2026

COLORADO CLIMATE DAMAGES & ADAPTATION COSTS REPORT

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"Between 2025 and 2050, our analysis finds that **climate change could impose roughly $33–$37 billion in additional costs** and resilience needs across Colorado's health, infrastructure, wildfire, flooding, and winter recreation impacts. The largest quantified drivers are extreme heat, which could lead to about 1,800–1,900 additional heat-related deaths (about $24–$25B in losses), and infrastructure pressures, totaling about $8.3–$8.7B in added costs and upgrades as roads, bridges, stormwater systems, and building cooling demand are pushed beyond historical design conditions. Wildfire smoke and property impacts add another $1.3B, with additional resilience needs on the order of $2.3B. **These figures don't capture every hazard or indirect loss, but they make one point clear: planning and investment now can save lives and avoid much larger costs later.**"

-Pegah Jalali

EXECUTIVE SUMMARY
(2025 - 2050)

Colorado is already experiencing the effects of a warming climate: hotter summers, longer wildfire seasons, more smoke exposure, and mounting pressure on critical infrastructure and water-dependent industries. These changes are not abstract, they influence public health, household costs, and the reliability of roads, bridges, and stormwater systems, while increasing the risk of disruptive, high-loss events.

Across the impacts we quantify, total projected costs in 2025–2050 are on the order of $50–$54B, of which $36–$37B represents additional costs directly attributable to climate change (plus defined resilience investments).

This executive summary highlights projected climate-related damages and resilience needs for 2025–2050. It is intended for policymakers, community leaders, and reporters who need a clear, comparable set of numbers to understand the scale of the challenge. Results are shown under two global emissions pathways that bracket plausible futures: a medium-high pathway (SSP3-7.0) and a high-end emissions pathway (SSP5-8.5).

Among Colorado's health, infrastructure, wildfire, flooding, and winter recreation impacts, the largest quantified drivers are extreme heat, which could lead to about 1,800–1,900 additional heat-related deaths (about $24–$25B in losses), and infrastructure pressures, totaling about $8.3–$8.7B in added costs and upgrades as roads, bridges, stormwater systems, and building cooling demand are pushed beyond historical design conditions. Wildfire smoke and property impacts add another $1.3B, with additional resilience needs on the order of $2.3B. These figures don't capture every hazard or indirect loss, but they make one point clear: planning and investment now can save lives and avoid much larger costs later.

How we estimated impacts: for each sector, we combine Colorado-specific historical records with downscaled climate projections to quantify how key hazards change over time. We then estimate climate-attributable impacts by comparing projected outcomes to a counterfactual that holds climate hazards at 1995-2014 baseline levels while allowing underlying trends to continue. Where relevant, we also estimate defined resilience investments (for example, bridge upgrades, stormwater improvements, wildfire mitigation, and snowmaking) that can reduce future losses. All monetary values are reported in 2024 dollars.

Because not every climate impact can be modeled with available data, these estimates should be viewed as conservative: they cover major, quantifiable pathways but do not include every hazard, indirect economic spillover, or non-fatal health effects.

This summary highlights projected Colorado climate-related damages and resilience needs for 2025–2050 (all values in 2024 dollars) under two emissions pathways: a medium-high pathway (SSP3-7.0) and a high-end pathway (SSP5-8.5). Where applicable, values reflect the climate-attributable portion of impacts (scenario minus a counterfactual holding climate hazards at baseline levels), along with defined resilience investments (e.g., bridges, stormwater, wildfire mitigation, snowmaking).

Across sectors, extreme heat is the dominant driver of projected economic impacts through mid-century, followed by infrastructure stress (especially building cooling demand and bridge resilience needs), and wildfire impacts (property damage plus smoke-related mortality). Flood damages are highly sensitive to rare tail events; we report both a conservative typical-year estimate and a tail-risk sensitivity.

TABLE ES-1. PROJECTED CLIMATE-ATTRIBUTABLE COSTS AND RESILIENCE INVESTMENTS, 2025–2050 (2024$).

Category	SSP3-7.0	SSP5-8.5	Notes
Heat mortality	$23.6B	$24.9B	~1,802–~1,901 excess deaths (VSL=$13.1M)
Wildfire impacts (property + smoke	$1.33B	$1.34B	Central estimate (property + smoke
Wildfire resilience investments	$2.3B	$2.3B	Mitigation/adaptation program costs (central)
Infrastructure (total climate-attributable)	$8.28B	$8.68B	Includes buildings, roads, stormwater, and
• Buildings: net energy costs	$4.75B	$4.94B	
• Bridges: resilience investment needs	$2.42B	$2.58B	
• Roads: maintenance	$0.785B	$0.817B	
• Stormwater: adaptation	$0.321B	$0.342B	
Natural ski season length (avg days)	83.5	82.4	Average over 2025–2050
Effective season length with	124.9	125.1	Average over 2025–2050
Skiers visit losses without snowmaking (total, 2025–2050)	29.0M	32.2M	Demand sensitivity η=1.0
Ski industry: snowmaking cost	$101.1M	$74.2M	
Storm damages (flood-type storms	$6.6M–$184.2M	$7.9M–$220.3M	Typical-year estimate to tail-risk sensitivity
Total Cost	**$35.7 B**	**$37.4 B**	

See the appendix for total costs including both non climate-change attributable costs and climate-change attributable costs.

These mid-century projections are conservative and incomplete: several costly hazards and spillovers are not modeled, and some categories are shown as sensitivities. The results nonetheless provide a clear prioritization signal: reducing heat risk, hardening infrastructure, and lowering wildfire exposure deliver the largest benefits.

Limitations and exclusions

These estimates are intended to be policy-relevant and comparable across sectors, but they do not capture every climate impact. Several categories are excluded because statewide data are incomplete, relationships are not robust enough for projection, or monetization would be speculative.

Key exclusions include: non-fatal health impacts (e.g., hospitalizations, emergency department visits, lost work time, or longer-run health consequences), many indirect economic losses (supply-chain disruption, business interruption, housing-market impacts, migration, or productivity losses beyond the sectors explicitly modeled), ecosystem and biodiversity losses, agricultural yield and water-quality damages outside the modeled pathways, and some high-cost storm hazards (such as hail and severe convective wind) that are difficult to project credibly with available data. In addition, flood damages are shown both as a conservative typical-year estimate and as a tail-risk sensitivity to illustrate uncertainty in rare catastrophic years. We are also in the process of quantifying drought damages to the agriculture sector, which will be added to the report shortly.

For these reasons, the totals reported here should be interpreted as conservative and incomplete. They are useful for prioritizing action, but not as an exhaustive accounting of all climate-related costs Colorado may face through mid-century.

Conclusions and policy implications

Across the categories quantified in this report, mid-century costs are dominated by impacts that are already emerging today: extreme heat risk, wildfire exposure (property loss and smoke-related mortality), and growing strain on infrastructure systems. The central message is that Colorado’s future costs are not driven by a single sector; they reflect compounding pressures on health, the built environment, and climate-sensitive industries.

The biggest opportunities for risk reduction come from actions that both save lives and avoid expensive system failures. Heat-risk reduction (cooling access, worker protections, urban heat mitigation, and public health preparedness), infrastructure hardening (especially bridges and stormwater capacity), and wildfire mitigation (fuel treatments, defensible space, ignition prevention, and smoke preparedness) stand out as high-value priorities because they address frequent, high-consequence outcomes.

Finally, these results should be interpreted as a floor rather than a ceiling. Several important impacts are excluded or only partially captured (for example, some storm types, non-fatal health impacts, ecosystem losses, and broader economic disruption).

1. HEAT

INTRODUCTION

Extreme heat is one of the most consequential climate-related hazards for public health because it can trigger acute cardiovascular and respiratory stress, worsen chronic conditions, and increase mortality risk, especially among older adults, people with pre-existing illness, outdoor workers, and households with limited access to cooling. Epidemiological evidence consistently finds a nonlinear relationship between temperature and mortality, with risk rising more steeply on very hot days and often varying across locations and over time (Basu 2009; Gasparrini et al. 2015).

Colorado has already experienced a clear shift toward more frequent and intense heat conditions. The Colorado Climate Change Assessment notes that hot days and heat waves have become more common across the state in recent decades, with significant increases in extreme heat across most regions. The same assessment reports that heat waves could increase dramatically; potentially by up to ten-fold by mid-century under continued warming. These changes are consistent with statewide warming trends documented for Colorado in recent decades.

Because heat-related mortality is sensitive to both climate conditions and population exposure, the economic damages from heat can rise even when per-capita risks are partially offset by acclimatization and adaptation (e.g., access to air conditioning, behavioral changes, public cooling resources). Our analysis quantifies the climate-attributable portion of future heat mortality in Colorado (2015–2050) relative to a historical reference climate (1995–2014), and monetizes these impacts using a value per statistical life consistent with standard U.S. regulatory practice.

1. HEAT

RESULTS AND METHODS

CLIMATE, POPULATION, AND GEOGRAPHIC AGGREGATION

Daily temperature projections come from LOCA2, a statistically downscaled dataset built from CMIP6 global climate model simulations and designed for local-to-regional impact analyses. We compute daily county-level mean temperature by combining daily minimum and maximum temperature fields and aggregating grid-cell values to counties using a fixed county–grid mapping (so county boundaries and the reference grid are handled consistently across models and scenarios).

We project outcomes under two emissions scenarios that span a middle-to-high and very high forcing pathway: SSP3-7.0 and SSP5-8.5.

Baseline mortality rates and historical populations are constructed from the CDC WONDER annual county data used in this project, while future county populations come from Colorado demographic projections (DOLA). This ensures that projected damages reflect both climate change and population exposure.

1. HEAT

HEAT-MORTALITY RESPONSE AND THE MMT APPROACH (QUANTILE GENERALIZATION)

The peer-reviewed literature typically estimates a location-specific exposure–response relationship between temperature and mortality using flexible nonlinear models (often distributed lag nonlinear models) and identifies a minimum mortality temperature (MMT) (the temperature at which mortality risk is lowest)(Gasparrini et al. 2010; Gasparrini et al. 2015).

Because county-level estimation of full temperature–mortality curves requires detailed daily mortality time series and careful modeling choices, the implementation here uses a pragmatic MMT proxy approach: for each county, MMT is approximated as a chosen quantile of the county's historical warm-season temperature distribution. This generalization is useful because it (i) preserves geographic heterogeneity in "typical" summer conditions, and (ii) makes the sensitivity of results to the assumed MMT transparent. We adopt q=0.90 as our primary specification to be conservative about the heat-risk threshold.

1. HEAT

CLIMATE-ATTRIBUTABLE DEATHS AND MONETIZATION

For each future year and county, we compute expected heat-related excess deaths implied by projected temperatures relative to the county's MMT proxy and baseline mortality. To isolate the climate-change-attributable component (rather than demographic growth alone), we compare projected future outcomes to a counterfactual that preserves the historical reference-climate risk conditions while allowing population to evolve.

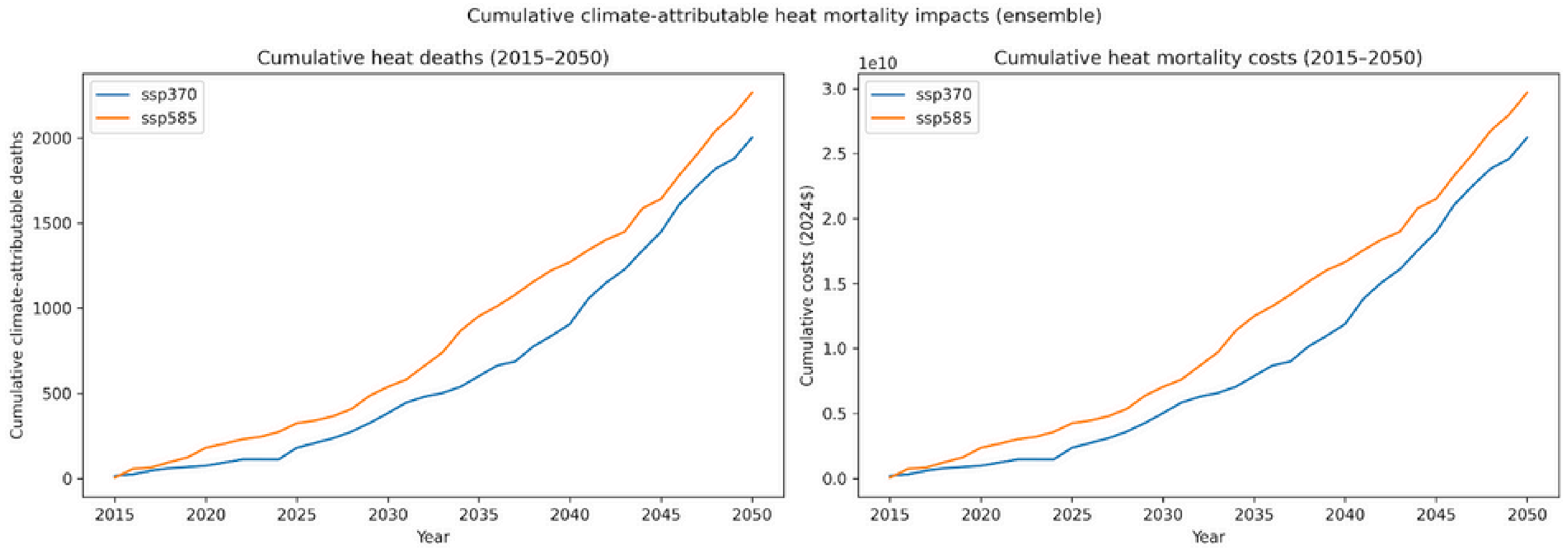
We monetize climate-attributable deaths using a value per statistical life (VSL) of $13.1 million (2024 dollars), consistent with U.S. Department of Health and Human Services (HHS) standard values used in regulatory analyses.

Summary results (2015–2050 totals)

With the q = 0.9 quantile-MMT approach and VSL = $13.1M in 2024 dollars, statewide climate-attributable heat mortality damages over 2015–2050 are:

- **SSP3-7.0: 2,002** climate-attributable deaths, **$26.2B** in damages (2024$), which corresponds to an average of **56 deaths per year** and **$0.73B per year** over the period.
- **SSP5-8.5: 2,266** climate-attributable deaths, **$29.7B** in damages (2024$), which corresponds to an average of **63 deaths** per year and **$0.82B per year** over the period.

These totals reflect higher heat exposure under SSP5-8.5, resulting in a larger mortality burden and higher monetized damages. The spread between scenarios underscores the sensitivity of health outcomes to emissions pathways, consistent with multi-country attribution work showing a measurable fraction of warm-season heat deaths attributable to human-induced climate change.



This figure shows how climate-attributable heat mortality impacts accumulate over time in Colorado from 2015 to 2050 under SSP3-7.0 (blue) and SSP5-8.5 (orange). In both panels, the curves rise gradually in the early years and then steepen after roughly the mid-2030s, reflecting increasing heat exposure as warming intensifies later in the projection period. Across the full horizon, **SSP5-8.5 consistently generates a larger cumulative burden than SSP3-7.0, reaching about 2.27 thousand deaths and $29.7B (2024$) by 2050 versus about 2.00 thousand deaths and $26.2B under SSP3-7.0.** Because costs are computed by valuing each death at a constant VSL in 2024 dollars, the cost curves mirror the deaths curves with the same divergence between scenarios.

