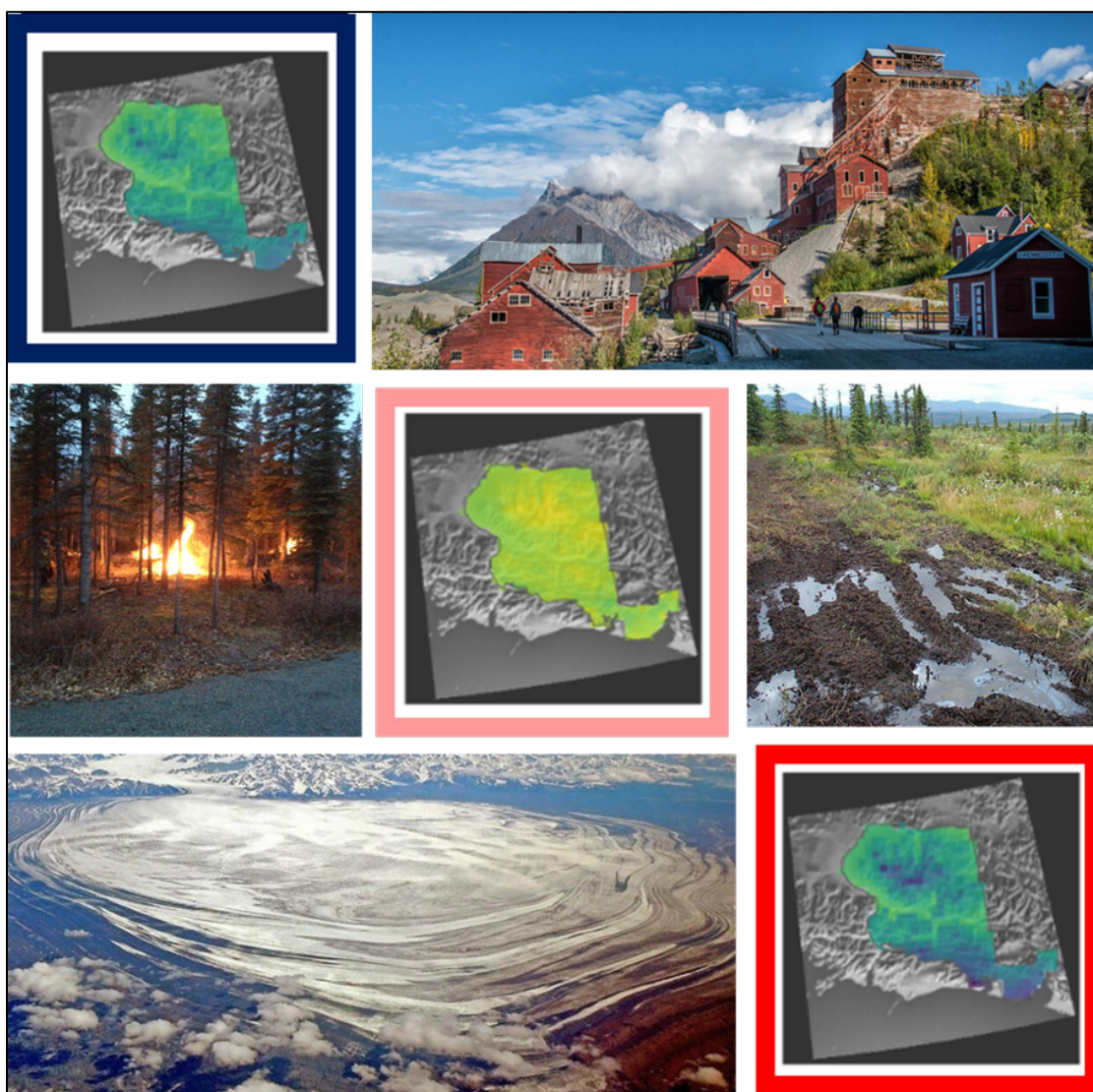




Climate-Resource Scenarios to Inform Climate Change Adaptation in Wrangell-St. Elias National Park and Preserve

Summary of 2021 Climate Change Scenario Planning

Natural Resource Report NPS/WRST/NRR—2024/2613



ON THE COVER

Average annual precipitation change for WRST in Scenario 1 (top left), Kennecott Mine National Historic Landmark (top right), fires in boreal forest (middle left), average annual precipitation change for WRST in Scenario 2 (middle center), sub-alpine region (middle right), aerial photo of Malaspina Glacier (bottom left), average annual precipitation change for WRST in Scenario 3 (bottom right).

NPS

Climate-Resource Scenarios to Inform Climate Change Adaptation in Wrangell-St. Elias National Park and Preserve

Summary of 2021 Climate Change Scenario Planning

Natural Resource Report NPS/WRST/NRR—2024/2613

Amber N. Runyon¹, Gregor W. Schuurman¹, Brecken C. Robb^{2,3}, Jeremy Littell⁴, Mark E. Miller⁵,
Joel H. Reynolds¹

¹ National Park Service
Climate Change Response Program
Fort Collins, CO

² Contractor to the United States Geological Survey
North Central Climate Adaptation Science Center
Boulder, CO

³ Boise State University
Boise, ID

⁴ United States Geological Survey
Alaska Climate Adaptation Science Center
Anchorage, AK

⁵ National Park Service
Wrangell-St. Elias National Park & Preserve
Copper Center, AK

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U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Executive Summary

This report illustrates use of scenario planning as a climate change adaptation tool supporting Wrangell-St. Elias National Park and Preserve's Resource Stewardship Strategy. The primary objective of scenario planning is to help resource managers and scientists make management and planning decisions informed by assessments of critical future uncertainties. This report outlines a process that synthesized future climate projections into three distinct but plausible and relevant climate summaries for the focal area and used them to develop climate-resource scenarios through participatory scenario planning.

Initial steps identified the priority resource management topics and the corresponding related climate uncertainties. Next, local climate summaries were used to develop divergent climate futures: those that describe the broadest possible range of plausible conditions while capturing relevant uncertainty. The final phase further developed the climate futures and their resource implications. These participatory scenario planning exercises occurred virtually in fall (August–November) 2021. The climate-resource scenarios informed adaptation strategies in conjunction with the park's Resource Stewardship Strategy development. The scope and complexity of this effort is unique but elements from the scenarios and resource implications have broad applicability to other large, protected areas in Alaska and Northwest Canada.

Acknowledgments

We thank the scenario planning participants for their insights, participation, and tremendous energy. This research was funded by the National Park Service Climate Change Response Program, and in-kind contributions were made by the Alaska Climate Adaptation Science Center. We thank Andrew Newman and the National Center for Atmospheric Research for providing access to the climate data and guidance on usage in analyzing downscaled climate data for Alaska. We also thank Garrett Knowlton, John Bates, and Kaylin Thomas for assistance in this project and preparation of this report. Finally, we acknowledge and thank reviewers of this report, including Nicola Bredenkamp, Jim Lawler, Amy Pocewicz, and Dave Schirokauer, as well as Joel Reynolds for managing the review process.

