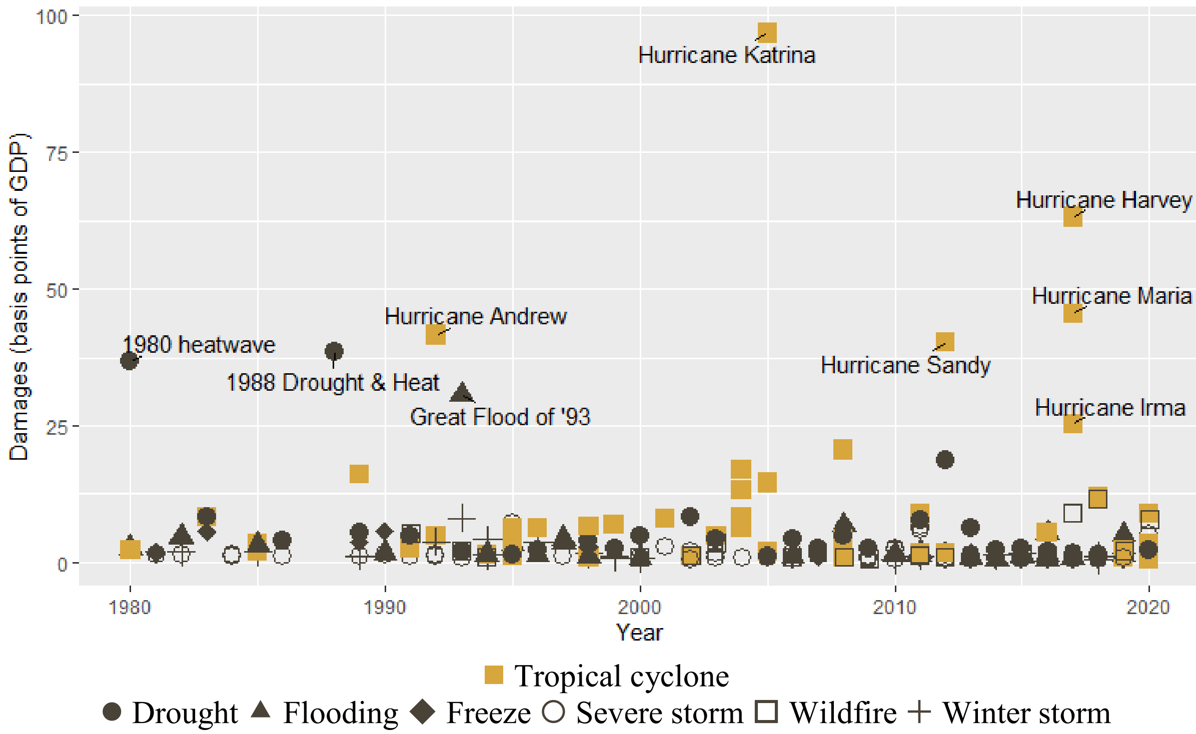
According to Figure 1, damages associated with *strong Atlantic hurricanes that hit large metropolitan areas* are increasing in severity, even adjusting for increases in GDP over time. Damages as a percentage of GDP is a proxy for our collective ability to pay for disasters. Figure 2 uses the same dataset, except basis points of GDP are plotted instead of CPI-adjusted dollars.[13]

[11] Tropical cyclone is a general term that includes tropical depressions, tropical storms, and hurricanes. Tropical cyclones are delineated by their maximum sustained surface winds (MSSW). Tropical depressions have MSSW less than 39 mph, tropical storms have MSSW between 39 mph and 73 mph, and hurricanes have MSSW equal to or greater than 74 mph (National Aeronautics and Space Administration, n.d.).

[12] NOAA uses the CPI as their tool to inflation-adjust and includes disasters above $1 billion as updated in October 2021. The 2021 numbers are multiplied by 93.6 percent (CPI-U) to inflation-adjust back to 2020 dollars.

[13] NOAA provides non-CPI adjusted data, but the noticeable series on its frontpage excludes data above $1.0 billion in current dollars but not in previous dollars. So, for consistency, we used the CPI-adjusted damages data. The CPI-adjusted damages data were multiplied by (annual CPI-U corresponding to the start date of the disaster ÷ Oct. 2021 CPI-U). This was then divided by annual current-dollar GDP figures from BEA. Alternatively, one could have taken the CPI-U adjusted disaster data and divided

Figure 2. Damages of Billion Dollar Disasters from 1980-2020, Cost in Basis Points of GDP[14]



Source: NOAA Billion-Dollar Weather and Climate Disasters database (2021); Annual current-dollar GDP figures from the Bureau of Economic Analysis.

Since 2000, damages associated with *strong Atlantic hurricanes that hit large metropolitan areas* represent a majority of the outlays of the Federal Government towards coastal disasters. Figure 3 plots Federal spending data from the Congressional Budget Office (CBO, 2019) for 58 relevant[15] "hurricane winds and storm-related flooding"[16] disaster declarations from 2005-2016. During that period, only three declarations had Federal spending above $10 billion: (1) Category 5 Hurricanes Rita, Wilma, Katrina, and Hurricane Ophelia; (2) Hurricane Sandy; and (3) Category 4 Hurricanes Ike and Gustav and Tropical Storm Fay.

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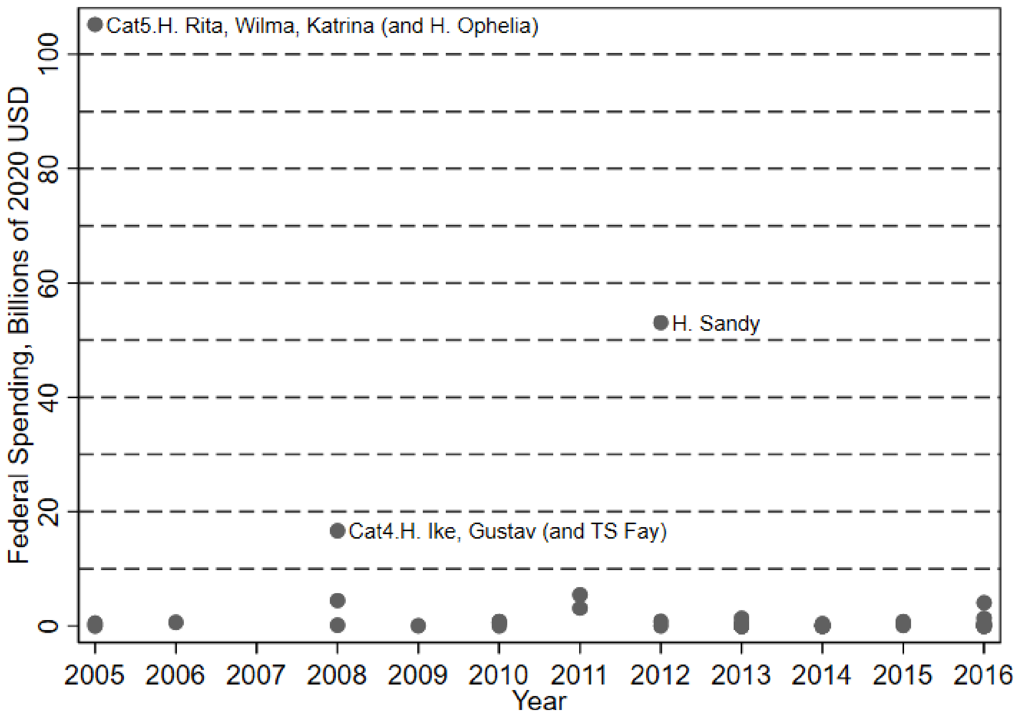
by a constant-dollar GDP—adjusted to 2020 dollars—but NOAA explicitly used the CPI for its inflation adjustment and not the implicit price deflator. These distinctions will only have a negligible impact on the data.

[14] Flood of 1993 is given the designation "Great Flood of 1993." See for instance, Johnson, et.al. (2003).

[15] CBO "…included all hurricanes during the 2005-2016 period that made landfall in the continental United States and that were Presidentially declared disasters." In addition, they included many inland storms that were Federally declared disasters, depending on two different criterion that were available—one for storms between 2005-2011, and the other for storms between 2012-2016.

[16] Note that this excludes disasters such as wildfires and droughts.

Figure 3. Federal Government spending on 58 Federally-declared disasters, 2005-2016 (CBO)[17]



Source: Congressional Budget Office (2019)

Because the preponderance of coastal Federal disaster outlays is devoted to damages associated with *strong Atlantic hurricanes hitting large metropolitan areas*, this chapter will focus on Federal financial risks from hurricanes. In CBO 2016[18], OMB discussed a Congressional Budget Office report on hurricane disasters. Like in OMB (2016), the summary presented here repurposes CBO's (2016) analysis, updating some calculations and making a few imputations.

Knutson, et al. (2020) summarizes research on the climate impacts on tropical cyclones in each ocean basin. For the Atlantic basin, there is mixed evidence that there will be an increase in the number of hurricanes, and the median draw actually shows a decrease. However, it is possible that the hurricanes that do occur are likely to be more intense; in other words, a Category 4 hurricane in 2100 would potentially have been only a Category 3 hurricane but for climate change. As implied by the charts above, circumstantial evidence spanning the last four decades indicates that the combination of hurricane frequency and increased coastal development has had a rather dramatic effect on damages: Experiencing a major hurricane can be orders of magnitude more expensive than experiencing a smaller hurricane or tropical storm. Because climate change is projected to increase the intensity of tropical cyclones (Kossin et al., 2017), damages are

[17] Federal expenditure in this graph includes storm-related Federal expenditures from FEMA's Disaster Relief Fund, HUD's Community Development Block Grant Disaster Recovery Program, the Army Corps of Engineers, the Department of Transportation, the Department of Defense, the Department of Health and Human Services, and "Other Agencies" (the Environmental Protection Agency and the Depts. of Education, Agriculture, Veterans Affairs, and Commerce).
[18] Also, technical documentation in Dinan (2016).

similarly expected to increase. [19] In this regard, the dimension of increase in Federal outlays will hinge on how hurricane intensity increases because of climate change.

Beyond more rain and wind at the coast, increased tropical cyclone intensity from climate change may contribute to additional increased damages. For instance, according to the NCA4, increased sea levels may cause storm surges to flood further inland. Further, according to the U.S. Climate Resilience Toolkit, coastal storms may bring torrential inland flooding from rain. If, due to climate change, these storms increase in intensity or their resiliency allows them to remain a threat further inland, then it is likely that inland floods will occur more frequently.

Some novel—possibly causality-intractable and less predictable—unknowable future damages will likely also occur because of increased tropical cyclone susceptibility. Depending on the determined causality and the tractability of the damages, these tangential damages may or may not be presented in the CBO study or future studies of tropical cyclone damages. Whether to include events such as this as an effect of climate change, at all, in whole, or in part, requires many judgment calls.

As an example of a novel event, Hurricane Ivan likely introduced soybean rust, a fungal soybean contamination that can spread through "aerial currents," into the United States (Isard et al., 2005). For instance, if climate change impacted Hurricane Ivan and caused soybean rust to proliferate, then it might be considered an effect of climate change. However, whether Ivan would have been just as severe without climate change might be debated. Further, soybean rust may have still arrived on a weakened Ivan, which would have made it not an impact of climate change. Even if soybean rust had not arrived on Ivan, it may have arrived on a subsequent hurricane—and thus, early soybean rust losses may be an effect of climate change, but late losses would have occurred anyway. Many other events like this require additional judgment calls, so it is impossible to precisely know the full impact of climate change on coastal disasters.

Risk Assessment

CBO (2016) uses simulation to build distributions of total damages from hurricanes in 2050 and 2075, which allows them to describe predicted credible intervals for total damages. CBO pulls thousands of draws of simulated outcomes, drawing on "changes in sea levels for affected states, hurricane frequency, population in counties vulnerable to hurricane damage, and per capita income in those counties—that would lead to differences in expected hurricane damage." For hurricane frequency, they rely on two studies—Knutson, et al. (2013) and Emanuel, et al. (2013)—which describe possible future hurricane scenarios. To quantify the damage, CBO

[19] It is difficult to translate hurricane strength to damages, as there are so few Category 4 and 5 hurricanes. To translate category of hurricane to damages, CBO (2016) used damage functions from Risk Management Solutions, "a catastrophe risk modeling company." These functions "…simulat[ed] tens of thousands of physically realistic hurricane seasons under current conditions…." There was a clear relationship between damages and hurricane strength. According to the damage functions used, Category 5 hurricanes occurred only every 26.3 years but caused more damage averaged over every year (3 billion rounded 2015 USD) than Category 1 hurricanes, which occurred every 1.3 years (2 billion rounded 2015 USD when averaged over every year). (Congressional Budget Office. (2016). Potential increases in hurricane damage in the United States: Implications for the Federal budget. https://www.cbo.gov/publication/51518.].].).]

employed functions relating hurricanes to dollars of damage ("damage functions") that were created by an outside agency.

The interaction between damages from hurricanes and the Federal budget is complex, especially when projecting into future years. CBO found that Federal spending was roughly 17 percent of total damages for pre-Katrina, post-2000 hurricanes with over $1 billion in damages.[20] From Hurricane Katrina to Sandy, this had increased to 62 percent. As demonstrated by the sudden increase of Federal spending in the time frame studied, it is likely that the Federal spending percentage will increase as storms increase in intensity. Finally, the Federal Government guarantees flood insurance payouts through its National Flood Insurance Program (NFIP). It is likely that flood insurance payouts will increase because of coastal storms, but the financial loss to the Federal Government might be mitigated by increased premiums. OMB analyzes the climate-related financial risks of the NFIP separately in the "Flood Insurance" section of this report.

To provide results in 2020 dollars consistent with the other analyses, OMB's assessment made a number of adjustments to CBO's original analysis:

- There are three germane potential avenues for increased damages on coastal disasters: (a) climate change-only damages given no coastal development (denote A), (b) coastal development-only damages given no climate change (denote B), and (c) damages caused by the interaction between coastal development and climate change (denote C). For C, as an example, someone who moves to the coast may now experience additional losses from climate change. They would not have experienced these losses had they not moved to the coast, and they would not have experienced these losses but for climate change. As another example for C, additional income may also lead current residents to develop their properties, which may lead to more damages from climate change.
    - CBO distributes a portion of the impact of the interaction effect, C, to what they consider total increased climate-change induced damages. CBO's total increased climate-change induced losses equals $A + C \times [A/(A+B)]$. For our analysis, as in OMB (2016), total increased climate-change induced losses are calculated as $A + C$, reflecting damages that would not have occurred absent climate change, regardless of whether they would have additionally not occurred absent coastal development.
- OMB's assessment made several adjustments to prices from the price deflator, and 2020 GDP is assumed as reported by the Bureau of Economic Analysis (an assumption not available at the time of the report). GDP in 2075 is calculated from damages and percent of GDP devoted to damages found in CBO (2016), and GDP is imputed in between years.
- CBO provided damages as a percentage of future GDP for 2025, 2050, and 2075; these are transformed into 2020 dollars. CBO also provided equivalent 2015 dollars for mean damages in 2075, along with the mean of components A, B, and C.

[20] In CBO (2016), the number of programs considered for Federal spending appears to be roughly the universe of Federal expenditure, as they mention, "To estimate spending by all other agencies, CBO drew from obligations data as available, the text of legislation and accompanying reports, and analyses of appropriations and agency spending produced by the Congressional Research Service."

  - The low (and high) value simulation(s) are assumed to show A, B, and C damages in the same proportion for 2075, adjusted for the lower (higher) mean amount.
- CBO provided insight into the simulated contributions to the growth in coastal development-only damages, which allows us to extrapolate contributions to damages emanating from climate change and coastal development, separately, in 2050. See the appendix for more information.
- CBO allocates Federal spending as a proportion of total damages. On the low end, they use 40 percent of total damages; mean, 60 percent; high, 80 percent. These estimates are used in approximation—but adjusted roughly 2.9 percentage points to account for the National Flood Insurance Program. According to CBO, mandatory spending, which includes NFIP subsidies, accounted for this percentage of total damages in the disasters they analyzed.

Table 3 summarizes the results of OMB's assessment relative to baseline of no climate change.

Table 3. Summary of Annual Federal Spending increases

	Billions 2020 USD	
	2050	2075
Low	4	22
Average	15	50
High	32	94

The scale of damages in 2075 is concerning. The Federal Government has been able to provide funding for costly one-off events. However, the chart above shows a "typical" *annual* pull. In other words, the results are equivalent to the U.S. suffering from just under a 2008 Hurricane Gustav every year: CBO (2016) computed the Federal Government spent roughly $60 billion in 2015 dollars, which is $65 billion in 2020 dollars. If climate change is not abated and the United States is in the higher scenario, this represents an increase of roughly a Hurricane Katrina every year (CBO 2016 & CBO 2019).

Key Limitations and Uncertainties

As OMB mentioned in 2016, one limitation of the CBO study is that it may not adequately address adaptation. Communities, governments, and systems may be able to reduce some of the increased financial risks from hurricanes by becoming more resilient. The study does, however, make assumptions that damages emanating from coastal development will increase more slowly than income or population, meaning that communities will potentially build newer, more hurricane-resilient infrastructure as communities grow.

CBO appropriately used Monte Carlo simulation to develop these estimates. Underlying these estimates is wide uncertainty, which is reflected in the results both in the original CBO study and our updated calculations. Also worth noting is that the analysis does not include hurricanes in 2017 and after, such as Hurricane Harvey, Hurricane Maria, Hurricane Irma, Hurricane Florence, and Hurricane Michael, which were all costly storms in terms of Federal expenditures. More work will need to be done in order to narrow the bands of uncertainty.

Finally, the study used loss functions from Risk Management Solutions, an outside agency. These losses should certainly account for more novel long-term losses, but the traceability of losses to specific hurricane events requires some judgement.

Notable Agency Actions to Mitigate Identified Risks

As with other climate change-related impacts, the Administration is taking a whole-of-government approach to addressing and mitigating the severity of coastal damage. The White House has formed a Coastal Resilience Interagency Working Group that is co-led by the Council for Environmental Quality and NOAA. Through the Interagency Working Group, agencies are sharing best practices and coordinating their investments in improving coastal resilience, including through the use of nature-based solutions such as restoring coastal wetlands, planting mangroves and investing in other natural barriers that reduce damage from sea rise and storm surges.

The US Army Corps of Engineers (USACE) integrates climate change in their planning for coastal storms, modeling uncertain emissions pathways and how these pathways impact coastal risk. It also has developed a "Resilience Roadmap" to assist planners in designing flood-resilient structures. Earlier this year, the Army Corps invested $645 million in 15 projects to reduce coastal flood risk.

NOAA has several existing programs that they intend to continue to invest in, including the Coastal Zone Management Program, the National Estuarine Research Reserves Program, the National Marine Sanctuary System, the National Oceans and Coastal Security Fund, and Community-Based Habitat Restoration. Further, NOAA has a "Digital Coast" platform, which provides, "the data, tools, and training communities need to address coastal issues" (Office for Coastal Management, 2022). Federal agencies, including NOAA, and academic institutions make up the Interagency Sea Level Rise and Coastal Flood Hazard and Tool Task Force,[21] which recently published the *Sea Level Rise Technical Report* (e.g., Sweet et al., 2022) providing the Federal Government and others with sea level rise scenarios for the United States. NOAA also shares data on the marine economy with other agencies. In association with the Bureau of Economic Analysis, the U.S. Census Bureau, and the Bureau of Labor Statistics, NOAA provides statistics on the marine economy through its NOAA ENOW (Economics: National Ocean Watch) Explorer. NOAA is expanding the ENOW Explorer to include U.S. territories.

The Federal Emergency Management Agency (FEMA) has four "hazard mitigation assistance programs" to mitigate flood risk and build more resilient communities. The Infrastructure Investment and Jobs Act (IIJA) codified the Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act, establishing a new program at FEMA "to provide capitalization grants to states or eligible tribal governments to establish revolving loan funds to provide hazard

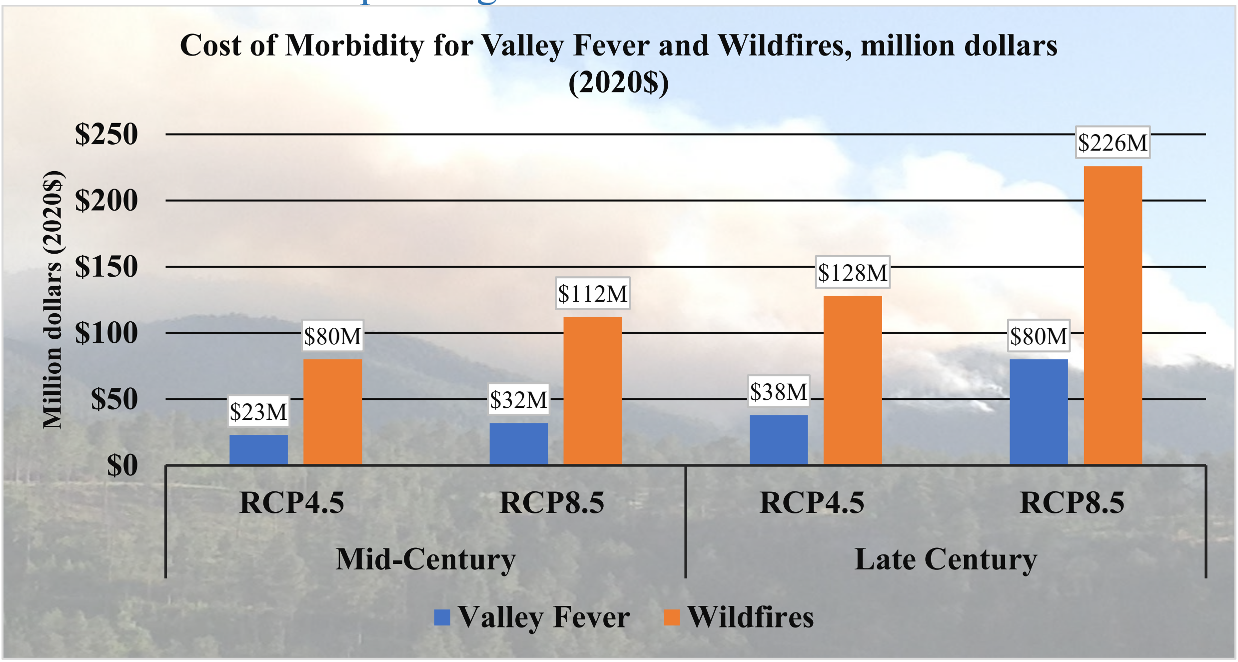
[21] According to NOAA, regarding the 2022 report, "This multi-agency effort is a product of the Interagency Sea Level Rise and Coastal Flood Hazard and Tool Task Force, composed of NOAA, NASA [National Aeronautics and Space Administration], EPA [Environmental Protection Agency], USGS [United States Geological Survey], DoD [Department of Defense], FEMA[Federal Emergency Management Agency] and the U.S. Army Corps of Engineers, as well as several academic institutes. The report leverages methods and insights from both the United Nations Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report and supporting research for the U.S. DoD Defense Regional Sea Level." (NOAA, 2022).

mitigation assistance to local governments to reduce risks to disasters and natural hazards." (FEMA, Nov. 15 2021).

FEMA has recently made resiliency investments. In August 2021 FEMA announced nearly $5 billion for FEMA hazard mitigation programs to "increase [communities'] preparedness in advance of climate-related extreme weather events and other disasters" (White House, Aug. 2021). Additionally, IIJA provided $1 billion for FEMA's competitive grant program Building Resilient Infrastructure and Communities (BRIC) over 5 years, $3.5 billion for the Flood Mitigation Assistance (FMA) grant program over 5 years, and $100 million per year for five years to the STORM Act (White House, Nov. 2021).

These pre-disaster investments are "cost-effective, help communities become safer and more resilient to natural hazards, and further the Administration's Justice40 priority to ensure benefits reach disadvantaged communities" (White House, Nov. 2021). These investments will be subject to a higher flood resilience standard for flood projects in the floodplain under FEMA's interim implementation of the Federal Flood Risk Management Standard.

Federal Healthcare Spending



OMB estimates that Federal healthcare spending could increase between $824 million and $22 billion each year by the end of the century (2020$) commensurate with some expected public health effects of climate change. Additional Federal healthcare costs due to climate change specifically related to Valley Fever, southwest dust, and wildfires could range from $169 million to $353 million by the end of the century. However, this may only be a small portion of the increased Federal costs of health care brought on by climate change.

Introduction

The Centers for Medicare and Medicaid services note that national healthcare spending equaled $4.1 trillion in 2020, and accounted for 19.7% of Gross Domestic Product (GDP). The largest shares of total health spending of this total are from the Federal Government (36 percent) and households (26 percent). Private businesses account for 16.7 percent of total healthcare spending, State and local governments accounted for 14.3 percent, and other private revenues accounted for 6.5 percent. Healthcare spending in the U.S. is projected to grow at a rate of 5.4 percent through 2028.[22]

The USGCRP's Climate and Health Assessment draws from a large body of scientific, peer-reviewed research and other publicly available resources to provide a comprehensive, evidence-based, and, where possible, quantitative estimation of observed and projected climate change

[22] Centers for Medicare and Medicaid Services. NHE Fact Sheet. Accessed 1/8/2022. https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NHE-Fact-Sheet

related health impacts in the United States. It shows how climate change endangers human health by affecting the nation's food, water, air quality, weather, and built and natural environments.

Extreme weather events, amplified by climate change, can also impact healthcare spending through damage to healthcare facilities, evacuating hospitals, and other relief needs caused by those events. For instance, of the approximately $8.2 billion made available by FEMA to the Gulf Coast States after Hurricanes Katrina, Rita, and Wilma, about $3.4 billion (41 percent) was for permanent work such as repairing and rebuilding schools, hospitals, and water systems.[23] Of the $40 billion in repairs and prevention costs that the New York Governor requested in Federal aid after Hurricane Sandy, $3.1 billion was designated for hospitals and other health facilities.[24] Officials in Galveston, Texas estimated the costs for rebuilding and repairing six hospitals, medical school and various research centers after Hurricane Ike to be $609 million.[25] Along with rebuilding healthcare infrastructure, extreme weather events can severely damage ongoing operations. One study that examined the costs of evacuating just one Georgia hospital found the costs to be over $4 million, with a recurring daily cost of over $1 million until the hospital was back operating.[26]

Along with affecting healthcare expenditures, more acute extreme weather events and climate change also impact a number of more chronic hazards. Worsened air quality from ozone, particulate matter, and higher pollen counts will elevate the risk of cardiovascular and respiratory illness (NCA, 2018). Climate change is also expected to alter the risk of vector-borne disease by changing the distribution of existing disease vectors and causing new vector-borne pathogens to emerge. Ticks, for example, will show earlier seasonal activity, increasing risk of human exposure to Lyme disease. More frequent, severe, prolonged extreme heat events will lead to elevated temperature exposure and increased heat-related deaths and illnesses (USGCRP, 2016). Exposure to climate or weather-related disasters can cause or exacerbate stress and mental health consequences, with greater risk for certain populations (ibid). Risk of food-borne illness may grow with increased exposure of food to certain pathogens and toxins (ibid). Increases in water temperatures will likely alter the timing and location of water-born illnesses (ibid). Increased growth of pathogens, such as Salmonella, are expected due to increased warmer winters (ibid). Many impacts of climate change will create a greater need for healthcare and related community facilities. They will also create a greater demand for specialists in related medical fields.