1. HEAT

Our primary estimates use a conservative MMT definition (the 90th percentile of each county's historical warm-season temperature distribution), yielding **statewide climate-attributable heat mortality totals of roughly 2,000–2,300 deaths over 2015–2050** (about 56–63 deaths per year) These magnitudes are consistent with the broader range reported in other regional assessments. For example, New York's ClimAID analysis reports baseline heat-related deaths in New York City on the order of several hundred per year and projects increases of roughly 150–300 additional heat-related deaths per year by the 2050s for NYC alone under warming scenarios. California's Fourth Climate Change Assessment similarly cites estimates of thousands of additional annual temperature-related deaths by mid-century under high emissions, with adaptation (e.g., expanded air conditioning) moderating but not eliminating the risk. At the national scale, EPA's CIRA health summaries indicate that extreme-temperature mortality impacts in the thousands are plausible even when analyses are limited to subsets of U.S. cities.

This chapter quantifies only mortality impacts attributable to heat exposure and monetizes them using a value per statistical life. It does not estimate nonfatal health outcomes (morbidity) such as emergency department visits, hospitalizations, lost work time, or longer-run health consequences, which can add a meaningful economic burden during extreme heat events. In addition, our approach does not explicitly model future adaptation or acclimatization (such as increased air-conditioning penetration, improved building performance, heat warning systems, occupational protections, or behavioral responses) which could reduce heat-related mortality risk relative to a no-adaptation baseline. As a result, these estimates should be interpreted as climate-attributable heat mortality costs under current-style risk relationships and demographic exposure assumptions, rather than a full accounting of all health and welfare costs of extreme heat.

1. HEAT

HEAT MORTALITY: OBSERVED HISTORICAL BURDEN AND PROJECTED CLIMATE-ATTRIBUTABLE IMPACTS (1995 - 2024 AND 2025 - 2050)

To complement the modeled results reported in this chapter (which use 1995–2014 as the reference climate period and project outcomes for 2015–2050), we add a summary table that splits outcomes into an observed historical series versus modeled climate-attributable projections. The “Observed (1999–2024)” columns report documented heat deaths from CDC WONDER where the underlying cause of death is ICD-10 X30 (exposure to excessive natural heat); the 2024 value comes from CDC WONDER Provisional Mortality Statistics and is labeled provisional because it may be revised. Separately, the “Modeled climate-attributable” columns report the incremental burden attributable to climate change relative to the chapter’s 1995–2014 reference climate, shown as an optional “past-to-date” subtotal for 2015–2024 and the primary projection window 2025–2050. This presentation keeps observed historical counts and modeled climate-attributable increments distinct while providing the requested past–future split in a consistent format.

Scenario	Observed deaths 1999-2024 (includes 2024 provisional)	Observed cost (1999-2024), 2024$ (B)	Climate deaths (2025-2050)	Climate cost (2025-2050, 2024$) (B)
ssp370	91	1.192	1802	23.6
ssp585	91	1.192	1901	24.9

2. WILDFIRES

INTRODUCTION

Wildfire is a defining and growing risk in Colorado—affecting lives, homes, local economies, and public health. Over the last two decades, Colorado has experienced multiple "landmark" events that illustrate both the scale of wildfire impacts and the types of losses communities face. In 2012, the Waldo Canyon Fire burned more than 18,000 acres and destroyed 347 homes, with insured losses reported around $454 million. More recently, the December 2021 Marshall Fire destroyed nearly 1,100 homes and businesses, with losses estimated above $2 billion, making it the costliest wildfire in Colorado history.

Wildfires impose costs on Colorado in two major ways. First, they can cause direct property losses when fires destroy homes, businesses, and community assets, especially where development expands into the wildland–urban interface (WUI), where structures and flammable vegetation meet. Second, wildfires generate smoke pollution, particularly fine particulate matter (PM2.5), which is a well-established driver of adverse health outcomes and is the primary health concern during smoke events. Climate change is expected to increase wildfire risk by creating warmer, drier conditions that intensify fuel aridity and lengthen periods favorable for fire growth.

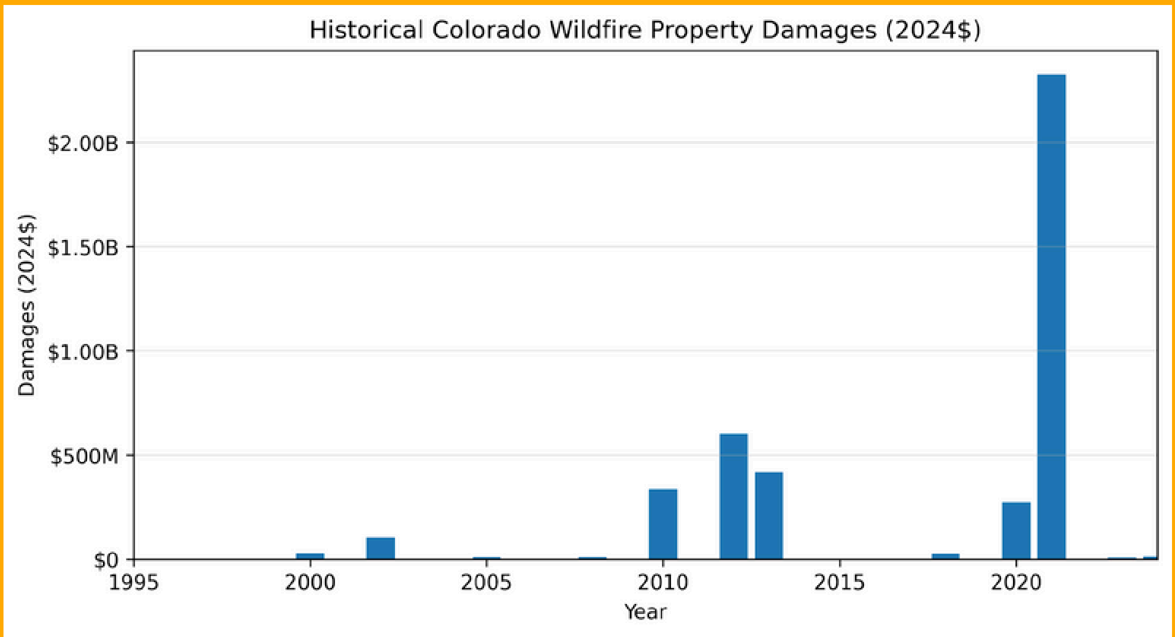
In this section, we quantify (1) future wildfire-related property damage attributable to climate change, (2) health impacts from wildfire smoke (PM2.5), and (3) the scale of adaptation investment needed to reduce risk. We estimate historical relationships using 1995–2014 as the reference climate and project impacts over 2015–2050 under two climate scenarios—SSP3-7.0 (SSP370) and SSP5-8.5 (SSP585) using downscaled climate projections (LOCA2/CMIP6).

2. WILDFIRES

RESULTS

CLIMATE-ATTRIBUTABLE WILDFIRE PROPERTY DAMAGES

We begin with historical wildfire losses reported in NOAA's Storm Events Database, which provides standardized event records (including damages) compiled by the National Weather Service and archived by NOAA/NCEI. We aggregate event-level losses to county–year totals and express all values in inflation-adjusted (2024) dollars.



This figure shows annual statewide wildfire property damages in Colorado (inflation-adjusted to 2024 dollars) based on the NOAA Storm Events records aggregated by year. Damages are highly uneven across time and a few catastrophic years drive the total. Wildfire damages are not smooth or predictable year-to-year, which is why the analysis focuses on long-run totals and expected damages rather than trying to "forecast" any single year.

2. WILDFIRES

To connect damages to climate conditions, we summarize wildfire-conducive dryness using the Keetch–Byram Drought Index (KBDI) for wildfire control and fire potential assessment. We compute historical KBDI from Daymet daily temperature and precipitation. Because wildfire damages are highly "zero-inflated" (most county-years have no reported losses, while a small number have very large losses), we use a count-data style regression (PPML) designed to handle many zeros and heavy right tails in a statistically stable way.

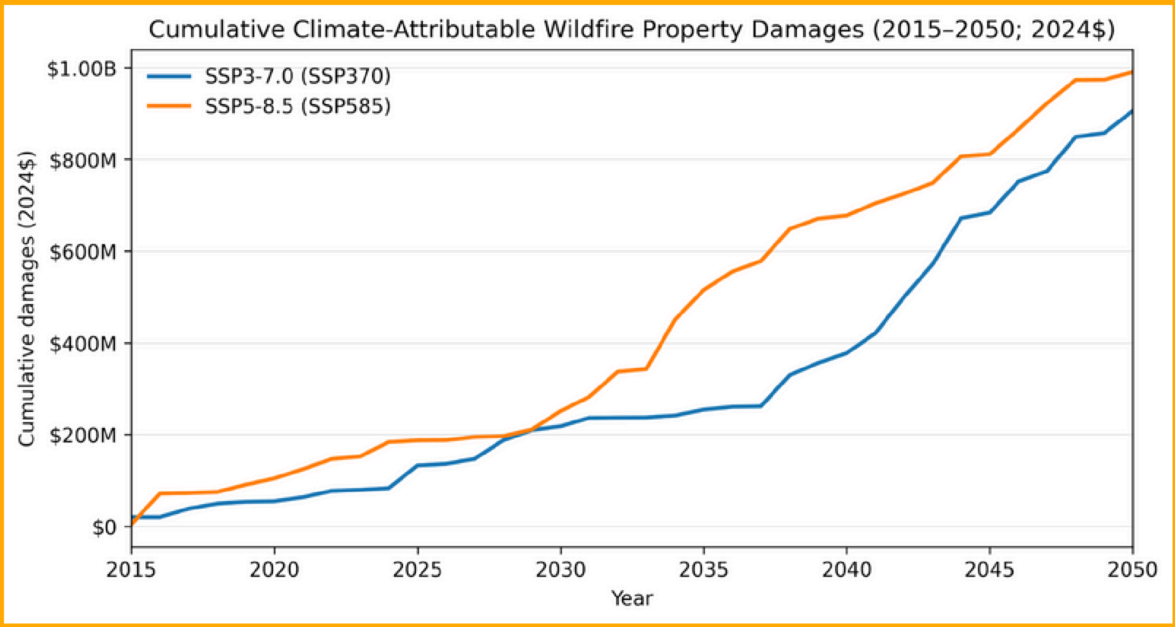
We then estimate how county-year wildfire damages vary with KBDI, while accounting for persistent differences across counties. Finally, we project future KBDI under two CMIP6 pathways using LOCA2 downscaled climate projections, which provide higher-resolution information suitable for regional impacts analysis.

Applying the estimated relationship to projected KBDI yields expected wildfire property damages for 2015–2050 under each scenario. The climate-attributable portion is computed as the difference between (i) scenario damages and (ii) a reference baseline holding the historical climate pattern constant.

Over 2015–2050, the estimated incremental property damages attributable to climate change are:

SSP370: $906.0M (2024$)
SSP585: $990.6M (2024$)

For context, total modeled wildfire property damages over 2015–2050 are $3.34B (SSP370) and $3.42B (SSP585), compared with $2.48B under the baseline reference climate (all in 2024 dollars).



The above figure shows that under both scenarios climate-attributable damages are steadily rising over time. *By construction, this is the cumulative "extra" expected damage attributed to climate change, not total wildfire damage.*

2. WILDFIRES

2-2.2 SMOKE-RELATED MORTALITY IMPACTS FROM WILDFIRE PM2.5

Smoke impacts are quantified through changes in PM2.5, the pollutant most closely tied to wildfire smoke health risk. We estimate how wildfire activity translates into smoke-PM2.5 exposure using a calibrated relationship based on observed smoke-PM2.5 patterns, and then we project changes in PM2.5 under future climate scenarios. We use daily wildfire smoke PM2.5 exposure estimates developed by Childs et al. and distributed by Stanford's Environmental Change and Human Outcomes (ECHO) Lab, then aggregate these exposures and project changes under future climate scenarios.

To translate incremental PM2.5 into mortality impacts, we use a standard log-linear concentration-response approach consistent with widely used health impact assessment frameworks (e.g., BenMAP-style methods). For the mortality risk relationship, we apply a commonly used benchmark of roughly 1.06 relative risk per 10 μg/m³ change in long-term PM2.5 exposure (with uncertainty bounds).

We then monetize mortality impacts using U.S. EPA guidance on the Value of a Statistical Life (VSL), a standard benefit-cost analysis method for valuing small changes in mortality risk (not the value of any individual life), with a central value of **$13.1M,** which matches HHS/ASPE "Standard Values for Regulatory Analysis" (central estimate).

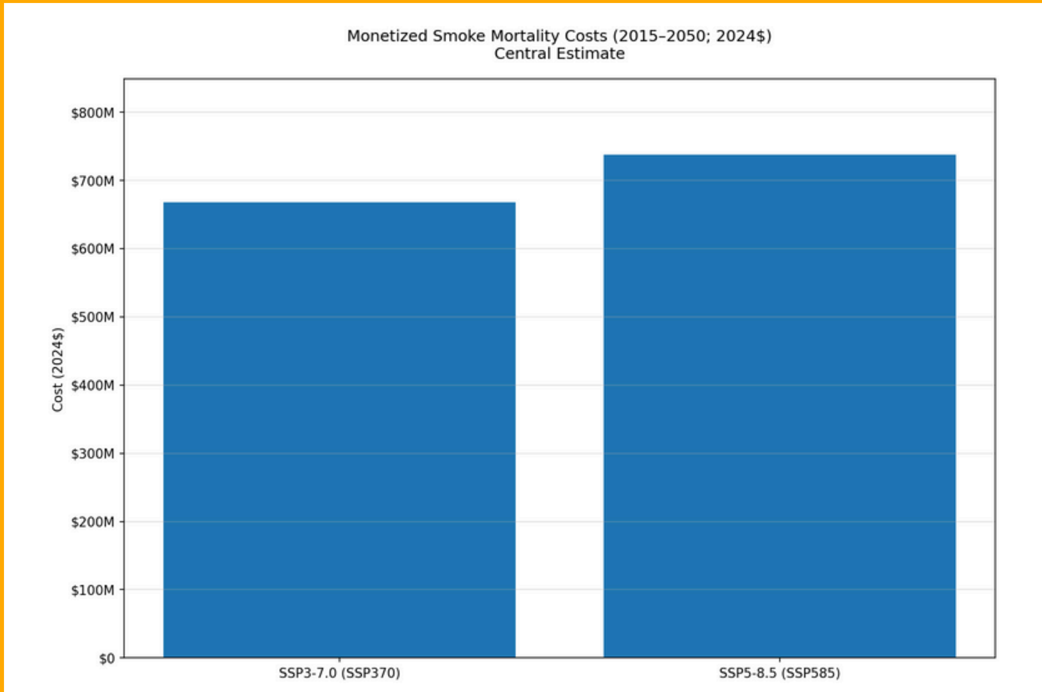
Over 2015–2050, estimated excess premature deaths attributable to wildfire smoke are:

- **SSP370: 51**
- **SSP585: 56.3**

Monetized mortality impacts (2024$) are:

- **SSP370: $668M**
- **SSP585: $737.5M**

These health totals reflect mortality only. They do not include other important smoke burdens such as hospital visits, asthma exacerbations, medication use, lost workdays, or broader quality-of-life impacts. As a result, they should be viewed as a conservative measure of total smoke-related harm.