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Acronyms

AK CASC:	USGS Alaska Climate Adaptation Science Center
AKRO:	Alaska Regional Office
AML:	Abandoned mine lands
BCSD:	Bias correction and spatial disaggregation
BLM:	Bureau of Land Management
CAKN:	Central Alaska Inventory & Monitoring Network
CCRP:	NPS Climate Change Response Program
CF:	Climate future
CMIP:	Coupled Model Intercomparison Project
CMIP5:	Coupled Model Intercomparison Project Phase 5
CR:	Copper River
DJF:	December, January, February
ET:	Evapotranspiration
GCM:	Global climate model
GLBA:	Glacier Bay National Park and Preserve
GLOF:	Glacier lake outburst floods
JJA:	June, July, August
KEFJ:	Kenai Fjords National Park
MAM:	March, April, May
NC CASC:	USGS North Central Climate Adaptation Science Center
NCAR:	National Center for Atmospheric Research
NDVI:	Normalized Difference Vegetation Index
NHL:	National Historic Landmark
NOAA:	National Oceanic and Atmospheric Administration

NPS:	National Park Service
PC:	Principal component
PCA:	Principal components analysis
RCP:	Representative concentration pathway
RSS:	Resource stewardship strategy
SEAN:	Southeast Alaska Inventory & Monitoring Network
SME:	Subject-matter expert
SON:	September, October, November
SWE:	Snow water equivalent
USDA:	U.S. Department of Agriculture
USGS:	U.S. Geological Survey
VIC:	Variable infiltration capacity
WiLDCAST:	Wildlife Potential Habitat Forecasting Project
WRST:	Wrangell-St. Elias National Park and Preserve
YUCH:	Yukon-Charley Rivers National Preserve

Introduction

Ongoing anthropogenic climate change is evident across the National Park System, causing widespread physical changes in the environment that directly impact organisms, resources, assets, and values and generating powerful effects by driving ecological changes (e.g., Stewart et al. 2005, Wang et al. 2014, Mallakpour and Villarini 2015, O’Neel et al. 2015, Lara et al. 2016, Hayhoe et al. 2018, Markon et al. 2018). Despite observed and potential changes, many consider anticipatory management for climate change daunting because plausible projections of climate change and its impacts can span a broad range of potential outcomes. Forward-looking resource stewardship in an era of continuous change requires effective approaches for understanding and working with such consequential uncertainty (Peterson et al. 2003, Rowland et al. 2014). These uncertainties can present a challenge for decision making yet are inherent to planning around complex environmental issues (Gregory et al. 2012) and can be addressed by resource managers in a variety of ways.

Scenario planning is a structured approach to work with consequential uncertainties that is increasingly used by resource managers (Rowland et al. 2014, Star et al. 2016, Miller et al. 2022). It is a flexible tool for understanding potential climate change implications and uncertainties relevant to resource and landscape management (IPBES 2016). Scenario planning facilitates decision making by providing a structured process for considering a broad range of plausible futures that managers may face. Rather than seeking to focus only on the most likely future conditions and trajectories, scenario planning focuses on a broader range of what is plausible, relevant, and highly consequential in management contexts (NPS 2013).

National parks develop a Resource Stewardship Strategy (RSS) through an internal, facilitated process to set goals and objectives for natural and cultural resource stewardship, identify activities to achieve and maintain desired conditions, and track progress. A park’s RSS is intended to inform near-term decisions and actions (i.e., over the next decade or so), be updated periodically, and focus on a subset of park-determined priority resources. (Schuurman et al. 2024). The National Park Service (NPS) and partners have developed and refined a climate change scenario planning approach that solicits expert opinion and applies syntheses of published science (NPS 2013, Star et al. 2016, Miller et al. 2022), as well as providing comprehensive guidance for application to RSS development (detailed in NPS 2020). Undertaking scenario-based impact assessment is a component of the NPS adaptation process (Figure 1, step 2; NPS 2021) and aligns with other frameworks for managing ecological change (e.g., Schuurman et al. 2022, Magness et al. 2022, etc.).

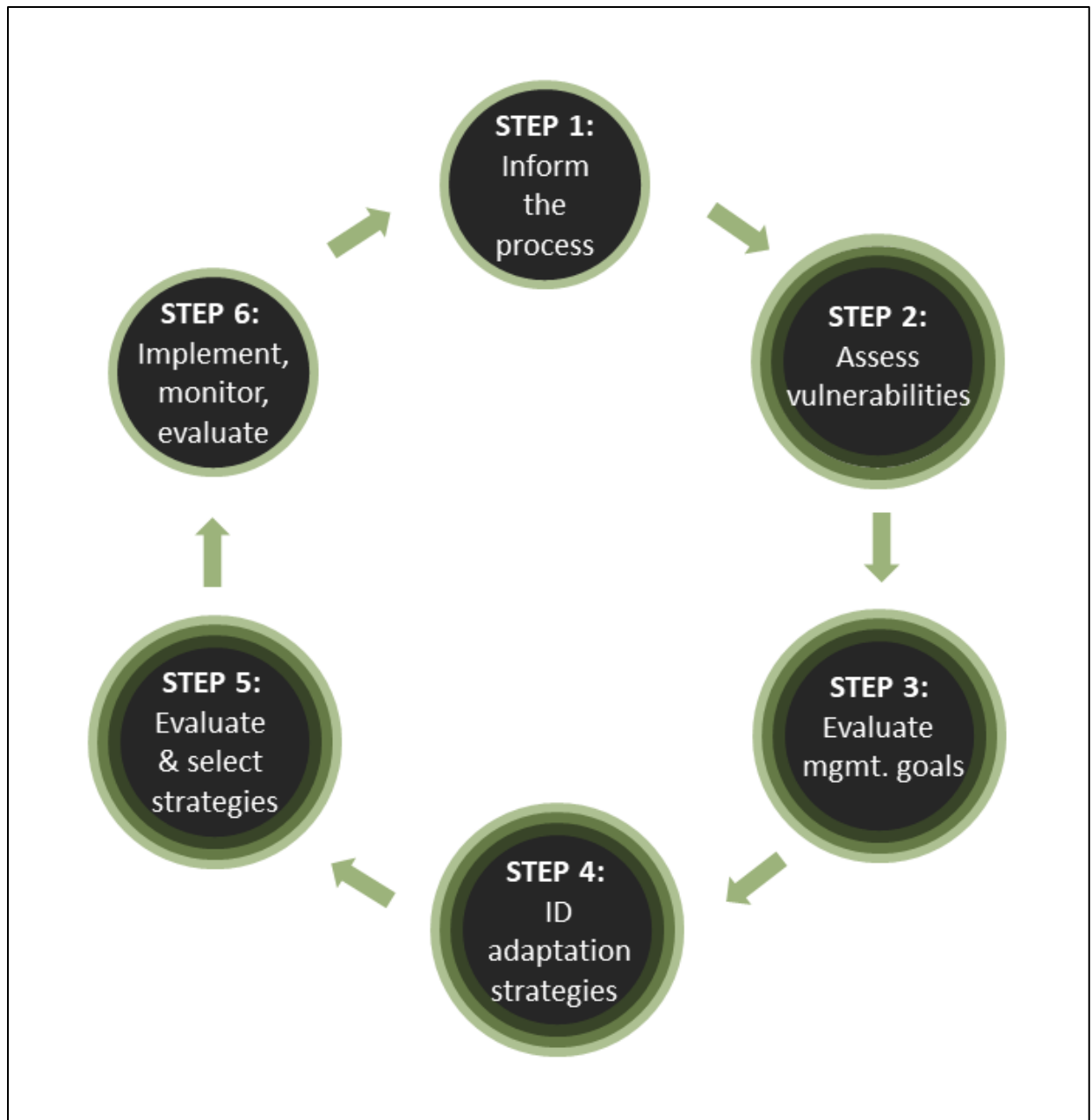


Figure 1. Representation of the NPS climate change adaptation process. Concentric rings around Steps 2–5 represent consideration of multiple climate-resource scenarios (NPS 2021).

In climate change scenario planning, NPS scientists works iteratively with park staff and other subject-matter experts (SMEs) to (1) create divergent *climate futures*: descriptions of the physical attributes of climate (derived from global climate models; GCMs) that could plausibly occur at a specific place and time (Lawrence et al. 2021); (2) create robust *climate-resource scenarios* that

describe resource implications under each climate future (Schuurman et al., 2019); and (3) use climate-resource scenarios to inform decision making (Runyon et al. 2020).¹

The RSS development process for Wrangell-St. Elias National Park and Preserve (WRST) built on scenario planning-RSS integration projects at Devils Tower National Monument (Schuurman et al. 2019) and Wind Cave National Park (Runyon et al. 2021). The WRST scenario planning-RSS integration included lessons from past iterations (Miller et al. 2022) and developed new processes and methodologies. Park staff, other SMEs², and the climate change team³ developed a set of plausible climate-resource scenarios for WRST built around the park's priority natural and cultural resources. In lieu of a single scenario planning workshop, scenario development occurred through a series of remotely conducted (virtual) meetings, August–November 2021 (Figure 2; Appendix 1) that included WRST and regional NPS resource stewardship staff, climatologists, natural and cultural resource planners, and many other SMEs (Appendix 2). This report documents development of the WRST climate-resource scenarios and evaluation of climate implications for management objectives (Figure 1, steps 2 and 3). A companion report documents their use in the WRST RSS process to develop climate change-informed goals and activities using the Resist-Accept-Direct framework (Figure 1, steps 4 and 5; see companion report Schuurman et al. 2024).