Health impacts from climate change can cause an increase in both premature death (mortality) as well as non-fatal health problems (morbidity). Higher morbidity rates have a large impact on healthcare expenditures, increasing total healthcare expenditures by private insurers as well as public programs like Medicare and Medicaid. Expenditures from climate-related medical conditions can also come from out-of-pocket expenses (Syamlal, 2020), along with additional Federal programs and other sources.[27] In order to identify the full breadth of Federal fiscal risk

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[23] https://www.gao.gov/assets/gao-07-1079t.pdf
[24] https://www.fiercehealthcare.com/healthcare/hurricane-sandy-costs-new-york-3-1b-healthcare-damages#:~:text=Hurricane%20Sandy%20is%20leaving%20New,hospitals%20and%20other%20health%20facilities
[25] https://www.nytimes.com/2008/09/23/us/23ike.html
[26] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6579826/
[27] Veterans Administration/CHAMPVA, TRICARE, and other Federal sources include Indian Health Service, military treatment facilities, and other care by the Federal Government. Other state and local sources include community and neighborhood clinics, state and local health departments, and state programs other than Medicaid, and workers' compensation. Other unclassified sources include sources such as automobile, homeowner's, and liability insurance and other miscellaneous or unknown sources.

related to climate change and health, more work is needed to quantify potential morbidity outcomes from the broad set of climate change health effects pathways. Despite a rapidly growing body of scientific literature, quantitative projections that link to climate change are only available for a subset of morbidity effects. Within this assessment, quantitative morbidity projections are only available for a handful of health impacts caused by climate change, and the results of this assessment therefore only estimate a small portion of the total health-related fiscal risks of climate change.

Climate change can directly affect human health, but it also interacts with non-climate stressors to indirectly affect individual and community health. These interactions make it difficult to quantify overarching climate impacts on healthcare. This assessment examines, and begins to quantify the Federal financial risks, of health impacts from climate change in these key areas: temperature-related death and illness; air quality impacts; extreme events; vector-borne diseases; water-related illness; food safety, nutrition, and distribution; and mental health and well-being.

Risk Assessment

EPA's recently published Framework for Evaluating Damages and Impacts (FrEDI) provides a method of utilizing existing climate change sectoral impact models and analyses to create estimates of the physical and economic impacts of climate change by degree of warming (EPA 2021). These relationships between temperature and impacts in the United States (U.S.) can then be applied to custom scenarios to rapidly estimate impacts and damages under different emission or policy pathways. EPA developed FrEDI to provide a quantitative storyline of physical and economic impacts of climate change in the U.S., by degree of warming or custom temperature trajectory, region, and sector.

The FrEDI framework was used to quantify morbidity and mortality at mid and late century using two main greenhouse gas emission scenarios (RCP4.5 and RCP8.5) used in the NCA4.[28] Mortality estimates are available for air quality and extreme temperatures, summarized in Table 4, whereas both mortality and morbidity estimates are available for Valley Fever, Southwest dust, and wildfires. Where mortality obviously has a large impact on families, communities, and the U.S. economy, morbidity estimates have more direct linkages to Federal expenditures, and are therefore a focus of this assessment.

[28] For more information of FrEDI, please see www.epa.gov/cira/fredi and www.github.com/USEPA/FrEDI. For certain sectors, especially those related to transportation infrastructure and coastal property effects, FrEDI can analyze the potential for adaptation to reduce the physical and economic impacts of climate change. No additional adaptation measures beyond those utilized in the observed period were assumed for extreme temperature, southwest dust, Valley Fever and wildfire estimates.

Table 4. Mid- and Late-Century Mortality Estimates

Sector	Impact Type	RCP 4.5 Mortality		RCP 8.5 Mortality	
		Mid-Century annual premature deaths	Late-Century annual premature deaths	Mid-Century annual premature deaths	Late-Century annual premature deaths
Air Quality	Ozone	360	550	510	1200
	PM2.5	1,120	1,790	1,580	3,700
Extreme Temp.	Extreme Heat and Cold	5,000	7,460	6,800	14,780

The climate effects on air quality are not expected to occur uniformly across the country. There is robust evidence from models and observations that climate change is worsening ozone pollution in many locations (NCA, 2018). Ground-level ozone can cause health problems, especially on hot sunny days when ozone can reach unhealthy levels. People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. The net effect of climate change on particulate matter pollution is less certain than for ozone but increases in smoke from wildfires and windblown dust from regions affected by drought are expected. People with asthma are at the greatest risk of harm from breathing air containing high ozone levels. Particulate matter, specifically particles less than 2.5 micrometers in diameter (PM2.5), can lead to serious health effects such as: nonfatal heart attacks, decreased lung function, premature death in people with heart or lung disease, and aggravated asthma.

While there is established literature quantifying the number and value of ozone attributable deaths and illnesses due to climate change (e.g. Fann 2015), modeling the impact of climate change on future Federal healthcare spending is in its early stages. Prior research found that ozone-related premature deaths and illnesses alone may increase by tens to thousands per year and could cause an economic burden of these health outcomes of hundreds of millions to tens of billions of U.S. dollars (2010$) (Fann, 2015). EPA's recent FrEDI methodology estimates close to 5,000 annual premature deaths caused by climate-driven changes in ozone and PM2.5 under a higher emissions scenario by the end of the century. Since morbidity estimates for ozone and PM2.5 are currently unavailable under FrEDI, this paper does not include an updated quantification of potential Federal health expenditures related to future ozone and PM2.5 scenarios. Instead it relies on a prior 2016 OMB assessment, which found that financial risks from air quality due to climate change could range from $0.7 billion to $21.5 billion per year (adjusted to 2020$). That assessment reflected increased costs in an unmitigated climate change scenario compared to a mitigation scenario, rather than current weather conditions as in the other assessments in this report (the no-climate baseline).

Heat-related stresses are one contribution to those expenditures that are expected to impact Federal health expenditures. Research shows that hot days are associated with an increase in heat-related illnesses, including cardiovascular and respiratory complications, renal failure, electrolyte imbalance, kidney stones, negative impacts on fetal health, and preterm birth (NCA, 2018). Also, a National Bureau of Economic Research study shows that productivity declines 1.7 percent for each 1-degree C rise in temperature above 15 degrees Celsius (NBER, 2015). High temperatures also increase the likelihood of injury or illness and can result in higher medical costs. Knowlton et al. (2011) identified total health costs associated with a 2006 California heat wave to be $5.4 billion, though a significant portion of the estimated cost was due to premature death. Moreover, a 2019 study (Liu et al., 2019) used a statistical framework to estimate excess deaths and illness associated with cold and hot temperature extremes in the Minneapolis/St. Paul Twin Cities Metropolitan Area. On average, moderately and extremely low and high temperature was associated with healthcare costs of $9.40 billion per year in 2016$ (over $10 billion in 2020$), with mortality and cold-related costs being the majority of the economic burden. Healthcare costs for heat-related illness hospitalizations are shown to be disproportionally higher for some racial/ethnic minorities, as well as low income populations (Schmeltz, 2016).

Prior research shows that continued warming, increases in heat-related deaths are generally projected to outweigh reductions in cold-related deaths (Sarofim, 2016). Similarly, EPA's FrEDI methodology estimates an increase of over 14,000 late-century pre-mature deaths due to increases in extreme heat deaths and decreases in extreme cold deaths across the United States under a high emissions scenario.[29] Since morbidity estimates for heat-related illnesses are unavailable under FrEDI, this paper does not attempt to quantify potential Federal health expenditures due to heat-related illness under future scenarios, though work using a similar framework looking only at urban residents under 65 years old estimated that treatment costs of increased hyperthermia emergency department visits resulting from a high future climate scenario could reach $9 million to $118 million (for 28,000 to 65,000 additional visits) by the end of the century (Lay et al., 2018).

Table 5. Annual Mid- and Late- Century Morbidity Estimates[30]

Sector	Impact Type	RCP 4.5		RCP 8.5	
		Mid-Century annual impact (millions of US$)	Late-Century annual impact (millions of US$)	Mid-Century annual impact (millions of US$)	Late-Century annual impact (millions of US$)
Valley Fever	Morbidity	23	38	32	80
Southwest Dust	Respiratory Morbidity	>1	1	1	3
	Cardiovascular Morbidity	>1	2	1	4
Wildfires	Morbidity	80	128	112	226

[29] FrEDI considers the impact of the top 1% of hot days and the bottom 1% of cold days, which will have a large marginal effect on temperature-related mortality. However, the effects outside of these days is not quantified, so actual temperature-related mortality is likely underestimated.
[30] FrEDI estimates impacts in 2015$. Those outputs were inflated to 2020$ for the purposes of this assessment.

In addition to air quality estimates, OMB estimates that additional healthcare costs due to climate change related to Valley Fever, Southwest dust, and wildfires could range from $169 million to $353 million by the end of the century, summarized in Table 5.

Valley Fever (coccidioidomycosis) is a disease endemic to arid regions in the Western Hemisphere, and is caused by soil-dwelling fungi. Previous research has indicated relationships linking temperature and precipitation to outbreaks of coccidioidomycosis. National Oceanic and Atmospheric Administration (NOAA) data was used in a recently published study that linked the increase in Valley Fever cases with the surge in the number of dust storms from climate change (Tong, 2017). FrEDI estimates that the annual economic impacts of climate change on Valley Fever could cost between $38 million and $80 million by the end of the century. Increases in annual Federal expenditures on Valley Fever due to climate change could reach $29 million.

People living in the American Southwest have also experienced a dramatic increase in windblown dust storms, which are likely driven by large-scale changes in sea surface temperature (according to new NOAA-led research). Increased dust emissions from severe and prolonged droughts in the American Southwest could result in significant increases in hospital admissions and premature deaths (Achakulwisut, 2018). Some research estimates that the implications for airborne dust in the Southwest could result in a 300 percent increase in hospital admissions due to cardiovascular and respiratory illness (ibid). FrEDI estimates that the annual economic impact of climate change from Southwest dust on combined respiratory and cardiovascular morbidity could cost between $3 million and $7 million by the end of the century. Increases in annual Federal expenditures on the impacts of increased Southwest dust due to climate change could reach $3 million.

As discussed in the "Federal Wildland Fire Suppression Expenditures" assessment of this paper, the number of acres burned and Federal expenditures on wildfire suppression is expected to increase due to climate change. The increased intensity of wildfire will also have a significant impact on human health, as smoke can make outdoor air unhealthy to breathe. Wildfire smoke can also impact indoor air quality depending on the proximity of the fire and the density of the smoke. A 2018 study (Fann, 2018) estimates that the economic value of long-term mortality exposures to wildfires is between $76 billion and $130 billion per year (2010$) with a net present value of $450 billion. FrEDI estimates increased morbidity costs, including hospitalization costs and loss of productivity, under various future scenarios of climate-driven changes in wildfire activity. Under the high emissions scenario, FrEDI estimates between $128 million and $226 million in annual morbidity costs by the end of the century. Increased Federal expenditures by the end of the century could reach $96 million.

The Federal share of these costs was isolated by applying current payer share ratios for each health condition. These ratios were derived from Medical Expenditure Panel Survey (MEPS) data, generated by the Department of Health and Human Services. For the purposes of this analysis, only spending financed directly by Federal programs (Medicare, Medicaid, Veterans Administration Health Care, and other care provided by the Federal Government) was included in calculating the Federal share. In practice, however, the Federal Government also significantly subsidizes private insurance coverage.

Lyme disease in the U.S. is caused by the bacterium Borrelia burgdorferi sensu stricto (B. burgdorferi) and is carried by ticks. Climate change is expected to alter the geographic range, seasonal distribution, and abundance of this disease vector (NCA, 2018). A 2015 study estimates 240,000 to 440,000 new cases of Lyme disease will be diagnosed every year, resulting in increased costs to the U.S. healthcare system from between $712 million and $1.3 billion a year (Adrion, 2015). Despite an estimated $2.8 billion to $5 billion aggregated welfare loss in the Northeastern United States due to Lyme Disease (Berry, 2018), individuals do make substitute activities away from outdoor activities when there are confirmed cases nearby. This substitution can have complicated impacts on Federal revenues, as evidence shows people may often switch from untaxed to taxed forms of leisure (ibid). In this instance the Federal budget implications of climate change may not be well aligned with the welfare implications.

Overall, commensurate with some expected public health effects of climate change, and assuming a consistent Federal share of Medicare and Medicaid ratio of spending, OMB estimates that Federal climate-related healthcare spending in a few key areas could increase by between $824 million and $22 billion (2020$) by the end of the century.[31] This increase alone would tally up to approximately 1 percent of additional national health expenditures. Summing prior climate-related impact estimates on human health due to air quality, plus recent morbidity estimates using FrEDI (and assuming a consistent Federal share of Medicare and Medicaid ratio of spending) quantifiable estimates of Federal healthcare spending range from $824 million to $21.9 billion dollars each year by the end of the century (2020$).

Key Limitations and Uncertainties

The extent to which climate change could impact human health will depend not just on the magnitude of local climate change but also on individual and population vulnerability, exposure to changing weather patterns and climate-related disturbances, and capacity to manage risks (Balbus, 2016). Modeling health outcomes are sensitive to assumptions and limitations in underlying temperature prediction models, and the functions that translate pollution exposure levels to expected health outcomes (USGCRP, 2016). For example, the influence of changes in precipitation and atmospheric mixing on particulate matters—combined with variability in projected changes to those variables—has prevented consensus in the scientific literature with regard to the net effect of meteorological changes on PM2.5 levels in the United States.

This assessment uses EPA's FrEDI methodology to estimate mortality and morbidity for two RCP scenarios. However, these assessments are limited in their ability to factor in the possibility of future changes in air quality regulations past 2040, population distribution, healthcare or other technology, or human behavior that may impact the extent and pattern of air pollution exposure across the United States. These uncertainties are discussed in EPA's Technical Documentation on the Framework for Evaluating damages and Impacts (EPA, 2021). For example, Americans may migrate to areas of the country with cleaner air, install air conditioning in greater numbers, or adapt using new technology to reduce exposure to poor air quality. While adaptation behaviors like these will feasibly happen to some degree, opportunities may not be available to the most vulnerable communities in the United States, further complicating the budgetary and

[31] This calculation sums estimates on air quality impacts from a previous 2016 OMB assessment (adjusted for inflation), plus recent OMB morbidity impact assessments for Valley Fever, southwest dust, and wildfires: OMB, 2022.

human healthcare impacts of climate change. Complex relationships also exist between the impacts of climate change and interactions those impacts have with economic consequences. Several health risks, including risks to vector-borne diseases and mental health issues or psychological responses, can be impacted by climate change but are not assessed in this paper.

Estimating the Federal share of future healthcare expenditures is also limited and based on assumptions that future Federal spending will mirror today's share compared to private (or other) payments. While these assumptions and limitations are generally consistent with existing peer-reviewed climate and health assessment literature, actual future Federal healthcare expenditures will be sensitive to several economic and policy variables, such as Medicare enrollment growth rates, advancement of technology, and availability of Federal subsidies.

Notable Agency Actions to Mitigate Identified Risks

Environmental Protection Agency Actions

EPA is actively working to reduce the adverse health risks associated with climate change by promulgating rules that will reduce GHG and other climate-forcing emissions, as well as conventional air pollutants associated with adverse health effects (mitigation measures). At the same time, EPA is also identifying mechanisms to minimize the on-going health burdens associated with a changing climate (adaptation measures). Recent or upcoming rulemakings that may reduce the emissions that lead to air pollution and climate warming and increased Federal healthcare spending include: greenhouse gas emissions standards for light-, medium-, and heavy-duty vehicles; a phase down of the U.S. production and consumption of hydrofluorocarbons (HFCs) by 85% over the next 15 years, as mandated by the American Innovation and Manufacturing (AIM) Act of 2020; and reductions of methane emissions from both new and existing sources in the oil and natural gas industry.

EPA is also working with States and other Federal agencies to better inform communities about the health risks associated with wildfire smoke, which has increased in the U.S. due to climate warming. Through EPA's AirNow Fire and Smoke map, real-time observations of PM2.5 air quality from low-cost sensors as well as permanent monitors are available to the public and local planning organizations, along with guidance intended to inform people how to protect themselves from unhealthy smoke exposures. EPA is developing a Cool Communities Challenge to bring together Federal support to help communities equitably plan for extreme heat and invest in innovative infrastructure that will protect people from the health impacts of extreme heat over the long-term. These EPA actions, along with international partnerships, are designed to help mitigate and adapt to future climate warming and thereby reduce the financial risk to the Federal healthcare spending sector from factors such as air pollution, heat stress, and wildfire smoke.

EPA also works directly with communities, Tribes, States, regional entities, and other partners to help them find and implement solutions to growth and development challenges that produce multiple co-benefits, including health, environmental, and climate resilience benefits.[32]

[32] For these resources and more information about the direct technical assistance, see EPA's Smart Growth website: https://www.epa.gov/smartgrowth.

Department of Health and Human Services Actions

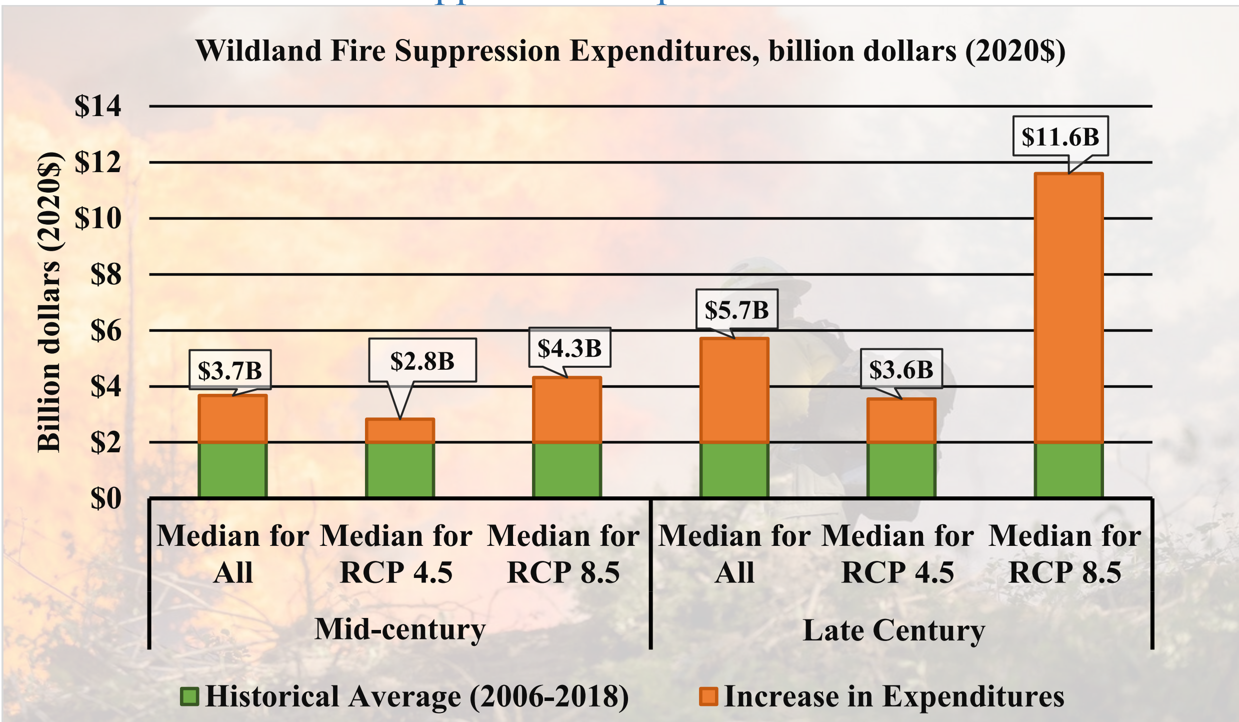
Several Department of Health and Human Services (HHS) activities and initiatives aim to help address threats presented by climate change (i.e., threats to human health, threats to healthcare services, threats to facility integrity). For instance, HHS launched, in August 2021, its new Office of Climate Change and Health Equity (OCCHE), which has a mission of protecting those living in the United States – and especially the nation's most vulnerable - from the catastrophic and chronic impacts of climate change. It carries out its work by forecasting climate change's impacts on vulnerable populations, by developing strategies and tools to mitigate those impacts and by mobilizing the healthcare sector to both be more prepared and resilient in service of those populations and take responsibility for reducing its own contributions to climate change (i.e., greenhouse gas emissions).

Other Federal Actions

The Department of Health and Human Services (HHS), the Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Agency (NOAA) co-lead an Interagency Working Group that coordinates the Federal response to debilitating and often deadly heat events. This group will help forecast heat events and ameliorate them through better public health and healthcare response, and will ensure access to preparedness tools, resources and technical assistance to prepare health systems to limit the harm associated with climate change and maintain operations during climate-induced disasters. HHS is also exploring updates to Centers for Medicare and Medicaid Services (CMS) facility conditions of participation that will require facilities to better anticipate climate risks and explore flexibilities in programs like Medicaid that will allow states and providers to authorize beneficiary spending in response to health challenges associated with climate change. This also includes expanding national utilization of the Low-Income Home Energy Assistance Program for vulnerable populations (Administration for Children and Families).

Also, the Department of Labor has initiated a heat-related worker safety standard-setting and enforcement initiative. Lastly, the Department of Transportation and the USDA are investing in infrastructure and urban forestry programs that will reduce heat island effects.

Federal Wildland Fire Suppression Expenditures



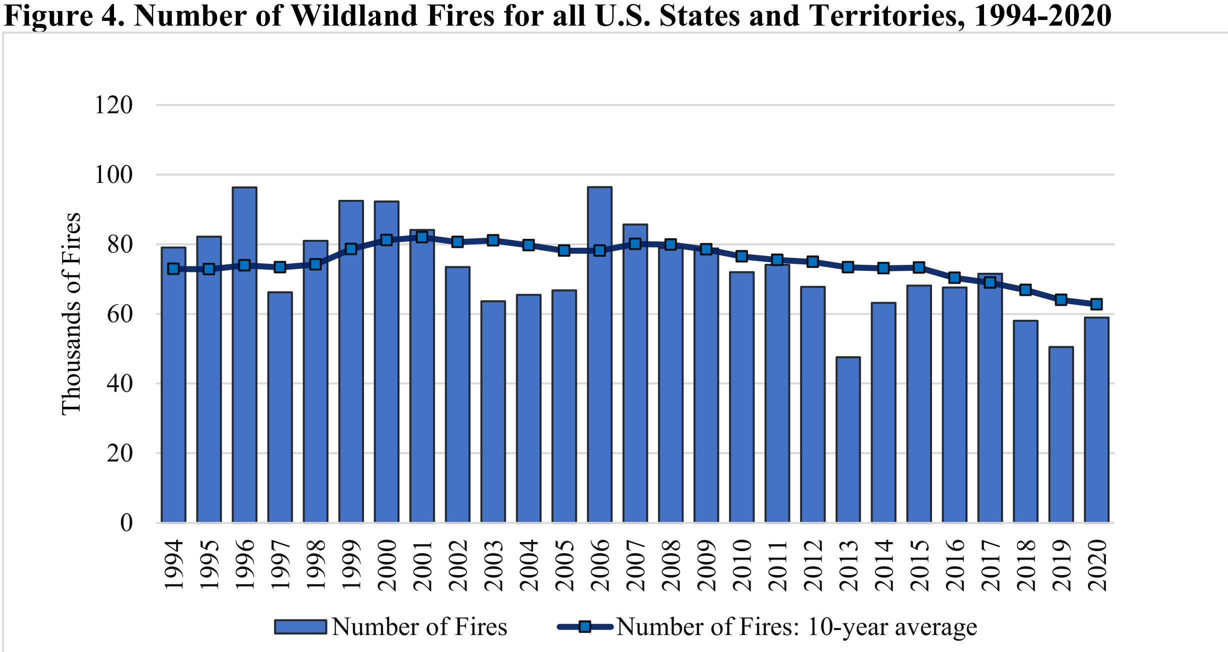
The historical baseline for wildland fire expenditure between 2006-2018 is $2.0 billion in 2020 dollars. Wildland fire suppression expenditures of the U.S. Department of Agriculture—Forest Service and Department of the Interior are anticipated to increase due to climate change. For the mid-century period, the lower warming scenario is anticipated to increase outlays by $0.83 billion (2020$) annually, while the high emissions scenario projects an increase in outlays by $2.32 billion (2020$) per year. For the late-century period, the lower warming scenario is anticipated to increase outlays by $1.55 billion (2020$) annually, while the high emissions scenario is projected to increase outlays by as much as $9.60 billion (2020$) annually.

Introduction

Climate change is contributing to an increase in wildland fire extent and severity across the western US and Alaska (Park and Abatzoglou, 2020). NCA4 found the increasing duration of the wildland fire season in the western United States is primarily caused by higher temperatures and earlier snowmelt (Vose et.al, 2018). While wildfire is more commonly associated with the western United States, the NCA4 notes that the southeastern United States is projected to experience increasing wildfire activity due to climate change. The damages associated with wildland fire have been increasing over the past several decades. Much of this increase has occurred in the western United States, where climate change is contributing to an increase in the area burned by wildland fire and the severity of wildland fire. The effects of climate change on wildland fire are complex and go beyond the weather's direct impact on fire behavior: for example, climate change is also increasing the likelihood of tree mortality from drought and insect outbreaks which subsequently increases the risk of wildland fire (ibid). In addition, the impacts of climate change on wildland fire behavior interact with other human impacts on the environment such as increased development that expands the wildland urban interface. The complex problem of increasing risk of damage from wildland fire will require collective action across a wide variety of agencies and jurisdictions in the coming years.