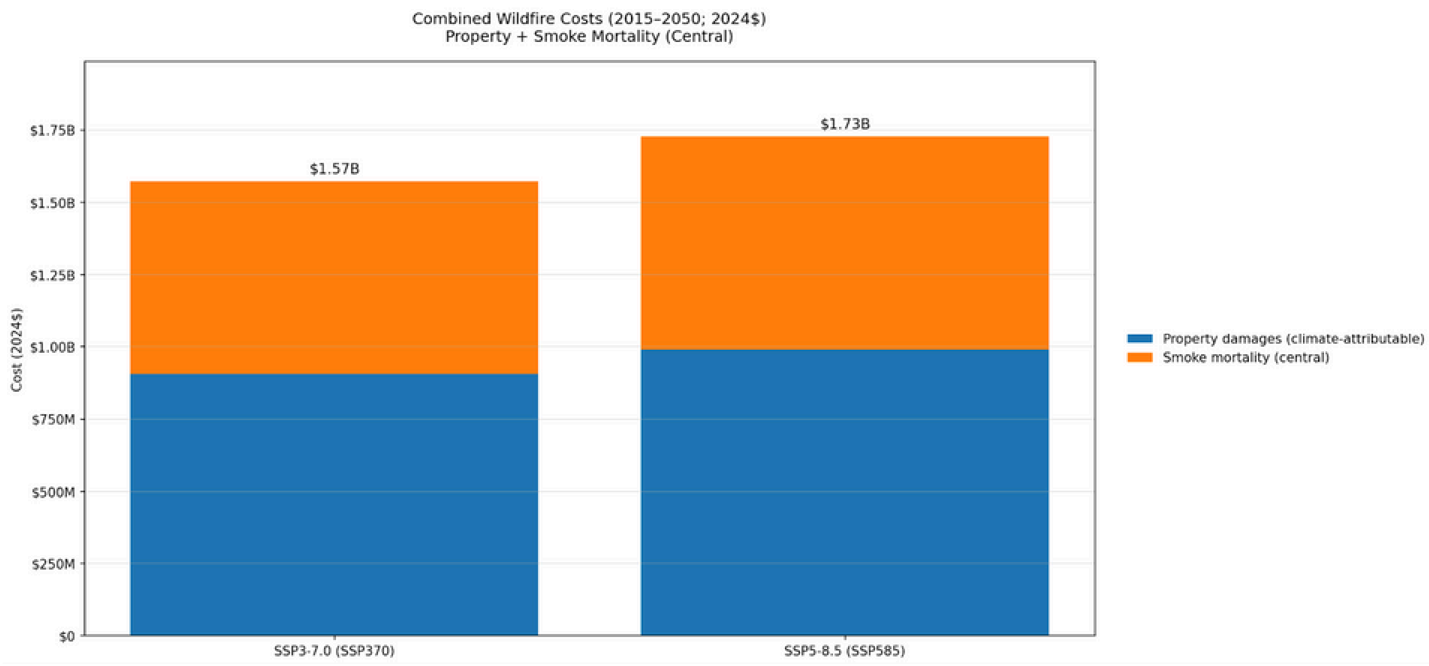
2. WILDFIRES

COMBINED CLIMATE-ATTRIBUTABLE WILDFIRE COSTS: PROPERTY + SMOKE MORTALITY (2015–2050)

Putting together climate-attributable property damages and smoke mortality costs yields total wildfire costs of:

- **SSP370: $1.57B**
- **SSP585: $1.73B**

These totals help communicate that wildfire risk is not only a property-loss issue; smoke-related public health impacts are a meaningful share of the overall climate-attributable burden.



2-2.4 ADAPTATION INVESTMENT: REDUCING WILDFIRE RISK THROUGH HOME HARDENING AND DEFENSIBLE SPACE (2025-2050)

Many of the most effective wildfire risk-reduction actions occur at the home and neighborhood scale, especially in the WUI. These include home hardening (e.g., ember-resistant vents, reducing ignition pathways) and defensible space (reducing fuels immediately around structures). Research and practice guidance from organizations such as IBHS and applied policy groups emphasize that these actions can meaningfully reduce structure vulnerability, particularly for ember-driven ignitions.

We present a transparent "planning-scale" estimate of what it would cost to expand basic mitigation actions statewide. This method converts projected population into estimated households (using an average household size assumption), sets a target share of households adopting core mitigation measures (here, a gradual ramp-up to a target by 2050), and multiplies the number of adopting households by a per-household mitigation cost.

We start the rollout in **2025** and ramp adoption through **2050.** (This is intended as a realistic scale-up path rather than an overnight retrofit assumption.)

Previous studies suggest that many effective retrofit actions often fall in the low-thousands to low–tens-of-thousands of dollars for common measures, with wide variation depending on the home and the level of protection pursued. Consistent with that evidence, we use a per-household cost range and report totals as low/central/high. ($2500,$3400, and $6000).

Total adaptation costs for 2025–2050 are estimated at:

- **$1.69B (low), $2.30B (central), and $4.06B (high) in 2024$.**

For adaptation, the low / central / high totals reflect uncertainty in the unit cost per household (how expensive it is, on average, to implement a package of risk-reduction measures at scale), not uncertainty in climate projections. This is appropriate because the adaptation actions are largely a policy choice and cost varies by home type, local labor/material costs, and the extent of work performed.

Interpretation of damages vs. adaptation costs.

We report projected wildfire property damages and adaptation expenditures separately because the analysis is designed as an accounting of (i) the scale of climate-driven risk and (ii) the scale of investment implied by commonly discussed adaptation strategies. Translating adaptation spending into avoided damages would require a detailed, spatially explicit model of intervention targeting, effectiveness, and persistence (e.g., where treatments occur, how much they reduce fire intensity or structure loss under extreme weather, maintenance cycles, and implementation constraints). These relationships are highly uncertain and vary substantially across landscapes and communities. To avoid embedding strong, hard-to-validate assumptions about effectiveness, we do not net damages against adaptation spending; instead, damages should be interpreted as expected losses under future climate conditions absent an explicit modeled adaptation response, while adaptation costs represent the resources required to pursue risk-reduction actions.

2. WILDFIRES

WILDFIRE COST SPLIT: 1995-2024 VS. 2025-2050

To keep the story clear (and to avoid mixing “what happened” with “what could happen”), the wildfire chapter separates observed historical damages from forward-looking projections. The 1995–2024 period is based on recorded wildfire property losses and is meant to summarize Colorado’s real, experienced damages in inflation-adjusted 2024 dollars. This historical total is not labeled “climate-attributable” in the accounting; it is the best available record of what communities have already paid, influenced by many factors at once (weather, fuels, suppression, development in the WUI, and chance extreme years).

Starting in 2025, the analysis shifts to a projection framework that estimates how wildfire-related costs evolve under different future emissions pathways. We begin the projection window at 2025 to cleanly separate it from the observed record and to align with the report’s forward-looking planning focus. For property damages, we report (i) a baseline expectation anchored to historical conditions and (ii) scenario totals under each pathway; the difference between the scenario and baseline is what we label climate-attributable property damages. For smoke mortality, we similarly project smoke-related health impacts and monetize them (reporting a low/central/high range), so the health component represents an additional climate-linked burden in the future period.

This split makes interpretation straightforward: Colorado’s observed wildfire property damages total about $4.16B (2024$) over 1995–2024 (about $138.5M per year on average). Looking ahead to 2025–2050, projected wildfire property damages sum to about $1.87B under the baseline, rising to $2.68B (SSP3-7.0) or $2.64B (SSP5-8.5) under the scenarios, implying climate-attributable property damages of $823M (SSP3-7.0) and $807M (SSP5-8.5) over 2025–2050. Smoke mortality adds another $522M (central) in each scenario over 2025–2050 (with a wider low/high range reported in the table). Put together, the combined climate-attributable wildfire costs (property + smoke mortality, central) over 2025–2050 are about $1.34B (SSP3-7.0) and $1.33B (SSP5-8.5) in 2024 dollars.

It is important to keep in mind that the split is not meant to suggest that “the past had zero climate influence.” It’s an accounting choice to keep observed outcomes (what we know happened) separate from modeled increments (what additional costs are expected going forward under different emissions futures). Colorado has already suffered large wildfire losses, and future climate conditions are projected to add substantial additional costs, especially when smoke health impacts and adaptation needs are included.

2. WILDFIRES

WILDFIRE COST TOTALS BY PERIOD AND SCENARIO (2024$)

Metric	1995–2024 (observed)	2025–2050 (SSP3-7.0)	2025–2050 (SSP5-8.5)
Property damages (observed total, 2024$)	$4.16 B		
Property damages (climate-attributable increment, 2024$)		$807 M	$823 M
Smoke mortality costs (central, 2024$)		$ 521 M	$522 M
Combined climate-attributable (property + smoke mortality, central; 2024$)		$1.33 B	$1.34 B
Smoke-attributable excess deaths (central)		45.25	45.33
Wildfire adaptation/resilience costs (central, 2024$)		$2.3 B	$2.3 B

It may look counterintuitive that the high-emissions pathway (SSP5-8.5) produces wildfire costs that are similar to SSP3-7.0 in 2025–2050. This result reflects how the wildfire module is driven: projected property damages and smoke mortality are tied to regional fire-weather conditions (heat, dryness, and related meteorological variables) and their year-to-year variability, rather than to emissions labels alone. Over the mid-century window (2025–2050), the two scenarios are often still relatively close in the downscaled climate inputs for Colorado, and small differences in temperature can be offset by small differences in precipitation or humidity patterns that affect dryness and fire potential. As a result, the scenario spread in the ensemble mean is very small. The appropriate interpretation is not that SSP5-8.5 reduces wildfire risk, but that scenario divergence is modest relative to natural variability and modeling uncertainty in this mid-century period; larger scenario separation would generally be expected in later decades as emissions pathways diverge more strongly.

3. INFRASTRUCTURE

INTRODUCTION

Colorado’s infrastructure (roads, bridges, drainage systems, and buildings) was largely designed for a historical climate that is rapidly changing. Warmer temperatures increase heat stress on pavement and other materials, while more intense rain events can overwhelm stormwater systems and accelerate erosion and flood damage at bridge crossings. These impacts show up in two ways: direct damage and service disruptions after extreme events, and rising long-run costs to keep infrastructure safe and functioning (more frequent maintenance, larger drainage capacity, stronger structures, and higher energy needs for cooling).

Local studies in Colorado already show that infrastructure adaptation comes with real price tags, even before scaling up to the whole state. A Boulder County climate cost assessment estimates $96–$157 million in total adaptation costs by 2050 (depending on assumptions), with transportation adaptation making up a large share ($75.4–$123.7 million). In short: even at the county scale, the cost of keeping infrastructure resilient is already in the tens to hundreds of millions of dollars.

This chapter extends that same practical question statewide: What will it cost Colorado to keep essential infrastructure working under future climate conditions? We focus on four subsectors that are both highly exposed and budget-relevant:

- Roads (climate-related increases in maintenance and repair costs)
- Bridges (adaptation investments for bridges exposed to river/stream flooding)
- Stormwater / urban drainage (upgrading drainage capacity as heavy precipitation intensifies)
- Building energy (changes in heating and cooling costs driven by warming)


Photo : CDOT

3. INFRASTRUCTURE
RESULTS

3-2.1 ROADS

We translate projected warming into incremental road costs using a “climate driver × cost sensitivity” approach: as temperatures rise relative to a historical baseline, the model scales up expected road maintenance/repair needs. Results are reported as total additional costs over 2015–2050 in 2024 dollars under two climate pathways.

We estimate incremental road maintenance costs attributable to warming by connecting three ingredients:

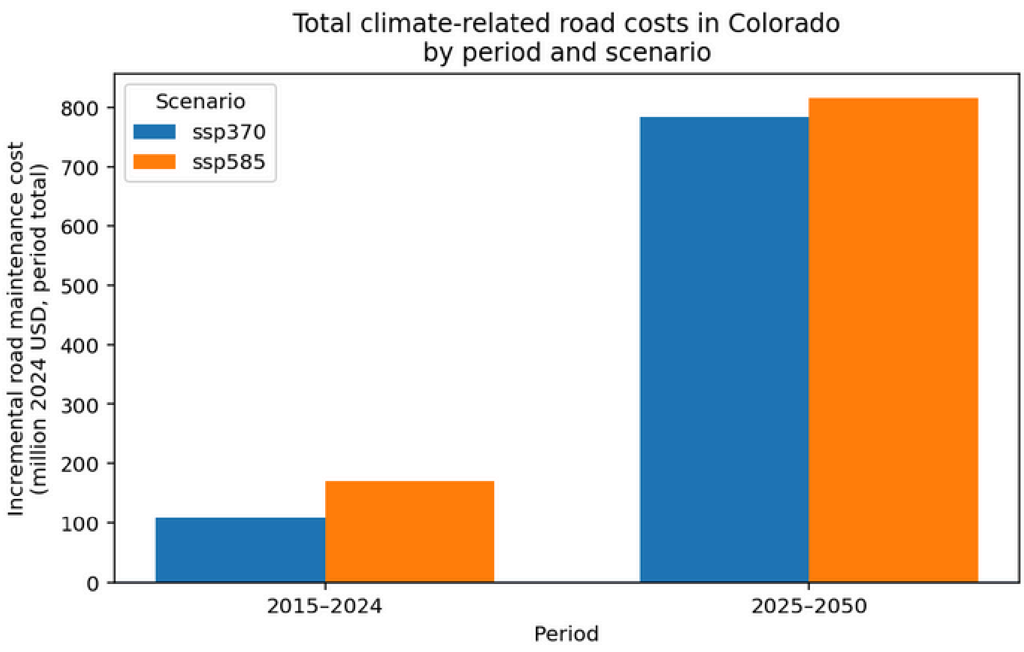
1- How much hotter it gets in each county over time (relative to a historical baseline).We use downscaled climate projections based on CMIP6-LOCA2-derived metrics (multi-model) to estimate temperature changes through 2050.

2-How many road-miles are exposed in each county. We use a county road inventory (lane-miles or road-miles by county) to represent the amount of pavement that must be maintained.

3- A stressor–cost relationship: hotter conditions accelerate deterioration and increase maintenance needs. This approach follows widely used “stressor-response” infrastructure costing frameworks that translate climate stress (heat, heavy precipitation) into incremental maintenance or adaptation spending.