¹ A complete glossary of climate-related terminology can be found in NPS (2021).
<https://irmadev.nps.gov/DataStore/DownloadFile/665664>

² See NPS (2020) for details regarding teams involved in a scenario-based RSS process.

³ The climate change team included scientists and adaptation specialists from the NPS Climate Change Response Program (CCRP) and the U.S. Geological Survey (USGS) North Central Climate Adaptation Science Center (NC CASC) for all climate change team-led steps, and from the USGS Alaska Climate Adaptation Science Center (AK CASC) for most.

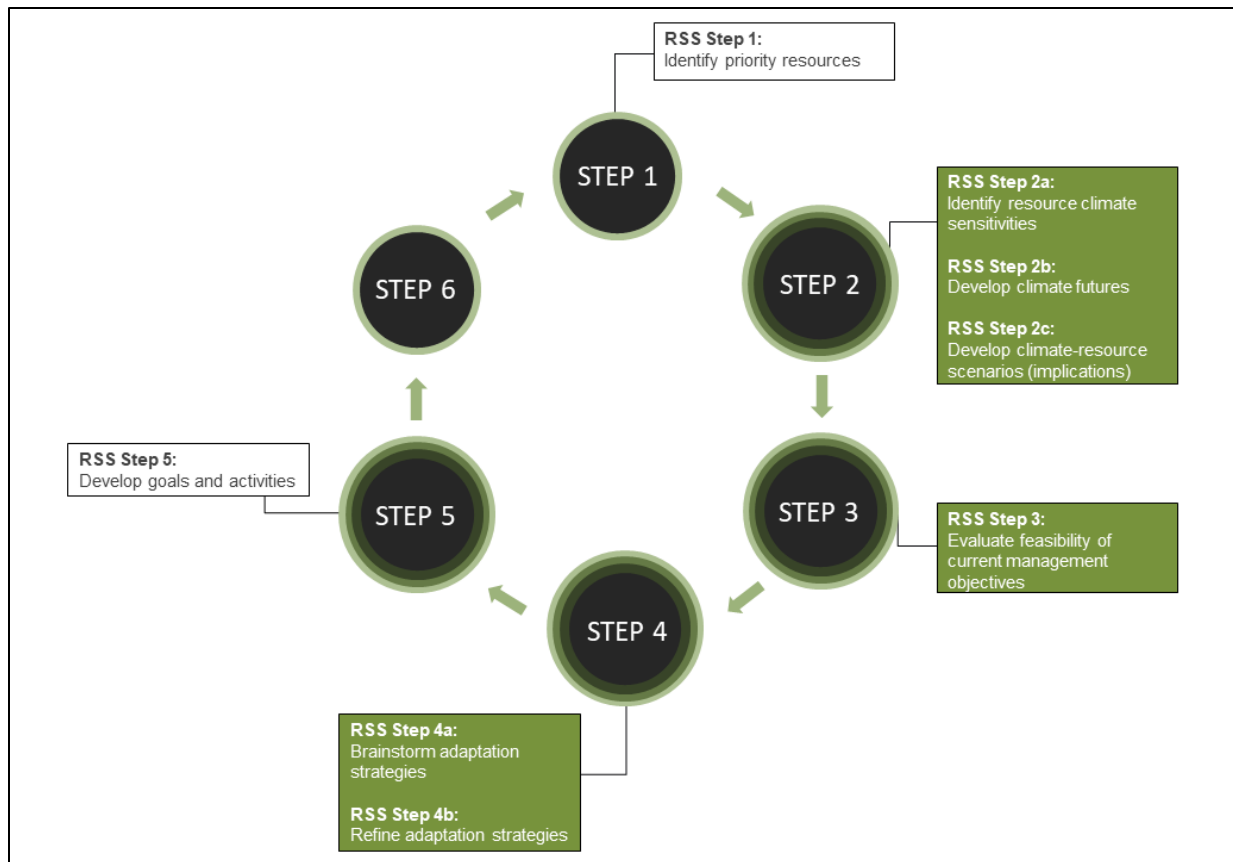


Figure 2. WRST RSS development timeline and facilitators of each step (modified from NPS 2020 Appendix E). Unless specified, park staff and other SMEs developed information in all steps. The NPS Denver Service Center planning team facilitated initial and final steps (white boxes) and the climate change team led intermediate scenario-planning steps (green-filled boxes). Adaptation strategy development—the latter part of the scenario planning process—is detailed in Schuurman et al. (2024). For additional information on all steps, see NPS (2020).

Resource climate sensitivities

Early in the RSS development, WRST park managers identified the priority resources, i.e., focal natural and cultural resources of the RSS and scenario planning process.⁴ To develop climate-resource scenarios, we assessed the sensitivity of those priority resources and their specific components⁵ to various aspects of climate by asking WRST staff to describe how past climate affected resources and concerns they have about future climate impacts. This step generated a preliminary list of climate metrics to which the priority resource components are expected to be sensitive as candidate climate sensitivities (see Appendix 3 for list of priority resources, components and corresponding climate sensitivities). The climate change team then surveyed a broader pool of SMEs identified by WRST staff (Appendix 2) to select climate metrics relevant to resource climate sensitivities, add any missing metrics, and describe important interactions among metrics impactful to a resource. The final list included all climate sensitivities identified as important to at least one resource. The climate change team then developed quantitative projections for each climate sensitivity metric. The information from surveys and interviews was summarized to calculate the proportion of respondents identifying a climate metric as a sensitivity for a specific priority resource, and park staff responses were given double weight (Appendix 3).

The climate change team refined the long list of climate sensitivities to those that “pose the greatest risk for achieving one’s agreed-upon conservation goals and objectives” (Stein et al. 2014), based on the average proportion of responses. WRST resource managers reviewed the reduced list for validation. The final list of climate metrics deemed most influential included: seasonal (winter, spring, summer, fall) temperature and (winter, spring, summer) precipitation, average shoulder-season (March, April, May [MAM]; September, October, November [SON]) snowfall, maximum annual snow depth, and climatic water deficit (annual precipitation minus evapotranspiration [ET]) (see Tables A3.1 and A3.2 for full list). We used these to select relevant and divergent climate futures for the next step in the scenario planning process.

⁴ Priority resources are defined as “A cultural or natural resource or value that the NPS manages or monitors to maintain a park unit’s purpose and significance, to address policy/law mandates, or to address scholarly and scientific research needs or findings.”

⁵ Because RSS priority resources are often broad groupings of resource types (hydrology, wildlife, cultural resources, etc.) climate sensitivities and implications are more useful when developed at the component level (e.g., glaciers, streams, caribou, salmon, etc.).

WRST climate futures

A crucial part of climate change scenario planning is understanding and planning around the plausible range of future values of critical climate metrics. Climate scientists use complex models to project future climate. Because our understanding of all the forces that influence Earth's climate is incomplete, each of these models is unique in the way it represents the various physical and biological forces that influence climate patterns. Consequently, each GCM produces a different view of future climate. Moreover, the magnitude of future climate changes also depends on societal decisions that affect the emissions and absorption of gases that influence climate. Climate scientists use representative concentration pathways (RCPs), i.e., multiple projections of future atmospheric greenhouse gas concentrations, to represent ways in which societies may manage greenhouse gas emissions. Most commonly available GCMs use these RCPs, producing a range of scientifically plausible projected future climates.

While this range provides resource managers a realistic representation of the uncertainties about future climate, the volume of information can be daunting to incorporate into their planning. The goal of NPS scenario planning is not to “predict” the future but instead to explore the variation in emissions and model uncertainty by selecting a small but representative subset of future climates and developing their implications. These “climate futures” are the foundation of climate-resource scenarios, which are developed by adding associated resource implications (often referred to as “vulnerabilities”) to the climate futures.