Recent historical trends show strong patterns in acres burned by wildland fire and consequently in wildland fire suppression costs. While the number of fires across the United States has decreased significantly over the last 30 years (Figure 4), the number of acres burned by wildland fire is rising (Figure 5). In 2015, 2017, and 2020, over 10 million acres burned annually. By 2020, the 10-year average of burned acres exceeded 7.5 million, almost 150% higher than the 10-year average of burned acres 26 years ago[33]. The cost of wildland fire suppression continues to increase faster than inflation (Figure 6). When using 2020 as the base year for inflation-adjustment, the Federal Government spent over $3 billion for the first time in 2017 on wildland fire suppression cost alone, only to face record high spending again in 2018, and to then spend over $4 billion in 2021. While spending over $3 billion in fire suppression is a sobering milestone, the 10-year average for Federal funding of wildland fire suppression has been trending upward for decades. The 10-year average in 1994 was $723 million (2020$) annually for the U.S. Department of Agriculture—Forest Service (FS) and the Department of the Interior (DOI) combined. Twenty-six years later, the 10-year average has climbed to $2.2 billion (2020$) annually.

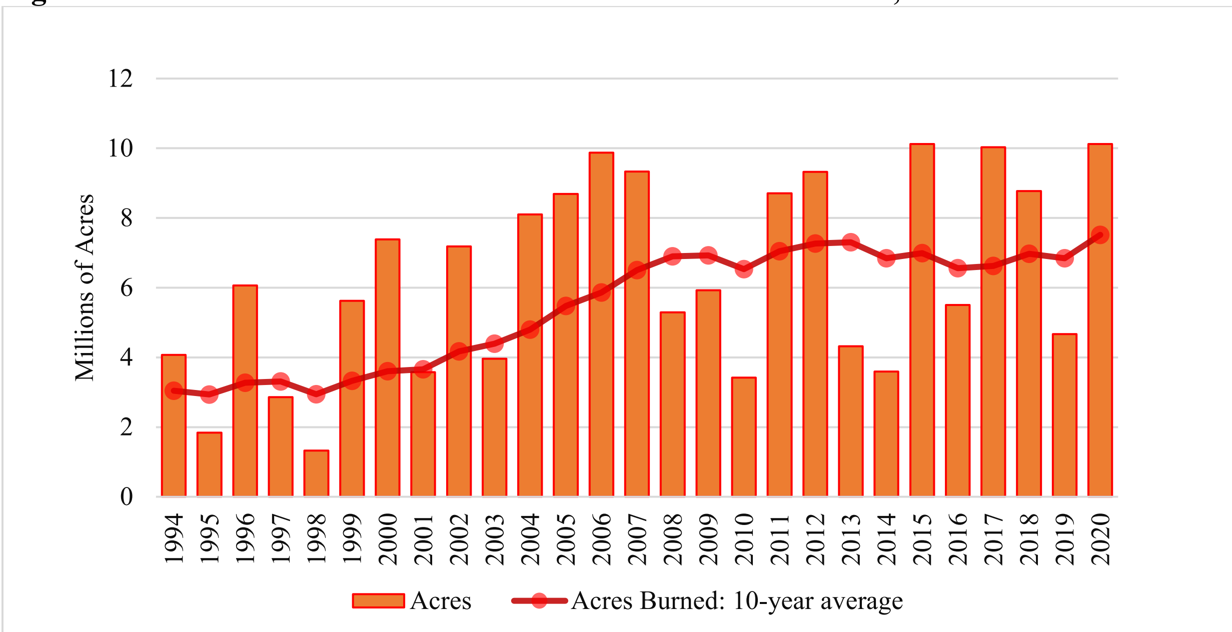
Figure 4. Number of Wildland Fires for all U.S. States and Territories, 1994-2020



Source: National Interagency Fire Center (2021). Note: 2004 fires do not include state lands for North Carolina.

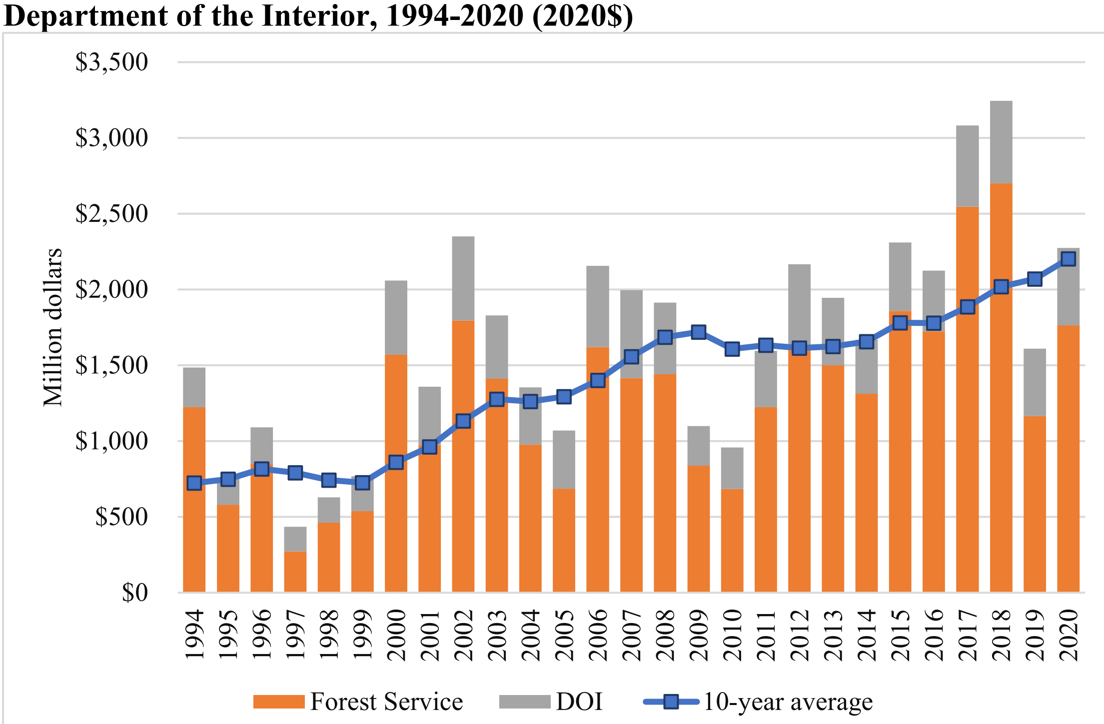
[33] The 10-year average for 2020 includes the years 2011-2020, and the 10-year average for 1994 includes the years 1985-1994.

Figure 5. Number of Acres Burned all U.S. States and Territories, 1994-2020



Source: National Interagency Fire Center (2021) Note: 2004 acres burned does not include state lands for North Carolina.

Figure 6. Wildland Fire Suppression Spending by USDA Forest Service and the Department of the Interior, 1994-2020 (2020$)



Source: National Interagency Fire Center (2021); Office of Management and Budget for the GDP-chain deflator (2021)

Wildland fire management requires complex coordination at the national, state, and local levels. The DOI is responsible for wildland fire management on Federal lands managed by DOI, including lands managed under the Bureau of Land Management, National Park Service, the Fish and Wildlife Service, Bureau of Reclamation, and the Bureau of Indian Affairs, and wildland fires in the National Forest System are the responsibility of the FS. For State, local, and private lands, State agencies are responsible for wildland fire suppression. States can enter into cooperative agreements with Federal agencies to determine and allocate protection responsibilities and/or combine resources of personnel and equipment to suppress wildland fires. To provide a nationally coordinated response to wildland fire, the States and Federal agencies coordinate through the National Multi-Agency Coordination Group housed at the National Interagency Fire Center in Boise, ID. Additionally, Federal financial resources are available to States through the Federal Emergency Management Agency's Fire Management Assistance Grants (FMAGs), as authorized by the *Robert T. Stafford Disaster Relief and Emergency Assistance Act*. These grants to State, local, and tribal governments can be used for equipment or personnel and can reimburse up to 75 percent of eligible suppression costs (Hoover, 2021).

In 2016, the Office of Management and Budget released a report entitled *Climate Change: The Fiscal Risks Facing the Federal Government*, which outlined how Federal expenditures and revenue could be affected by climate change later this century (Office of Management and Budget, 2016). Since the 2016 report, there have been significant developments in wildland fire policies. The *Stephen Sepp Wildfire Suppression Funding and Forest Management Activities Act* enacted as Division O of the *Consolidated Appropriations Act, 2018* (P.L. 115–141) amended the *Balanced Budget and Emergency Deficit Control Act*, authorizing a cap adjustment for wildland fire suppression costs (also known as the "fire fix"). The cap adjustment provides additional budget authority for wildland fire suppression —beyond the discretionary budget score for Federal wildland fire suppression costs in the FY 2015 baseline year. By placing this additional spending outside of discretionary caps, there is no longer a need to borrow funds from other budget accounts to fund Federal wildland fire suppression costs that exceed discretionary appropriations. FY 2020 was the first year in which the fire fix was implemented (U.S. Department of Agriculture, 2021). The fire fix provides a solution to near-term liquidity issues of funding fire suppression. However, this does not address or slow the longer-term trend in increasing suppression costs. In 2022, the FS introduced a new 10-year plan to address wildland fire through landscape level fuel treatments (Forest Service, 2022). Landscape level fuel treatments can be defined as hazardous fuel removal and maintenance at a much larger scale than previously done, often crossing jurisdictional boundaries, and leveraging the capacity of States and communities in a shared stewardship approach. And while the implementation of this plan may eventually lead to lower overall suppression costs and reduce the risk of destructive wildland fires to communities in the long run, it cannot mitigate changes to fire behavior that are attributed to weather, which varies widely from year to year, obscuring spending impacts.

Federal researchers revisited the analysis of wildland fire suppression costs to more accurately characterize potential costs to the Federal Government due to direct impacts of climate on fire behavior. Like the 2016 report, there is considerable uncertainty when projecting estimates so far in time. However, the new analysis has better explanatory power, assesses more end-of-century climate scenarios, and considers updated data on wildland fire activity.

Risk Assessment
For this assessment, researchers at the FS updated the methodology and data used for the prior projections in the 2016 OMB report, which is provided as a technical appendix at the end of this white paper. As in the previous assessment, the researchers project the increase in acres burned by wildland fire and the cost of wildland fire suppression by the DOI and FS during the mid-century (2041-2059) and late-century (2081-2099). The researchers made these projections, for the FS and DOI, by first estimating models of historical acres burned in each of eight regions of the continental U.S. using the historical monthly average of daily maximum temperature and historical monthly average of daily vapor pressure deficit in each of those regions. The FS expenditure data are divided into the regions aligning with the Geographic Area Coordination Centers of the National Interagency Fire Center (Figure 7). Therefore, regional spending models could be developed for the FS. Due to data constraints, expenditures by the DOI are only available on a national level.

Figure 7. Map of Geographic Area Coordination Centers

Source: Geographic Area Coordination Centers (2021)

The researchers were able to make several substantial updates over the previous report; although, the time span of observations on suppression spending in the current report is shorter (2006-2018) than in the previous report (1993-2013), the frequency of spending data for the current effort was updated from annual to monthly. The monthly spending data allowed for better fit to similarly monthly historical wildfire data. Monthly data for acreage burned spanned 1993-2018 (DOI) or 1993-2019 (FS), allowing for a longer time series for wildfire model fitting and evaluation than in the previous report. Given the seasonality of wildland fires, the ability to observe monthly averages is a refinement of the data that notably increases the model's accuracy in predicting acreage burned. FS suppression monthly expenditures at the different regions were then modeled using the coinciding month and previous two months of wildland acres burned. The remainder of the Forest Service (RFS) expenses—spending not linked to a specific region but pertaining to suppression—and suppression expenses for the Department of the Interior were modeled at the national level with the same explanatory variables.

To provide a more comprehensive range of results, the authors provided a wider range of scenarios compared to the 2016 report. The FS researchers utilized the RCP scenarios 4.5 and 8.5, while the previous analysis only utilized the RCP 8.5 scenario. The RCP scenarios are projections of radiative forcing developed for use by the Intergovernmental Panel on Climate Change (IPCC). Radiative forcing is the change in energy flux caused by a driver, such as greenhouse gas emissions. In other words, positive radiative forcing means the earth is absorbing more energy from sunlight than it is radiating into space, which causes warming. RCP 4.5 is considered a lower climate change scenario with GHG emissions peaking mid-century then declining. RCP 8.5 is an unmitigated high emissions scenario (IPCC, 2014). The radiative forcing is translated into changes in climate factors like temperature and precipitation through General Circulation Models (GCMs). Instead of using just three GCMs as in the previous effort, the researchers employed five GCMs, all of which are commonly used in the scientific community and which additionally offer, due to their varying model structures and parameters governing physical processes, a wide range of climate outcomes.

In order to compare the projections of mid- and late-century to the recent past, the researchers offered two approaches. The first approach is to compare the projections directly to the historical observed values of 2006-2018. The second approach is to compare modeled historical values, also known as backcast data, in which the historical period of 2006-2018 is modeled using the same methodology as the projections of the mid- and late-century. The benefit of using a percentage difference between the backcast data and the projections of the mid- or late-century is that bias introduced through modeling is minimized when comparing to the backcast data. For this reason, when providing dollar values of the projected changes in expenditures, the observed historical values from 2006-2018 are multiplied by the percentages derived from the difference between the backcast data and the projected values of mid- and late-century, in order to decrease bias in the estimates.

Results

The ten projected climate projections (two RCP scenarios and five GCMs) result in a wide range of possibilities for burned wildland acreage in the future. Note acres burned for the period 2006-2018 average 3.9 million annually in the continental United States (CONUS). For the combination of FS and DOI land burned by wildland fire, compared to backcast historical climate (2006-2018), these percentage increases range from 22% to 201% higher in mid-century and 65% to 1641% higher in late-century. The medians across all climate projections are 106% and 241% increases compared to modeled historical area burned for mid- and late-century, respectively. Across all ten climate projections for the FS, median area burned is 129% and 306% higher by mid- and late-century when compared to modeled historical area burned. Compared to modeled historical area burned in CONUS, DOI median area burned in CONUS is projected to be 83% and 180% higher in mid- and late-century, respectively.

Wildland fire suppression expenditures of FS and DOI are anticipated to increase due to climate change, noting the historical expenditures between 2006 and 2018 averaged $2.0 billion (2020$) annually. For the midcentury period, the lower warming scenario is anticipated to increase outlays by $0.83 billion annually, while the high emissions scenario is projected to increase outlays by $2.32 billion annually. The median projected increase (across all GCMs and emission scenarios) for expenditures by the mid-century is $1.67 billion annually. For the late century period, the lower warming scenario is anticipated to increase outlays by $1.55 billion annually, while the high emissions scenario is projected to increase outlays by $9.60 billion annually. The median projected increase for expenditures in the late century across all GCMs and emission scenarios is $3.71 billion annually.

Key Limitations and Uncertainties

While the analysis has been refined and has improved prediction abilities, there are still caveats with regards to this work. The modeling is unable to account for changes in landscape, including shifts in vegetation types and increased development in the wildland-urban interface. Vegetation may change due to climatic variables such as temperature and precipitation, which would affect available fuel for wildland fires, and in turn acres burned and fire suppression costs. The wildland-urban interface is strongly affected by population growth and shifts in population centers (Office of Management and Budget, 2016). Given that in 2020, over 53,000 wildfires were ignited by humans, burning almost 6 million acres, shifts and expansions of the wildland-urban interface are and will continue to be a critical variable in ignition of wildland fire (National Interagency Fire Center, 2021). Lastly, the model holds technology and policy for wildland fire management constant over time. Historically, policy changes have shifted spending, such as the upward shift in Federal outlays caused by the implementation of the National Fire Plan in FY2000 (Office of Management and Budget, 2016). Looking forward, several government programs are anticipated to reduce wildland fire suppression costs, which are further discussed in the *Notable Agency Actions to Mitigate Identified Risks* section below.

The cost of wildland fire extends far beyond the Federal expenditures outlined here. Expenditures of States are not included nor are Federal grants from FEMA. For example, the California Department of Forestry and Fire (CalFire) spent approximately $2 billion from California's General Fund for 2020-2021, which does not include Federal funds or reimbursements that total another $0.9 billion. Noting that CalFire spent $1.5 billion from California's General Fund for 2019-2020, indicating that wildfire suppression may be a growing portion of expenditures from California's General Fund (Legislative Analyst's Office, 2021). Wildland fire places intense strain on infrastructure, including systems for evacuations and warnings, water treatment, and electrical transmission. Therefore, action taken to mitigate climate change and its impact on wildland fire has wider ranging impacts compared to what is accounted for in this analysis.

Notable Agency Actions to Mitigate Identified Risks

Given these high costs and very troubling trends, the Federal Government is devoting significantly more attention in increasing the resilience of forests and rangelands to wildland fire events by investing in landscape scale and strategically placed fuels treatments, prioritizing the areas at highest risk of wildland fire. Deploying science-based thinning and prescribed fire across the landscape can be an effective and cost-efficient way to maintain fire-adapted ecosystems, making them more resilient to fire. The USDA FS 10-year strategy implemented in coordination with DOI, States, Tribe and local governments may be the largest single factor to reduce long-term financial exposure. The 10-year strategy outlines a ten-year plan to increase the treatment of forested lands by 20 million acres within the National Forest System and 30 million acres of other Federal, State, tribal, and private lands (Forest Service, 2022).

Funding and resources provided by the IIJA provides an initial influx of resources to implement these actions, however sustained funding over 10 years will be required to make a significant and long-term difference, as will funding to maintain restoration treatments, and restore burned landscapes. Reforestation on USFS lands via the new funding—facilitated by the removal of the Reforestation Trust Fund cap in the IIJA—ensures that burned areas can be restored, i.e. prevented from being permanently converted to brush or grassland, and remain resilient in the face of climate change. IIJA also has established a new Wildland Fire Mitigation and Management Commission, which will work closely with the Wildfire Resilience Interagency Working Group that is co-led by the USDA, DOI, and OMB. Lastly, research programs are an important piece of the equation in reducing wildland fire suppression costs. The Joint Fire Science Program (JFSP) is funded by the FS and the DOI to address problems associated with managing wildland fuels, fires, and fire-impacted ecosystems and received additional funding through IIJA (U.S. Department of Agriculture, 2021).

Federal Facility Flood Risks

Of over 57,000 inventory records reviewed in coastal areas, OMB and NOAA identified 10,250 individual Federal buildings and structures, with a combined replacement cost of $32.3 billion, that would be inundated or severely affected by typical high tide under an eight-foot sea level rise scenario. Under a ten-foot 'worst case' sea level rise scenario, at least 12,195 individual Federal buildings and structures would be inundated, with total combined replacement cost of over $43.7 billion.

Depicted above is the San Diego Bay area, including the North Island Naval Air Station and Naval Base Point Loma. From left to right depictions show the area at current sea level, with 8 feet of sea level rise, and with 10 feet of sea level rise. Green represents low-lying but hydrologically unconnected areas. Blue represents areas inundated at high tide. Source: NOAA Sea Level Rise Viewer (https://coast.noaa.gov/slr/).

Introduction

The facility portfolio held by the Federal Government is substantial. The Federal Executive Branch owns or leases more than 285,000 buildings, 2.8 billion square feet of buildings, over 537,000 structures, and over 27 million acres of land, with annual operating costs in excess of $36 billion (GSA, 2020).[34] Just under half of these annual operating costs are for Department of Defense-run assets. The total reported replacement cost of Federal property is estimated at nearly $1.9 trillion. Federal facilities face a number of climate change enhanced hazards, including increased risks of flooding, extreme weather events, and fire. For example, flooding damage from heavy downpours is projected to increase in various regions across the country (AECOM, 2013). Also, sea level rise is expanding the coastal floodplain, causing increased frequency and magnitude of coastal flooding and compound damages from storm surges. This increase has led to record numbers of events that caused over $1 billion in damages (NOAA, 2021).

FEMA shows that ninety-eight percent of U.S. counties have experienced a flooding event, and flood waters continue to pose a greater potential for damage than other natural disasters (Grimm, 2020). Floods have caused over $155 billion in property damages in the last decade, and they continue to account for the majority of Federally declared disasters (ibid). When adjusting for the long-term impact of a changing climate, recent research finds there are nearly 4.3 million

[34] These statistics are limited to CFO Act agencies.

residential homes across the country with "substantial" flood risk (First Street, 2021).[35] Similar to residential homes, the risk of flooding to Federal Government buildings is expected to increase due to climate change. In each of these cases, increased risk of flooding also increases risk of financial loss.

Flood zones are geographic areas that FEMA categorizes by level of flood risk.[36] FEMA refers to areas with at least a 1% estimated annual chance of flooding as the 100-year floodplain; areas with at least a 0.2% estimated annual chance of flooding are referred to as a 500-year floodplain. Areas at high risk for flooding are generally identified as being within the 100-year floodplain, while those at moderate risk include areas between the limits of the 100-year and 500-year floodplain. These areas are also used to designate base flood elevations of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot.

A 2013 study conducted for FEMA demonstrated the scale of climate impacts on flood risk, finding that by 2100 the 100-year floodplain area would grow by 40-45 percent largely due to climate change (AECOM, 2013). This growth is likely to cause structures in the current 100-year floodplain to see more frequent and severe flooding (ibid). However, while FEMA has mapped flood risk in the most populated areas of the United States, data on specific impacts of future risks, (i.e., future flood risks due to climate change) is not readily available for many areas.

Yet, future coastal flood risks can be identified where sea level rise projections have been mapped. NOAA has mapped projected sea level rise in the continental United States and Hawaii, showing the relative depth of inundation from 0 to 10 feet above mean higher high water (MHHW). In other words, the maps show areas that would be inundated by typical high tides in different projections of future sea level rise. To estimate areas at substantial risk from future floods, sea level rise projects would need to be combined with coastal flood modeling to estimate the future 100-year floodplain.

In 2014, the IPCC used RCPs to assess future climate change, making predictions of how concentrations of greenhouse gases in the atmosphere will change as a result of human activities. NCA4 considered RCP 8.5 and RCP 4.5 to estimate the cumulative costs of sea level rise and storm surge to coastal property, projected to year 2100. Without adaptation, cumulative damages to coastal properties across the contiguous United States under RCP 8.5 are estimated at $3.6 trillion[37] through 2100. By contrast, these damages could be avoided by measures to adapt coastlines to sea level rise, which are estimated to cost $820 billion over the same time. Under the less-severe RCP 4.5 scenario, estimated cumulative damages without adaptation are reduced by $92 billion relative to RCP 8.5 and by $20 billion when accounting for potential adaptation over the same period (USGCRP, 2018).

The Federal Interagency Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Task Force, a joint task force of the National Ocean Council (NOC) and USGCRP, was charged with

[35] The report defines "substantial risk" as carrying a 1% chance of flooding in any year.
[36] A flood is temporary inundation of normally dry land from overflow of inland or tidal waters or unusual and rapid accumulation or runoff of surface waters from any source. In addition to inundation, direct impacts of floods include mudslides and episodic shoreline erosion or collapse caused by undermining waves or floodwater currents.
[37] Value calculated in 2015 dollars.

developing and disseminating future sea level rise and associated coastal flood hazard scenarios and tools for the entire United States to support coastal preparedness planning and risk management processes. This effort assessed the most up-to-date scientific literature on scientifically supported upper-end global mean sea level (GMSL) projections. NCA4 describes two intermediate scenarios as the most likely (intermediate-low and intermediate-high) to avoid the interpretation of a single scenario. These intermediate scenarios project a range of additional sea level rise by the end of the century (depending on future emissions and other factors) as between 1.6 and 3.9 feet of sea level rise by 2100. However, sea levels may also exceed that range, based on recent research of the potential Antarctic ice melt contribution to sea level rise. While RCP scenarios illustrate a range of sea level rise projections, for the purposes of this assessment the upper potential bounds of RCP 4.5 and RCP 8.5 were used, including the recent inputs from rapid potential Antarctic ice melt. Under the upper bounds of scenario RCP 8.5, a 'worst case scenario' estimate, sea levels could reach up to 10 feet above the current global mean sea level by 2100. Under scenario RCP 4.5, sea levels could reach 8 feet above the current global mean sea level over the same timeframe. Regardless of the scenario followed, it is extremely likely that global average sea level rise will continue beyond 2100 (USGCRP, 2018).

Risk Assessment (Flood maps)

A comprehensive dataset for all Federal buildings and structures does not exist at this time. The most comprehensive data set, the Federal Real Property Profile Management System (FRPP MS), is the successor to the Federal Real Property Profile, the government-wide inventory developed in 2004 to house information about the nature, use and extent of the Federal Government's real property assets. It contains data on all Executive Branch agency real property assets within and outside the United States, including improvements on Federal land, except when otherwise required for reasons of national security.

As the FRPP MS was not designed or intended to be used for geospatial mapping, precise location data for all of the Federally-owned buildings is not captured. As a result, a full and complete assessment of Federal property flood risk is not feasible with data from the FRPP MS alone. However, assessing flood risks using the data that is available from the FRPP MS does provide details that can show significant financial risks to Federal facilities and increasing risks due to climate change.

In addition, estimating Federal costs due to a flood event is imprecise. Similar to a home or business, if a Federal facility is flooded, damages can vary significantly based on the severity of the event. Flooding could cause damage to the ground floor of an office building, for instance, or cause more severe structural damage to a facility. This assessment does not attempt to estimate future damages to individual Federal facilities due to the range of potential scenarios and the lack of precise methodology for such estimates. Instead, to highlight the risks to Federal facilities, this assessment uses the FRPP MS-defined total replacement value[38] of the Federal facilities.[39]

[38] Replacement Value is defined as the cost required to design, acquire and construct an asset to replace an existing asset of the same functionality, size, and in the same location using current costs, building codes, and standards. Neither the current condition of the asset nor the future need for the asset is a factor in the replacement value estimates.

[39] Note that 'total replacement cost' does not represent projected Federal expenditures. Expenditures on Federal facilities due to future flooding is not projected and is expected to be a subset of the summed total replacements costs.

Using the FRPP MS, OMB identified over 40,000 individual buildings and structures with a total combined replacement cost of $81 billion (2020$) located in the current 100-year floodplain. Based on current FEMA floodplain maps, these structures represent roughly 9 percent of the subset of records and 10 percent of the subset replacement value. Using FRPP MS data, approximately 160,000 structures, with a total replacement cost of $493 billion, were identified in the current 500-year floodplain. The Federally-owned structures not examined, falling outside of the FRPP MS dataset, have an estimated total replacement cost of over $1 trillion (GSA, 2020). Assets that were not assessed include national security-sensitive facilities, as well as several types of non-building assets such as transportation and communications infrastructure. The portion of assets reviewed generally includes non-defense facilities like office buildings, warehouses, housing, laboratories, and hospitals. It is also worth noting that assessing Federal facilities within existing FEMA floodplains only considers the current flood risk for those facilities. It does not estimate future risks from flooding, which is expected to increase in many areas due to climate change.