Over 2015–2050, total climate-related road costs are estimated at **$892.5 million** (SSP3-7.0) and **$986.6 million** (SSP5-8.5). Overall, the results indicate substantial climate-related pressure on road maintenance budgets, with higher costs under the higher-emissions scenario and most of the burden occurring after 2025 as warming accumulates.

- **2015–2024:** $108.0M (SSP370) vs $170.5M (SSP585)
- **2025–2050:** $784.5M (SSP370) vs $816.1M (SSP585)



3-2.2 BRIDGES

We estimate statewide bridge adaptation costs by scaling an empirical benchmark from the Boulder County Resilient Analytics (2017) report, which provided a planning estimate of roughly $68 million (2015 USD) to adapt or retrofit 238 bridges exposed to flood and waterway hazards in Boulder County following the 2013 Front Range floods. Consistent with methods used in that report and in subsequent infrastructure-climate assessments, we assume that adaptation needs are driven primarily by exposure to water crossings (i.e., bridges located over rivers, creeks, or drainage channels).

Applying the above method, the National Bridge Inventory identifies 8,990 bridges statewide, of which approximately 7,517 (84%) span waterways or drainage channels. Boulder County contains 288 such bridges. Using the Resilient Analytics calibration of $68 million (2015 USD) for Boulder's 238 bridges, this corresponds to $92.8 million (2024 USD) after CPI adjustment, or about $323,000 per bridge.

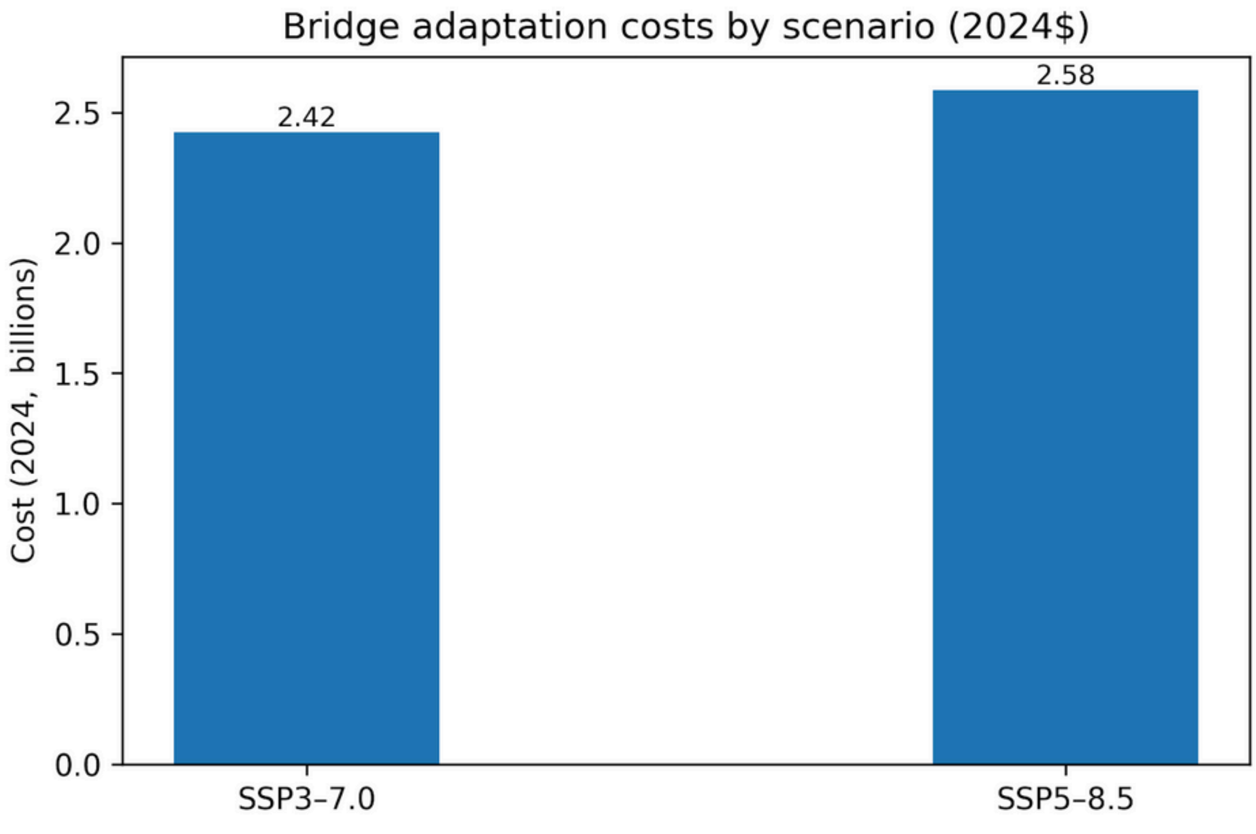
Scaling this cost by the ratio of statewide to Boulder waterway bridges (7,517 / 288 ≈ 26.1) yields an estimated statewide adaptation cost of $2.42 billion (2024 USD). This figure represents the approximate replacement or flood-protection investment required to enhance resilience of bridges exposed to hydrologic and flood hazards across Colorado through 2050.

The bridge risk is expected to grow with heavier precipitation extremes (which raise flood peaks and scour pressure). Boulder County report's bridge analysis explicitly connects climate-driven precipitation changes to higher flows and identifies two future "eras" when upgrades might be needed, reflecting bridges' long design life (often 50–100 years) and the fact that upgrades are typically a one-time investment over the lifetime of a bridge.

3. INFRASTRUCTURE

Because the baseline scaling is anchored to a single planning estimate and bridge exposure counts, it does not vary by emissions pathway on its own. To reflect the fact that flood and scour pressure increases as extreme precipitation becomes more frequent, we apply a scenario multiplier derived from LOCA2 climate projections. We construct a precipitation extremes "driver" (normalized to the historical baseline so values near 1.0 represent today's design climate), then use the late-century average (2040–2050) to scale the statewide baseline.

Under SSP3–7.0, this adjustment does not increase the statewide total, so the bridge adaptation estimate remains $2.42B. Under the higher-emissions scenario SSP5–8.5, projected extreme rainfall is higher late in the period, which raises the estimated statewide bridge adaptation need to $2.58B (2024$); about $162 million more than the baseline estimate. This is a conservative way to reflect that higher emissions can translate into higher bridge resilience needs, while keeping the estimate grounded in Colorado-specific planning evidence.



3-2.3 BUILDING ENERGY: COOLING COSTS OVERWHELM HEATING SAVINGS

We estimate climate-driven changes in building energy expenditures using a degree-day scaling approach. Heating Degree Days (HDD) and Cooling Degree Days (CDD) summarize how much (and for how long) outdoor temperatures fall below or rise above a reference “balance point,” commonly 65°F. HDD and CDD are widely used as reduced-form proxies for space-heating and space-cooling demand, respectively.

To construct HDD65 and CDD65 for Colorado, we use daily near-surface temperature projections from LOCA2, a statistically downscaled climate dataset designed to provide spatially detailed daily climate variables for impacts analysis. We compute daily HDD65 and CDD65 for each county-day and aggregate to annual statewide totals using population weights, so that changes in degree days reflect the temperatures experienced by residents in more populated counties. County population projections/estimates are taken from the Colorado State Demography Office. Future projections are evaluated under SSP3-7.0 (SSP370) and SSP5-8.5 (SSP585).

We translate degree-day changes into dollars by calibrating “cost per degree day” using observed baseline building-sector energy expenditures. Specifically, we use the U.S. Energy Information Administration’s State Energy Data System (SEDS) total energy expenditures series for the residential and commercial sectors, sum them to obtain total building energy expenditures, and convert to constant dollars (then report results in 2024 dollars).

We then allocate baseline building expenditures into a heating-related component and a cooling-related component using fixed expenditure shares. Finally, annual heating (cooling) cost deltas are computed as the baseline heating (cooling) expenditure multiplied by the proportional change in annual HDD65 (CDD65) relative to the baseline mean; the net building-energy cost delta is the sum of heating and cooling deltas.
We allocate total residential + commercial building energy expenditures into heating and cooling components using fixed shares (40% heating; 10% cooling) to create a transparent, first-order estimate. These shares are consistent with end-use shares reported by the U.S. Energy Information Administration: Colorado households devote a majority of site energy to space heating (52%) and a smaller share to air conditioning (4%) (2020 RECS), while U.S. commercial buildings devote roughly one-third of end-use energy to space heating (32%) and about one-tenth to cooling (9%) (2018 CBECS).
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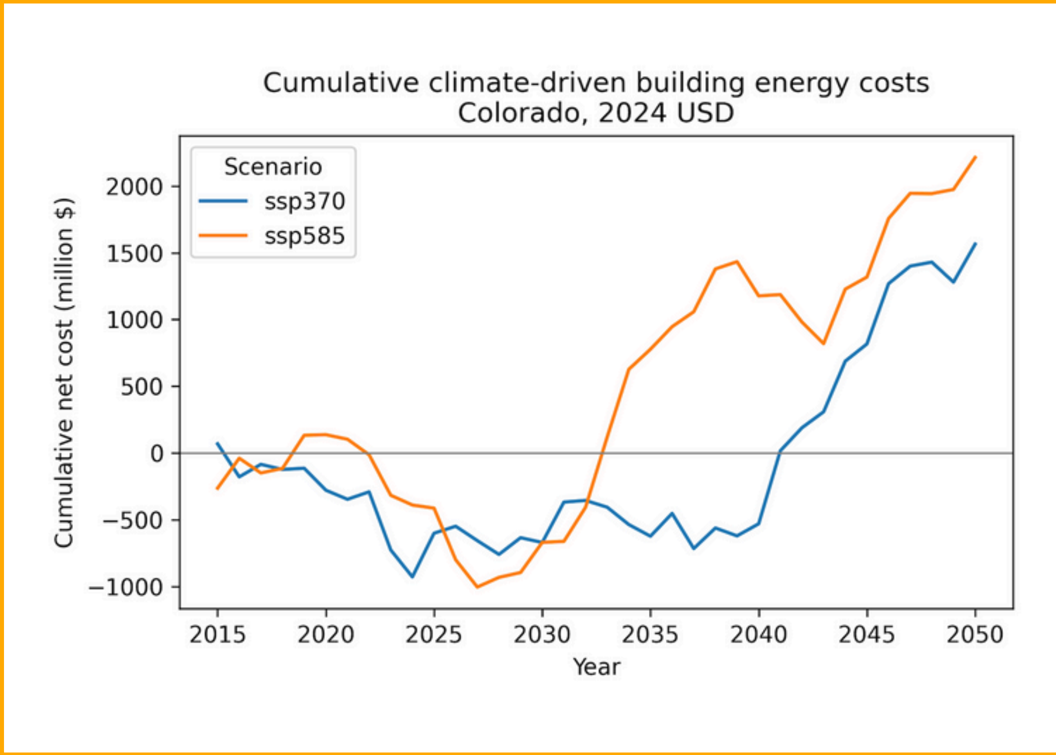
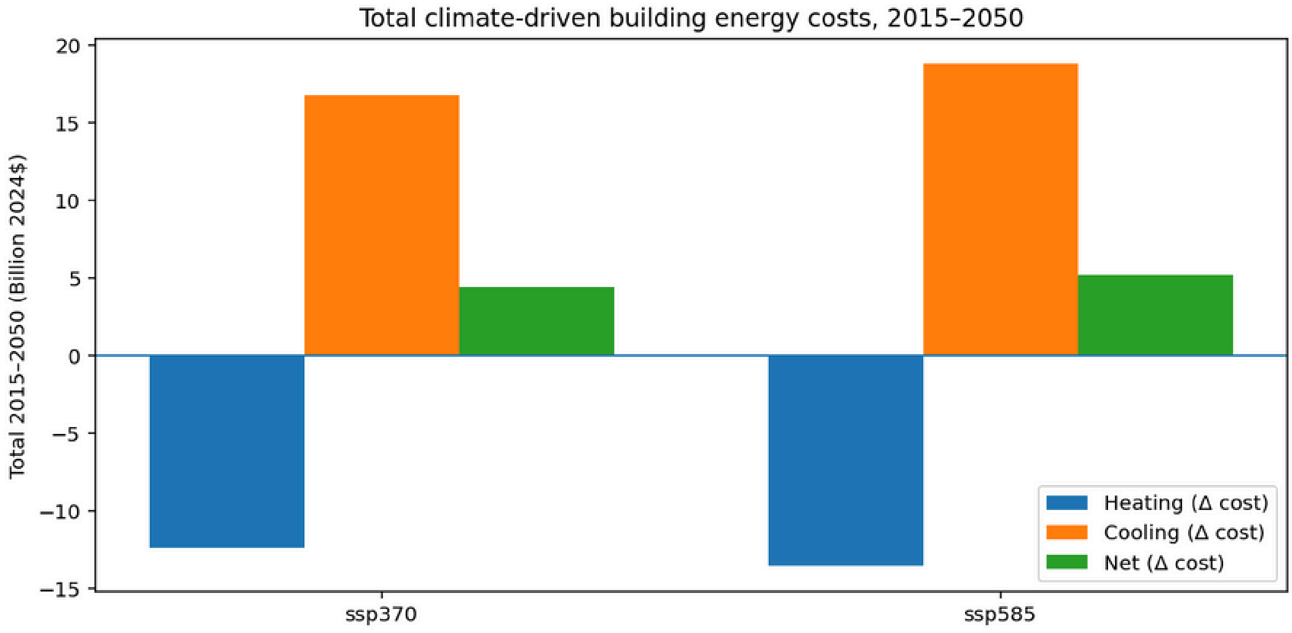
This approach captures first-order demand pressure from warming (fewer HDD, more CDD) while holding constant other determinants of energy spending (e.g., building stock growth, efficiency improvements, electrification, fuel switching, technology adoption, and behavioral adaptation). As a result, the estimates should be interpreted as a stylized measure of climate-driven pressure on building energy costs rather than a full structural forecast of the energy system.

Across scenarios, Colorado experiences the expected directional shift in thermal demand: annual heating degree days trend downward over time while cooling degree days trend upward. Consistent with this, heating expenditures decline (a cost savings) while cooling expenditures rise (an added cost). In baseline calibration, total building energy expenditures are about $7.58B (2024$), with baseline HDD65 ≈ 6,791 and baseline CDD65 ≈ 369, implying a much higher $/CDD than $/HDD because cooling expenditures are allocated to a much smaller number of annual cooling degree days.

Over 2015–2050, the heating component is negative (savings) while the cooling component is positive (added costs). **Cumulatively, the model implies roughly $10.5–$11.0B (2024$) of heating savings and $15.3–$15.9B (2024$) of cooling increases, yielding a net increase of about $4.8–$4.9B (2024$) in building energy costs through 2050.** The annual series shows substantial year-to-year volatility (and wide model spread bands), but the smoothed trajectories are clear: heating savings deepen over time, cooling costs rise over time, and net costs become persistently positive in later decades.