Projections specific to WRST vary among individual models and RCPs. Based on expert input, we used downscaled projections and models with adequate skill (i.e., model quality and accuracy; Terando et al. 2020) in Alaska (Mizukami et al. 2022), indicating plausibility of each selected climate future. We used CMIP5 (Coupled Model Intercomparison Project Phase 5) climate projections from NCAR (National Center for Atmospheric Research; Mizukami et al. 2022) specifically downscaled (12km, Bias Correction and Spatial Disaggregation, or BCSD; Wood et al. 2004) for Alaska. We considered two simulations each of 10 GCMs selected for their independence, prior performance under CMIP5, and representiveness of the range of conditions in Alaska and Hawai'i climate relative to the ensemble mean (Mizukami et al. 2022). For each GCM, one simulation used a moderate greenhouse gas concentration pathway (RCP 4.5) and the other a high greenhouse gas concentration pathway (RCP 8.5). See Lawrence et al. (2021) for additional methodological details.

Across WRST, these twenty climate projections indicate a range of warming in average annual temperature from +2.1 °F to +6.6 °F, and a range of annual precipitation change from –1.3 inches (–3%) to +13.2 inches (+31%) in 2040 (2025–2055) compared to downscaled historical (1950–1999) average annual temperature and precipitation, aggregated (Mizukami et al. 2022) from 1km 1980–2017 DAYMET version 3 (after Thornton et al. 2016). Seasonal shifts in precipitation patterns (type, frequency, and intensity) and growing season conditions (onset, duration, and soil moisture levels) varied among the projections. Given this range of projections, planning for a single future is highly unlikely to prepare a manager for what will actually occur in the coming decades. Identifying and

developing several climate futures relevant to key resource sensitivities captures a range of plausible futures and allows managers to decrease risk of surprises (Lawrence et al. 2021).

Alaska is among the most rapidly warming regions on Earth, and future climates are expected to exceed historical extremes (Markon et al. 2018). To ensure consideration of a wide range of plausible future climate conditions and explore implications, we selected three projections (Table 1) from the twenty, using the scatterplots in Figure 3. The three climate futures capture divergence in resource implications among the available model futures: **Climate Future 1** (INMCM4 RCP 8.5 [GCM from Institute for Numerical Mathematics, Russia]); **Climate Future 2** (ACCESS1-3 RCP 4.5 [GCM from Australian Community Climate and Earth System Simulator, CSIRO]); and **Climate Future 3** (CanESM2 RCP 8.5 [GCM from Canadian Centre for Climate Modeling and Analysis, Canada]). Literature indicates that two to four futures are a reasonable balance between characterizing divergence to manage risk (Brekke et al. 2009, Snover et al. 2013, Miller et al. 2022) and usefulness in multi-resource scenario planning, where the complexity increases with the number of climate futures (Lawrence et al. 2021).

Table 1. Projections selected as climate futures. Climate future colors are consistent throughout this document.

CF	Projection
Climate Future 1	inmcm4.rcp85
Climate Future 2	ACCESS1-3.rcp45
Climate Future 3	CanESM2.rcp85

While this allowed us to explore the consequences of uncertainty and identify implications using a range of climate futures to bracket future conditions (Dessai et al. 2009), it does not reduce all sources of uncertainty. The resulting climate futures characterize the range of climate projections from a limited ensemble of models and intentionally ignore other plausible futures from the full range of available CMIP5 GCMs and RCPs. Had other methods been used in the selection process (e.g., by using a different ensemble of models or accounting for model skill; Littell et al. 2011), we might have seen different climate futures outcomes and different ideas of future implications. Our treatment of the available subset of futures assumes they are equally plausible regardless of model skill; it emphasizes a wide range of plausible climate futures to better understand potential WRST climate vulnerabilities and develop robust strategies by planning for a range of possible outcomes.

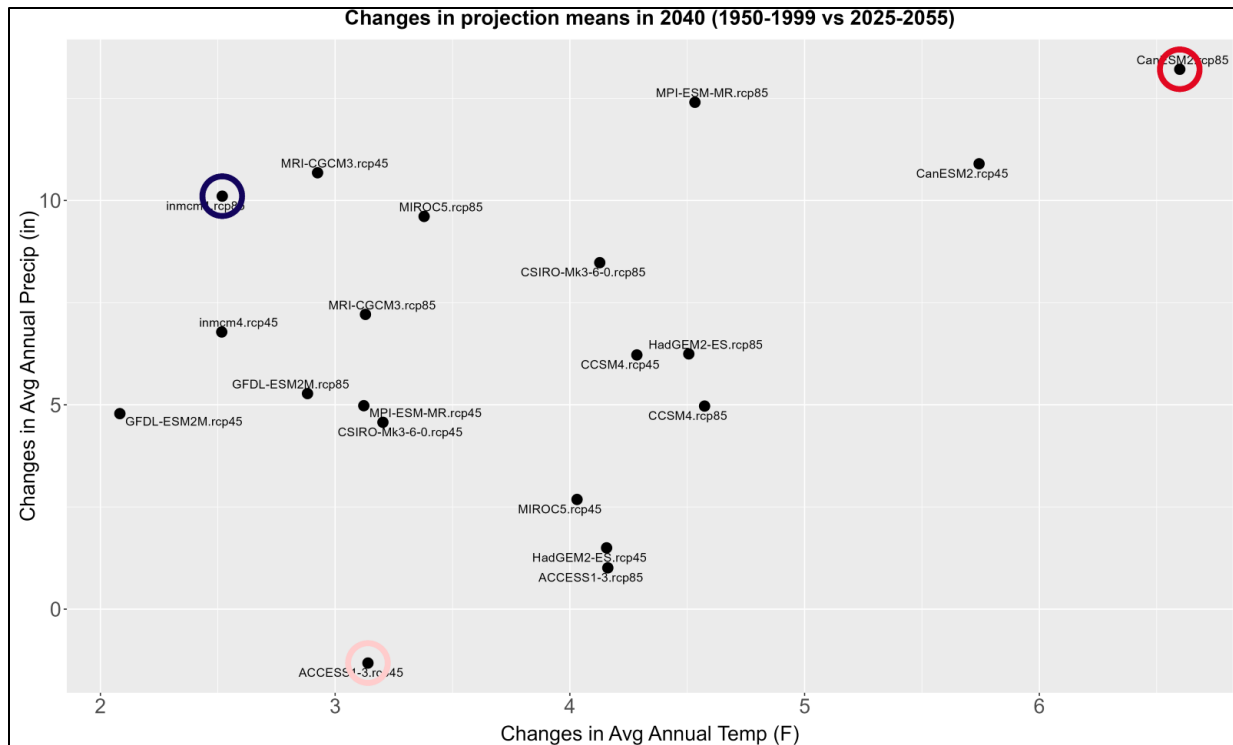


Figure 3. Projected changes in average annual temperature and precipitation for WRST. Points represent differences between average values for the 3-decade period 2025–2055 and 1950–1999 for each of the twenty projections. Circled projections were selected as climate futures. Circle color corresponds with the color of the climate futures and climate-resource scenarios used throughout this document (Table 1).

The climate change team identified the small set of divergent climate futures by first characterizing, for each of the twenty projections, the (10) climate metrics that summarize key climate sensitivities (Appendix 3, Tables A3.1 and A3.2). Next, they used a principal components analysis (“PCA”, using “prcomp” function in R with standard arguments) to “map” the twenty projections from the 10-dimensional space of climate metrics to a 2-dimensional space describing 68% of the original variation among projections (Appendix 3, Table A3.3). Based on loadings on the first two principal components (Appendix 3, Table A3.3), the climate change team identified “most extreme” projections and selected as the (divergent) climate futures (Figure 3, which displays them in terms of changes in average annual temperature and precipitation). The three selected climate futures were then more fully developed by characterizing associated changes in each of the remaining climate metrics that were relevant to all other climate-sensitive park resources, stressors, management activities, and management concerns (see Appendix 3, Tables A3.1 and A3.2).