Risk Assessment (Sea Level Rise)

Shoreline counties hold 49.4 million housing units, while homes and businesses worth at least $1.4 trillion sit within approximately 0.125 miles of coasts (McNeal, 2014). Some research has estimated and quantified financial risks to homes and businesses related to sea level rise. Recent economic analysis shows that under RCP 8.5, between $66 billion and $106 billion worth of real estate will be below sea level by 2050. These estimates increase to between $238 billion and $507 billion by 2100 (Houser, 2015). Similar to homes and businesses, the Federal Government owns a significant portfolio of buildings and structures in coastal areas. Yet, quantified financial risk assessments to Federal facilities due to sea level rise is in its nascent stages.

The extent of future changes in flood risk has not been estimated across the full Federal inventory. For instance, assets that were not assessed include national security-sensitive facilities, as well as several types of non-building assets such as transportation and communications infrastructure. However, OMB and NOAA evaluated the FRPP MS dataset using NOAA's Sea Level Rise Viewer to assess inundation risk at coastal facilities. Of over 57,000 inventory records reviewed in coastal areas, OMB and NOAA identified 10,250 individual Federal buildings and structures, with a combined replacement cost of $32.3 billion, that would be inundated or severely affected by typical high tide under an eight-foot sea level rise scenario, the upper bounds of RCP 4.5. Under a ten-foot 'worst case' sea level rise scenario, the upper bounds of RCP 8.5, 12,195 individual Federal buildings and structures would be inundated, with total combined replacement cost of over $43.7 billion (2020$).[40] It is also worth noting that a portion of these facilities appear to be located outside of the current 100-year floodplain, reinforcing the expectation that sea level rise will appreciably expand the number and value of Federal facilities facing flood risk in the coming decades.

Outside of estimating the total replacement costs of the facilities that could be inundated by routine future flooding, OMB has not estimated the likely costs associated with potential

[40] Navigation structures, such as ocean buoys, were removed from the data, so they would not be included in the totals.

damages related to sea level rise. Replacement value is an imperfect indicator (and effectively an upper bound) of the rough scale of an individual facility's financial risks to flooding. While inundation could require outright abandonment and/or replacement of a Federal facility, an individual flood event or the presence of flood risk may be mitigated by less costly adaptations, infrastructure investments, or repairs. To estimate areas at substantial risk from future floods, sea level rise projections would need to be combined with coastal flood modeling to estimate the future 100-year floodplain. These future floodplain estimates could then be combined with building inventory information and building damage models to estimate future costs.

Key Limitations and Uncertainties

This paper assesses the future flood risks at Federal facilities, but does not assess other climate-related financial risks that Federal facilities will face. For instance, Federal facilities are at risk to an array of hazards related to climate change that are not quantified here and could be examined further, such as risks to wildfire or other forms of extreme weather.

Currently, data limitations prevent the Federal Government from identifying the full extent of flood risk facing Federal facilities under current and future conditions. For instance, projected floodplain maps, reflecting expected changes due to climate change, are not available. FEMA's maps are used to implement the National Flood Insurance Program and to provide communities with accurate flood hazard information, and therefore reflect existing flood risk. Without future projections, the full extent of the impact of climate change on flood risk for Federal facilities is not clear.

Also, as previously described, a more detailed and individualized damage methodology has not been conducted on the Federal inventory to determine actual expected costs due to flooding. This type of assessment would provide a clearer picture of Federal fiscal risk exposure than replacement cost. In combination with assessments of current and future flood risk, assessing individualized damage scenarios on Federal property would enable better planning for investments and divestments across the Federal inventory.

Another limitation to pinpointing the financial risks to Federal facilities due to climate change is that the Federal Government lacks a comprehensive dataset that would enable precise spatial analysis of the entire Federal property inventory. The FRPP MS does not include geographic coordinates for a broad set of facilities that are related to national security. Similarly, the FRPP MS includes several types of non-building assets such as transportation and communications infrastructure for which geographic coordinates are not reported and street addresses are unreliable for the purposes of accurately determining flood risk. The FRPP MS dataset was not designed for geospatial mapping, and precise location data may be incomplete for some specific facility locations. In June 2020, GSA revised the FRPP MS data dictionary to clarify the reporting of street addresses as well as latitude and longitude coordinates. Longitude and latitude coordinates were used for the purposes of this assessment.

In addition to these data limitations, risk assessments for individual facilities are imperfect using geospatial mapping data like FEMA's flood maps and NOAA's Sea Level Rise Viewer.

Individual flood impacts are difficult to estimate due to the challenges of downscaling global change models to the local level. Additionally, while there is high confidence that sea levels will continue to rise, the pace of that rise and the ability for communities and governments to adapt to flood events is difficult to pinpoint. NOAA's Sea Level Rise Viewer is also not meant to be used for site-specific analyses. The data in these maps also do not consider future construction, 100-year future flood risk, or natural processes such as erosion, and subsidence. The nature of the geospatial maps also varies. FEMA's maps show the risks of large magnitude floods. NOAA data represent the projected extent of inundation levels rather than what a future flood risk would be.

Impacts to Federal facilities will also depend on investments made outside of the Federal Government that could mitigate some of the risks due to flooding. For instance, local and state governments can also make investments, such as pump stations or levees to manage flood waters, that could help reduce risks to Federal facilities. The degree to which Federal, State, and local governments will invest in measures to reduce future risk is unclear and will often be specific to individual communities.

Notable Agency Actions to Mitigate Identified Risks[41]

Capital Planning and Program Management

OMB and CEQ are exploring options to integrate climate change considerations into capital planning and program management. OMB's Capital Programming Guide, a supplement to Circular A-11, provides current guidance. In general, forward-looking climate information should be incorporated into major acquisitions. Evaluation of the exposure to climate risks and comprehensive risk management should mitigate the possibility of disruption to the mission, the supply chain or the ability of the agency to deliver critical products and services to the public. Federal assets should be able to perform reliably over their intended service life under changing conditions whether the changes are acute events (hurricanes, floods, wildfires) or long-term shifts in climate patterns (sea level rise).

Federal Flood Risk Management Standard

On May 20, 2021, President Biden issued Executive Order (EO) 14030, "Climate-Related Financial Risk", reinstating EO 13690, "Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input "(January 30, 2015), which established the Federal Flood Risk Management Standard (FFRMS). The FFRMS is a flood risk reduction and resilience standard to increase resilience against flooding and help preserve the natural values of floodplains. The standard ensures that agencies expand management from the current base flood level to a higher vertical elevation and corresponding horizontal floodplain for Federal actions and Federally funded projects (including Federal facilities) taken in a floodplain to address current and future flood risk. The FFRMS includes approaches for determining the level of protection, and where actionable data and tools are available, a climate-informed science approach is the preferred methodology to ensure Federal investments last as long as intended.

[41] Note that these are only a handful of agency actions that will help mitigate risks to future flooding. This list is not all inclusive, and it also does not capture agency actions to reduce risks from other climate-related hazards, such as wildfire or other extreme weather events.

Agencies have begun a process to update their internal procedures, funding notices, policies, manuals, program guidance, and rules to implement the FFRMS. Specifically, for Federal facilities, FFRMS applies to new construction and modernization of Federal buildings and facilities, and repair of Federal buildings and facilities that have been substantially damaged as a result of natural or manmade hazards. A subgroup of the National Climate Task Force's Flood Resilience Interagency Working Group (IWG), the Federal Flood Risk Management Standard (FFRMS) Science Subgroup (co-chaired by NOAA, HUD, and OSTP) is charged with updating the Climate Informed Science Approach with the latest actionable science guidance and developing tools and resources for agency implementation of the standard.

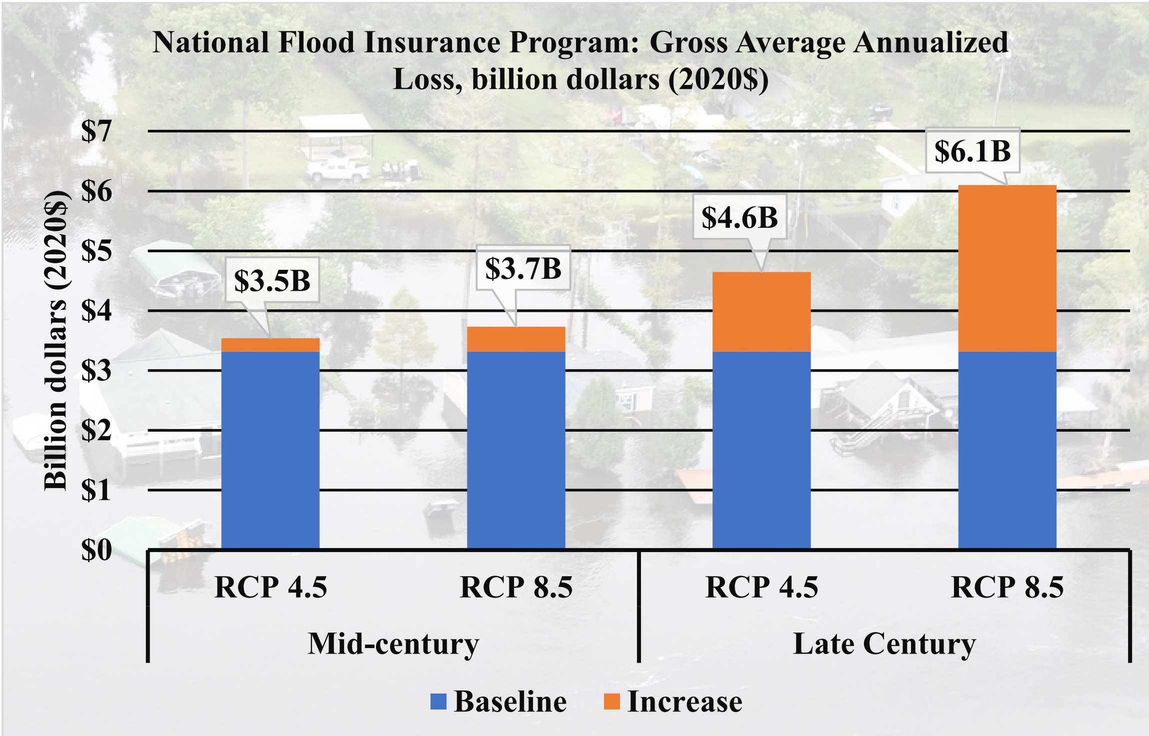
General Services Administration Actions

As part of its Climate Change Risk Management Plan, GSA committed to evaluating flooding risks to its buildings, updating the Building Assessment Tool (BAT) to monitor and evaluate climate impacts, and identifying, assessing, and managing the financial risks of climate change.

In 2020, GSA conducted a high-level assessment of the flood vulnerabilities of the assets under its jurisdiction, custody and control that were constructed prior to establishment of flood maps and reported those findings to Congress. To mitigate the damage caused by floods, GSA has a robust project planning and development process in place to avoid underestimation of flooding risk, given the observed and expected changes in extreme precipitation and climatic trends, in addition to the historic data. As a risk management activity, GSA incorporates flood resiliency measures by integrating the latest building codes, resilience methodologies and forward-looking information into its existing capital investment processes and the Facilities Standards for the Public Buildings Service (PBS-P100).

GSA has started the process of integrating considerations for the financial impacts of the physical and transition risks of climate change into GSA decision-making processes. Since 2014, GSA has reviewed approximately 100 capital projects for climate risks for new construction and major renovations, based on specific requests from the capital project team. This was accomplished by leveraging climate science and information developed by the US Global Change Research Program to assess the observed extremes and expected long-term changes during an asset's service life. The reviews lead to capital projects with greater adaptive capacity, and therefore reduce the potential for damages and costly repairs from climate events. Similar reviews are currently being conducted for the Land Ports of Entry projects funded through the Bipartisan Infrastructure Deal.

Flood Insurance



In a baseline scenario, the Gross Average Annualized Loss (AAL) of the National Flood Insurance Program is $3.3 billion. However, under RCP 4.5, this increases to $3.5 billion by mid-century and $4.6 billion by late-century. Under RCP 8.5, the Gross AAL is $3.7 billion by mid-century and $6.1 billion by late-century.

Introduction

Water risk is discussed throughout this assessment, and, in addition to this section on the National Flood Insurance Program (NFIP), floods are discussed in depth in other sections as a risk to Federal facilities and as a risk in the context of coastal disasters, particularly hurricanes. According to NCA4 and NOAA's Global and Regional Sea Level Rise Scenarios for the United States, climate change will do the following:

- Cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes,
- Contribute to the increased severity of hurricanes,
- Contribute to sea level rise along U.S. coastlines, with emissions to date contributing about 2 feet of sea level rise between 2020 and 2100, and
- Increase precipitation in the Midwest, with impacts on riverine flooding.

This section discusses the long-term Federal fiscal risk of the NFIP—a program in which, both through private insurance companies as intermediaries and through a direct Federal program, the

Federal Government provides flood insurance to homeowners and businesses (Floodsmart.gov). At the end of FY 2021, NFIP provided nearly $1.3 trillion of flood coverage for over five million policyholders (FEMA: Flood Insurance). The program is statutorily required to be actuarially sound,[42] with some exceptions for discounts or subsidies to certain property types (Horn and Webel, 2021; CBO, 2017). Until recently premiums were largely based on a structure's elevation within a regulatory flood insurance rate map (FIRM). FIRMs only reflect flood hazards at the time the map is updated and do not account for potential future flood risk[43]. Because the NFIP guarantees flood losses as a Federal obligation, larger than anticipated long-term losses can theoretically, and have in the past, become the responsibility of the Federal Government.

The program has had particular setbacks with large-loss hurricanes. While the program has the ability to borrow directly from Treasury, it was never intended to be deeply indebted to Treasury from an ill-fated sequence of strong Atlantic hurricanes that hit large metropolitan areas. The program is not designed to support large-loss hurricanes, and as a result, Congress extended the NFIP's borrowing capacity after the 2005 hurricane season (Katrina, Rita, and Wilma). After Hurricane Sandy in 2012, Congress further extended the borrowing ability of the program. In 2017, Congress cancelled $16 billion in debt to allow NFIP to pay for Harvey, Irma, Maria, and other 2017 losses (Horn, 2021). [44]

According to FEMA, historically, NFIP flood maps and home elevation largely determined policyholder rates. This legacy program had downsides. An inadvertent result of the rating methodology was policyholders with low valued property subsidized those with high value property (FEMA: "FEMA Updates"). Additionally, because the premium was largely based on location in or outside of the special flood hazard area, the legacy system did not represent an individualized view of risk (FEMARR2PD, 2021). CBO (2017) found actuarial shortfalls and implicit subsidies.

To adequately respond to risks and ensure actuarial soundness, FEMA designed a new rating methodology, Risk Rating 2.0, and the first phase was rolled out in late 2021. Rather than relying on flood maps and home elevation, the new system considers a variety of variables to profile properties individually, in line with modern actuarial science. According to FEMA, "[t]hese include flood frequency, multiple flood types—river overflow, storm surge, coastal erosion and heavy rainfall—and distance to a water source along with property characteristics such as elevation and the cost to rebuild." Under Risk Rating 2.0, all NFIP premiums reflect a single property's unique flood risk and over time this new methodology will help close the gap between premiums and losses, even as the risk changes due to climate change and other effects. (FEMARR2PD, 2021 and "FEMA: Risk Rating 2.0: Equity in Action Website"[45]). Outlier properties which currently have high flood risk and low premiums will become actuarially sound

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[42] Citation: FEMA "Risk Rating 2.0 is Equity in Action," public version, 2021; henceforth, "FEMARR2PD, 2021"".""

[43] Horn, D. P. (2021). *National Flood Insurance Program: The Current Rating Structure and Risk Rating 2.0*. Congressional Research Service. Retrieved February 28, 2022 from https://crsreports.congress.gov/product/pdf/R/R45999 .
Cackley, Alicia Puente (2021). National Flood Insurance Program: Congress Should Consider Updating the Mandatory Purchase Requirement. U.S. Government Accountability Office. Retrieved February 28, 2022 from https://www.gao.gov/assets/gao-21-578.pdf

[44] Information from entire paragraph is from Horn (2021).

[45] Paragraph information is from these two sources, with some verbiage from FEMA during review.

over a number of years because rates are statutorily prohibited from increasing more than 18 percent annually (FEMARR2PD, 2021).

NFIP also collects some monies to support a reserve account at Treasury. The mechanism for obtaining funds for the reserve account includes (a) a "Reserve Fund Assessment," in which FEMA charges policyholders to build up the fund and (b) an annual "Homeowner Flood Insurance Affordability Act Surcharge," which is $25 for policies on primary residences and $250 for policies not on primary residences (Sept. 2020 NFIP Report to Congress). Statutorily, the reserve account should contain at least 1 percent of the value of potential losses in the program and while the FEMA Administrator can raise that percentage if appropriate, accumulating a reserve fund balance of $13.4 billion is near impossible solely through policyholder collections.

According to FEMA's most recent NFIP public financial report, NFIP has sufficient resources between the National Flood Insurance Fund and the Reserve Fund to pay for a $6.3 billion loss event. With its $9.9 billion in additional borrowing authority, an event up to $16.2 billion could be covered prior to any reinsurance recoveries. However, the Reserve Fund, which should have $13.4 billion per statute to cover catastrophic events, only has $2.1 billion (FEMA "The Watermark," 2021-Q3, FEMA calculations).

FEMA has attempted to protect the NFIP against major losses by purchasing reinsurance. In 2021, FEMA transferred a total of $2.43 billion of risk for approximately $362 million in reinsurance fees. This reinsurance coverage bolsters NFIP claims paying capacity from $16.2 billion to $18.629 billion (FEMA, NFIP Reinsurance; Communication with FEMA regarding reinsurance information). FEMA has indicated the reinsurance is for named disasters of a certain size. Several moderate-sized disasters under the contractual trigger may result in depletion of reserves without a reinsurance payment. According to FEMA, reinsurance that covered several moderate-sized disasters is likely economically infeasible.

Risk Assessment

NFIP analyzed the program using its modeling software, Katrisk. Katrisk is one of a few "catastrophe models" used by FEMA for these purposes. NFIP uses a variety of catastrophe models to analyze losses: Katrisk has particular features that make it useful for the purposes of a climate exercise. Like other sections of this report, NFIP focused on RCP 4.5 and RCP 8.5 in 2050 and 2100—leading to four scenarios[46] plus a baseline scenario.

For each of the five scenarios, NFIP ran hundreds of thousands of stochastic flooding events in Katrisk to determine typical losses (average annual loss, or "AAL"), 1-in-20 annual loss levels, and 1-in-50 annual loss levels. The 1-in-20 and 1-in-50 annual loss levels are annual loss levels at which the yearly losses are larger than 95% and 98% of loss years, respectively.

All scenarios use NFIP's property portfolio as it currently exists.[47] The baseline scenario is a simulated expected loss in today's environment. The other four scenario simulations take the

[46] RCP 4.5 in 2050, RCP 8.5 in 2050, RCP 4.5 in 2100, RCP 8.5 in 2100
[47] Specifically, NFIP used its policy holders as of May 31, 2020

properties in the portfolio—as they currently are—and expose them to a simulated climate that would exist in each of the four respective scenarios. Thus, the properties as they currently exist are not assumed to make further adaptation under climate change, and losses are referenced to 2020 prices. The Katrisk model simulation considers, "losses and probability distributions from storm surge, inland flood, and tropical cyclone-induced precipitation flooding sources." Table 6 shows the results from this simulation.

Table 6. Katrisk Gross AAL and Occurrence Exceedance Probabilities Under Baseline and Climate Sensitivity Scenarios, million dollars (2020$)

		RCP 4.5		RCP 8.5	
	Baseline	**Mid-Century (2050)**	**Late-Century (2100)**	**Mid-Century (2050)**	**Late-Century (2100)**
Gross AAL	$3,317	$3,539	$4,648	$3,734	$6,098
Increase over baseline	-	7%	40%	13%	84%
1-in-20 loss level	$10,315	$11,025	$13,906	$11,370	$16,896
Increase over baseline	-	7%	35%	10%	64%
1-in-50 loss level	$17,208	$18,476	$22,591	$18,996	$26,507
Increase over baseline	-	7%	31%	10%	54%

As shown in the Table 6, in current conditions, a 1-in-50-year loss event alone would be $14 billion larger than an average annual loss. In an RCP 8.5 scenario late-century, the current portfolio of properties would sustain a $20 billion larger loss from a 1-in-50 years event compared to an average annual loss in the late-century. This additional risk creates scenarios in which nearby large loss years add additional risk to the taxpaying public and to the Federal Government if debt cancellation, appropriations, or an increase in borrowing authority is required.

Key Limitations and Uncertainties

The simulation in this analysis assumes the 2020 NFIP property portfolio and projects America as it is today, but under future climate scenarios. As such, the economic or the fundamentals may change course over the century. Long-term macroeconomic indicators may influence the housing market: property values may go up (or down) in real terms, current policy holders may choose to purchase more flood insurance, and/or non-customers may change their mind and purchase a policy. Further, changes in climate change hazards, mandatory insurance coverage and prices, and housing prices will impact adoption of adaptation strategies and coastal development. These economic changes are not part of the simulation. Finally, this is one of many models used by NFIP to model climate risk; other models may have slightly different results.

As communities face continuous climate change impacts, and as Risk Rating 2.0 is rolled out, more work may need to be done to analyze how NFIP risk models are behaving. The full risk may hinge on whether the 2005-2012-2017 hurricane seasons are simply three bad draws of a well-modeled system—or whether actuarial modeling will need to continue to change along with climate change.

Notable Agency Actions to Mitigate Identified Risks

FEMA has various strategies for managing the financial risk posed by climate change, including addressing equity. First, Risk Rating 2.0 will annually reassess an individual's flood risk, considering short-term impacts of a changing climate. As policyholders move towards actuarially sound premiums, the Agency will have a stronger financial footing to withstand swings in annual flood claims over the long run. As policyholders understand their individual risk, they may choose to take mitigation actions to lower their flood insurance premiums and overall risk. Additionally, Risk Rating 2.0 produces premiums that are equitable and reflect the unique flood risk of a building. FEMA's legacy rating system does not consider repair costs, which means many policyholders with lower-value homes are paying more than they should and policyholders with higher-value homes are paying less than they should. The cost to rebuild is key to an equitable distribution of premiums across all policyholders because it is based on the value of their home and the unique flood risk of their property. Finally considering the cost to rebuild is not only more equitable, but is also consistent with industry standard. Additionally, the FY 2022 and 2023 President's Budgets proposed a means-tested program that would provide assistance to low- and moderate-income policyholders.

Second, FEMA has hazard mitigation assistance programs that support property owners. Examples of mitigation activities occurring at the State-level include elevation of homes and purchasing of homes at pre-disaster market values. FEMA can work with States to prioritize homes that have repeated losses so that those homes can be acquired or elevated to avoid future losses. Third, FEMA's reinsurance program provides an additional level of financial protection that helps the Agency guard against individual flood events that can exceed certain claim levels, as agreed upon with reinsurers. Finally, FEMA is undertaking various procedural and regulatory updates, including implementing the Federal Flood Risk Management Standard and reviewing the floodplain minimum standards that a community must adopt to participate in the NFIP) and receive Federal disaster assistance. The minimum floodplain standards have not been updated since 1976 and revising those standards could incorporate the current understanding of flood risk and flood risk reduction approaches.

FEMA, NOAA, USGS, USDA, and other agencies collaborate in a number of ways to develop data and mapping that support flood hazard identification, risk reduction, and risk communication. Some of this supports the NFIP, such as water levels, bathymetric, topographic, and land cover data and various types of modeling by NOAA that are used in FEMA NFIP flood studies. Multiple Federal agencies (NOAA, USGS, USACE, USDA) participate on FEMA's Technical Mapping Advisory Council, providing advice to the FEMA Administrator on flood risk analysis and mapping practices in support of the NFIP. Federal agencies are also working together under the National Climate Task Force's Flood Resilience Interagency Working Group on science and decision-support services to identify and mitigate future flood hazards, including sea-level rise and other climate impacts.

NOAA has indicated that it will develop coastal and inland forecast inundation mapping and capabilities to better understand subseasonal to annual integrated water capabilities, as coastal communities are increasingly impacted by periods of flooding, even in the absence of storms or heavy rainfall. In addition, NOAA will work on updating precipitation frequency atlases.

Regarding the NFIP, NOAA also, will continue to provide science support for coastal community participation in the Community Rating System Program (CRS), and will continue to serve on the FEMA Technical Mapping Advisory Council. According to FEMA "Community Rating System":[48]

> *The Community Rating System (CRS) is a voluntary incentive program that recognizes and encourages community floodplain management practices that exceed the minimum requirements of the National Flood Insurance Program (NFIP). Over 1,500 communities participate nationwide.*
>
> *In CRS communities, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community's efforts that address the three goals of the program:*
>
> 1. *Reduce and avoid flood damage to insurable property*
> 2. *Strengthen and support the insurance aspects of the National Flood Insurance Program*
> 3. *Foster comprehensive floodplain management*

The CRS Task Force is currently focused on developing plans for CRS Next, the new version of the CRS Program that aligns with Risk Rating 2.0. NOAA's continued involvement on the CRS Task Force will help to promote the use of nature-based solutions, the incorporation of NOAA climate science, and NOAA's Tsunami Ready Program as key components of CRS Next.

[48] Quote provided in part by communication with NOAA.

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Technical appendix: Climate Risk Exposure: Coastal Disasters

OMB based this assessment by modifying CBO's calculations CBO (2016), while also modifying some imputation assumptions. First, the real annual GDP growth rate from 2020-2075 is imputed as slightly above 2 percent. This comes from 2020 GDP from the Bureau of Economic Analysis and CBO's 2075 GDP—calculated as $150 billion in damages divided by 0.22 percent (0.22 percent is GDP as a proportion of damages, found in CBO's analysis. 2075 GDP is adjusted to 2020 dollars using the GDP price deflator. From this growth rate, 2050 GDP is determined—which multiplied by damages as a percentage of GDP found in CBO's analysis—gives us low, medium, and high 2050 damages in 2020 dollars (denote this as T_{2050}).