3. INFRASTRUCTURE



The estimates in this chapter are best interpreted as the cost of maintaining service and safety under a changing climate, or the extra investment needed to keep roads functional in hotter conditions, reduce bridge vulnerability to floods/scour, expand or harden drainage systems for heavier downpours, and manage higher cooling needs in buildings. In other words, they are *proactive* costs to reduce disruption and avoid much larger damages later. They are also not exhaustive: they do not include every infrastructure category (e.g., electric grid upgrades, water supply systems, rail, wildfire hardening), and they do not count all disaster losses.

3-2.4 STORMWATER AND URBAN DRAINAGE

To approximate the built environment that drives stormwater runoff management needs, we measure impervious surface area across Colorado and use it as the key "exposure" input for stormwater/urban drainage adaptation costs (i.e., more impervious cover generally implies more runoff volume and greater drainage system burden). We construct county-level impervious area by linking (i) 12-digit Hydrologic Unit Code (HUC12) polygons from the USGS Watershed Boundary Dataset (WBD) with (ii) the EnviroAtlas national impervious-cover metric reported at the HUC12 level (percent impervious). We then intersect HUC12 polygons with Colorado county boundaries and compute the impervious area as (intersected area × impervious fraction), aggregating to counties and statewide totals. This yields a statewide impervious estimate of 2,520.96 km^2.

We parameterize baseline stormwater/urban drainage adaptation costs using a per-area cost calibrated in the applied adaptation-cost literature and local planning applications. In particular, the Boulder County climate cost report presents a stormwater/urban drainage unit cost (reported per square mile of impervious/built area) and uses it to compute total and climate-incremental costs for urban drainage systems. Following this calibration logic, we apply a unit cost of $300,000 per square mile (2015 USD) and convert it to 2024 USD using CPI-based rebasing/ratio adjustment methods .

This "cost per square mile" approach is consistent with how national urban drainage assessments report stormwater adaptation costs and how local planning studies apply unit-cost methods. We use the same baseline unit cost in both scenarios. That means baseline stormwater needs are not assumed to be "lower" in SSP3–7.0; scenario differences come only from projected changes in precipitation extremes.

To account for climate change, we adjust annual costs using a precipitation-extremes index built from LOCA2 climate projections. Each year's "extreme precipitation pressure" is measured as the frequency of very heavy precipitation days relative to the historical baseline (1995–2014), so values near 1.0 represent baseline conditions and values above 1.0 represent more frequent heavy-rain extremes. We apply this index proportionally. To avoid implying "climate benefits" in years with fewer extremes, we use a conservative convention where climate-incremental costs are not allowed to go below zero (no negative damages).

3–2.4

After accounting for projected changes in heavy precipitation, we estimate statewide stormwater/urban drainage adaptation needs of:
Total gross stormwater adaptation cost:

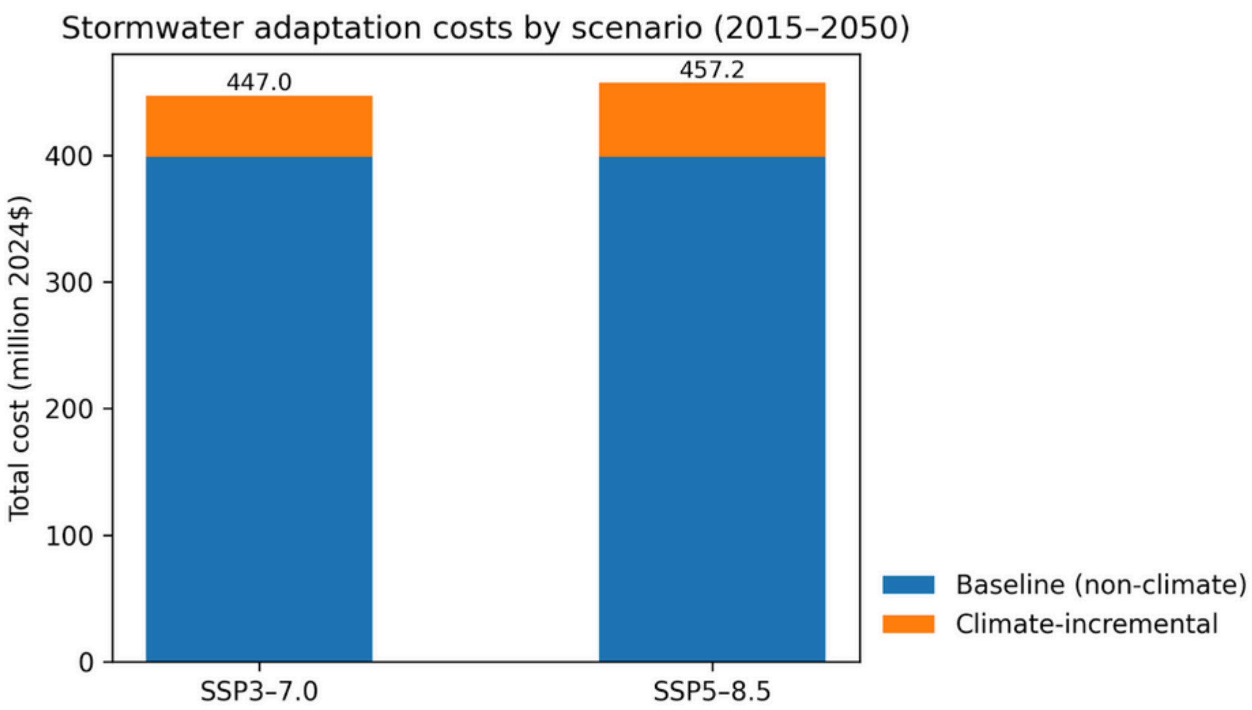
- **SSP3–7.0: $447 million**
- **SSP5–8.5: $457 million**

Climate-driven incremental cost (additional cost attributable to climate change):

- **SSP3–7.0: $48 million**
- **SSP5–8.5: $59 million**

These climate-incremental costs correspond to an average added burden of roughly $1.3M/year under SSP3–7.0 and $1.63M/year under SSP5–8.5, and represent about 11–13% of total stormwater adaptation costs through 2050.

These estimates should be read as adaptation investment needs: the added cost of ensuring stormwater systems can keep pace with a changing climate and the existing built footprint. The largest component is the baseline need driven by impervious surfaces and system capacity, while climate change adds a meaningful additional burden by increasing the frequency of heavy downpours.



INFRASTRUCTURE COST SPLIT: 1995–2024 vs. 2025–2050

To keep the infrastructure chapter consistent with the rest of the report, we report results in two time windows: 1995–2024 (historical) and 2025–2050 (forward-looking). All values are shown in 2024 dollars and reported under two emissions pathways (SSP3-7.0 and SSP5-8.5). The tables summarize climate-attributable incremental costs (the portion of infrastructure-related costs that is attributable to climate conditions relative to a counterfactual baseline), rather than total spending from all causes.

Historical reporting differs by sector based on data availability. For hazards like wildfire and storms, we report observed historical damages (1995–2024). For infrastructure and energy, comprehensive observed time series of adaptation spending are not available statewide, so we report modeled climate-attributable incremental costs (and investment needs) over historical and future periods using consistent cost relationships.

The split makes the main takeaway clear: most of the infrastructure burden occurs in the future period. Total infrastructure climate-attributable costs are -$44.9M to $644.9M in 1995–2024, depending on scenario, but rise sharply to $8.28B (SSP3-7.0) and $8.68B (SSP5-8.5) in 2025–2050. The smaller historical totals reflect offsetting effects in some components, while the future totals are driven by large increases in cooling demand and major resilience needs.

Sector results explain this pattern. Roads show positive incremental costs in both periods, increasing from $184.0M–$246.0M in 1995–2024 to $784.8M–$816.5M in 2025–2050, consistent with rising climate stress on pavements and maintenance needs. Stormwater adaptation costs are also positive in both periods ($114.9M–$126.2M historically and $320.7M–$341.7M in 2025–2050), but they are smaller than the building and bridge components.

Bridges are reported only for the forward-looking period. In this chapter, bridge results are framed as resilience investment needs that are planned and implemented as a future program, rather than as a reconstructed historical time series. For 2025–2050, projected bridge resilience needs total $2.42B (SSP3-7.0) to $2.58B (SSP5-8.5).

Buildings dominate the totals, and they also explain why historical totals can be small or even negative. Cooling costs increase in both periods ($1.49B–$2.85B in 1995–2024 and $7.12B–$7.79B in 2025–2050), while heating costs decline (negative values) in both periods (-$1.84B–-$2.57B historically and -$2.37B–-$2.85B in 2025–2050). In the historical period, reduced heating demand can offset much of the cooling increase, producing net building energy impacts of -$355.1M (SSP3-7.0) and $283.0M (SSP5-8.5). After 2025, cooling increases become much larger and dominate these offsets, yielding net building energy impacts of $4.75B–$4.94B over 2025–2050.

Overall, the 1995–2024 vs. 2025–2050 split highlights two points: (1) future infrastructure impacts are substantially larger than historical impacts, and (2) buildings, bridges, and roads account for most of the increase, with cooling-driven energy costs and resilience investments emerging as the main drivers in the decades ahead.

3. INFRASTRUCTURE

TOTAL INFRASTRUCTURE CLIMATE-ATTRIBUTABLE COSTS BY SCENARIO AND PERIOD 1995–2024 VS. 2025–2050, 2024$)

Period	SSP3-7.0	SSP5-8.5
1995–2024	**-$44.9M**	**$644.9M**
2025–2050	**$8.28B**	**$8.68B**

INFRASTRUCTURE: CLIMATE-ATTRIBUTABLE COSTS BY SECTOR AND PERIOD (1995–2024 vs. 2025–2050, 2024$)

Metric	Period	SSP3-7.0	SSP5-8.5
Roads – incremental costs (central)	1995–2024	$184.0M	$246.0M
Roads – incremental costs (central)	2025–2050	$784.8M	$816.5M
Bridges – resilience investment needs	1995–2024	—	—
Bridges – resilience investment needs	2025–2050†	$2.42B	$2.58B
Stormwater – adaptation costs (gross)	1995–2024*	$126.2M	$114.9M
Stormwater – adaptation costs (gross)	2025–2050	$320.7M	$341.7M
Buildings – cooling cost change	1995–2024	$1.49B	$2.85B
Buildings – cooling cost change	2025–2050	$7.12B	$7.79B
Buildings – heating cost change	1995–2024	-$1.84B	-$2.57B
Buildings – heating cost change	2025–2050	-$2.37B	-$2.85B
Buildings – net energy cost change	1995–2024	-$355.1M	$283.0M
Buildings – net energy cost change	2025–2050	$4.75B	$4.94B
Total	**1995-2024**	**–$45M**	**$644.9M**
Total	**2025-2050**	**$8.28B**	**$8.68B**

3. INFRASTRUCTURE

Across infrastructure systems, the 1995–2024 values reported here represent modeled climate-related incremental costs (the difference between costs implied by the observed climate in 1995–2024 and a historical reference climate anchored to the 1995–2014 baseline). This is not a statewide accounting of actual budgets or invoices. Instead, it is an internally consistent estimate of how climate conditions over the historical period would be expected to shift costs across three modeled components: road maintenance and repair, stormwater adaptation needs, and building energy expenditures (cooling and heating).

The net total can be negative under SSP3-7.0 because the infrastructure "total" is reported as a net sum that includes both cost increases and cost reductions. In the historical period, the modeled reduction in heating costs is large enough under the lower-emissions pathway to more than offset the increases in cooling-related electricity use as well as the positive incremental costs for roads and stormwater. A negative net value should therefore be interpreted as net operational savings in building heating dominating the combined infrastructure balance for 1995–2024, not as evidence that climate pressures are absent; the road and stormwater components still show positive climate-related cost increases over the same period.

4-1

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

INTRODUCTION

A warmer atmosphere can hold more water vapor, which increases the potential for intense precipitation and can amplify flood risk when storms occur. Consistent with this physical mechanism, assessments of observed and projected climate change find increases in heavy precipitation across much of the United States, alongside increases in the likelihood and intensity of extreme precipitation events under higher warming pathways.

Colorado's flood risk is shaped by steep terrain, burn-scar hydrology, and a large share of population and infrastructure concentrated along the Front Range. While total precipitation can be highly variable year to year, the state has experienced damaging extreme events, including the September 2013 Front Range flood, which produced widespread flash flooding and landslides and caused damages exceeding $2 billion. Colorado's statewide climate assessment also highlights that warming alters hydrologic conditions (including snowpack and runoff timing) and that heavy precipitation and flooding remain key hazards with material consequences for communities and infrastructure.

This chapter quantifies storm and flood related economic damages using historical loss records and a climate-driven hazard projection approach. This analysis focuses on storm damages that are most directly linked to heavy precipitation and flooding, specifically Storm Events categories Flood, Flash Flood, and Heavy Rain, because these event types have a clear physical connection to the precipitation hazard drivers used in our projections.

We do not model other high-damage storm categories such as hail and thunderstorm wind. While these hazards can contribute substantially to historical losses, projecting them credibly would require a separate hazard translation step that is not available in our current modeling pipeline. As a result, the damages reported in this chapter should be interpreted as flood/heavy-precipitation related storm damages, and therefore represent a subset of total storm-related damages.

4-2.1

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

RESULTS

4-2.1 DATA AND SCOPE

We use the NOAA/NCEI Storm Events Database to measure historical damages in Colorado and to build a county-by-year panel of property and crop losses (inflated to constant dollars). To keep the damage function tightly linked to a precipitation hazard that can be credibly projected, the analysis focuses on event categories most directly associated with rainfall-driven flooding (e.g., Flood, Flash Flood, Heavy Rain). This scope choice intentionally excludes hazards such as hail and thunderstorm wind, which are important in Colorado but are not well explained by precipitation extremes alone and would require different meteorological predictors (e.g., convective indices, hail-size distributions, wind gust fields) to project defensibly.

We summarize precipitation extremes using rx1day: the annual maximum 1-day precipitation for each county-year. Historical baseline hazards are derived from Daymet daily gridded observations. Future hazards are derived from LOCA2 downscaled CMIP6 projections under SSP3-7.0 and SSP5-8.5, and then harmonized to the Daymet baseline using a delta/bias-adjustment approach so that projected changes reflect modeled climate shifts while preserving the observed baseline spatial pattern.

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

4-2.2 DAMAGE MODEL AND PROJECTION APPROACH

Damages are highly skewed with many county-years near zero and a small number of catastrophic years. To handle zeros and skewness without dropping observations, we estimate a Poisson pseudo-maximum likelihood (PPML) damage model with county and year controls and rx1day as the primary climate driver. PPML is widely used for nonnegative outcomes with many zeros and is robust to common forms of heteroskedasticity.

For projections (2015–2050), we compute two predicted damage paths for each scenario:

1. **Scenario damages:** predicted damages using projected rx1day under SSP3-7.0 or SSP5-8.5.
2. **Counterfactual damages:** predicted damages holding climate at the baseline (Daymet) hazard level.