Scenario planning participants were provided climate future descriptions—including text, figures, and tables—in handouts that were specific to each priority-resource group, for use when developing resource implications (see Appendix 4). Descriptions were presented as change relative to late-20th-century (1950–1999) conditions and generally expressed as mean conditions for the time period; substantial variation occurs around these means. A high-level summary of the climate futures is presented in Table 2.

Climate futures summary

Key features of each climate future were identified from the figures and tables in Appendix 4 and summarized in the following tables.

Table 2. Commonalities and differences among the climate futures. Unless geography is specified, estimates are averaged across WRST. See Appendix 4 for maps of geographies identified. Relative comparisons are made among the climate futures. To save space, month or variable names may be abbreviated to: winter=DJF, spring=MAM, summer=JJA, fall=SON, maximum/minimum/mean temperature=tmax/tmin/tmean, precipitation=precip, SWE=snow water equivalent.

Metric	Climate Future 1: Warm wet; cool, rainy summers; increasing snow	Climate Future 2: Dry; early snowmelt and drying summers and falls	Climate Future 3: Hot wet; loss of winter, hot summers; rainy	Common to all
Temperature	- Least change in annual tmean (+2 °F) with lowest interannual variability - Low (+1–2 °F) tmax inc. in DJF and SON; less warming in mountains. 3 more days tmax >68 °F per year - Lowest warming across most seasons (+1–3.5 °F) with lowest in JJA. SON warming concentrated in mountains. 20 fewer days below freezing and 3 fewer freezing days in DJF +6 °F freeze-thaw events per year	- Annual tmean increasing +3 °F with less warming in mountains, but high interannual variability (some years lowest tmean of all CFs, other years highest) - Lowest (+1 °F) DJF tmax increase with no winter change in WRST mountains, moderate (+2–4 °F) increase in other seasons. 10 more days tmax >68 °F per year - Moderate warming. Lowest in MAM (+2.5 °F) with little change in mountains during that season. 30 fewer days below freezing and 2 fewer freezing DJF days - Slight decline (–0.6/year) in freeze-thaw events	- Hottest climate future with annual tmean increasing +6 °F. Less warming in eastern coastal and most warming in coastal mountain areas - Highest (>+8 °F) tmax increase in JJA; +4–6 °F increase in other seasons. Highest rates of warming in Coastal Mountains, particularly in DJF and JJA with little change in eastern coastal areas during those time periods. 20 more days tmax >68 °F per year - Highest tmin increase in all seasons. +10 °F in DJF, about +6 °F in other seasons. Warming most concentrated in Coastal Mountains. 40 fewer days below freezing and 7 fewer freezing DJF days –2 freeze-thaw events per year	- Average annual temperature warming in all seasons 20–40 fewer days tmin < 32 °F and increasing DJF thaw events (tmin >32 °F) - Increasing tmax >68 °F
Precipitation	- Increasing (+9 in/yr) annual precip. Highest rates of change in mountain and coastal areas - Little change in MAM precip; DJF +7 in, JJA +10 in, SON +17 in. Increases most heavily concentrated in coastal and mountain areas - Large precip events (daily precip >0.5 increasing) by 14%	- Slightly decreasing (–0.4 in/yr) annual precip with some very dry years. WRST mountains greatest precip declines - Slight increase (+2 in) in DJF precip, concentrated in eastern coastal area. Little change in MAM precip but slight drying in eastern coastal area. Declines in JJA (–2 in) and SON (–6 in) precip, concentrated in mountains - Large precip events (daily precip >0.5 decreasing) by –6%	- Increasing (+10 in/yr) but highly variable annual precip. Highest rates of change in mountain and coastal areas - Increasing precip across all seasons, most heavily in coastal areas in SON (+12 in) and in WRST mountains in DJF and JJA (+12 in and +10 in) - Large precip events (daily precip >0.5 increasing) by 17%	–
Water balance	Water balance increasing (+8 in/yr), with most increases in mountain areas	Water balance declining (–0.9 in/yr) across WRST with some years half of historical average	Water balance increasing (+10 in/yr), with most increases in mountain areas but high degree of interannual variability	Runoff is earlier with declines in late summer (JJA) and fall (SON) runoff
Snow	- Slight increase (8%) in proportion of precip falling as snow with increased variability from year-to-year 20% increase in mean annual SWE. Increasing (22%) shoulder season (MAM/SON) SWE	- Slight increase (10%) in proportion of precip falling as snow with increased variability from year-to-year 5% increase in mean annual SWE. Slight decrease (–2%) in shoulder season (MAM/SON) SWE	- Slight decline in proportion of precip falling as snow (–5%) with increased variability from year-to-year. Declines in WRST mountains with increasing snow in Copper plateau 15% increase in mean annual SWE - Slight increase (3%) in shoulder season (MAM/SON) SWE	Slightly increasing mean annual SWE, but declining in coastal areas

Climate-resource scenario development and implications

Climate-resource scenario development

During the fall-2021 scenario planning process, participants from each priority-resource specialty group (see Appendices 1 & 2) were asked to describe potential effects of each climate future on each of the resource components, using the climate futures packets (Appendix 4), the non-climate stressors worksheet (Appendix 5), and information compiled earlier about other priority resource implications. The priority-resource groups were strategically sequenced so information from previous groups' work could be integrated into implications to create internally consistent scenarios. The end-point of this process was three cohesive climate-resource scenarios.

Each priority-resource group built climate futures into scenarios in two working sessions. During the first session, the climate change team presented a summary of the climate futures and an introduction to scenario planning. The participants then determined the response of priority resource component to each characterized climate future. Due to limited time in the session to develop the scenarios, post-workshop discussions and work by individuals resulted in additions, modifications, and clarifications to the scenarios. In the second session, participants reviewed and drafted summaries of the implications they developed, and identified critical uncertainties for each resource component. The summary scenario descriptions are not vetted research statements of responses to the climate futures, but are synthetic insights based on available science, local expert knowledge, and management experience.

Climate-resource scenarios

The following sections identify the resource implications (vulnerabilities) for WRST climate futures for each priority resource and resource component, developed by each priority-resource workgroup. In the spirit of scenario planning, the implications describe the resource condition for each plausible climate future written in future-tense statements. Because each scenario is considered plausible, statements such as “will” and “may” do not characterize likelihood and are not predictions; instead, they are expectations of resource response *if* climate were to change along the lines of a particular climate future. ***Bold-italicized text*** signifies “red flag” events, i.e., impactful outcomes unique to a single scenario (NPS 2020) and are shown in Table 3 (see Operationalizing climate-resource scenarios section for description of determination of “red flag” events). Implications that are common across the scenarios are also identified in Table 3. Text used in this section is as developed by participants and has not been altered for consistency, clarity, or based on updated information. Critical uncertainties unique to a scenario are identified within that scenario, and common critical uncertainties are grouped below all. A supplemental tabulated version of this information is available at <https://irma.nps.gov/DataStore/Reference/Profile/2301553>.

Table 3. Final critical implications for each resource. Because the Adaptation Workshop focused on high priority park management, some resources were omitted and the subsistence/harvest implications were integrated with the resource.