CBO assessment describes the proportion of increased damages attributed to—(a) climate change-only damages given no coastal development (denote A), (b) coastal development-only damages given no climate change (denote B), and (c) damages caused by the interaction between coastal development and climate change (denote C)—for 2075's mean scenario. For 2075, the proportion of total damages attributed to A, B, and C is assumed to be the same for the low, mean, and high scenarios. Since this proportion is provided for the mean scenario in the form of dollars in CBO's assessment, once total damages for 2075 is calculated under the low and high scenarios—equal to percentage of GDP in these scenarios provided in CBO's analysis multiplied by imputed GDP—it is straightforward to find the costs of components for A, B, and C in dollars in the low, mean, and high scenarios in 2075.

CBO also described that in its base case, 64 percent of damages are from wind damage and 36 percent are from storm surge. In the mean response 2075 case, wind damages would grow 1-to-1 with per capita income, 1-to-4 with population; and storm surge damages would grow 3-to-4 with per capita income and 1-to-2 with population. As a convex growth combination, denote then $\alpha_{\text{population}} = 64\%*0.25 + 36\%*0.5 = 0.34$ and $\alpha_{\text{income}} = 64\%*1.0 + 36\%*0.75 = 0.64$.

CBO simulated populations and provided a coastal population percentage for 2025, 2050, and 2075. For this report, newer projections of population from CBO have been downloaded,[49] which, in addition to the simulated populations from the 2016 report, imply a simulated coastal population vulnerable to losses:

Coastal population (millions of people) vulnerable to losses

	Low	Mean	High
2025	0.34	2.04	3.06
2050	0.75	5.24	13.1
2075	1.21	8.45	20.93

Income per-capita is assumed to grow at the same rate as GDP per-capita at the national level. GDP per-capita is given by CBO's implied projection of GDP from the report, divided by CBO's population projections. Given these calculations, the ratio of real GDP per-capita in 2050 is 1.67 times that of 2015, and for 2075, it is 2.98 times that of 2015.

[49] The Census 2020 preliminary count along with intercensal estimates to adjust populations were downloaded. The 2015 population was taken to equal 320.5 million and the 2020 population to equal 331.4 million (the 2015 population is used in calculations here as the baseline, but the 2020 is also a check on projections).

Compared to 2015, the coastal population vulnerable in 2050 is simulated as 2.34 to 4.54 times as high (low to high simulation, mean = 2.73), and 3.77 to 7.26 times as high in 2075 (mean = 4.40). Compared to coastal damages due to climate change, coastal damages due to coastal development may increase along a different path from the present, to 2050, and on to 2075. For coastal damage increases due to coastal development, the 2050 increase is calculated as a proportion relative to 2075 increases, namely: The proportion of <increased coastal development-only damages given no climate change 2050 relative to 2015> to <increased coastal development-only damages given no climate change in 2075 relative to 2015>. The formula is shown here, along with the calculation for the mean:

$$\frac{\text{Income Growth 2050 Relt. 2015} \times \alpha_{Income} + \text{Population Growth 2050 Relt. 2015} \times \alpha_{Population}}{\text{Income Growth 2075 Relt. 2015} \times \alpha_{Income} + \text{Population Growth 2075 Relt. 2015} \times \alpha_{Population}}$$

$$= \frac{(1.67 - 1) \times 0.64 + (2.73 - 1) \times 0.34}{(3.75 - 1) \times 0.64 + (4.40 - 1) \times 0.34} \approx 0.35 =: \rho_{coast,mean}$$

In the 2075 CBO scenario, 55 percent of damages are due to coastal development, and 45 percent are due to climate change. This gives us decomposed interaction components from the low, mean, and high scenario for 2075.

2075 damages in Billions 2020 USD

	Low	Mean	High
Total interaction effect	33.31	48.85	68.83
Interaction effect attributable to coastal development ($\sigma_{coast,2075}$)	18.32	26.87	37.86
Interaction effect attributable to climate ($\sigma_{climate,2075}$)	14.99	21.98	30.98

Two value series for 2050 are given already:

- Total damages, indicated by the imputed GDP for 2050 and the percentage of GDP estimates found in CBO's analysis. To get increases in damages, subtract $32.6 billion (2020 USD), which is the amount of damages from a baseline scenario ($30 billion in 2015 USD).
- Coastal development-only effects for 2050, equal to $B_{2050,\cdot} := \rho_{coast,\cdot} B_{2075,\cdot}$. For low, mean, and high effects ($B_{2050,low}$; $B_{2050,mean}$; $B_{2050,high}$), use the coastal development-only damages under the low, mean, and high scenarios in 2075 ($B_{2075,low}$; $B_{2075,mean}$; $B_{2075,high}$).

Denote the following:

$T_{2050,low}$; $T_{2050,mean}$; $T_{2050,high}$: Total damages in 2050 (low, medium, high)
$A_{2075,low}$; $A_{2075,mean}$; $A_{2075,high}$: Climate change-only damages in 2075
$B_{2050,low}$; $B_{2050,mean}$; $B_{2050,high}$: Coastal development-only effects 2050
$\rho_{coast(low\ to\ high)}$, $\sigma_{coast(low\ to\ high)}$, $\sigma_{climate(low\ to\ high)}$: As above
$\rho_{climate(low\ to\ high)}$: Proportion of <increased damages due to climate change only in 2050 relative to 2025> to <increased damages due to climate change only in 2075 relative to 2025>.

Then,

$$
\begin{aligned}
T_{2050,low} &= \rho_{climate,low}A_{2075,low} + B_{2050} + \overbrace{\left(\rho_{coast,low}\sigma_{coast,low} + \rho_{climate,low}\sigma_{climate,low}\right)}^{\text{Interaction between climate change and development}} \\
\rho_{climate,low} &= \frac{T_{2050,low} - \rho_{coast,low}\sigma_{coast,low} - B_{2050,low}}{A_{2075,low} + \sigma_{climate,low}}
\end{aligned}
$$

Then, the climate change-only 2050 increased damages are $\rho_{climate,low}A_{2075,low}$, and the interaction effects are $\rho_{coast,low}\sigma_{coast,low} + \rho_{climate,low}\sigma_{climate,low}$.. The mean and high calculations are similarly calculated.

By getting $\rho_{\text{climate(low to high)}}$ and $\rho_{\text{coast(low to high)}}$, one can now compute the entire combination of damages in 2050 by taking the 2075 values and appropriately applying **ρ** to both the decomposed 2075 interaction effects and the climate change-only and development-only damages in 2075.

Technical Appendix: Climate Risk Exposure: Federal Wildfire and Suppression Expenditures. Research and Development, USDA Forest Service[50,51]

Executive Summary

Climate change is anticipated to raise land and sea temperatures globally, including in the United States, and this change is likely to lead to shifts in the rate, severity, and extent of wildfire on Federal lands. Relevant to Federal budgets, such changes bring with them the expectation that spending to suppress and manage wildfires would generally change as the climate changes.

This report extends similar work done in 2016. We build on the 2016 analysis by updating information on climate change to comprise a larger number of future climate projections, updating data on wildfire suppression expenditures through 2020, increasing the observation frequency for suppression and wildfire to monthly compared to annual in the previous effort, increasing the time span of historical wildfire to fiscal years 1993 through 2018, and expanding our consideration of the potential drivers of wildfires. Similar to the 2016 report, we evaluate how changes in climate in the United States could lead to changes in annual spending to suppress wildfires on USDA Forest Service (FS) and Department of the Interior (DOI) managed lands by the middle and the end of the current century. As in 2016, we developed statistical models of wildfire at regional spatial scales based on historical data on climate and wildfire. Given the new monthly frequency of our data on both wildfire area burned and wildfire suppression spending for both FS and DOI, we are additionally able to estimate separate models of wildfire suppression spending by region for the Forest Service. Because Interior Department spending detail is not available at regional spatial scales, its suppression spending model was based only on historical *nationwide* monthly expenditures as related to departmental area burned nationwide.

In the current effort, we assembled an expanded set of projections by five global climate models (GCMs) and two alternative projections of radiative forcing levels (representative concentration pathways [RCPs] 4.5 and 8.5 Watts/m^2) to the year 2100. Hence, we show projections for five GCMs x two RCPs, i.e., 10 projections of future climate for the continental United States. Expanding from the previous effort, we tested model uncertainty on multiple measures of historical climate, including maximum daily temperature, vapor pressure deficit, average daily precipitation, potential evapotranspiration, the climate moisture index, and minimum relative humidity. With the exception of relative humidity, observations on all variables were available for both the historical time series and the projected time series to 2100. Area burned models' uncertainty analysis showed that, nationwide, the combination of average daily vapor pressure deficit (VPD) and average daily maximum temperature performed best across nearly all regions

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of the continental United States (CONUS). Forest Service suppression monthly expenditures were modeled for each region as a linear function of current area burned and area burned in the previous two months. The remainder of the Forest Service (RFS) expenses, whose spending is not directly associated with particular regions, and the aggregated nationwide suppression expenses for the Department of Interior were similarly modeled but at the national level. Region 10 (Alaska) of the Forest Service was found to not be related to area burned in that region and was specified as a simple constant model. All spending projections were done with constant 2020 dollars. Uncertainty in the area burned and suppression spending for each climate projection was quantified using Monte Carlo simulation, while overall uncertainty about climate was captured by projecting wildfire and spending under the ten projections (5 GCMs x 2 RCP scenarios). The ten projections differed widely in their projected futures by intention, with GCMs selected to capture a range of plausible futures in two climate dimensions: temperature and precipitation (Langner et al. 2020).

This analysis uses two methods to construct a baseline for historical burned areas with which to compare future projections. One is based on *observed* historical area burned. The other is based on *modeled,* or *backcast,* historical area burned, where climate variables were projected by the GCM for fiscal years 2006-2018 and then area burned projected from that climate backcast. Results show that median area burned, across both USDA and Interior lands and across all climate projections, is projected to be 104% higher by mid-century and 237% by late-century, when compared to observed historical (fiscal years 2006-2018) area burned. When compared to modeled historical area burned, these percentages are 106% and 241% higher by mid- and late-century, respectively. Given such changes in area burned, annual spending of both the Forest Service and DOI is projected to rise. Compared to back-cast spending, fiscal years 2006-2018, in real, inflation-adjusted 2020 dollars, expenditures would rise by 83% by mid-century and 186% by late-century. Applying these percentage increases to observed historical spending, we project that total Federal spending for the Forest Service and Department of the Interior would rise from a historical median (fiscal years 2006-2018) of $2.0b per year to a projected $3.66b per year in mid-century and $5.70b per year by late-century. Additional detail of the area burned and spending projections are presented in Figure A-1 and Table A-1 of this Appendix's Executive Summary.

The statistical modeling approach used in this study and the projected results are conditional upon several assumptions, violation of any of which would alter both the projected changes in spending and the ranges of our uncertainty bands. Primary assumptions include aggregation biases, omitted variables biases, and model structures. The details and caveats of these assumptions are treated in detail in the full report. An overarching assumption is that hazardous fuels were not modeled, and so no what-if scenarios were carried out that would evaluate how Federal efforts to accelerate rates of hazardous fuel reduction would affect wildfire and suppression spending. Even with these caveats and assumptions, our models, along with the literature we have cited (and much that we have not), provide evidence that both wildfire extent and suppression expenditures are expected to increase with climate change. Our models, specifically, show that temperature and vapor pressure deficit do a sufficient job of accounting for monthly area burned and associated suppression spending. Our models also show that increases in area burned and inflation-adjusted suppression spending could plausibly double over the next 80 years.

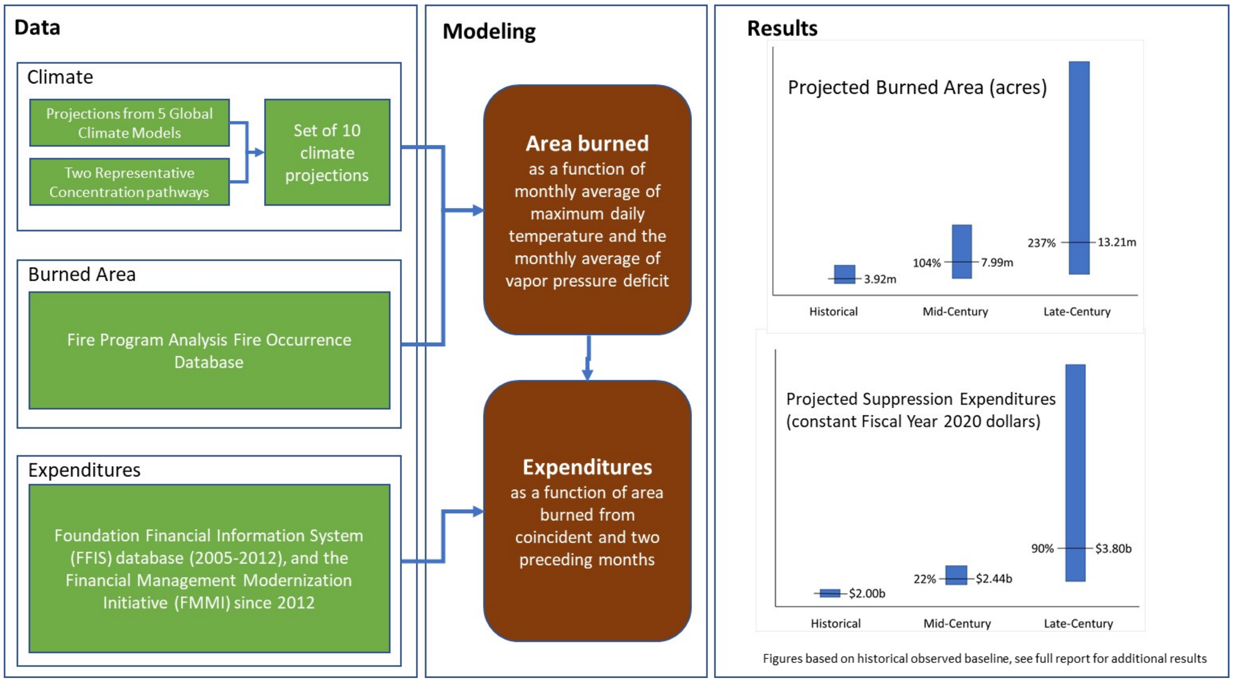

Figure A-1. Summary of area burned and suppression expenditure projections methods and results across FS and DOI lands combined. Note: range and height of area burned and suppression spending bars in the right panel reflect an 80% uncertainty bound.

Table A-1. Detailed projections of area burned and suppression spending, by DOI and FS and combined.

Projected change in area burned by mid-century (fiscal years 2041-2059)

Compared to:	Forest Service (FS)	Dept. of Interior (DOI)	Combined FS & DOI
Observed climate	94%	114%	104%
Modeled, climate back-cast	129%	83%	106%

Projected change in real suppression expenditures by mid-century (fiscal years 2041-2059)

Compared to:	Forest Service (FS)	Dept. of Interior (DOI)	Combined FS & DOI
Observed climate	16%	57%	22%
Modeled, climate back-cast	109%	48%	83%

Projected change in area burned by late-century (fiscal years 2081-2099)

Compared to:	Forest Service (FS)	Dept. of Interior (DOI)	Combined FS & DOI
Observed climate	244%	226%	237%
Modeled, climate back-cast	306%	180%	241%

Projected change in real suppression expenditures by late-century (fiscal years 2081-2099)

Compared to:	Forest Service (FS)	Dept. of Interior (DOI)	Combined FS & DOI
Observed climate	85%	128%	90%
Modeled, climate back-cast	234%	114%	186%

Introduction

There is little doubt that changes in climate will affect wildlands, wildland fire, and suppression of fire (Abatzoglou and Kolden 2013, Abt et al. 2009, Flannigan et al. 2005, Flannigan et al. 2006, Flannigan et al. 2016, Littell et al. 2009, Littell at al. 2016, Liu et al. 2014, McKenzie et al. 2016, Mitchell et al. 2014, Prestemon et al. 2009, Riley et al. 2019, Westerling et al. 2006). Direct increases in area burned and numbers of large fires, resulting from more days with extreme fire weather, longer periods of sequential days with extreme fire weather, and longer fire seasons in many parts of the world are to be expected (Abatzoglou et al. 2021, Gao et al. 2021, Jolly et al. 2015, Lenihan et al. 2003, Riley and Loehman 2016). Natural ignition patterns may change with shifting storm tracks and lightning occurrence (Romps et al. 2014), and there are likely to be changes in human ignition patterns due to land use change. Using an approach similar to that used in Hope et al. (2016), this analysis evaluates an aggregate set of data on US Federal wildfire area burned and Federal suppression expenditures and projects both area burned and expenditures to calculate the effect of climate on Federal area burned and Federal expenditures in mid-century (2041-2059) and late-century (2081-2099). We evaluate area burned and wildfire suppression expenditures for both the USDA Forest Service (FS) and the US Department of the Interior (DOI). The FS and DOI were modeled separately because their management objectives differ, as did data availability.

Methods

Overview

This study extends similar work done in 2016 (Executive Office of the President 2016, USDA Forest Service 2016). In the 2016 study, we used the two-step model approach where area burned was projected and then projected area burned was used in a model of suppression expenditures. We take this two-step approach in the 2021 study also. However, we refined the models in terms of variables and time period and expanded the number of climate projections used. For this analysis, we were able to obtain data and project suppression expenditures for Alaska. For model fitting on wildfire to climate variables for the continental United States (CONUS), we assembled monthly data from fiscal year 1993 to fiscal year 2019 for the Forest Service and fiscal year 1993 to fiscal year 2018 for the Department of the Interior.

In the present study, the final burned area models, specified by region of the continental United States (CONUS), were Poisson pseudo-maximum likelihood (PPML) models with variables of monthly maximum temperature and vapor pressure deficit (e.g., Motta 2019).[52] This combination of variables for projected area burned performed better out of sample (random and

[52] The assumption of a constant mean/variance proportion restriction of the PPML model could have been relaxed with estimation of other functional forms. See the Variable Preselection and Model for Area Burned section for additional explanation of the choice of the PPML model.

end of series hold-out) than alternatives (linear, log-transformed area burned). Log-transformation of maximum temperature (in degrees Kelvin) and VPD in the PPML specifications slightly improved the out-of-sample goodness-of-fit (as measured by root mean squared error and bias) of the area burned projections compared to leaving temperature and VPD untransformed. Each CONUS region of the Forest Service and each corresponding collection of lands managed by the Department of the Interior defined by the boundaries of each CONUS Forest Service region, was allowed to differ in its relationship of area burned to climate variables.

For model fitting on suppression expenditures, we had consistent monthly data for each region of the Forest Service from 2005-2020. For DOI, suppression expenditures were available only in aggregate across the entire agency, 2013-2020. We considered evaluating suppression spending using preparedness levels, but the preparedness level (PL) time series was short, and the use of PL's would have required development of a new method to project them to 2100, which was beyond the scope of this study.

<u>Variable Preselection and Model Formulation for Expenditures</u>

We initially tested linear models of suppression expenditure as a function of area burned to test for model feasibility, and we found that these models performed well, particularly when compared with univariate time series models (i.e., modeling spending as a function of lags of spending and seasonal components). For the Forest Service, we considered fixed-effects three-staged-least squares models of area burned, an approach used in the 2016 effort, but opted to exploit the greater frequency of expenditure data (as monthly) and specify expenditures separately for each of FS regions 1-9 with two-stage least squares (2SLS) methods, with expenditures in the region as a function of instrumented current month area burned in the region and the two most recent months' lags of area burned in the region. Instruments current month area burned were the current number of fires reported and the current month natural log of human population of counties (U.S. Census Bureau 2021) containing national forests in the region. For Forest Service Region 10 (Alaska), expenditures were statistically unrelated to area burned and, given that they have been historically relatively low compared to the agency overall, averaging $1.4m/year, 2005-2020, they were modeled as a function of a constant only. For the Rest of the Forest Service (covering national contracts, the Washington, DC, office, and research stations), expenditures were also modeled as a function of the current month area burned on all national forests in regions 1-9, with current area burned instrumented by the total number of wildfires on national forests in regions 1-9 and the natural log of the sum of the population of counties containing national forest lands across each of the Forest Service regions 1-9. Because Department of the Interior expenditures were not available for physical regions like the Forest Service, total nationwide DOI expenditures, also reported monthly, were modeled with 2SLS methods, with expenditures specified as a function of current month area burned (instrumented with the number of wildfires on DOI lands across all of CONUS and the natural log of population in counties containing DOI lands in CONUS—i.e., excluding Alaska and Hawaii).

Because stationarity is required for regressors in the models described above, we also carried out several tests (augmented Dickey-Fuller, DFGLS, Phillips-Perron) of stationarity of the time series of real dollar monthly expenditures at the regional level for the Forest Service and the national level for DOI. All Phillips-Perron stationarity tests rejected a unit root at stronger than 1% for all Forest Service regions, Rest of Forest Service, and for the aggregate of DOI expenditures. Dickey-Fuller generalized least squares tests rejected stationarity for FS regions 1, 2, 8, 9, 10, and RFS when specifying lagged difference terms using the Schwarz Information Criterion but less commonly under other optimization criteria. We therefore evaluated the existence of long-term stable relationships (cointegrating relations) between RFS spending and CONUS area burned on Forest Service lands, and between DOI spending and CONUS area burned on DOI lands with a Johansen cointegration rank test for these two series. Rank tests could not reject nulls of no cointegration. Given the non-confirmatory test outcomes on cointegration, as a further examination of the possibility that expenditures were nonstationary, expenditures for RFS and DOI in aggregate were each modeled in first-differences, regressed on the first-differences of current and two months' lags of CONUS area burned. Tests with a small number of Monte Carlo iterations with those specifications produced unstable long-term projections (to late-century), with increasing variance and even negative expenditures projected for DOI. We therefore retained models of expenditures in levels as a function of area burned in levels for the projections reported here.

With monthly data on expenditures, it is natural to consider the existence of seasonal effects in spending that need to be accounted for. However, for the expenditures of the Forest Service and DOI, in nearly every case in every region, seasonality—measured with month indicator (dummy) variables—was found to be not statistically significant, after controlling for area burned. Therefore, we ignored potential seasonality in our expenditure models.

Finally, given the possibility of serial correlation in spending, we tested for residual serial correlation in the second stage equations of our suppression expenditure models. Durbin-Watson tests on the residuals confirmed nonsignificant serial correlation.

Variable Preselection and Model Formulation for Area Burned

Given accepted research, it has been shown that area burned in the United States can be adequately and accurately modeled as a function of temperature, moisture, and a variety of indices that derive from those two variables that determine flammability and rate of spread of wildfire. We tested a suite of climate variables that have been projected into the future by the Global Climate Models, downscaled using the Multivariate Adaptive Constructed Analogs (MACA) process (Abatzoglou 2013, Abatzoglou and Brown 2012). These climate variables included monthly average of daily maximum temperature, monthly total of daily precipitation, monthly average of vapor pressure deficit (VPD) and monthly total potential evapotranspiration

(PET). In the 2016 study, the single climate variable selected for inclusion in the 2016 model was the fiscal year annual average of daily maximum temperature. However, with the longer historical timeline, we chose to use monthly, regional observations as the basis for the area burned models for each agency. We tested the strength of the relationship between area burned and other climate variables in addition to temperature. Temperature has been shown to influence fuel moistures, fire season length, extreme fire weather, and lightning and storm tracks—all conditions that are known to influence area burned (Flannigan et al. 2009, Flannigan et al. 2016, McKenzie et al. 2004, Mueller et al. 2020, Romps et al. 2014, Wang et al. 2016). Abatzoglou and Kolden (2013) state that area burned is influenced by temperature, precipitation, and drought but contend that using temperature is merely a proxy for the many ways climate can influence wildfire. Precipitation has also been shown to have a strong link with area burned, particularly when standardized to percentile across an observed period (Abatzoglou and Kolden 2013, Holden et al. 2018, Keeley and Syphard 2017, Mueller et al. 2020, Riley et al. 2013). While we did test total monthly precipitation, we chose not to test the percentile of precipitation; finding a way to combine historical and projected data to provide reasonable percentile precipitation estimates by region and month may prove fruitful but was not completed in this study due to time constraints. Vapor pressure deficit (VPD) is a metric incorporating both temperature and relative humidity. VPD indicates how much moisture is in the air relative to the maximum amount of moisture that the air could hold. VPD has also been shown to correlate strongly with large fire events and area burned (Mueller et al. 2020, Seager et al. 2015, Williams et al. 2019). PET was included as a candidate variable because area burned has been found to correlate with drought (Abatzoglou and Kolden 2013, Lammon et al. 2014, McKenzie et al. 2017, Riley et al. 2013). We had initially hoped to include Energy Release Component (ERC) as a candidate variable due to its high documented correlation with area burned (Riley et al. 2013, Riley and Loehman 2016), but the computational time required for obtaining forecasts of ERC at spatial and temporal scales suitable for our analysis were beyond the study timeframe.

Research on human-caused fires indicates that local population and income can influence ignitions (Mercer and Prestemon 2005, Prestemon et al. 2013) and area burned (Prestemon et al. 2016). In addition, anecdotal evidence implies that as population increases, buildings and other structures increase, which diverts suppression efforts from land protection to point protection. This, too, could lead to increases in area burned, all else held constant. Increases in income are hypothesized to influence the extent of local power and influence, which has been shown to lead to increased suppression expenditures (Donovan et al. 2011). Such effects have been identified at small spatial scales, at the level of the county or smaller. However, less research exists on such relationships at such large spatial scales as whole collections of national forests (e.g., FS regions). Testing of area burned models that included population in the counties containing national forests or DOI lands revealed no significant effects. We estimated Poisson pseudo-maximum likelihood (PPML) models of regional area burned as a function of the level and first-difference of regional human population. Significances were uncommon across the 8 physical FS regions and 8 physical DOI regions and signs on parameter estimates were not consistent. Absence of evidence does not provide evidence of absence: population estimates in counties contain errors, and changes between months within the short time series of years therefore are unlikely to provide accurate information on the effects of humans on spending at the scale of the region. We concluded that the area burned in an entire region and the population in the counties of that region may not have been as spatially connected as would be required to identify significant effects of population on wildfire (and its spending).

Modeling of area burned should address the zero bound on area burned. One way to recognize this is through either log-transformation of area burned (assuming no months with zero area burned, in our case) or the application of models such as the Tobit or pseudo-Poisson maximum likelihood specifications. We evaluated linear models (which ignored zero-truncation) and PPML models under out-of-sample forecasting conditions over historical data. We found that PPML models out-performed linear models and avoided the possibility that projected area burned would be negative. We did not test all alternative functional forms that would recognize zero-truncation of the dependent variable (area burned). However, we tested the fit of a Negative binomial maximum likelihood (NBML) model. The NBML model had a slightly better fit out-of-sample, but random samples drawn during Monte Carlo simulation using that functional form sometimes did not allow for convergence of the likelihood function, making the method less reliable for simulations. Therefore, we opted to model area burned as using PPML models, as a function of monthly maximum daily temperature in degrees Kelvin, transformed by the natural logarithm, and monthly average vapor pressure deficit, also log-transformed. Exceptions to the two variable specifications were made for FS regions 3 and 5, where maximum temperature was dropped, and DOI regions 4, 5, and 6, where VPD was dropped.