The climate-attributable incremental damages are the difference (scenario minus counterfactual), summed across counties and years. To avoid any single extreme baseline year dominating projections through the time fixed effects, we report a conservative “typical-year” approach that averages year effects multiplicatively (geometric averaging). A sensitivity check using arithmetic averaging produces larger expected-value totals (see below), reflecting the influence of rare catastrophic years in the historical record (e.g., 2013).

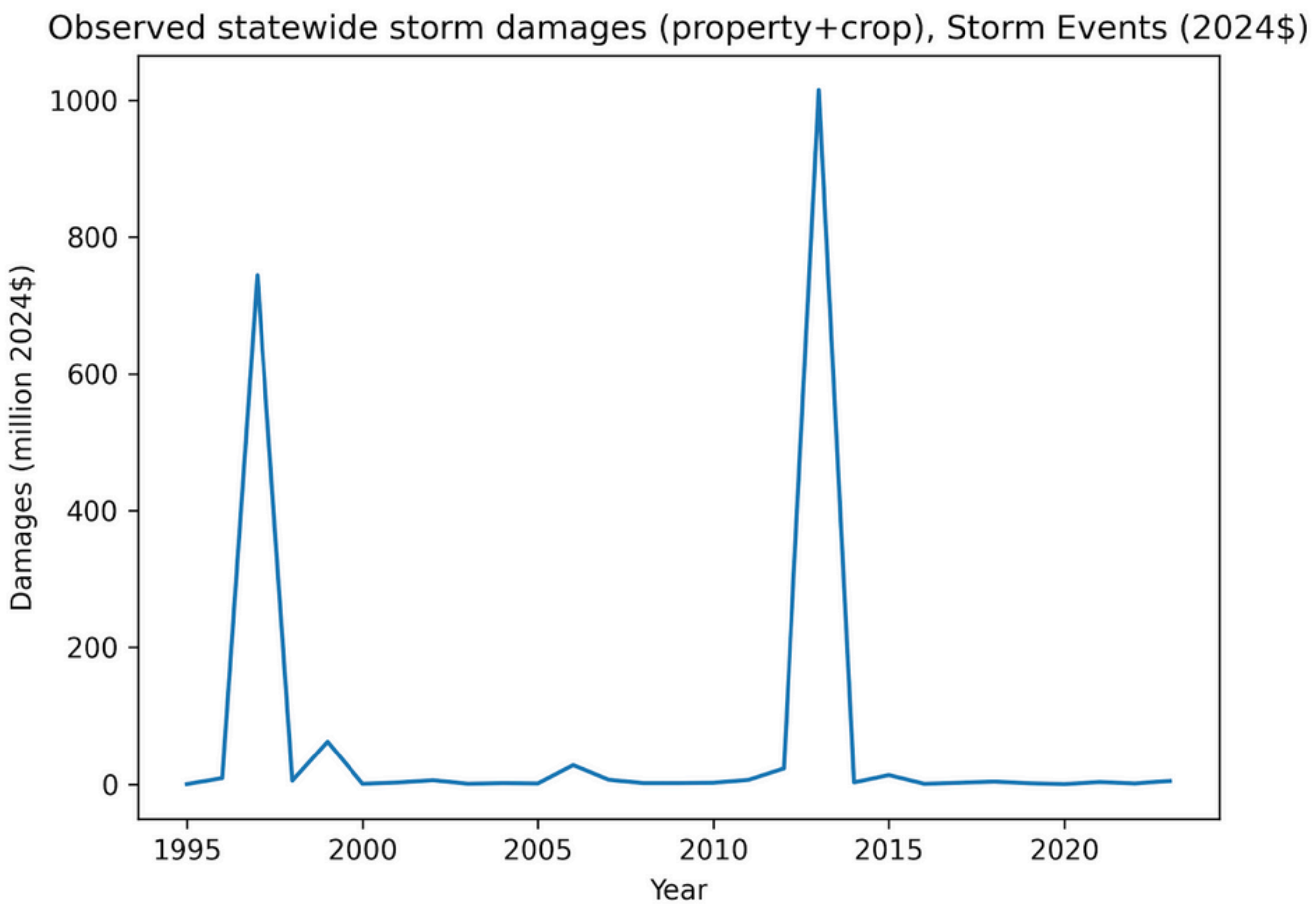
4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

SUMMARY RESULTS

4-2.3 SUMMARY RESULTS (2015–2050 totals)

Totals:
Colorado’s storm damages are highly skewed: a small number of catastrophic years account for a large share of historical losses, which is reflected in the Storm Events record (the baseline mean far exceeds the median). To avoid having a few extreme historical years dominate projections, our primary estimates summarize the fitted year effects using a geometric-mean average over baseline years. This produces a conservative “typical-year” representation of the damage environment while still allowing climate-driven changes in the precipitation hazard (rx1day) to shift expected damages. Importantly, the model is designed to capture the component of damages that covaries with extreme one-day precipitation for flood-related event types (Flash Flood, Flood, Heavy Rain); therefore, the reported climate-attributable increment should be interpreted as the precipitation-linked portion of projected flood-type damages rather than total storm risk in Colorado.

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)



SSP3-7.0: total predicted damages = **$131.1M (2024$) over 2015–2050;** climate-attributable increment = **$9.0M.**

SSP5-8.5: total predicted damages = **$131.4 M (2024$) over 2015–2050;** climate-attributable increment = **$9.4M.**

Total predicted damages are about **$131.1–$131.4M (2024$) over 2015–2050**, of which about **$9.0–$9.4M** is the climate-attributable increment under the typical-year specification. Under this conservative specification, most projected storm damages reflect the baseline risk of flood-related losses, while climate change adds a modest incremental increase in expected losses via higher precipitation extremes.

4. STORMS

(FLASH FOOD/HEAVY RAIN/ FLOOD)

STORMS AND FLOODS: OBSERVED RECORD (1995–2024) VS. PROJECTED CLIMATE-ATTRIBUTABLE IMPACTS (2025–2050)

To keep the story consistent across the report, we split storm-related costs into (i) what has already happened and is directly observed and (ii) what we project forward under different emissions pathways. For storms, the historical side comes from NOAA/NCEI Storm Events data (Flood, Flash Flood, Heavy Rain), aggregated to statewide annual totals and inflated to 2024 dollars. The forward-looking side comes from our damage model, which translates projected changes in extreme precipitation into expected changes in statewide damages, reported as the climate-attributable increment (scenario minus a counterfactual holding hazards at baseline levels).

Over 1995–2024, total statewide storm damages in the observed record sum to $1.95B (2024$), which is about $64.9M per year on average. Because this is an observed historical total, it is the same regardless of scenario (there is no “SSP” attached to the past).
For 2025–2050, we estimate climate-attributable storm damages by predicting damages under each scenario’s projected precipitation extremes and subtracting a counterfactual where hazards are held at baseline (“no additional climate change” relative to the reference). Under the typical-year approach (geometric averaging over baseline year fixed effects, which downweights the influence of rare catastrophic years), the projected climate-attributable increment is $7.9M (SSP5-8.5) and $6.6M (SSP3-7.0) over 2025–2050. This result reflects that, in this specification, projected mid-century shifts in the precipitation extreme index translate into relatively small changes in expected damages once the historical distribution is “typical-ized.”

STORM DAMAGES: OBSERVED (1995–2024) VS. PROJECTED CLIMATE-ATTRIBUTABLE INCREMENT (2025–2050), TYPICAL-YEAR (2024$)

Metric	Units	1995–2024 (observed)	2025–2050 (SSP3-7.0)	2025–2050 (SSP5-8.5)
Observed storm damages (Flood/Flash Flood/Heavy Rain),	USD	$1.95B		
Total flood-type damages (2024$)	USD		$100.1M	$101.4M
Climate-attributable incremental storm damages total (2024$)	USD		$6.6M	$7.9M

4–2.3

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

Tail-risk sensitivity (expected-value). Because storm damages are highly skewed—dominated by a small number of extreme-loss years—we also report a tail-risk sensitivity using an arithmetic mean over baseline year fixed effects (an “expected-value” style estimate that preserves the influence of rare, high-loss years in the historical distribution). Under this tail-risk approach, the projected climate-attributable increment rises to $220M (SSP5-8.5) and $184M (SSP3-7.0) over 2025–2050.

STORM DAMAGES: OBSERVED (1995–2024) VS. PROJECTED CLIMATE-ATTRIBUTABLE INCREMENT (2025–2050), TAIL-RISK SENSITIVITY (EXPECTED-VALUE) (2024$)

Metric	Units	1995–2024 (observed)	2025–2050 (SSP3-7.0)	2025–2050 (SSP5-8.5)
Observed flood-type property damages (total,	USD	$1.95B		
Total flood-type damages	USD		$2.80B	$2.84B
Climate-attributable flood-type damages (tail-risk)	USD		$184.2M	$220.3M

Even under the tail-risk sensitivity, these projections should be interpreted as conservative. The arithmetic-mean approach is designed to preserve the influence of rare, high-loss historical years in the baseline distribution, rather than smoothing them away in a “typical-year” estimate. However, that sensitivity is still anchored to the historical record and the set of hazard types we can quantify consistently statewide.

Colorado’s observed storm damages include a small number of catastrophic years that dominate long-run totals, most notably the Front Range flood in 2013 (on the order of a couple of billion dollars in damages) and an additional major late-1990s event with damages in the hundreds of millions. Because these events are few, the historical distribution of extremes is necessarily sparse; the tail-risk sensitivity preserves those tails, but it does not assume that future climate conditions will generate events that exceed the historical maximum in magnitude, frequency, spatial footprint, or compounding impacts. In that sense, even the tail-risk results likely understate the true downside risk if extreme precipitation produces more “2013-type” years or more costly variants of them.

4. STORMS
(FLASH FOOD/HEAVY RAIN/ FLOOD)

LIMITATIONS

This assessment is designed to be transparent and decision-relevant, but it is not a complete accounting of every way climate change affects Colorado. Several limitations matter for interpretation. First, most results are built from available statewide datasets and planning-style scaling methods, so they capture order-of-magnitude impacts rather than project-by-project engineering estimates. Second, some hazards are highly driven by rare extremes (especially flooding and wildfire), which means totals are sensitive to how tail events are treated and to uncertainty in future variability. Third, the analysis focuses on direct damages and a defined set of adaptation-related costs; it does not fully model how future policies, building codes, land-use decisions, or adaptation investments could reduce impacts, nor does it quantify indirect economic ripple effects (e.g., supply-chain disruption, business interruption, housing-market impacts, migration, or productivity losses beyond the sectors explicitly modeled). Finally, several important climate impact categories are excluded or only partially covered due to data or scope constraints, including (depending on the chapter coverage) ecosystem and biodiversity losses, water supply and hydropower constraints, mental-health impacts, long-term morbidity from smoke and heat (beyond mortality), and distributional impacts across income, race, age, and occupation. For these reasons, the totals reported here should be viewed as conservative and incomplete, and best used as a baseline for prioritizing resilience planning and targeted follow-on analysis.

5. DROUGHT

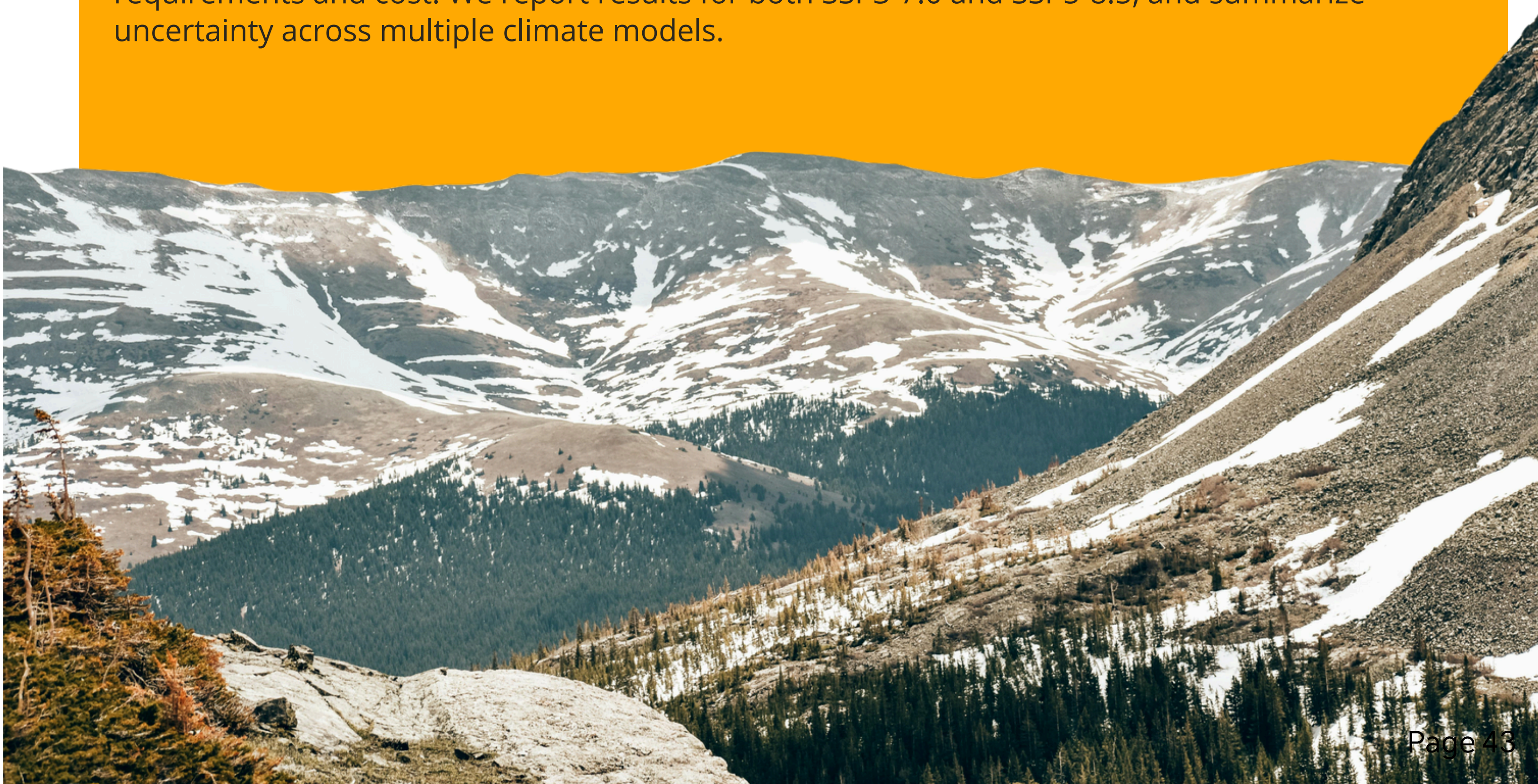
INTRODUCTION

5-1 WINTER SPORTS

Colorado's ski season depends on reliable winter snowpack, both how much snow accumulates and how long it persists into the core winter months. As temperatures rise, more winter precipitation falls as rain instead of snow, and snow that does accumulate melts earlier. For Colorado's mountain communities and winter recreation economy, that means the natural "margin of safety" shrinks: good seasons become less consistent, and the risk of poor conditions increases, especially around the holiday period when visitation and revenue are typically highest.