Resource	Common to all scenarios	Not common to all scenarios
Hydrology: Glaciers	- Glacier area will continue to decrease through mid-century, with most loss at lowest elevations and associated safety issues - Tidewater and lake-terminating glaciers will experience more variable and generally more rapid change - Glacier-melt and runoff will increase through next decade, but rate of runoff post-2030 uncertain (scenario-dependent)	[no critical implications in this category]
Hydrology: Glacial Rivers	- Increasing runoff, particularly in spring with variable peaks - Declining navigable river ice - Declining bank stability from erosion and extreme events	- Disappearing navigable river ice and accessibility of park via river ice may disappear - Clear side-channel habitat blown-out by spring freshet - Lateral erosion from mid- and late-season flood events - Magnitude of runoff increases
Hydrology: Non-glacial streams	Increasing length of ice-free season	- Increasing stream discharge and frequency and magnitude of high-flow events - Channel instability or disruption
Hydrology: Lakes	- Outburst floods and ongoing and increasing hazards - Changing shape, size, and volume of lakes - Reduced habitation for cold-tolerant species - Forming of new scour lakes	[no critical implications in this category]
Hydrology: Wetlands	- Wetland habitat degradation due to trail migration (overall wetlands in WRST may increase) - Reduced ice integrity in permafrost dominated wetlands	- Expansion of riverine wetlands - Non-riverine and subsurface ice-perched wetlands lost
Vegetation: Boreal forests	[no critical implications in this category]	- Increased rot and disease - Upslope expansion - Conversion to deciduous species or grasses - Changes to fire regimes and increased fuel loads
Vegetation: Coastal forests	[no critical implications in this category]	- Upslope expansion - Increased rot and disease - Increased erosion from disturbances (wildfires, flooding, avalanches, landslides) - Ecological transformation and emergence of novel vegetation communities - Potential loss of unique non-forest habitats (fens and fen-related species, orchids, ferns, etc.)
Vegetation: Subalpine shrublands / woodlands	- Overall and upslope expansion of distributions - Implications for wildlife (upland areas, more willow, moose; north section of WRST with alpine lichens utilized by caribou, potential loss due to shrubification; USGS Wildlife Potential Habitat Forecasting Project (WiLDCAST) implications of shrubification on wildlife)	- Increased erosion from disturbances (wildfires, flooding, avalanches, landslides) with possible post-disturbance regeneration - Possible establishment of and competition from invasive species
Vegetation: Alpine tundra	- Reduction from shrubification and boreal forest encroachment - Reduction and/or extirpation of rare plant species	- Conversion to drier plant communities - Erosion from increased slides and slumps due to thermokarst
Vegetation: Berry production	- Upward shift in distributions of berry-producing species, recognizing limitations by soil type and tradeoffs between temperature and precipitation - Loss of tundra berry-producing species - Phenological mismatch of harvest times and changing access for berry-producing species - Phenological mismatch of pollinators & berry-producing plants	[no critical implications in this category]
Wildlife: Caribou	- Large changes in abundance are unlikely, but smaller changes may occur (declines possible in all scenarios; increases possible in a subset) (note that Kyle Joly has concerns that this characterization is overly optimistic, given declines in caribou across the range) - Warming increases meat care challenges, particularly if access becomes more difficult - Permafrost thaw constrains access in some areas - Possible arrival of new pathogens or diseases brought by climate change-driven expansion of other ungulate species - Possible shifts in animal movement patterns due to changing temperatures	- Harvest opportunities and ease decline substantially (scenarios 1 & 3), due to soggy trails, widespread permafrost thawing, and shrubification but higher water levels will make boat-based harvest easier - Harvest opportunities and ease remain good due to dry trails (scenario 2)
Wildlife: Moose	- Modest abundance increases or decreases are possible—depending on the relative influences of different climate change impacts - Large declines in abundance and quality of the resource (meat and hide) if climate changed enough to allow establishment of a novel (to WRST moose) parasite or pathogen (e.g., winter tick in western Canada moves north, or deer introduce brain worm and/or liver fluke as seen in northern Minnesota) - Harvest ease and opportunities decline due to high water at stream crossings	- Harvest opportunities and ease decline substantially due to soggy trails (scenarios 1 & 3) and widespread permafrost thawing and shrubification (scenario 3), but higher water levels make boat-based harvest easier - Harvest opportunities and ease remain good due to dry trails (scenario 2), although (as in scenarios 1 and 3) stream crossings still become more difficult (due in scenario 2 to enhanced glacial melt) - Increasing meat-care challenges due to a combination (in scenario 2 and especially scenario 3) of warming temperatures and declines in ease of ORV-based harvest leads to a shift in subsistence harvest 1) towards cooler end of season and 2) towards more road-, boat-, and aviation-based harvesting
Wildlife: Dall's sheep	Large declines in abundance are possible in mid- and late-21st century (although not assured; scientific uncertainties exist)	[no critical implications in this category]

Table 3 (continued). Final critical implications for each resource. Because the Adaptation Workshop focused on high priority park management, some resources were omitted and the subsistence/harvest implications were integrated with the resource.

Resource	Common to all scenarios	Not common to all scenarios
Wildlife: Wolves	• Large abundance changes are unlikely, but abundances may shift in direction of changes in prey abundance • Harvest ease declines due to shorter season when snowmachines or airplanes (ski-planes) can be used or a shorter season when fur is in prime condition, less stable ice on water crossings, and the need for increased trap check frequency • A decline in extreme cold conditions (increasingly severe from scenario 1 through to scenario 3) reduces fur quality proportionately • Trapping participation declines	[no critical implications in this category]
Wildlife: Black and Brown bears	• Large changes in abundance are unlikely, but smaller changes may occur	• Harvest opportunities and ease decline (scenarios 1 & 3), perhaps substantially (scenario 3), due to soggy trails (e.g., Nabesna Road ORV trails), widespread permafrost thawing, and shrubification • Harvest opportunities and ease remain good due to dry trails (scenario 2), but permafrost thaw constrains access in some areas
Wildlife: Harbor seals	• The timing of the thinning and retreat of individual tidewater glaciers is uncertain. The overall outcome for now through mid-century will be a continuation of iceberg-generating tidewater ice on the WRST coastline, though possibly slightly less or slightly more than present • Mike Loso comment of 1 Feb 2022: the locus of iceberg production will vary by this chronology: GLBA proper wanes soonest, then Icy Bay. Disenchantment hangs in there longest of all the current tidewater glaciers on the outer coast, but then Malaspina turns tidewater (happening now) and it will be the “big daddy” of ice production into the most distant future we can possibly forecast • Changes (positive or negative) in ice habitat will likely result in changes in abundance of seals in coastal WRST, including the possibility of shifts to terrestrial habitats or other glacial ice sites (to Prince William Sound or Glacier Bay or other areas), which may have population-level consequences. • Across all scenarios, in addition to changes in ice habitat, bottom-up shifts in prey communities, due to marine heatwaves or other factors in the Gulf of Alaska or other nearby areas, will likely also play a key role in influencing distribution, abundance, condition, and reproductive rates of seals.	• Abundance—and therefore availability for harvest—increases or remains stable due to increases in ice habitat, and harvest opportunities also increase due to reduced boat travel distances (scenario 1) • Abundance—and therefore availability for harvest—decreases due to decreases in ice habitat, and harvest opportunities also decrease due to increased boat travel distances and cruise ship-driven impacts to access (scenarios 2 and particularly 3)
Aquatics: All Salmon	• Resource availability (abundance) may change, perhaps dramatically, in terms of both greater temporal variability and strong trends (complex system—change likely but difficult to predict). • Harvest opportunities shift in space as bank erosion on the Copper River (a result of increased glacial melt under all scenarios and increased precipitation under scenarios 2 and 3) causes loss of some fish wheel sites; impacts on subsistence harvest include additional time and effort needed to find suitable new locations for wheels, or a switch to less efficient (or more labor-intensive) dip-net harvesting, adding additional travel time to suitable sites and perhaps reduced overall harvest levels • Warmer weather poses a challenge to the meat care of salmon (similar to meat-care challenges for harvested mammals) as does potentially warmer non-glacial water in the case of sockeye and non-glacial watershed-rearing coho and Chinook, and potentially a need to check fish wheels more frequently • Warming of non-glacial tributary waters could significantly affect survival for sockeye and non-glacial watershed-rearing coho and Chinook	• In addition to high-water impacts on fish wheel-based harvest, low water also potentially reduces fish wheel effectiveness in some sites (scenario 2) • Wetter conditions (scenarios 1 and 3) pose a challenge to preservation via drying racks (not the most common means of preservation)
Aquatics: Freshwater Fishes	• Resource availability shifts and ease of harvest generally improves across the landscape—proportional to degree of warming—as contrasting (but largely positive) impacts of warming expand habitat (but increase thermocline depth, negatively impacting lake trout and burbot) and expand the ice-free period and increase dissolved oxygen, productivity, and winter survivorship • Ice-fishing harvesting opportunities (i.e., safe and comfortable conditions) shift (contract) towards mid-winter and away from late spring, at a rate consistent with air temperature warming rates (i.e., much faster if scenario-3 warming rates occur)	[no critical implications in this category]
Cultural resources: Archaeological resources	• Site integrity reduced (site/artifacts revealed, inundated, buried) • Site and artifacts destroyed • Impacts on unidentified sites and artifacts • Human landscape use patterns change • Impacts due to changing invasive species management	[no critical implications in this category]
Cultural resources: Cultural landscapes	• Site integrity reduced (includes resource burial, inundation, etc.) • Degradation of historic structures and cultural landscape character defining features • Structures and cultural landscape character defining features destroyed • Viewsheds and associated character defining features impeded (vegetation, wildfires, landslides, avalanches, etc.) • Associated circulation patterns obscured	[no critical implications in this category]

Table 3 (continued). Final critical implications for each resource. Because the Adaptation Workshop focused on high priority park management, some resources were omitted and the subsistence/harvest implications were integrated with the resource.