The models we selected projected area burned as a function of the monthly average of maximum daily temperature and the monthly average of vapor pressure deficit (VPD). This combination of variables for projected area burned, although very highly correlated in the historical time series ($r > 0.92$ in all regions evaluated), performed better out of sample (random and end of series hold-out). Log-transformation of maximum temperature (in degrees Kelvin) and VPD (in kPa) slightly improved the out-of-sample fitness of the area burned projections. Modeling area burned requires some strong assumptions, that, in the face of a changing climate, could be difficult to justify. We expect climate change to alter forest and range ecosystem compositions, and vegetation changes will, in turn, alter how many acres burn and how often and intensely they burn. In this analysis, because hazardous fuels are not directly modeled, our models carry an assumption that these vegetation changes *will not matter* to either area burned, nor to the expenditures we make to suppress wildfire. It is possible that, to the extent these changes have already begun to occur across Federal wildlands, our models incorporate some of these changes in ecosystems, but we cannot test this possibility using an aggregate model structure alone.

Likewise, our projections assume that parametric relationships only account for the effects of wildland hazardous fuels management efforts that have been taking place in the historical time period. Because we do not include variables directly indexing such management, no what-if scenarios were carried out that would evaluate how Federal efforts to accelerate rates of hazardous fuel reduction would affect wildfire and suppression spending. Detailed vegetation modeling would be required to determine the extent to which climate-induced and management caused changes in hazardous fuels would occur and therefore have effects on wildfire and suppression expenditures.

<u>Data</u>

Temporal and geographic extent: The expenditure data are monthly, based on the Federal fiscal year (October 1 to September 30). We divided the United States into regions that coincide with the USFS regions and roughly with the Geographic Area Coordination Centers of the National Interagency Fire Center. Climate data is monthly also and is aggregated to these regions based on Federal lands only. Socioeconomic data is aggregated to regions based only on counties which include Federal lands. Fire data, also monthly, is based on actual fire ignition locations from the FPA FOD (fiscal years 1993-2018) (Short 2021). Monthly expenditure data for DOI are available nationally, while consistent monthly data for the FS are available nationally for fiscal years 2005-2020 by Forest Service Region, whose regional boundaries closely match GACC boundaries. Given the varying starting and end-dates of wildfire and suppression data, model data used in this study were truncated at the end of fiscal year 2018.

We used the Forest Service's 2020 Resources Planning Act Assessment (RPA) climate projections, which comprise 5 climate models projecting under the Representative Concentration Pathways (RCPs) RCP 4.5 and RCP 8.5 scenarios (Langner et al. 2020). The RPA climate data set is a subset of the MACAv2METDATA set (Abatzoglou and Brown 2012, Abatzoglou 2013). Global climate historical modeled projections (1950-2005) and future projections (2006-2099) from the Coupled Model Inter-Comparison Project 5 (CMIP5) were downscaled to the 4-km grid size using the Multivariate Adaptive Constructed Analogs (MACA) method. The MACA method is a statistical downscaling method that uses historical observations to remove historical biases and match spatial patterns in climate model output.

The RPA data set contains the historical data (METDATA, 1979-2015), and the historical modeled data (1950-2005) and the future projections (2006-2099) (MACAv2-METDATA) for 5 climate models under two Representative Concentration Pathways (RCP 4.5, 8.5) (Table B1). Five climate models were selected to capture the future (2041-2059) range of the 20-model MACAv2-METDATA set (Langner et al. 2020). Rather than use an ensemble, a model that projected future change near the mean of all 20 projections was selected: NorESM1-M. The five models reflect the hottest projection (HadGEM2-ES365), the least warm projection (MRI-CGCM3), the wettest projection (CNRM-CM5), the driest projection (IPSL-CM5A-MR), and the middle of the range projection (NorESM1-M) (see http://maca.northwestknowledge.net/GCMs.php for detailed descriptions of these models). The data set and metadata are available at:

Historical: https://www.fs.usda.gov/rds/archive/catalog/RDS-2017-0070-2

Projections: https://www.fs.usda.gov/rds/archive/catalog/RDS-2018-0014

For this project, we added monthly vapor pressure deficit from MACAv2METDATA to the RPA historical and projected climate data sets. We also added four years' worth of monthly data to all variables in the RPA historical data set (2016-2019) from GRIDMET, which is the data set from which the RPA historical data were derived (Abatzoglou 2013).

We generated regional and national averages, monthly and annual, for maximum daily temperature, average VPD, total PET, minimum daily relative humidity, and the sum of daily precipitation. We created regional monthly averages by first converting all daily or monthly spatial data to Albers Equal Area Conic to ensure grid cells from differing datasets matched, and included only grid cells corresponding to Federal lands (USDA Forest Service or DOI) (Snyder 1987).

Most of the global climate models available in the MACAv2 data set have been evaluated for their performance relative to historical climate observations. Based on the analysis by Sheffield et al. (2013), at the conterminous US scale, the models that had the least bias in temperature included MRI-CGCM3, used in this study. For precipitation, the models with the least bias included CNRM-CM5 and NorESM1-M, used here. At the regional scale, the models that performed best included IPSL-CM5A-LR, used in this analysis. Simulations of the 20th century by CMIP5 models have been conducted for regions of the United States: Pacific Northwest (Rupp et al. 2013), Southeast (Rupp 2016), and for the Southwest (Rupp Pers. Comm.). Based on these regional analyses, the top five models, based on 18 metrics, included CNRM-CM5 and HadGEM2-ES, used in this analysis.

Figure B-1 shows the historical and projected maximum temperature and vapor pressure deficit area-weighted for nationwide by agency for the observed period and all modeled periods. The values of each variable during each time period differ by agency, but there are some trends to note. First, for both variables, values are higher for DOI lands than for Forest Service lands in the observed and backcast data, and that remains the case in the future periods. Second, for each agency, the median values across the ten futures for both variables are greater in the two future periods than for the backcast and observed periods, indicating increasingly hotter temperature extremes, and drier conditions expected on average. Compared with backcast values, maximum monthly temperatures for both DOI and Forest Service lands are expected to increase by nearly 2 degrees by mid-century and more than 3 degrees by late century on average across the 10 futures, with the greatest increases projected under the hottest (HadGEM2-ES365) and driest (IPSL-CM5A-MR) projections under RCP 8.5 for both agencies. Average projections of VPD for the U.S. across the ten futures show expected increases by 0.1 kPa at mid-century and 0.2

kPa at late century for Forest Service lands, and by 0.2 and 0.3 for DOI lands for the two time periods, respectively. In all cases for both variables and both agencies, the range in average values across the ten futures for the U.S. is greater at late century than for mid-century, corresponding with increasing uncertainty in the climate model projections over time. While the projected values for both variables differ by region, there are consistent trends by region (Appendix Figures B-1 and B-2). Increases in both maximum temperature and VPD are also expected for each region at mid-century and late century. Average projected maximum temperature was greatest in the Southern region for both agencies at mid-century and late century, while the greatest increases in maximum temperature were projected in the Eastern region. For VPD, on average across the ten futures, the greatest values were projected for Forest Service lands in the Southwestern region and for DOI lands in the Pacific Southwest, while the greatest increases were projected for both agencies' lands in the Southwestern region.

Area burned (in acres) and number of fires were provided by Karen Short from the Fire Program Analysis Fire Occurrence Database (Short 2021). This dataset includes point locations, discovery dates, and final area burned estimates from individual agency fire reports estimates that were aggregated by month and jurisdictional agency for FY1993 to 2018. Additional FS data for FY19 were obtained from FIRESTAT, as noted above. We were unable to acquire and properly compile additional FY19 data from DOI due to time constraints. We used area burned for CONUS (excluding Alaska) for both FS and DOI expenditure modeling, although we also projected Alaska spending for the Forest Service separately without making projections of area burned. Although spending in Alaska (Region 10) for the Forest Service is low, averaging less than $1m/year, wildfire area burned on DOI lands in Alaska are more significant. Alaska represents a significant acreage in many years (averaging 37%, 1993-2018, but ranging from 3% to 93% of total DOI area burned), but a much smaller expenditure (we only have five years of expenditure data by region, but the average is 8%, and the range is from 4-14% of total DOI expenditures). With this level of variability, and a clear disconnect between area burned and expenditures, along with inadequate data for modeling Alaska expenditures separately, we chose to not model area burned in Alaska and used projected CONUS area burned as the dependent variable in projecting total nationwide expenditures for both DOI and expenditures only for non-region spending for the category Rest of Forest Service. For Forest Service regions, 1-9, however, we model expenditures as a function of each region's area burned. For Forest Service Region 10 (Alaska), we model it as simply a constant.

Suppression expenditure data: All expenditures are in constant 2020 dollars (obtained from the President's Budget, "Table 10.1—Gross Domestic Product and Deflators Used in the Historical Tables: 1940-2026", at https://www.whitehouse.gov/omb/historical-tables/). Regional expenditure and RFS expenditure data for the Forest Service were monthly, 2005-2020. For the Department of the Interior, data were also monthly, 2013-2020. The national level data are from NIFC, and the FS regional data are derived from historical reports, the Foundation Financial

Information System (FFIS) database (2005-2012), and the Financial Management Modernization Initiative (FMMI) since 2012.

Projections

To generate a no-further-climate change average for area burned and expenditures for 2006-2018 for FS and DOI, we averaged the historical data. In addition, we produced a median of the backcast of the regression models using historical modeled climate variables. The projections for midcentury represent an average of 2041-2059, and late-century are an average of 2081-2099 (the year 2100 is not included in the MACA dataset).

We used the projected climate data in our selected models to generate future area burned for midcentury and late-century, and then used area burned in the expenditure projections. We also calculated a change in area burned from recent to the two future periods. There are two possible methods of projecting with the climate values from the GCMs: (1) use the historical observed data as the base and use the projected climate data to estimate the change, or (2) use the climate model backcast projection as the base and the projected data as the change. We report both in this document.

The Monte Carlo simulations involved (1) randomly sampling from monthly observations of area burned and backcast historical climate over fiscal years 2006-2018, monthly observations of FS suppression expenditures over fiscal years 2006-2018, and monthly observations of DOI suppression expenditures over fiscal years 2013-2018; (2) estimating statistical relationships for area burned and suppression spending with the randomly sampled data; (3) projecting area burned and spending through fiscal year 2099 with the estimated parameters; and (4) repeating steps (1)-(3) 500 times for each of the climate projections (each of the 10 GCM x RCP combinations). Monte Carlo projection results are summarized in terms of medians of area burned and expenditures, 80% and 90% upper and lower bounds of area burned and expenditures, and then medians across each of the 10 climate projections. We generated projected expenditures and area burned for each of the climate models. Results were also summarized in tabular form, reporting historical observed, historical modeled (fiscal years 2006-2018) for area burned and expenditures for the Forest Service and DOI and their total, including 80% and 90% upper and lower bounds and medians for mid-century and late-century.

Results

Area burned modeling results

Area burned model estimates are reported in Table B-1. Models indicate good fit and high significance of both maximum temperature and VPD. Constant terms are also significant in most cases. Pseudo-R^2's indicate that a sizeable portion of historical variation is explained by the data in most regions for both agencies. Generally, VPD is positively related to area burned. In cases when maximum temperature is included as an additional predictor, maximum temperature is negatively signed. In cases when VPD is not present (DOI regions 4, 5, and 6), maximum temperature is positively signed. Because maximum temperature is positively correlated with VPD, the latter set of results is expected. For any given value of VPD, a lower temperature means that relative humidity is lower, and thus fires would be expected to burn hotter.

Expenditure modeling results

Expenditure equation estimates are reported in Table B-2. Models indicate that current month area burned and two lags of area burned are usually significant for each region or aggregate modeled. Because the two lags were not significant in initial estimates of the Rest of Forest Service model, those lags were dropped for reporting and for models used in Monte Carlo projections.

Projections

Area Burned Projections

Area burned projections for the FS and DOI in aggregate are shown in Figures B-2 through B-4. (Regional detail of median area burned across all climate projections is presented in Appendix figures C-3 through C-6.) In the left panel of each of these figures is reported the median and the upper and lower bounds of an 80% confidence band for the total of FS plus DOI (48-state CONUS). The confidence bands only account for parameter uncertainty in the regional area burned models across the ten climate projections. In the right panel in each is the median for each of the ten climate projections. Figure B-2 is for total (FS + DOI), Figure B-3 is FS only, and Figure B-4 is DOI only. In all figures, it is apparent that late-century area burned varies widely across projections, with the highest area burned projected by the HadGEM2-ES365 (hot) climate model under the RCP 8.5 scenario. The lowest area burned projections emerged from the least-warm model, MRI-CGCM3 under the RCP 4.5 scenario. The figures demonstrate clearly how late-century area burned varies widely across climate projections, a result that might have been expected, given the wide variability across projections in late-century maximum temperature and VPD (Figure B-1).

Tables B-3 through B-5 report the Monte Carlo area burned projections numerically. Tables are organized to show observed area burned over our benchmark years of 2006-2018, model projections of area burned over the benchmark years using backcast climate data from each of the GCM x RCP projections, and then projections of median area burned in mid-century (2041-2059) and late-century (2081-2099). The "All Scenario Median" and the 80% and 90% upper and lower confidence bounds reported are based on the combined 10 climate projections x 500 iterations/projection = 5,000 total iterations.

Table B-3 shows the total of area burned for the FS and DOI. Broadly, the table shows general agreement between observed area burned for CONUS (3.92 million acres/year, 2006-2018) and backcast area burned for the same period (medians of the 10 climate projections range from 3.20-4.91 million acres/year). By mid-century, when compared to observed historical area burned, area burned in aggregate for FS + DOI is projected to be 21% to 251% higher and by late-century 35% to 1929% higher. Compared to backcast historical climate, these percentages range from 22% to 201% higher in mid-century and 65% to 1641% higher in late-century. The medians across all climate projections are 104% and 237% by mid- and late-century compared to observed historical and 106% and 241% compared to modeled historical area burned.

Table B-4 reports the results for just the FS CONUS lands. Variability is similar to that shown in Table B-3. Just as for the FS + DOI in aggregate, there is wide variation across the ten climate projections. Across all ten climates for the FS, median area burned is 94% and 244% higher by mid- and late-century, respectively, compared to observed historical area burned, and 129% and 306% higher by mid- and late-century when compared to modeled historical area burned.

Table B-5 shows the same results but for DOI lands in CONUS. Here again, there is wide variation across the ten climate projections and demonstrates the same trends as reported for FS lands in CONUS. Compared to observed historical (2006-2018) area burned in CONUS, DOI median area burned in CONUS is projected to be 114% and 226% higher by mid- and late-century, respectively. Compared to modeled historical, median area burned is projected to be 83% and 180% higher in mid- and late-century, respectively.

It is notable that the median values for area burned, 2006-2018, using backcast climate (maximum temperature, VPD) variables (second column of values in tables B3 through B5) reveal possible statistical biases produced by each of the climate projections (GCM x RCP scenario). Combined FS + DOI (Table B-3) has little overall bias when measured by the "all projections median" value (3.88 million acres/year) versus the observed value (3.92 million acres/year). For the Forest Service, however, the backcast projections tend to under-predict in the 2006-2018 benchmark period (1.51 million acres/year backcast versus 1.79 million acres/year observed), while the opposite is shown for DOI (2.33 million acres/year backcast versus 2.00 million acres/year observed). Because no climate projection can perfectly predict the backcast values of all climate variables, the lack of perfect alignment of median backcast predictions with the historical area burned is not unexpected, although particular GCMs tend to predict lower and others higher than the observed area burned. For example, the "least warm" model (at RCP 4.5 and 8.5) predicts the lowest, while the "dry" and "hot" models (at 4.5 and 8.5) predict the highest in the 2006-2018 backcast for both FS and DOI. Those tendencies to predict low or high might in part explain the lower and upper ranges of projected area burned outcomes projected for mid- and late-century shown in the tables.

<u>Expenditure Projections</u>

Graphs showing projections of expenditures are reported in figures B-4 through B-6. Just as for area burned, each figure has a left panel showing the median and 80% upper and lower bound projections of expenditures across all 10 climate projections, while the right panel in each shows the median projections for each of the 10 climate projections. Clear in all cases is that the high variability, particularly in late-century, in area burned is translated into high variability in projected expenditures.

Data from the graphs are summarized in tables B-6 through B-8. Data in the tables are reported in the same way as for area burned projections, enabling comparisons between annual totals of area burned observed and projected in the benchmark historical period of 2006-2018. Like for area burned, the "All Scenario Median" and the 80% and 90% upper and lower confidence bounds reported are based on the combined 10 climate projections x 500 iterations/projection = 5,000 total iterations. As reported in Table B-6, in mid-century compared to observed historical, median expenditures (in 2020 dollars) range from 24% lower to 121% higher, and for late-century 16% lower to 1353% higher. Compared to modeled historical, they range from 26% higher to 190% higher by mid-century and 42% to 1805% higher when compared to modeled historical. In aggregate across FS + DOI, median projected real expenditures across all ten climate projections are 22% and 90% higher by mid- and late-century, respectively. When compared to projected expenditures, they are 83% and 186% higher for mid- and late-century, respectively.

Tables B-7 and B-8 document how variability across projections in future expenditures is connected closely to variability in area burned. Across all climate projections, FS (Table B-7) median suppression spending is projected to be 16% higher and 85% higher in mid- and late-century compared to observed historical and 109% and 234% higher when compared to modeled historical. Comparable figures for DOI (Table B-8) are 57% and 128% higher in median suppression spending by mid- and late-century, respectively, when compared to observed historical and 48% and 114% higher when compared to modeled historical spending.

Discussion and Conclusions

The models developed here show that expenditures respond to changes in area burned as expected, and that area burned increases with increasing vapor pressure deficit and, in some cases, average maximum temperature. Area burned is projected to increase by double or triple-digit percentages across most of the ten projections we evaluated. Real dollar suppression expenditures are projected to increase by similarly large percentages.

While vapor pressure deficit and temperature are only two of several climate measures that have been linked to wildfire area burned, we found that unbiased backcasts of area burned and expenditures could be obtained from parameterizing these simple relationships. However, model simplicity likely trades off with higher uncertainty in making projections, so definitive conclusions about the long-run status of wildfire and associated suppression on Federal lands in the United States may not be warranted without acknowledgment of these uncertainties. In the following section, we detail several reasons why uncertainty is large when envisioning the evolution of wildfire and expenditures.

Wildfire area burned and suppression spending display high uncertainty in their projected futures, particularly by late-century. We note that actual FS spending (and total FS + DOI spending) since 2015 has exceeded even the 80% uncertainty upper bound modeled in this report, hinting that structural changes might be underway that will lead to spending that remains well above projected median levels indefinitely. Additional modeling, perhaps directed at finer spatial scales and accounting more directly for hazardous fuels, could reduce uncertainties and help to reduce biases in model predictions. Nevertheless, it is possible that, even with improved models based on historical data, there will be structural changes in how fires burn under novel climates and novel vegetation assemblages, how fire managers apply suppression resources under shifting wildfire regimes, and in the unit costs of suppression resources over time. Such changes would imply that the projections reported here provide progressively less useful guidance, moving from mid- to late-century.

Caveats and Assumptions

Our models involve a number of assumptions, violation of any of which would alter both the projected changes in spending and the ranges of our confidence bands. These assumptions, loosely grouped into aggregation bias (over space and time), omitted variable bias (including climate, fire and socioeconomic variables) and modeling limitations, are discussed in more detail below. Even with these caveats and assumptions, however, our models, along with the literature we have cited (and much that we have not) provide evidence that both wildfire extent and suppression expenditures are expected to increase with climate change. Our models, specifically, show that vapor pressure deficit and/or temperature can account for significant increases in area burned and that expenditures increase with increases in area burned.

Aggregation

The statistical models of area burned and of suppression spending are estimated using data aggregated to regions and nationwide. Such aggregation, in the presence of heterogeneity in area burned and spending processes, would bias parameter estimates in unknown directions. Aggregation across space and time can interact with biases associated with omitted variables (next caveat), resulting in findings of insignificance when in fact significant effects exist (i.e., it can raise statistical Type II error rates). For both the FS and the DOI models of area burned, the fact that each region's area burn function was estimated separately allowed for the relationship between wildfire and climate to differ across regions. Even so, the assumption involved for the reported models is that fine-scale (finer than region level) wildfire area burned responds identically to climate variables within that region. The FS models of the relationship between suppression spending area burned were also allowed to vary across regions, but they still forced the spending-burn relationship (i.e., real dollars per acre) to be constant within each region. For the Department of the Interior, because total departmental spending was modeled as a function of total area burned, the spending relationship to area burned implied constant spending per acre. A similar forcing assumption was implied by non-regional spending of the Forest Service.

Omitted variables

Our statistical models of area burned and expenditures are parsimonious, with area burned specified as a function of monthly maximum daily temperature and/or vapor pressure deficit. There is little doubt that potentially influential variables are omitted in our chosen specifications. Thus, these models assume that any omitted variables are orthogonal to the included variables, so that errors in projections are contained in error terms that are unrelated to the included variables. Alternatively, it could be that the omitted variables are perfectly correlated with the included variables, in which case parameter estimates for included variables completely contain the effects of the perfectly correlated omitted variables, and no bias would exist in resulting projections.

One key factor potentially missing from the suppression spending models is direct attention to human populations, which can lead to higher demands to protect property at the expense of area burned and which can affect the distributions of aggregate wildland fuels. In addition, a specific kind of omitted variables bias would emerge if past wildfires are negatively related to future wildfires in the same locations, then wildfire area burned modeled without attention to this process would be biased upward compared to reality. Although we tested for the relationship between spending and human population levels and changes and found inconsistent and usually non-significant effects, it is still possible that finer scale modeling of area burned could reveal robust effects.

Recent research has concluded both that temperature is a reasonable measure of climate change, but also that temperature is an insufficient measure of climate change influences on wildfire. In a statistical analysis of the relationship between meteorological variables and area burned in Canada, Flannigan and Harrington (1988) found that long sequences of days without rain, low relative humidity, and maximum temperatures were the best predictors of area burned, while rainfall and number of dry days per month were not significant. Romps et al. (2014) evaluated the impacts of climate change on lightning and found that (a) the precipitation projections do not show overall increases that would lead to increased lightning, and (b) increased temperature is the major controlling factor leading to increased lightning projections. Temperature has been shown to lead to a need for additional precipitation to hold fuel moistures constant (Flannigan et al. 2016). This results from the changes in amount of water the air can hold at higher temperatures—as temperatures increase the air can hold more water, which leads to drying of fuels, even if precipitation stays the same. Flannigan et al. (2016) also conclude that increasing temperatures lead to an increased number of extreme fire weather days.

For these analyses, we relied on mapping the association between temperature and vapor pressure deficit and area burned into the future. However, the association between temperature and area burned has been demonstrated to be relatively weak in the absence of some form of a dryness metric (Littell et al. 2009). It is reasonable to expect that temperature is only one, and perhaps not the most important one, of the climate variables affecting wildfire. However, this is a testable, and as yet untested, hypothesis in relation to projecting aggregate wildfire extent and expenditures. We show here only that temperature and vapor pressure deficit are significant, in the absence of other climate measures, in affecting area burned. The combination of VPD and maximum daily temperature in our models increased the goodness-of-fit of our models out-of-sample compared to inclusion of these and other combinations of variables and also when those measures were excluded.

In our models, many variables found in other research to affect both wildfire and suppression were assumed constant throughout the projections, when it is unlikely that constancy will be maintained to the end of this century. Thus, each of these assumptions represents an omitted variable. We assumed that wildfire suppression strategies and technology do not change, and so we did not need to include variables representing that change. We assumed that suppression will not become more or less effective at limiting wildfire. We assumed that wildland fuels management rates remain unchanged, in relation to overall wildfire activity. Research shows that management of aggregate fuels on landscapes can affect how wildfires burn, likely affecting suppression productivity and hence area burned or other damages upon which suppression is focused (Loudermilk et al. 2014, Mercer et al. 2005, 2007; Thompson et al. 2013). However, Bessie and Johnson (1995) compared the composite influences of fuels and climate and concluded that climate was the driving force in year over year changes in area burned. Nevertheless, the lack of direct statistical accounting for the effects of climate or management efforts to reduce hazardous fuels adds a degree of uncertainty to the projections that may not be reflected in our projections. Furthermore, models assume that allocations of suppression efforts across threatened people, property, and resources will be allocated in the same ways, in response to wildfire, as they have in the past. Because historical data on suppression spending and area burned reflect averages of policies to protect people, property, and resources, substantial changes in the ratios of these variables threatened by wildfires in the future could affect spending in ways not accounted for in our projections.

In this analysis, the general approach and structure of wildfire management was assumed constant over time. However, consequences to wildfires and costs from climate changes are outside the range of reliable futuring over long time frames, except that new climates will modify human activities and probably require alternative management approaches. Even within the near future (10 to 20 years) analyzed in the Quadrennial Fire Review (QFR) (https://www.forestandrangelands.gov/QFR/documents/2014QFRFinalReport.pdf) there exists "a strong possibility that today's regional wildland fire management dynamics will shift as a result of climate and environmental factors". Furthermore, the QFR identified the potential for a shock-type wildfire event to instigate a fundamental realignment of Federal land and fire management functions that would clearly alter the relationship between area burned and management cost. It is doubtful that biologists and foresters in 1900 could have predicted the magnitude of wildfire sizes, behaviors, damages to human and natural resources, and costs experienced today let alone the types of equipment and suppression responses that occur. Due to the increased uncertainty of both natural and human consequences of future climate, future management cost projections should be evaluated with caution.

We also assume constant socioeconomic variables, including prices, population, and income. If the per-unit cost of labor, capital, and other purchased inputs into suppression production were to rise at a rate higher than inflation, then suppression expenditures would tend to be higher, possibly also leading to lower overall suppression effort and then to greater area burned. Generally, wages and capital costs have not been rising faster than inflation in the last 20 years. However, as the economy and overall wealth grows, these per-unit prices of these inputs might.