A key implication is that snowmaking becomes more of a requirement than a supplement. Resorts have long used snowmaking to open terrain earlier, repair thin coverage, and stabilize conditions during dry spells. Under continued warming, snowmaking needs increase over time to maintain similar operating conditions, which in turn raises water and operating demands and, in the most challenging years, may still be unable to fully offset losses in natural snow reliability.

In this section, we use downscaled daily climate projections to estimate how winter conditions in Colorado's ski regions evolve over time. We translate daily temperature and precipitation into indicators of (i) natural season length and holiday reliability, (ii) effective season length with snowmaking under a simplified operational rule, and (iii) the implied snowmaking water requirements and cost. We report results for both SSP3-7.0 and SSP5-8.5, and summarize uncertainty across multiple climate models.



RESULTS

5-1.2 RESULTS

Climate inputs, spatial units, and ensemble framing
We use daily downscaled climate projections (precipitation and minimum/maximum temperature) from the CMIP6-LOCA2 downscaling framework, which provides consistent daily fields suitable for impact modeling at regional scales.
We compute winter-season metrics for a set of Colorado ski-intensive counties and aggregate them to a statewide index using fixed county weights (a transparent baseline approach; weights can be replaced by resort capacity or visitation shares if available). Results are reported for two emissions pathways: SSP3-7.0 (ssp370) and SSP5-8.5 (ssp585).

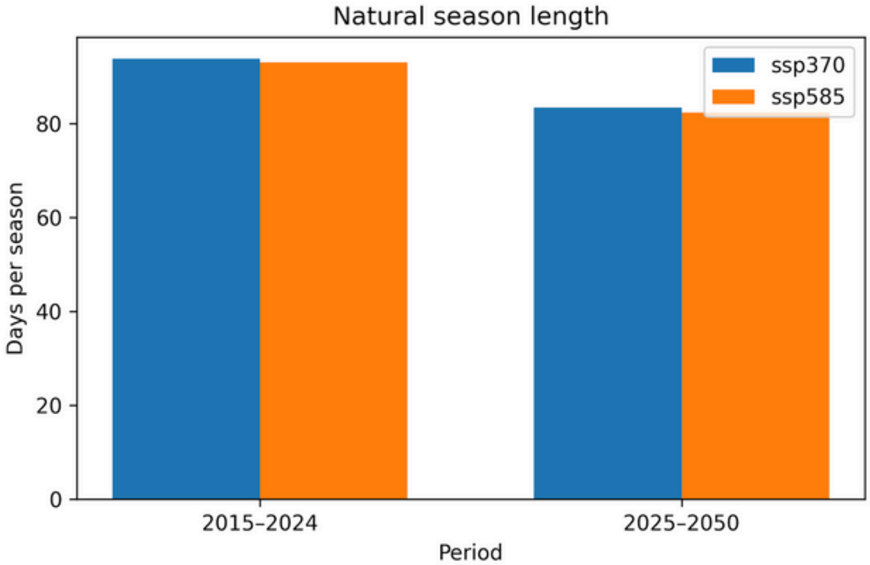
Season length and holiday reliability (natural snow)
We summarize ski-season reliability using two season-length concepts. The **natural season length** counts the number of November–April days that meet the minimum base-snow condition using climate-driven snowfall and melt alone. The **effective season length** applies the same snowpack simulation but allows snowmaking during the early season when nights are cold enough, subject to a seasonal production limit. The difference between these two series is the **snowmaking benefit,** interpreted as the number of additional skiable days enabled by snowmaking relative to natural conditions.

We translate daily precipitation and temperature into a simple snowpack proxy. Precipitation is partitioned into snow vs rain using daily mean temperature, and a temperature-driven melt rule reduces stored snow when conditions are warm. A day is counted as “snow-reliable” when the implied snowpack depth meets a minimum operational threshold (calibrated to a conventional minimum depth proxy used in ski-season studies). This class of threshold-based season reliability metrics is widely used because it is transparent, comparable across scenarios, and appropriate for multi-decade comparisons even when exact year-to-year realism is not the goal.

5. DROUGHT

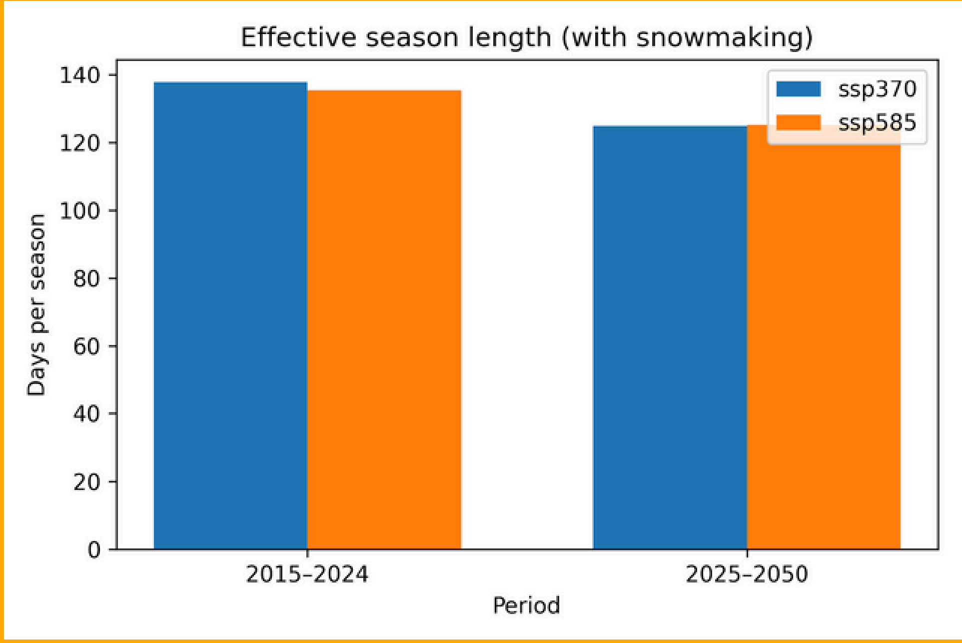
Figures 5-1–5-3 summarize projected changes in Colorado's ski-season reliability using two future windows (2015–2024 and 2025–2050) under SSP3-7.0 (ssp370) and SSP5-8.5 (ssp585), averaged across the climate-model runs used in this analysis.

Natural season length (Figure 5-1) declines noticeably between the near term and the later period in both scenarios. Under SSP3-7.0, the natural season averages 93.8 days in 2015–2024 and falls to 83.5 days in 2025–2050 (about 10.3 fewer days per season). Under SSP5-8.5, the natural season averages 93.1 days in 2015–2024 and falls to 82.4 days in 2025–2050 (about 10.7 fewer days).



As a historical reference point before climate-related impacts on the ski industry became widely discussed, we report modeled season conditions for the early 1980s using the same definitions applied throughout this analysis. In 1981, the modeled natural season length (snow conditions without snowmaking) was about 119 days statewide . Under our standardized effective season metric, which represents the season that could be sustained given the year's climate and a consistent snowmaking/operations rule applied across all years—the effective season in 1981 is about 156 days. This "effective" metric is intended as a comparability construct rather than a literal reconstruction of resort operations in 1981, when snowmaking existed but coverage and capability varied substantially across resorts.

When snowmaking is included, the effective season length remains substantially longer than the natural season in both periods, but it still declines over time (Figure 5-2). Under SSP3-7.0, the effective season decreases from 137.7 days in 2015–2024 to 124.9 days in 2025–2050 (about 12.8 fewer days). Under SSP5-8.5, it declines from 135.4 days to 125.1 days (about 10.3 fewer days.



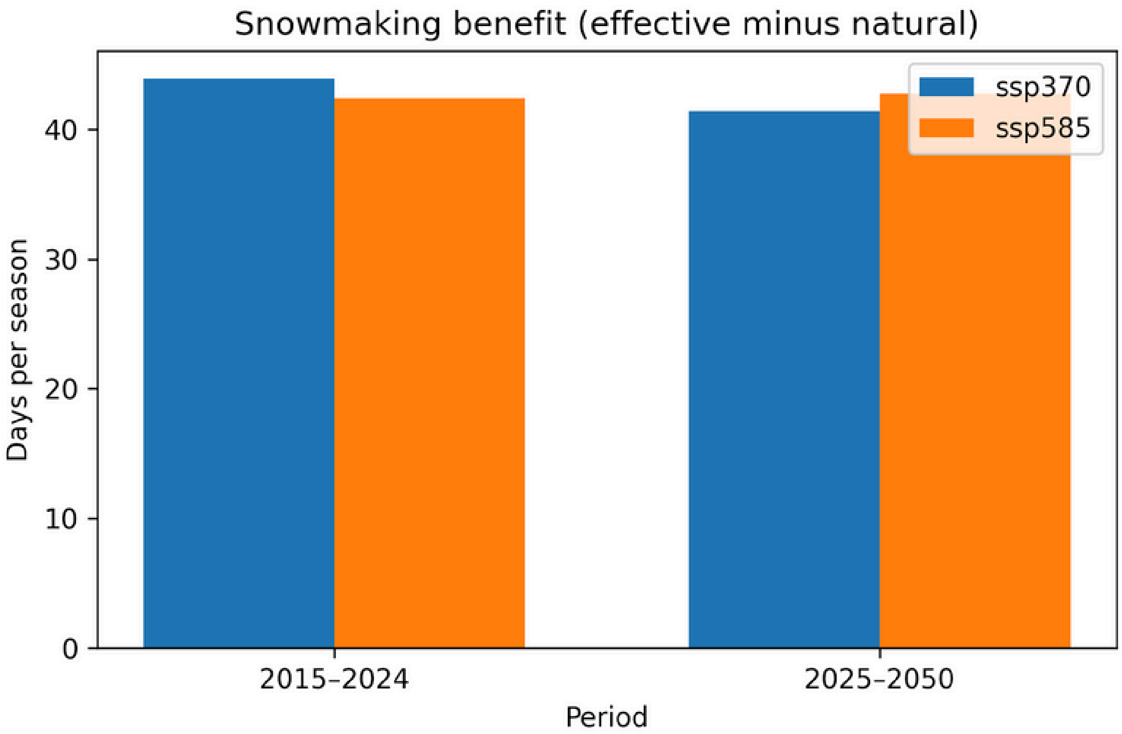


Figure 5-3 summarizes this directly as the snowmaking benefit (the difference between effective and natural season length) stays large in both scenarios, meaning snowmaking continues to “add back” a substantial number of skiable days even as the climate warms. Under SSP3-7.0, snowmaking increases season length by about 43.9 days in 2015–2024, falling to about 41.4 days in 2025–2050 (a modest reduction in benefit). Under SSP5-8.5, the snowmaking benefit is about 42.4 days in 2015–2024 and 42.7 days in 2025–2050 (roughly stable). The reason the benefit can hold steady (or even tick up slightly) is that the natural season can deteriorate faster than the modeled snowmaking-supported threshold in some cases; even so, the effective season still declines, meaning snowmaking helps a lot but does not fully prevent shortening over time.

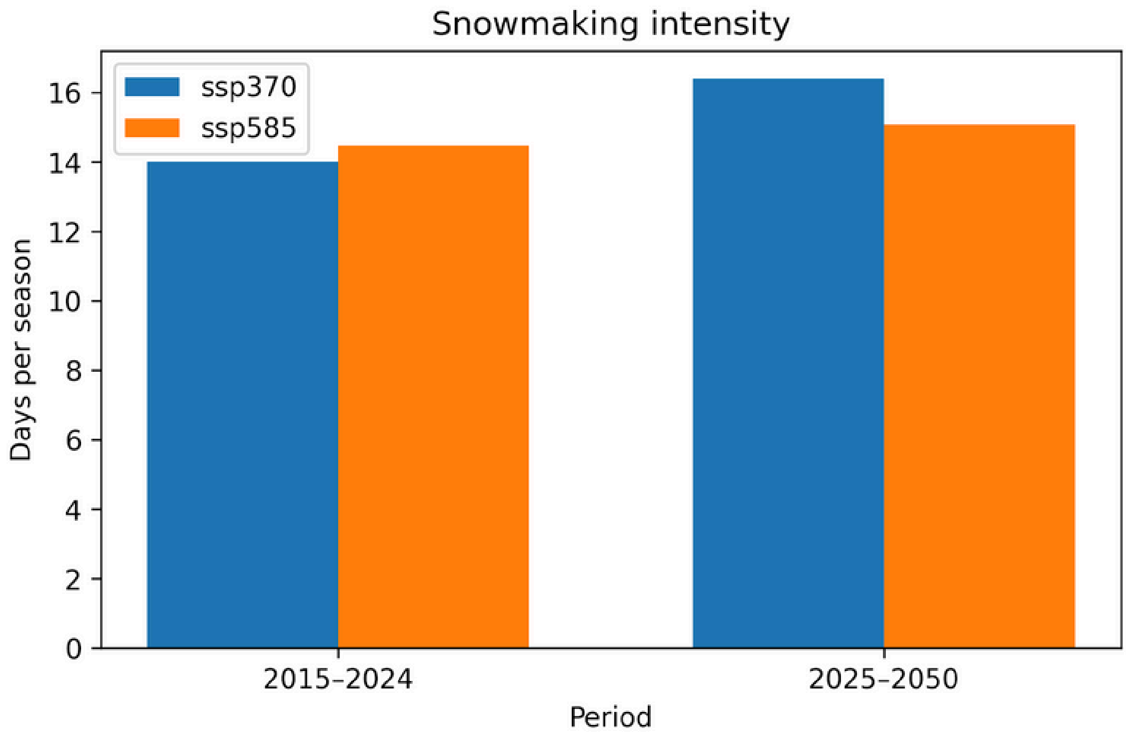
Snowmaking adaptation costs

We model snowmaking as a rule-based operational adaptation: when (i) conditions are cold enough (nighttime minimum temperature below a threshold) and (ii) the snowpack proxy is below the operational threshold, snowmaking adds snowpack up to a capped number of snowmaking days per season. This is the same conceptual structure used in the ski-tourism impacts literature: snowmaking can partially offset losses, but it is constrained by temperature windows and finite production capacity.