Resource	Common to all scenarios	Not common to all scenarios
Cultural resources: Historic & prehistoric structures	• Integrity of structures reduced (location, setting, design, materials, workmanship, feeling, and association) • Structures buried and/or destroyed • Associated circulation patterns obscured (visitor traffic and how it might change and how these changes interact with roads and access being impacted by erosion, etc.) • Access to restricted or blocked structures	• Wildfire risk increase (Scenarios 2 and 3); high concern in some geographic areas—lower in high elevations and along the coast
Cultural resources: Kennecott Mines NHL	• Integrity of structures reduced (location, setting, design, materials, workmanship, feeling, and association) • Structures destroyed • Integrity of context reduced (setting, feeling, and association)	[no critical implications in this category]
Cultural resources: Museum collections	• Degradation of museum collections • Loss/destruction of museum collections • Access to museum collections restricted or blocked • Impacts from exposure to pollutants	[no critical implications in this category]
Human Systems: Snowmachine, off-road vehicle, watercraft use	• Changing snow machine/watercraft/ORV suitability/opportunities are likely (increasing or decreasing, dependent on scenario and seasonality) • Expansion of jetboat/watercraft opportunities (although any expansion seems likely to be relatively small) • New watercraft opportunities due to expansion of proglacial lakes	• Increasing risk of snow machine accidents (due to warmer shoulder-seasons, ice instability, worsening avalanche conditions) • New watercraft hazards that vary spatially
Human Systems: Aviation use	• Highly variable (temporally and spatially) snow and ice conditions make landing more challenging/hazardous • Increased tourism/extraction and associated flying • Longer summer season	• More fires disrupt summer flying season except for fire suppression/monitoring • Increasing shrubification of landing sites (may lead to decline in fixed-wing aircraft landings, or decreased number of landing sites) • Increased gravel bars rearranging existing airstrips (creating new ones or washing out existing ones)
Human Systems: Recreating / backcountry use	• Mountaineering shifting to earlier-season—earlier staffing needs • Enhanced melt-season river flows causing increased drowning risk for travelers	• Increasing mountaineering incidents as routes change and past information becomes less reliable • Intensified need for trails • More concentrated visitor use • Variable early and late-season risks associated with river crossing
Wilderness: Solitude	• Decreased opportunities for solitude and remoteness	[no critical implications in this category]
Wilderness: Night skies	• Decreased night sky viewing opportunities (due to changes in cloud cover or smoke from increases in wildfires)	[no critical implications in this category]
Wilderness: Natural soundscape	• Degraded natural soundscapes from human activities • Implications for wildlife—decreased alerting/detection/communication distance for animals	[no critical implications in this category]
Wilderness: Wilderness character	• Degraded undeveloped quality from human activities (both public & park activities) • Increased hazards to unconfined recreation • Increased need to grapple with questions related to management interventions in Wilderness	[no critical implications in this category]



Little Bremner Glacier (left) feeding the braided channels of Little Bremner River and flowing into Tebay Falls (right). NPS photo by Jacob W. Frank.

Hydrology: Glaciers

Scenario 1

Glacier area will continue to decrease (by 2% by mid-century relative to 2010) with most loss at lowest elevations. Tidewater and lake-terminating glaciers will be subject to more variable, and generally more rapid, changes. Glaciers will continue thinning, though snowpack thickness in the highest areas may increase. Glacier melt and runoff will increase slowly through the 2060s.

Scenario 2

Glacier area will continue to decrease (by 5% by mid-century relative to 2010) with most loss at lowest elevations. Tidewater and lake-terminating glaciers will be subject to more variable, and generally more rapid, changes. Glaciers will continue thinning, with diminished snowpack at all elevations. Glacier melt and runoff will increase through the 2050s, at which point loss of glacier area may cause reductions in total cumulative runoff from melting glacier ice.

Scenario 3

Glacier area will continue to decrease (by 7% by mid-century relative to 2010) with most loss at lowest elevations. Tidewater and lake-terminating glaciers will be subject to more variable, and generally more rapid, changes. Glaciers will continue thinning, with diminished snowpack at all

elevations. Glacier melt and runoff will increase rapidly, but in more interior sites of the Wrangell Mountains loss of glacier area may cause reduction in total cumulative runoff from melting glacier ice around 2030.

Shared critical uncertainties

- Rate and extent of ocean- and lake-terminating glacial change.

Hydrology: Glacial rivers

Scenario 1

Runoff will increase by 14% (by mid-century relative to the historical period 1950–1999), and increases will be greater in Coastal Mountains than Wrangell Mountains. Compared with late 20th-century values, glacier runoff-dominated streams and rivers will have earlier but large spring freshet and earlier but large peak runoff in summer. They will return to base flows earlier in late summer, but with increasing frequency of precipitation-driven fall flood events. Runoff will increase in all seasons, but spring and fall will experience greatest % increase. Navigable river ice will decrease and accessibility of park via river ice may decrease, though accessibility via boat will be slightly enhanced in some circumstances due to longer ice-free season. Clear side-channel habitat (clearwater channels within larger braided glacier rivers) will be impacted in complex and unpredictable ways, but less so in this scenario. Bank stability will decline due to erosion from increased variability in extreme events.

Scenario 2

Runoff will increase by 6% (by mid-century relative to the historical period 1950–1999), while glacier runoff-dominated streams and rivers will return to lower base flows much earlier in late summer, with decreased frequency of precipitation-driven fall flood events and an earlier and possibly smaller spring freshet and earlier, smaller peak runoff in summer. Runoff will decrease in winter and increase in the other seasons. Spring and fall will experience greatest % increase in runoff due to earlier snowmelt and more precipitation falling as rain. Navigable river ice will decrease and accessibility of park via river ice may decrease, though accessibility via boat will be enhanced due to longer ice-free season. Clear side-channel habitat (clearwater channels within larger braided glacier rivers) will be impacted in complex and unpredictable ways, but will tend to get “blown out” by the spring freshet and then abandoned by low late summer flows more often than in other scenarios. Bank stability will decline due to erosion from increased variability in extreme events.

Scenario 3

Runoff will increase by 30% (by mid-century relative to the historical period 1950–1999) and increases will be greater in Coastal Mountains than Wrangell Mountains. Compared with late-20th-century values, glacier runoff-dominated streams and rivers will have an earlier spring freshet and earlier peak runoff in summer, returning to base flows earlier in late summer, but with increasing frequency of precipitation-driven fall flood events. Runoff will increase in all seasons, but spring and fall will experience greatest % increase. ***Navigable river ice will disappear and accessibility of park via river ice may disappear, though accessibility via boat may be enhanced due to longer ice-free season.*** Clear side-channel habitat (clearwater channels within larger braided glacier rivers) will be

impacted in complex and unpredictable ways, but will tend to get **“blown out” by the spring freshet and then remain occupied by summer flows** more often than in other scenarios. Bank stability will decline due to erosion from increased variability in extreme events. **Lateral erosion from increasing mid- and late-season flood events.**

Shared critical uncertainties:

- Specific impacts of temperature changes (e.g., how changing glacier ice melting over time and air temperature changes interact)—recognizing diversity of drainage types in the park.
- Spatial variability in navigable river ice—areas of greater or lesser stability.
- Bank stability—events leading to significant erosion or channel changes may be unpredictable (i.e., ice blockages, infrequent, large, late-season rain events). Lateral erosion from increasing late season precipitation-driven flood events and mid-season runoff. Largest % change occurs in spring/fall but summer runoff is significant (massive flows, just distributed temporally more), i.e., flows that will influence bank stability are more likely to be summer flows. Ice jams and glacial lake outburst floods can cause bank-altering high-water events.
- Shoulder-season uncertainties—there will continue to be a season where neither navigating over ice nor boating is possible, but the duration of that season and its timing (and variability thereof) will change in ways that are not well understood.