Our projections indicate that, under some climate projections, area burned would increase several fold over historical rates. As the projected annual area burned increases, however, this means that substantially more acres would need to reburn, or that wildfire would need to move into areas that historically have not burned, in order for these fires to have adequate fuel. Thus, our models would overestimate the projected area burned, at least in forested landscapes. Conversely, in drier, range ecosystems, it is possible that increases in burning rates could lead to the potential for more fire, as reburning rates are expected to be higher in these ecosystems. For these ecosystems, our models would underestimate the projected area burned. It is not known at what burning rate these limiting conditions would be reached in either forest or range ecosystems. Hope et al. (2016) capped their Canadian area burned estimates assuming a 20-year fire return interval, equivalent to burning 5% of the wildland each year. Our results suggest that by late-century, an average of nearly 6 million FS acres per year could burn, or about 3% of all FS land, and we felt we had little justification for, in the absence of a statistically modeled relationship, artificially capping our area burned estimates. Additionally, because the United States has wide variation across ecoregions in wildfire return intervals (Greenberg and Collins 2021), simple solutions such as artificial caps would possibly add more uncertainty to our projections, not less. It is possible that such relationships can be estimated, which would be an area worthy of additional study and modeling efforts.

Modeling

We assumed that the included information from climate projections was adequate to capture uncertainty regarding the effects of temperature and vapor pressure deficit on area burned on Federal lands. We assumed that these systems could be approximated by an exponential relationship, with no significant biases or added uncertainty due to spatial autocorrelation and no significant effects of our assumption of mean-variance proportionality. More fundamentally, because our models could only be based on historical relationships among variables, we assume that those relationships will endure to the end of the century. Our models make long-run projections, without evaluating which factors that are typically assumed fixed might be variable in the long-run, such as fire regimes, biomes, and suppression strategies. In addition, even at aggregate scales, the highly-modified forest and grassland ecosystems of U.S. Federal lands may not bear much relation to either natural ecosystems or to ecosystems expected in the distant future under climate change (McKenzie and Littell 2016).

Any model is an abstraction, a simplification of reality. In this analysis, we used only five climate models under each RCP scenario. Thus, we assumed that five global climate model realizations of future climate under the increased radiative forcing of either 4.5W/m^2 or of 8.5W/m^2 were sufficient to capture uncertainty regarding the temperature and climate futures on Federal lands. Undoubtedly, additional projections under each RCP would have narrowed the variability in the future. However, these five climate models allow us to explore a hot versus a warm future and a wet versus a dry future. The large end of century projections by the Hadley model under RCP 8.5 portend hot temperatures and increased wildfire area burned. In contrast, the Least Warm model (MRI-CGCM3) projects the least change in area burned. While our Monte Carlo simulations address uncertainty in the estimated coefficients as well as uncertainty reflected in the multiple GCM temperature projections, we did not incorporate any within-GCM uncertainty. The assumption here is that the multiple models can proxy for uncertainty within the GCMs.

Uncertainty in wildfire projection exists even at the incident level, over the timeframe of hours to days, and is compounded when working at decadal or century-long scales (Riley and Thompson 2016). One reason for compounding uncertainty is that shifts in vegetation assemblies and even biomes are likely during this timeframe due to climate change, meaning fire regimes will also shift (Lenihan et al. 2003, Loehman et al. 2014). Take, for example, the changes in fuels and vegetation documented since the turn of the 20th century (Loope and Gruell 1973, Gruell 1983, Gruell 2001). By first removing Indian burning (Lewis 1973, Barrett 1980), and then attempting to remove wildfires, European settlement altered vegetation composition and structure, insect outbreaks, and wildfire behavior beyond recognition in just 100 years of relatively subtle climate changes. Feedbacks between shifting vegetation assemblies, changing climate, and altered ignition patterns will be complex and may produce no-analog states.

Caveat summary

Wildfire and fire management, including suppression, is a complex system where individual factors interact in complex, non-linear, unpredictable ways. What happens in one component of the system will cascade through the system altering other components, and these cascades are multidirectional. Climate change is expected to influence ignition patterns, fire weather, ecological community composition, local community development, and our willingness and ability to manage wildfire. Each of these changes will reverberate through the system, adding uncertainty about the future of wildfire and suppression spending that may not be adequately captured by the simple statistical relationships that drive the results presented in this study.

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Table B-1. Area burned equation estimates for the USDA Forest Service and Department of Interior regions, Poisson pseudo-maximum likelihood models, in acres, monthly data, 2006 – 2018, 324 observations.

	Constant		Ln(Tmax) [a]		Ln(VPD) [b]		Pseudo R^2
Forest Service Region 1	650	**	-113	**	10.9	***	0.80
	(300)		(53)		(2.5)		
Forest Service Region 2	1064	***	-186	***	13.3	***	0.64
	(203)		(36)		(2.0)		
Forest Service Region 3	706	***	-123	***	9.0	***	0.53
	(207)		(36)		(1.6)		
Forest Service Region 4	9.08	***			6.2	***	0.75
	(0.32)				(0.9)		
Forest Service Region 5	708	**	-123	**	8.4	***	0.43
	(343)		(60)		(2.8)		
Forest Service Region 6	9.64	***			6.6	***	0.74
	(0.20)				(0.7)		
Forest Service Region 8	795	***	-138	***	9.0	***	0.37
	(217)		(38)		(2.2)		
Forest Service Region 9	429	***	-74	***	5.6	***	0.25
	(99)		(17)		(1.1)		
Department of the Interior Region 1	949	***	-165	***	11.0	***	0.67

	Constant		Ln(Tmax) [a]		Ln(VPD) [b]		Pseudo R^2
	(253)		(45)		(2.4)		
Department of the Interior Region 2	507	***	-88	***	6.3	***	0.47
	(176)		(31)		(1.5)		
Department of the Interior Region 3	832	***	-145	***	10.5	***	0.53
	(132)		(23)		(1.4)		
Department of the Interior Region 4	-511	***	92	***			0.66
	(76)		(13)				
Department of the Interior Region 5	-313	***	56	***			0.43
	(52)		(9)				
Department of the Interior Region 6	-559	***	100	***			0.69
	(68)		(12)				
Department of the Interior Region 8	769	***	-133	***	9.0	***	0.46
	(107)		(19)		(1.2)		
Department of the Interior Region 9	937	***	-163	***	9.3	***	0.53
	(149)		(26)		(1.4)		

Notes: Standard errors in parentheses; *** indicates significance at 1%, ** at 5%, * at 10%.

[a] Month average of the daily maximum temperature, in degrees Kelvin

[b] Month average of daily average vapor pressure deficit

Table B-2. Suppression expenditure equation estimates for the USDA Forest Service and Department of Interior regions, two-staged least squares linear regression models, in real inflation-adjusted (2020 dollars), monthly data, 2005 – 2019 (USDA Forest Service), 180 observations (regions 1-9) or 192 observations (Region 10, 2005-2020), or 2013-2017 (Department of the Interior), 60 observations.

	Constant		Acres $Burned_t$[a]		Acres $Burned_{t-1}$		Acres $Burned_{t-2}$		Root Mean Squared Error (Million)
Forest Service Region 1	1,241,545		114	***	191	***	65	***	11
	(918,254)		(16)		(12)		(11)		
Forest Service Region 2	-1,284		262	***	157	***	-37		7.5
	(674,614)		(56)		(22)		(23)		
Forest Service Region 3	-2,276,364		240	***	120	***	82	***	19
	(2,256,614)		(78)		(24)		(18)		
Forest Service Region 4	1,144,299		132	***	87	***	54	***	12
	(1,034,860)		(18)		(12)		(11)		
Forest Service Region 5	1,872,268		334	***	324	***	163	***	38
	(3,487,242)		(46)		(28)		(27)		
Forest Service Region 6	-358,264		425	***	222	***	150	***	27
	(2,353,933)		(61)		(34)		(31)		
Forest Service Region 8	3,674,111	***	-75	*	62	***	34		10
	(851,406)		(43)		(21)		(21)		
Forest Service Region 9	218,831		296	*	116	***	72	***	2.7
	(370,317)		(155)		(22)		(22)		

	Constant		Acres Burned$_t$[a]		Acres Burned$_{t-1}$		Acres Burned$_{t-2}$		Root Mean Squared Error (Million)
Forest Service Region 10	116,583	***							0.5
	(36,300)								
Rest of Forest Service	21,700,000	***	52	***					46
	(4,286,596)		(17)						
Department of the Interior Total	15,100,000	***	24	**	83	***	14	**	20
	(3,406,863)		(10)		(9)		(7)		

Notes: Standard errors in parentheses; *** indicates significance at 1%, ** at 5%, * at 10%.

[a] Instrumented in 2SLS estimation with current month number of wildfires reported, human population

Table B-3. Total Department of the Interior + USDA Forest Service area burned projected (CONUS), median values, Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.[a]

		Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		Million Acres				Percent			
CNRM-CM5 x RCP 4.5	Wet	3.92	4.90	6.00	8.89	53	127	22	82
HadGEM2-ES x RCP 4.5	Hot	3.92	4.91	10.84	17.10	177	336	121	248
IPSL-CM5A-MR x RCP 4.5	Dry	3.92	4.63	8.19	8.30	109	112	77	79
MRI-CGCM3 x RCP 4.5	Least Warm	3.92	3.20	4.75	5.29	21	35	49	65
NorESM1-M x RCP 4.5	Middle	3.92	3.76	7.94	9.82	103	150	111	161
CNRM-CM5 x RCP 8.5	Wet	3.92	3.97	8.59	23.16	119	491	116	484
HadGEM2-ES x RCP 8.5	Hot	3.92	4.57	13.75	79.54	251	1,929	201	1,641
IPSL-CM5A-MR x RCP 8.5	Dry	3.92	4.11	9.40	28.17	140	618	129	586
MRI-CGCM3 x RCP 8.5	Least Warm	3.92	3.47	4.94	10.28	26	162	42	196

		Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------------ Million Acres --------------------				-------------------------- Percent -------------------------			
NorESM1-M x RCP 8.5	Middle	3.92	3.99	10.54	24.99	169	537	164	525
	All Projections Median	3.92	3.88	7.99	13.21	104	237	106	241
	All Projections 80% Lower		2.32	3.58	4.57				
	All Projections 80% Upper		7.14	17.61	59.64				
	All Projections 90% Lower		2.08	3.16	3.88				
	All Projections 90% Upper		8.30	22.21	88.70				

[a] Note that median values shown in this table will not generally be equal to the median values for the USDA Forest Service plus the median values of the Department of the Interior.

Table B-4. Total USDA Forest Service area burned projected, median values, Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.

		Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------------ Million Acres --------------------				--------------------------- Percent -------------------------			
CNRM-CM5 x RCP 4.5	Wet	1.79	1.92	2.79	4.11	56	130	45	114
HadGEM2-ES x RCP 4.5	Hot	1.79	2.29	5.69	10.39	219	482	149	354
IPSL-CM5A-MR x RCP 4.5	Dry	1.79	1.74	3.59	3.56	101	100	106	105
MRI-CGCM3 x RCP 4.5	Least Warm	1.79	1.20	1.85	2.01	4	12	54	67
NorESM1-M x RCP 4.5	Middle	1.79	1.46	3.09	4.42	73	148	111	202
CNRM-CM5 x RCP 8.5	Wet	1.79	1.69	3.99	14.76	123	726	136	773
HadGEM2-ES x RCP 8.5	Hot	1.79	1.96	8.11	56.32	354	3,053	313	2,767
IPSL-CM5A-MR x RCP 8.5	Dry	1.79	1.60	4.11	14.59	130	717	157	814
MRI-CGCM3 x RCP 8.5	Least Warm	1.79	1.20	1.73	4.13	-3	131	45	245

		Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------------ Million Acres --------------------				--------------------------- Percent --------------------------			
NorESM1-M x RCP 8.5	Middle	1.79	1.48	4.80	13.28	169	643	225	798
	All Projections Median	1.79	1.51	3.46	6.14	94	244	129	306
	All Projections 80% Lower		0.78	1.26	1.62				
	All Projections 80% Upper		3.30	9.40	40.29				
	All Projections 90% Lower		0.62	1.05	1.30				
	All Projections 90% Upper		4.14	13.12	67.43				

Table B-5. Total Department of the Interior area burned projected, median values, Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.

		Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------------ Million Acres -------------------				-------------------------- Percent -------------------------			
HadGEM2-ES x RCP 4.5	Hot	2.00	2.74	5.17	7.57	159	279	89	176
IPSL-CM5A-MR x RCP 4.5	Dry	2.00	2.87	4.54	4.80	128	140	58	67
MRI-CGCM3 x RCP 4.5	Least Warm	2.00	2.01	2.85	3.27	43	64	42	63
NorESM1-M x RCP 4.5	Middle	2.00	2.34	4.07	5.21	104	161	74	122
CNRM-CM5 x RCP 8.5	Wet	2.00	2.29	4.49	9.20	125	361	96	302
HadGEM2-ES x RCP 8.5	Hot	2.00	2.68	5.93	19.54	197	878	122	630
IPSL-CM5A-MR x RCP 8.5	Dry	2.00	2.44	5.23	12.96	162	549	115	432
MRI-CGCM3 x RCP 8.5	Least Warm	2.00	2.20	3.08	5.77	54	189	40	162
NorESM1-M x RCP 8.5	Middle	2.00	2.50	5.66	10.72	183	437	126	328

	Area Burned Observed Historical Median	Area Burned Modeled Historical Median	Area Burned Projected Future Median	Area Burned Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
	2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
	------------------------ Million Acres -------------------				--------------------------- Percent --------------------------			
All Projections Median	2.00	2.33	4.26	6.51	114	226	83	180
All Projections 80% Lower		1.47	2.24	2.83				
All Projections 80% Upper		3.89	7.23	18.07				
All Projections 90% Lower		1.33	2.01	2.47				
All Projections 90% Upper		4.28	8.35	22.86				

Table B-6. Total Department of the Interior + USDA Forest Service real (2020 dollars) suppression spending projected, median values. Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.[a]

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		Billion Dollars				Percent			
CNRM-CM5 x RCP 4.5	Wet	2.00	1.54	2.24	3.35	12	68	45	117
HadGEM2-ES x RCP 4.5	Hot	2.00	1.48	3.12	5.36	56	168	111	263
IPSL-CM5A-MR x RCP 4.5	Dry	2.00	1.55	2.44	2.71	22	36	57	74
MRI-CGCM3 x RCP 4.5	Least Warm	2.00	1.17	1.52	1.67	-24	-16	30	42
NorESM1-M x RCP 4.5	Middle	2.00	1.30	2.58	3.15	29	58	99	142
CNRM-CM5 x RCP 8.5	Wet	2.00	1.42	2.66	9.55	33	378	87	573
HadGEM2-ES x RCP 8.5	Hot	2.00	1.52	4.42	29.00	121	1,353	190	1,805
IPSL-CM5A-MR x RCP 8.5	Dry	2.00	1.39	2.99	8.81	50	341	115	532
MRI-CGCM3 x RCP 8.5	Least Warm	2.00	1.20	1.51	3.03	-24	52	26	153

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------- Billion Dollars -----------------------				------------------------- Percent ---------------------------			
NorESM1-M x RCP 8.5	Middle	2.00	1.36	3.49	8.51	75	326	156	525
	All Projections Median	2.00	1.33	2.44	3.80	22	90	83	186
	All Projections 80% Lower		0.85	1.18	1.43				
	All Projections 80% Upper		2.16	5.26	21.60				
	All Projections 90% Lower		0.72	1.03	1.23				
	All Projections 90% Upper		2.47	6.64	34.05				

[a] Note that median values shown in this table will not generally be equal to the median values for the USDA Forest Service plus the median values of the Department of the Interior.

Table B-7. Total USDA Forest Service real (2020 dollars) suppression spending projected, median values. Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------- Billion Dollars -----------------------				------------------------ Percent ---------------------------			
CNRM-CM5 x RCP 4.5	Wet	1.52	1.02	1.66	2.50	9	65	63	146
HadGEM2-ES x RCP 4.5	Hot	1.52	0.97	2.31	4.29	52	183	138	343
IPSL-CM5A-MR x RCP 4.5	Dry	1.52	0.94	1.67	1.85	10	22	77	96
MRI-CGCM3 x RCP 4.5	Least Warm	1.52	0.69	0.94	1.08	-38	-29	37	57
NorESM1-M x RCP 4.5	Middle	1.52	0.80	1.79	2.35	18	55	124	193
CNRM-CM5 x RCP 8.5	Wet	1.52	0.93	1.88	8.18	24	439	102	780
HadGEM2-ES x RCP 8.5	Hot	1.52	1.00	3.48	26.52	129	1,649	248	2,556
IPSL-CM5A-MR x RCP 8.5	Dry	1.52	0.90	2.13	6.88	41	354	136	662
MRI-CGCM3 x RCP 8.5	Least Warm	1.52	0.73	0.96	1.99	-37	31	32	172

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099
		------------------- Billion Dollars -----------------------				------------------------- Percent ---------------------------			
NorESM1-M x RCP 8.5	Middle	1.52	0.85	2.62	7.05	73	365	207	725
	All Projections Median	1.52	0.84	1.75	2.80	16	85	109	234
	All Projections 80% Lower		0.46	0.69	0.85				
	All Projections 80% Upper		1.57	4.18	18.85				
	All Projections 90% Lower		0.29	0.47	0.62				
	All Projections 90% Upper		1.82	5.46	30.98				

Table B-8. Total Department of the Interior real (2020 dollars) suppression spending projected, median values. Monte Carlo 500 iterations per climate projection (GCM x RCP scenario); "All Projections Median" and the 80% and 90% bounds reported in this table are based on the combined 10 projections x 500 iterations/projection = 5,000 total iterations.

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 – 2099
		------------------- Billion Dollars -----------------------				------------------------ Percent --------------------------			
CNRM-CM5 x RCP 4.5	Wet	0.45	0.52	0.60	0.81	32	78	15	56
HadGEM2-ES x RCP 4.5	Hot	0.45	0.52	0.81	1.14	78	152	56	121
IPSL-CM5A-MR x RCP 4.5	Dry	0.45	0.55	0.73	0.78	62	72	34	42
MRI-CGCM3 x RCP 4.5	Least Warm	0.45	0.44	0.54	0.59	19	30	23	34
NorESM1-M x RCP 4.5	Middle	0.45	0.46	0.68	0.83	51	84	48	80
CNRM-CM5 x RCP 8.5	Wet	0.45	0.49	0.74	1.35	63	199	52	178
HadGEM2-ES x RCP 8.5	Hot	0.45	0.51	0.95	2.65	110	486	86	417
IPSL-CM5A-MR x RCP 8.5	Dry	0.45	0.51	0.84	1.72	86	280	67	241
MRI-CGCM3 x RCP 8.5	Least Warm	0.45	0.45	0.56	0.93	25	106	26	109

		Expenditures Observed Historical Median	Expenditures Modeled Historical Median	Expenditures Projected Future Median	Expenditures Projected Future Median	Change from Observed Historical Median	Change from Observed Historical Median	Change from Modeled Historical Median	Change from Modeled Historical Median
		2006 - 2018	2006 - 2018	2041 - 2059	2081 - 2099	2041 - 2059	2081 - 2099	2041 - 2059	2081 – 2099
		------------------- Billion Dollars -----------------------				------------------------ Percent ---------------------------			
NorESM1-M x RCP 8.5	Middle	0.45	0.51	0.90	1.54	98	240	76	200
	All Projections Median	0.45	0.48	0.71	1.03	57	128	48	114
	All Projections 80% Lower		0.36	0.46	0.55				
	All Projections 80% Upper		0.67	1.12	2.55				
	All Projections 90% Lower		0.33	0.42	0.49				
	All Projections 90% Upper		0.74	1.27	3.13				

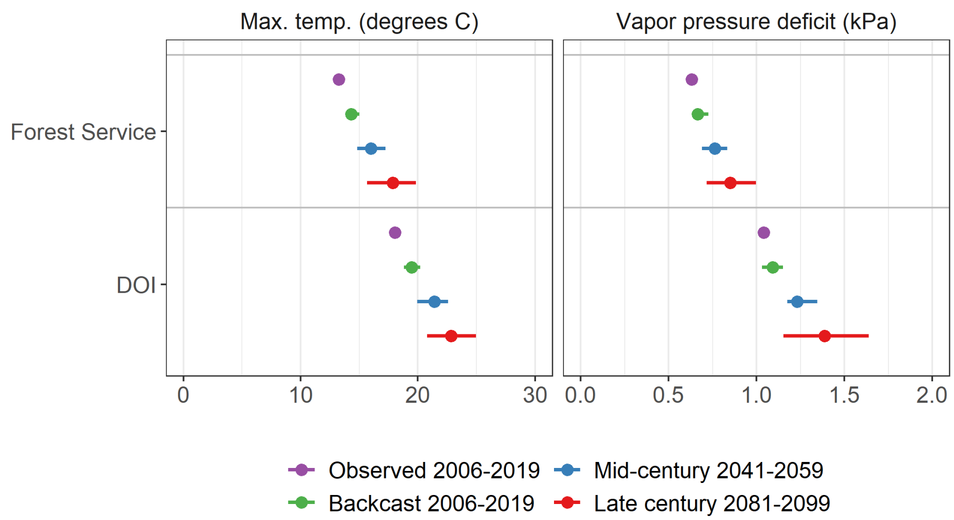


Figure B-1. Average (median) monthly maximum temperature and vapor pressure deficit on Forest Service and Department of Interior lands for the historical observed period (2006-2019) and for the ten plausible projected climate futures (5 GCMs x 2 RCPs) used in the projections for the backcast (2006-2019), mid-century (2041-2059) and late century periods (2081-2099). In the backcast, mid-century, and late century periods, the point indicates the median of average values across all ten plausible futures, while the bars represent the range in average values across all futures.

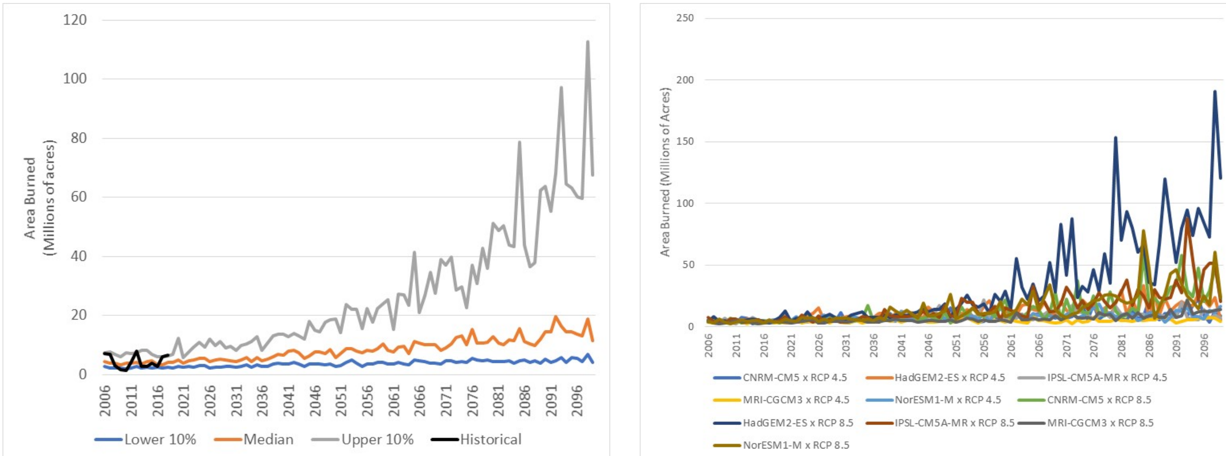


Figure B-2. Total Department of the Interior + USDA Forest Service area burned, projected, by fiscal year, all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

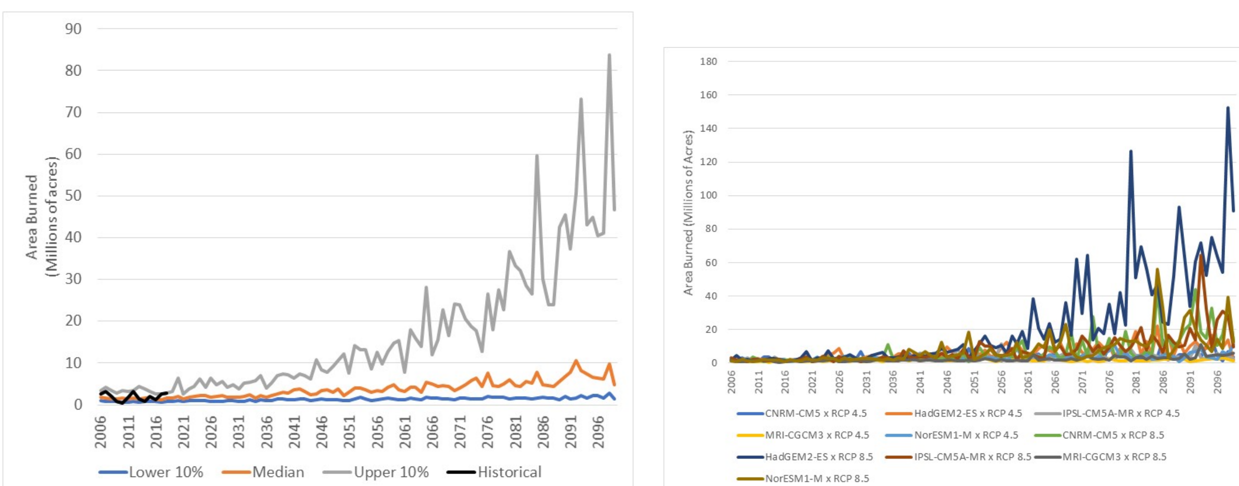


Figure B-3. USDA Forest Service area burned, projected, by fiscal year, all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

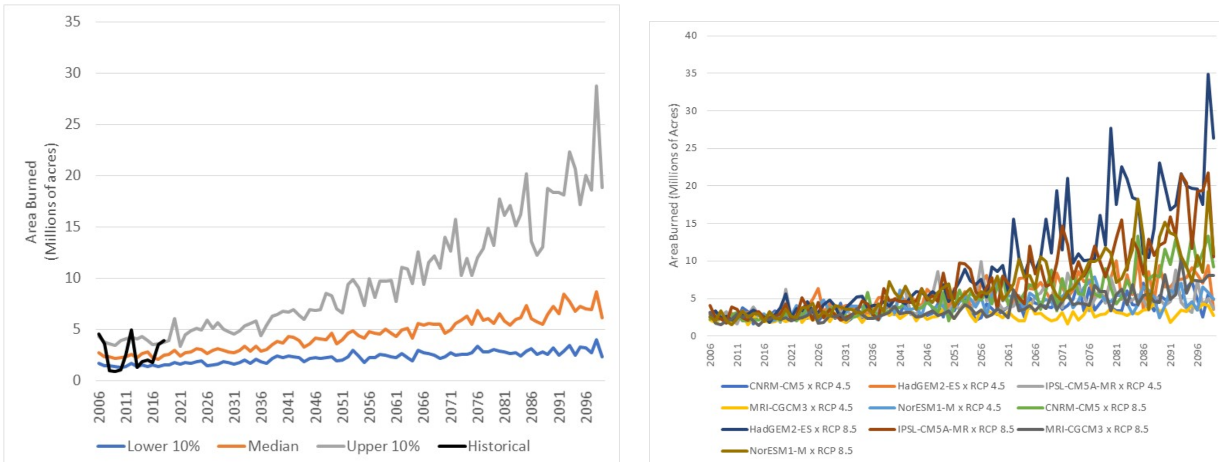


Figure B-4. Department of the Interior area burned, projected, by fiscal year, all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

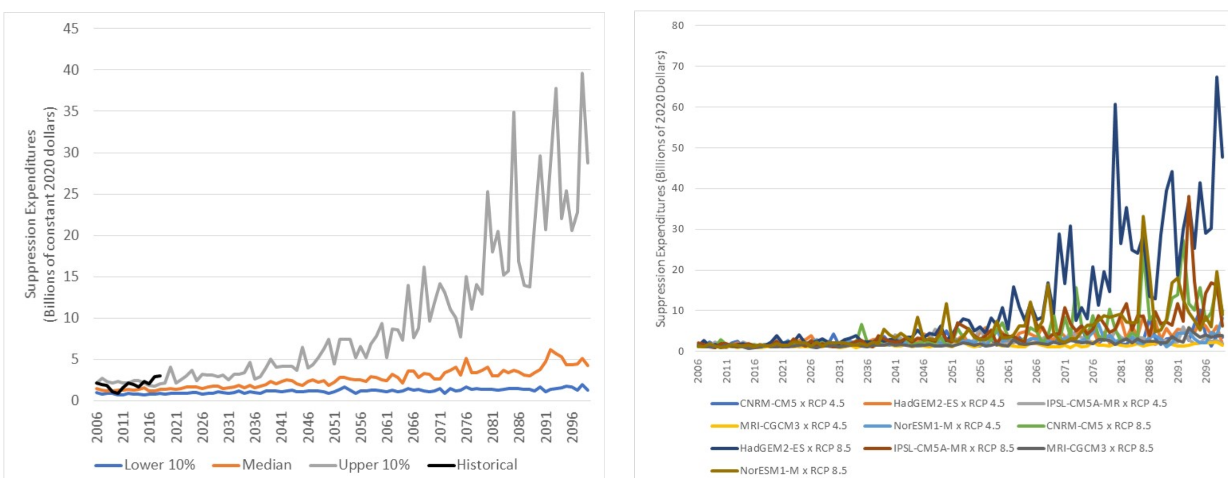


Figure B-5. Total Department of the Interior + USDA Forest Service suppression expenditures, projected, by fiscal year (inflation adjusted 2020 dollars), all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure). See Table B-2 for statistical models underlying the Monte Carlo projections presented in this figure.