Snowmaking intensity and water requirements

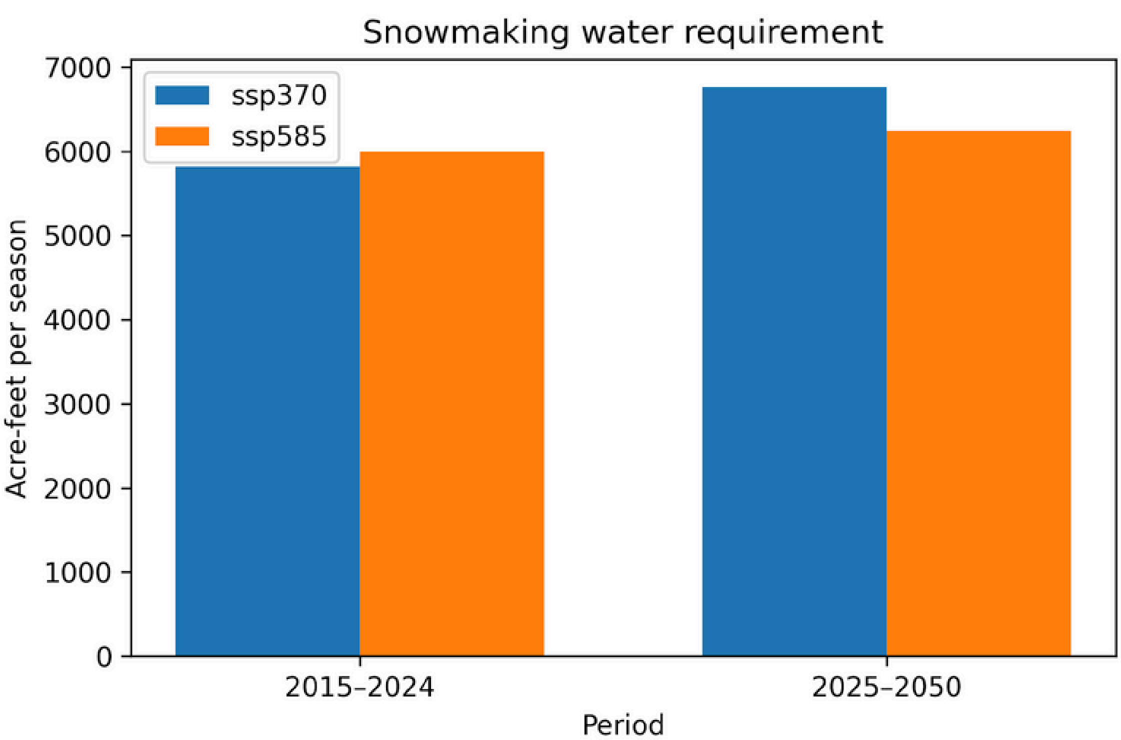
We track snowmaking pressure in two complementary ways. First, snowmaking intensity is measured as the number of "snowmaking days," defined as early-season days when natural conditions fall below the minimum base but temperatures are cold enough for snowmaking to be feasible (subject to the seasonal production limit). Second, water requirements convert daily snowmaking activity into acre-feet of water applied across the assumed snowmaking footprint, accounting for the assumed coverage and active fraction. To translate snowmaking water use into a cost proxy, we apply an assumed $2,000 per acre-foot (AF) as the marginal cost of water supply and delivery for snowmaking operations. Under this assumption, baseline snowmaking water use (about 4,820 AF/year in the baseline) corresponds to roughly $9.6M/year in baseline snowmaking water costs.

Figure 5-4 (Snowmaking intensity) shows how often snowmaking is needed under the model's operating rules. Average snowmaking days increase from 14.0 to 16.4 days per season under SSP3-7.0 between 2015–2024 and 2025–2050 (an increase of about 2.4 days). Under SSP5-8.5, snowmaking days increase more modestly, from 14.5 to 15.1 days per season (about 0.6 additional days).



This difference matters for interpretation: a smaller increase in snowmaking days under the hotter scenario does not automatically mean "less need" for snowmaking—rather, it can reflect that warming begins to constrain the number of nights cold enough to make snow (i.e., adaptation becomes more physically limited even as natural conditions deteriorate

Figure 5-5 (Snowmaking water requirement) translates modeled snowmaking into annual water demand (acre-feet per season), under the assumed snowmaking footprint and operating parameters. Under SSP3-7.0, average snowmaking water rises from about 5,820 acre-feet per season in 2015–2024 to about 6,758 acre-feet per season in 2025–2050 (an increase of roughly 940 acre-feet per season). Under SSP5-8.5, water demand rises from about 5,996 to 6,247 acre-feet per season (an increase of roughly 250 acre-feet per season).



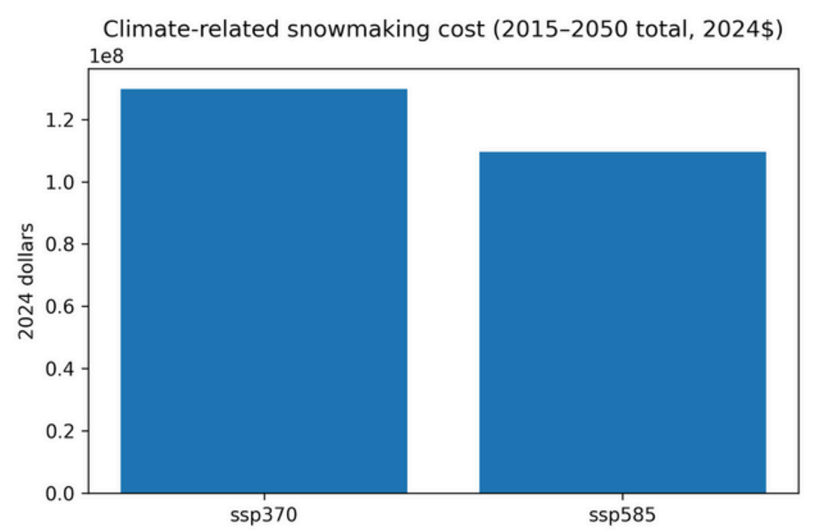
As with snowmaking days, the smaller increase under SSP5-8.5 should be read carefully: it is consistent with a world where warming reduces snowmaking-feasible conditions, limiting how much snowmaking can scale up even when the natural season is shrinking.

5. DROUGHT

From a drought and water-planning perspective, the main message is that sustaining ski operations increasingly requires additional winter water use, concentrated in the early season and competing with other winter and spring water demands.

Total incremental snowmaking cost (2015–2050, 2024$) is approximately:

- $121.1M under SSP3-7.0
- $98.2M under SSP5-8.5



We estimate the additional snowmaking expenditures required under future climate conditions relative to a baseline climate. This ‘incremental snowmaking cost’ represents the climate-attributable portion of adaptation spending, i.e., the extra cost resorts would incur to maintain skiable conditions as winters warm.

The fact that the higher-warming scenario can show lower incremental snowmaking cost is not a contradiction: in high-warming conditions, there can be fewer cold nights available to make snow, which can limit production (and therefore limit water use), even as natural snow conditions worsen. In other words, need rises, but feasibility can fall, and the modeled cost reflects the interplay.

5-1.3 WHAT THIS MEANS FOR COLORADO (DROUGHT LINKAGE AND PLANNING IMPLICATIONS)

These results imply three practical shifts for Colorado:

1. Natural reliability declines even before peak warming. By 2020–2039, natural season length is already 8–9 days shorter than the late-20th-century baseline, and holiday reliability drops meaningfully (from 0.39 to 0.31–0.33). By 2040–2050, natural holiday reliability is closer to ~0.24 in both scenarios—meaning that without adaptation, the probability of consistently meeting minimum snowpack conditions during the peak revenue window declines sharply.
2. Snowmaking becomes a structural dependency. Effective season length remains far higher than natural season length in all periods, but it still deteriorates by ~10–20 days by mid/late periods. Meanwhile, snowmaking days and water requirements increase, and uncertainty widens across climate models. This shifts winter operations toward higher fixed costs and greater exposure to water-system constraints during drought-stressed years.
3. Drought risk is amplified through demand and community channels. Even if snowmaking avoids most modeled visit losses, the state still faces risks through (i) years when snowmaking feasibility is limited by temperature, (ii) competition for water in multi-sector drought conditions, and (iii) spillovers to employment, lodging, and local tax bases in mountain communities. Earlier snowmelt and runoff timing also intensifies the system-wide challenge of storing water for late-summer needs—linking winter conditions to broader drought management.

SNOW SPORTS: PAST VS FUTURE (1995-2024 VS 2025-2050)

In this section, we report winter sports conditions and adaptation needs for 1995–2024 and compare them to projected conditions in 2025–2050 under two future emissions pathways (SSP3-7.0 and SSP5-8.5). We first summarize natural season length (the number of days with adequate natural snow conditions) and an effective season length that includes snowmaking as an adaptation. The difference between these two is the snowmaking benefit (the number of additional operational days that snowmaking can preserve relative to natural conditions). Because snowmaking requires both suitable temperatures and water, we also track operational intensity (snowmaking days) and the associated water requirement (acre-feet per season). We convert water requirements to an annual snowmaking cost using a constant unit cost of $2,000 per acre-foot (2024$), and we report totals over each period. To express the incremental adaptation burden relative to historical norms, we also compute incremental costs relative to the 1995–2014 baseline mean (with annual shortfalls below baseline not counted, consistent with the "incremental cost" definition used elsewhere in the report).

Results show a substantial shortening of the natural season in the future window: average natural season length declines from 99.3 days (1995–2024) to 83.5 days (SSP3-7.0) and 82.4 days (SSP5-8.5) in 2025–2050 (decline from natural season length of 112 days in 1995 to about 75 days in 2050). Even with adaptation, effective seasons are projected to average about 125 days, versus 143.5 days in the past window, implying meaningful pressure on winter recreation. Snowmaking remains an important buffer, contributing roughly 41–43 additional days in the future window, but maintaining that buffer requires higher snowmaking effort, with snowmaking days rising from 12.4 days/season (1995–2024) to 16.4 (SSP3-7.0) and 15.1 (SSP5-8.5) in 2025–2050.

Season length and snowmaking needs (1995-2024 vs. 2025-2050)

Metric	1995–2024	2025–2050 (SSP3-7.0)	2025–2050 (SSP5-8.5)
Natural season length (days)	99.3	83.5	82.4
Effective season length (days)	143.5	124.9	125.1
Snowmaking benefit (days)	44.2	41.4	42.7
Snowmaking days (days/season)	12.4	16.4	15.1

Because LOCA "historical" ends in 2014, 1995–2024 column is effectively 1995–2014 historical + 2015–2024 near-term scenario-based metrics (averaged across scenarios)

5. DROUGHT

These physical changes translate into higher resource use and costs. Total snowmaking water increases from 155,485 AF in 1995–2024 to 175,705 AF (SSP3-7.0) and 162,434 AF (SSP5-8.5) in 2025–2050, corresponding to total snowmaking costs of $311.0M in the past window versus $351.4M and $324.9M in the future window (2024$). Under the report's incremental-cost definition relative to the 1995–2014 baseline mean, incremental snowmaking costs rise to $101.1M (SSP3-7.0) and $74.2M (SSP5-8.5) in 2025–2050.

SNOWMAKING TOTALS (1995–2024 VS 2025–2050)

Metric	1995–2024	2025–2050 (SSP3-7.0)	2025–2050 (SSP5-8.5)
Total snowmaking water (AF)	155,485	175,705	162,434
Total snowmaking cost (2024$)	$311.0M	$351.4M	$324.9M
Incremental cost vs 1995–2014 baseline (2024$)	$30.8M	$101.1M	$74.2M

The fact that the higher-warming scenario can show lower incremental snowmaking cost is not a contradiction: In our framework, cost is driven by modeled snowmaking water demand (acre-feet) multiplied by a constant unit cost, and water demand reflects the joint effect of natural snow conditions and the availability of cold-enough windows to make snow. Over the mid-century period, the downscaled projections for Colorado show only modest scenario separation, and small differences in precipitation and temperature patterns can translate into slightly different snowmaking requirements. In higher-warming conditions, natural snow conditions can worsen, but snowmaking feasibility can also tighten if there are fewer cold nights suitable for production, so "need" and "ability to produce" can move in opposite directions. The resulting incremental cost reflects this interplay, and the small SSP3-7.0 vs SSP5-8.5 difference should be interpreted as mid-century climate-model variability, not evidence that higher emissions reduces long-run snowmaking pressure.

5. DROUGHT

5-1.3

Finally, using the visits model (reported as unmonetized counts), projected season shortening generates large visit losses without snowmaking; under η = 1.0, losses reach 29.0–32.2 million visits in 2025–2050, while snowmaking reduces losses dramatically (to 0.3–0.9 million visits), avoiding about 28–32 million visits over the future window.

LOST VISITS (1995-2024 vs. 2025-2050)

Scenario	Lost visits (no snow) 1995-2024 (M)	Lost visits (with snow) 1995-2024 (M)	Lost visits (no snow) 2025-2050 (M)	Lost visits (with snow) 2025-2050 (M)	Avoided loss 2025-2050 (M)
SSP3-7.0	9.5	0	29	0.9	28.1
SSP5-8.5	9.7	0	32.2	0.3	31.9

5-1.4 LIMITATIONS AND EXCLUSIONS

This module is designed to be transparent and policy-useful, but it omits several important factors:

- This is not a full snow physics model. The snowpack proxy is a simplified temperature-index balance suitable for period comparisons, not a calibrated, elevation-explicit energy-balance snow model. The literature emphasizes that this class of approach is best for multi-decade comparisons rather than recreating each individual historical year perfectly.
- No explicit elevation/aspect or within-county heterogeneity. Ski terrain sits at higher elevations than county averages; county aggregation can understate snow reliability in the highest terrain and overstate it in lower terrain.
- Snowmaking constraints are simplified. We model feasibility using a temperature threshold and a cap on snowmaking days; we do not explicitly model compressor capacity, reservoir storage, pumping limits, permitting, or operational decision rules that vary by resort.
- Water availability and water rights are not modeled. The module estimates snowmaking water requirements and a cost proxy, but does not test whether water can legally/physically be supplied in drought years without tradeoffs.
- No pricing, substitution, or trip reallocation. Visitors may shift timing, destination, or activity mix (summer recreation, shoulder season) in ways not captured by the sensitivity model.
- No disruptions from extremes. Closures due to major storms, avalanche control, transportation disruptions, wildfire smoke, or compounding hazards are excluded.

APPENDIX
Total costs for categories analyzed in this report, including both climate-attributable and non climate-attributable costs:

Sector	SSP3-7.0	SSP5-8.5	Uncertainty notes
Heat mortality (total damages)	**$32.74B**	**$34.08B**	Point estimate (no band in this output).
Wildfire (property + smoke health + adaptation)	**$4.89B–$7.26B**	**$4.86B–$7.23B**	Range = (adaptation low–high) + (smoke health low–high). Property is point estimate here.
Flood-type storms (projected damages; typical-year)	**$2.84B**	**$2.80B**	Point estimate (no band in this output).
Buildings (net energy cost change)	**$4.75B**	**$4.94B**	Point estimate; this is net *change* vs baseline, not total energy bills.
Bridges (resilience need; scaled lump-sum)	**$2.42B**	**$2.58B**	Lump sum (not annualized); no uncertainty band provided.
Roads (incremental climate cost)	**$516.8M–$1.06B**	**$548.1M–$1.07B**	Range = min–max from roads output (incremental vs baseline).
Stormwater (gross adaptation cost)	**$321.0M**	**$341.8M**	Point estimate (no band in this output).
Winter sports (snowmaking cost, total)	**$351.4M**	**$324.9M**	Point estimate (no band in this output).
TOTAL (sum of sector ranges)	**$49.83B–$52.20B**	**$51.46B–$53.82B**	Sum of available sector low/high ranges (not a probabilistic CI; ignores correlation).

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