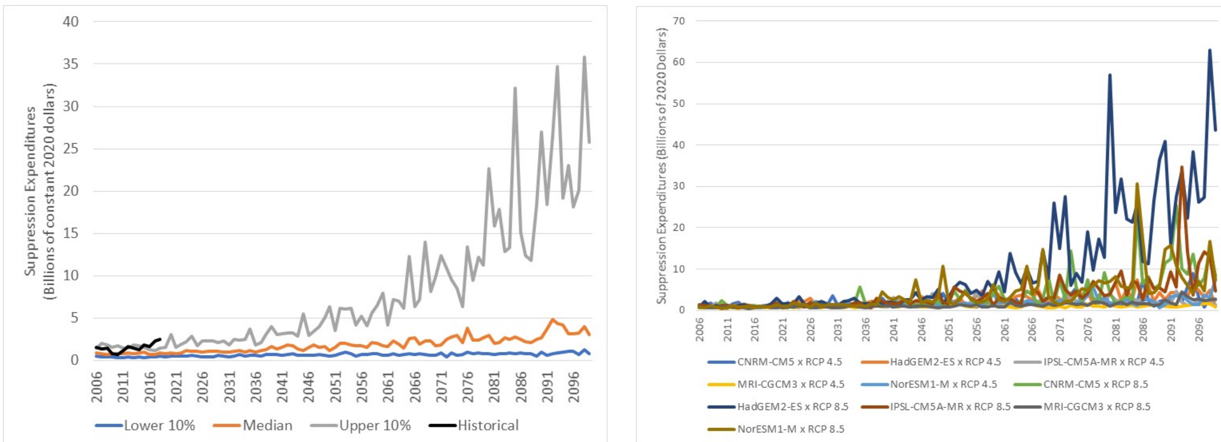


Figure B-6. USDA Forest Service suppression expenditures, projected, by fiscal year (inflation adjusted 2020 dollars), all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

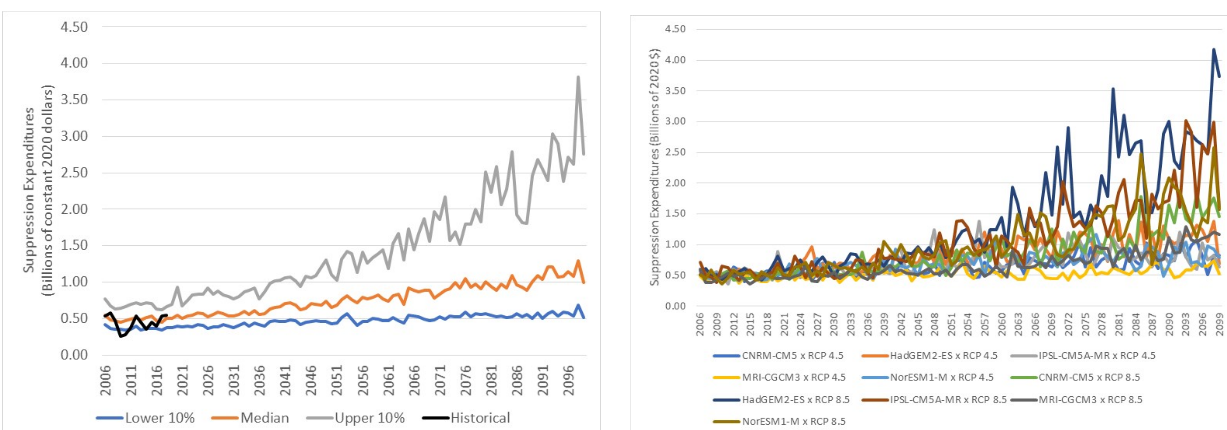


Figure B-7. Department of the Interior suppression expenditures, projected, by fiscal year (inflation adjusted 2020 dollars), all climate projections combined, and median by scenario. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

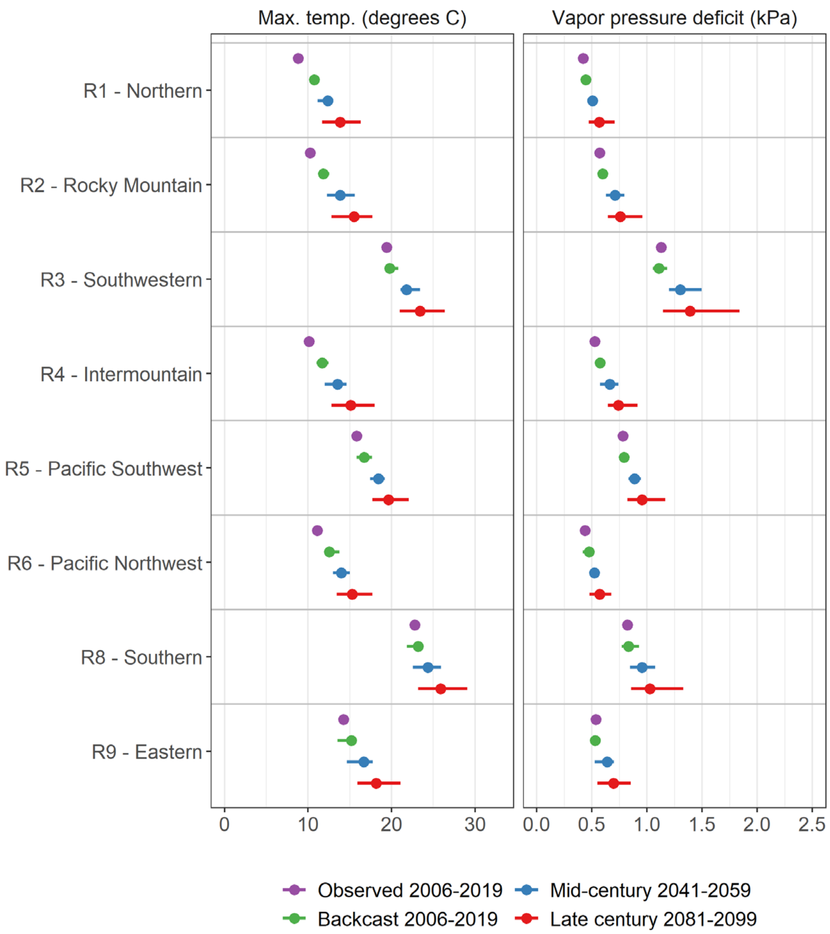


Figure C-1. Average (median) monthly maximum temperature and vapor pressure deficit by region on Forest Service lands for the historical observed period (2006-2019) and for the ten plausible futures (5 GCMs x 2 RCPs) used in the projections for the backcast (2006-2019), mid-century (2041-2059) and late century periods (2081-2099). In the backcast, mid-century, and late century periods, the point indicates the median of average values across all ten plausible futures, while the bars represent the range in average values across all futures. Both variables were used in regional models for FS lands, with the exception of models for regions 3 and 5, which only used VPD.

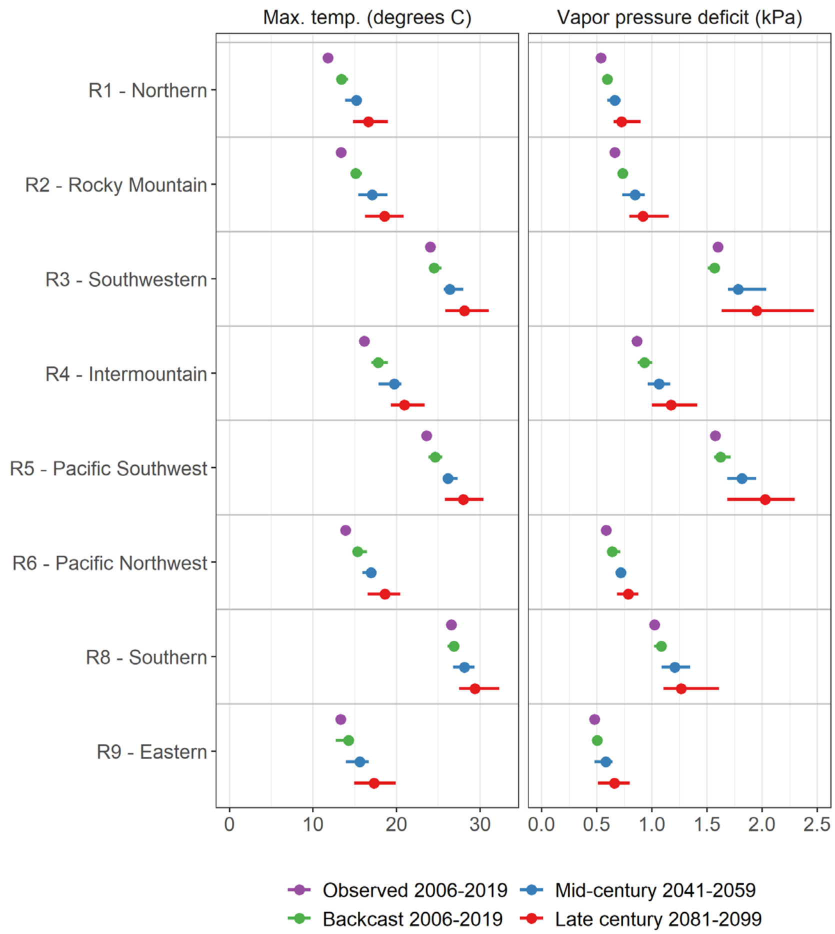
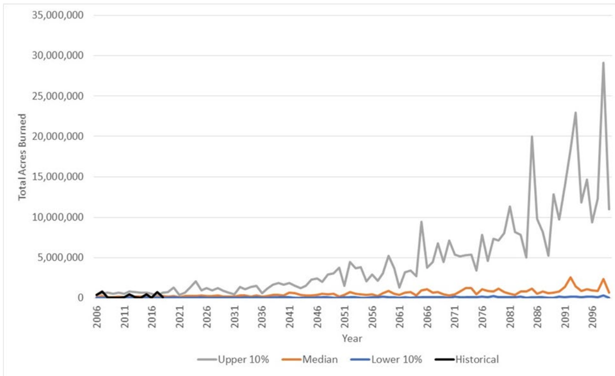
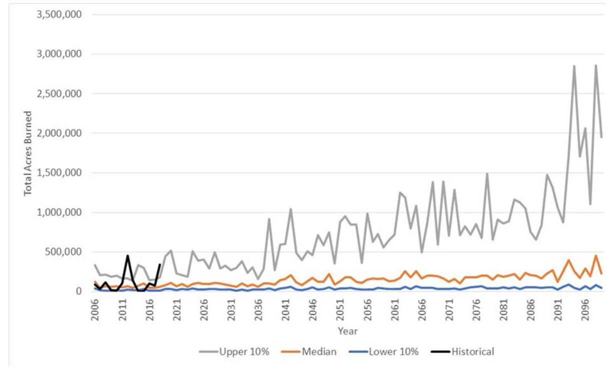


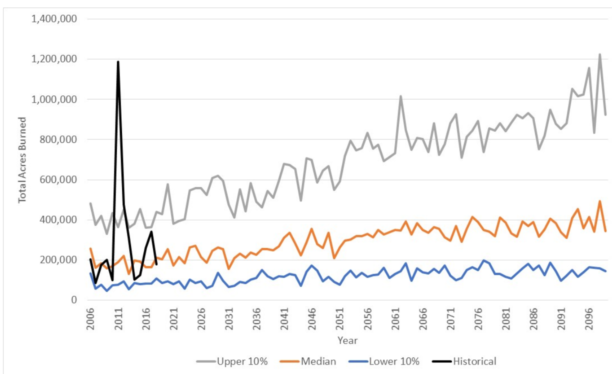
Figure C-2. Average (median) monthly maximum temperature and vapor pressure deficit by region on Department of Interior lands for the historical observed period (2006-2019) and for the ten plausible futures (5 GCMs x 2 RCPs) used in the projections for the backcast (2006-2019), mid-century (2041-2059) and late century periods (2081-2099). In the backcast, mid-century, and late century periods, the point indicates the median of average values across all ten plausible futures, while the bars represent the range in average values across all futures. Both variables were used in models for DOI lands, with the exception of regions 4, 5, and 6, which only used maximum temperature.



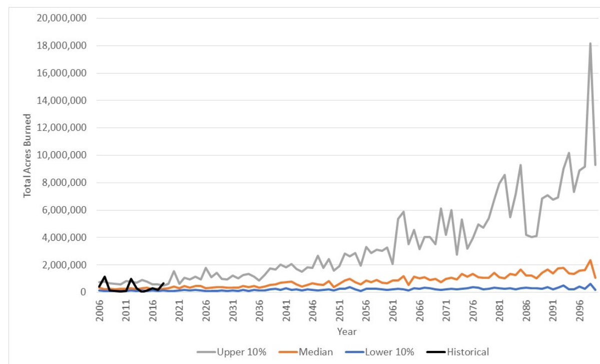
Region 1



Region 2

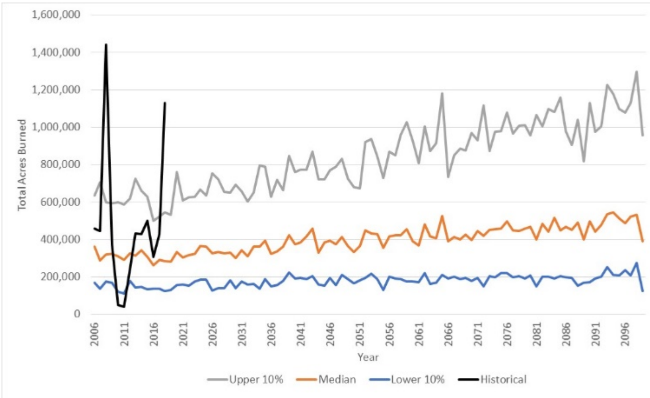


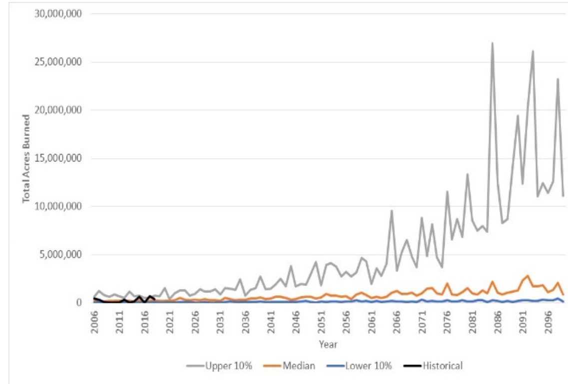
Region 3



Region 4

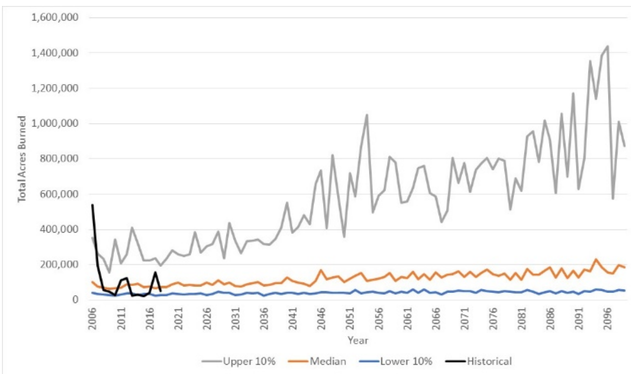
Figure C-3. USDA Forest Service regions 1-4 median and 80% upper and lower bounds of area burned projections, all climate projections combined. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).

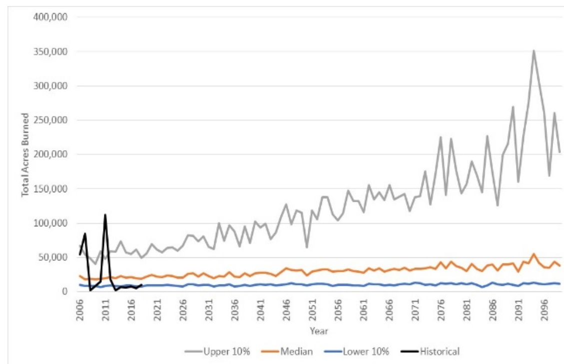




Region 5

Region 6

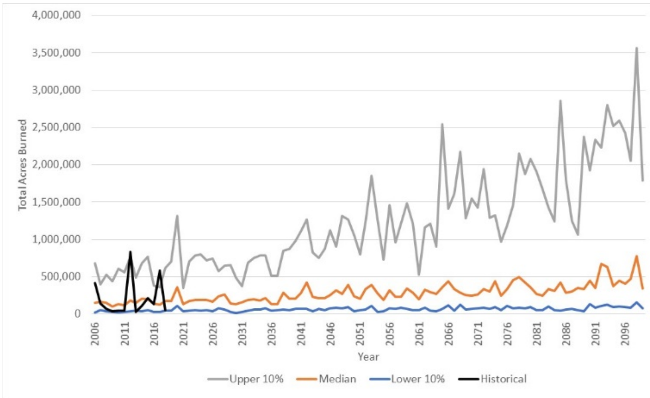




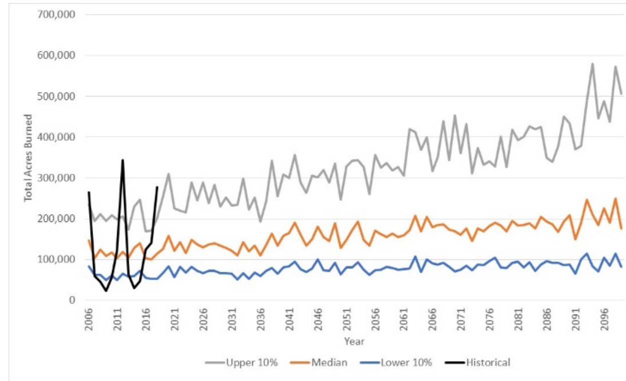
Region 8

Region 9

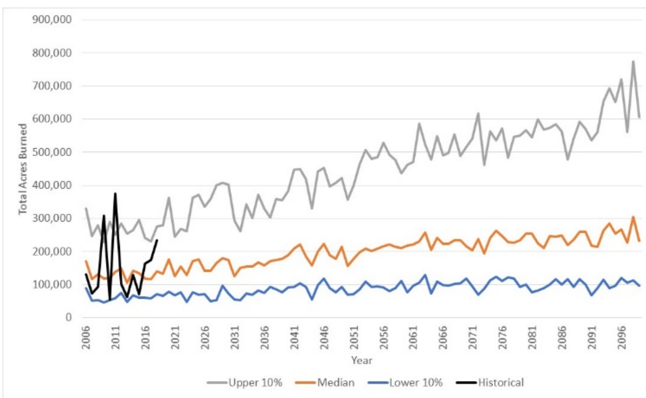
Figure C-4. USDA Forest Service regions 5-9 median and 80% upper and lower bounds of area burned projections, all climate projections combined. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).



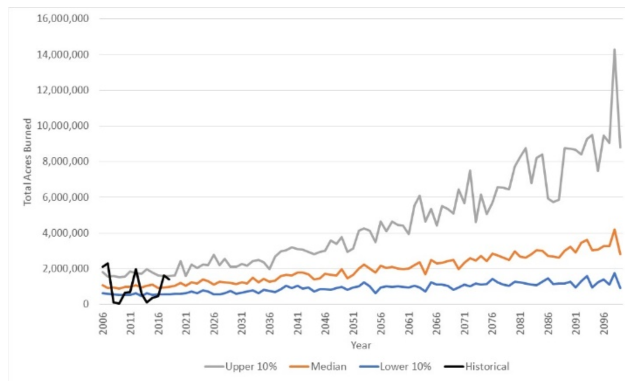
Region 1



Region 2

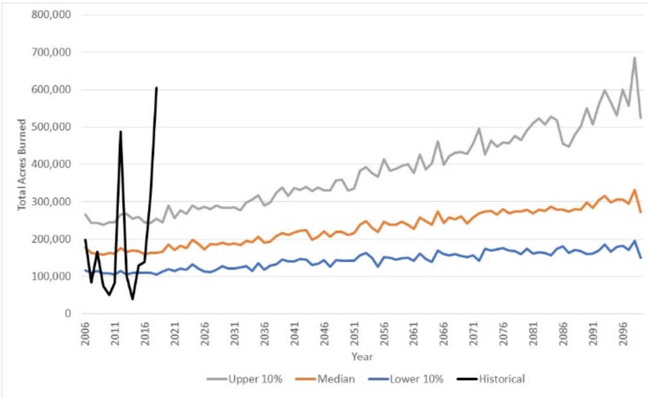


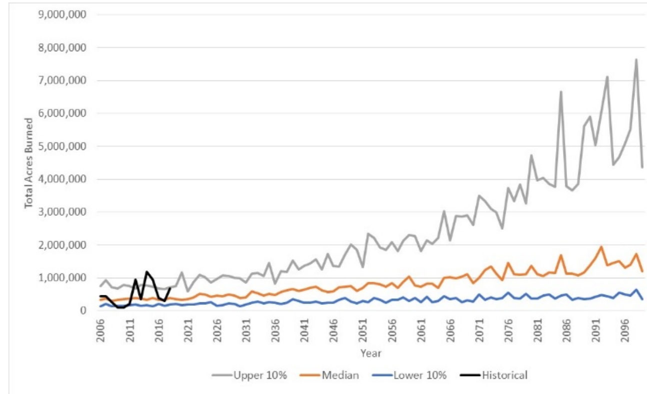
Region 3



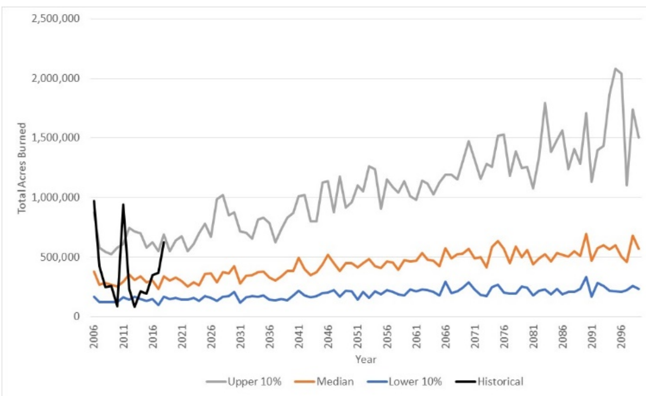
Region 4

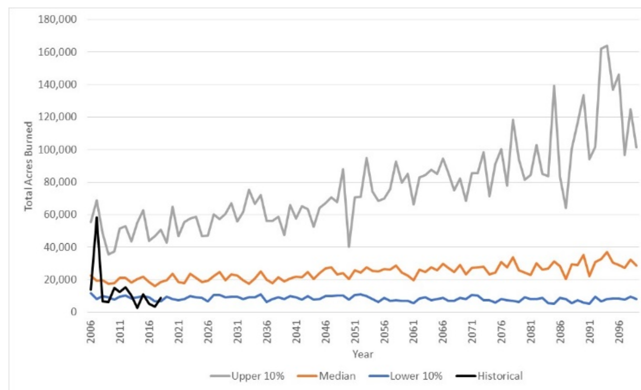
Figure C5. Department of the Interior median and 80% upper and lower bounds of area burned projections on lands contained in the boundaries of FS regions 1-4, all climate projections combined. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).





Region 5 Region 6





Region 8 Region 9

Figure C-6. Department of the Interior median and 80% upper and lower bounds of area burned projections on lands contained in the boundaries of FS regions 5-9, all climate projections combined. Monte Carlo 500 iterations per GCM x RCP scenario (i.e., 5,000 iterations included in this figure).