Hydrology: Non-glacial streams

Scenario 1

Stream discharge will increase in general, and runoff will occur earlier due to increased precipitation and spring runoff. Air temperature increases will lead to increasing length of ice-free season.

Frequency and magnitude of high-flow events will increase due to increased summer precipitation and rain-on-snow, potentially leading to **channel instability/disruption**.

Scenario 2

There will be small but uncertain changes in non-glacial streamflow due to modest declines in precipitation. Air temperature increases will lead to increasing length of ice-free season.

Critical uncertainties:

- Whether precipitation declines are enough to lead to decreases in channel-forming flows.

Scenario 3

Stream discharge will increase in general due to increasing precipitation, and winter streamflow may increase due to rain-on-snow. Air temperature increases will lead to increasing length of ice-free season. Frequency and magnitude of high-flow events will increase due to increased summer precipitation and rain-on-snow, potentially leading to **channel instability/disruption**.

Shared critical uncertainties:

- Degree to which increased infiltration into groundwater (from permafrost thawing) leads to increased baseflow and warmer water entering streams and creating winter refugia.

- Stream temperature effects—interannual variability possibly increasing but interactions between precipitation change and air temperature changes difficult to predict.

Hydrology: Lakes

Scenario 1

Ice marginal (proglacial and glacier-dammed) lakes: High numbers and sizes of proglacial lakes will buffer downstream flows. Outburst floods will be an ongoing but increasing hazard. Lakes will experience rapid change in size, shape, and volume.

Other lakes: Lakes will remain stable except for changes in surface elevation dictated by water balance. Thermocline depth increases will reduce habitation for cold-tolerant species due to longer ice-free periods. Lake levels will increase due to increasing runoff and glacial melt. New scour lakes will form due to glacial retreat.

Lake ice (all lake types): Lake ice will decrease due to increasing temperatures and rain-on-snow events. Ice travel will decrease with potential for marginal gains in boat access.

Critical uncertainties:

- Impact of frequency of rain-on-snow events on lake ice formation and persistence.

Scenario 2

Ice-marginal (proglacial and glacier-dammed) lakes: High numbers and sizes of proglacial lakes will buffer downstream flows. Outburst floods will be an ongoing but increasing hazard. Lakes will experience rapid change in size, shape, and volume.

Other lakes: Lakes will remain stable except for changes in surface elevation dictated by water balance. Thermocline depth increases will reduce habitation for cold-tolerant species due to longer ice-free periods. New scour lakes will form due to glacial retreat.

Lake ice (all lake types): Lake ice will decrease due to increasing temperatures. Ice travel will decrease with potential for marginal gains in boat access.

Critical uncertainties:

- Changes to lake levels uncertain due to interactions between glacial melt, lower precipitation, and higher evapotranspiration.

Scenario 3

Ice marginal (proglacial, glacier-dammed) lakes: High numbers and sizes of proglacial lakes will buffer downstream flows. Outburst floods will be an ongoing but increasing hazard. Lakes will experience rapid change in size, shape, and volume.

Other lakes: Lakes will remain stable except for changes in surface elevation dictated by water balance. Thermocline depth increases will reduce habitation for cold-tolerant species due to longer ice-free periods. Lake levels will increase substantially due to increasing runoff and glacial melt. New scour lakes will form due to glacial retreat.

Lake ice (all lake types): Lake ice will decrease due to increasing temperatures and rain-on-snow events. Ice travel will decrease substantially but boat access will increase.

Critical uncertainties:

- Impact of frequency of rain-on snow events on lake ice formation and persistence.

Shared critical uncertainties:

- Wind has a large influence on lake behavior (lake turnover vs. thermocline development, etc.).
- Timing and location of ice-marginal lakes and GLOF (glacier lake outburst floods).

Hydrology: Wetlands

Scenario 1

Riverine wetlands will expand due to increased flow conditions but with altered vegetation communities. Flow in fens in glacial valleys will increase due to increasing glacial output. **Wetland areas perched on subsurface ice will be lost** due to drainage. Wetland habitat degradation will increase due to trail migration from wetter conditions and increasing water temperatures. Ice integrity in permafrost dominated wetlands will reduce.

Scenario 2

Non-riverine wetlands and those perched on subsurface ice will be lost due to drainage and increased evapotranspiration. Flow in fens in glacial valleys will increase due to increasing glacial output. Wetland habitat degradation will reduce due to improvement in trails from drier conditions. Ice integrity in permafrost dominated wetlands will reduce.

Critical uncertainties:

- Riverine wetlands change is uncertain due to interactions with increased flow conditions and increasing evapotranspiration, but vegetation communities may be altered.

Scenario 3

Riverine wetland will expand due to increased flow conditions with significantly altered vegetation communities, however expansion may be somewhat moderated by increasing evapotranspiration. Flow in fens in glacial valleys will increase due to increasing glacial output. **Wetland areas perched on subsurface ice will be lost** due to drainage and evapotranspiration. Wetland habitat degradation will increase due to trail migration from wetter conditions and increasing water temperatures. Ice integrity in permafrost dominated wetlands will reduce.

Shared critical uncertainties:

- Wetland response to warming because increasing groundwater from glacial melt may expand habitat in major river valleys.
- Spatial variability in trail conditions in relation to off-road vehicle (ORV) use.
- Potential for range expansion of beavers into higher elevation areas than where they have typically been found in the past (consistent w/ increasing beaver activity elsewhere in AK).



Willow Lake and the surrounding boreal forests. NPS photo by Bryan Petryl.

Vegetation: Boreal forests

Scenario 1

Boreal forest abundance is uncertain. Increased temperatures and precipitation may promote growth, however it will **also increase rot, disease**, and infestations by spruce bark beetle and other forest pests.

Critical uncertainties:

- Boreal forests may expand upslope due to slightly warmer temperatures and increased precipitation.
- Slightly increased temperatures may promote a conversion (to deciduous species or grasses, as in Kenai Peninsula).

Scenario 2

Boreal forests will decline due to impacts of a warmer and especially drier climate, including increased drought, wildfires, and infestations by spruce bark beetle and other forest pests.

Moderately increased temperatures and wildfire will promote a conversion (to deciduous species or grasses, as in Kenai Peninsula).

Critical uncertainties:

- Boreal forests may expand upslope due to moderately warmer temperatures.

Scenario 3

Boreal forest abundance is uncertain. Significantly increased temperatures and precipitation and longer growing seasons will promote growth and denser forests and understory, however they will also **increase rot, disease**, and infestations by spruce bark beetle and other forest pests. **Risk and severity of wildfires will increase from increased fuel loads. Boreal forests will expand upslope** due to significantly warmer temperatures and increased precipitation.

Critical uncertainties:

- Increased temperatures and wildfires may promote a conversion (to deciduous species or grasses, as in Kenai Peninsula), however increased pests and precipitation may counteract this.

Shared critical uncertainties:

- Complicated dynamics between black and white spruce and the interactive climate conditions that will promote one over the other.

Vegetation: Coastal forests

Scenario 1

Increased precipitation will favor persistence of coastal forests, wetlands, and species; however, it will also lead to **moderately increased rot and disease, flooding, avalanches, and landslides that reduce forested areas**. Increased temperatures and precipitation will lead to **moderate upslope expansion** of coastal forests into alder shrub fields.

Scenario 2

Increased temperatures that lead to increased glacial melt will favor persistence of coastal forests, wetlands, and species; however, drier conditions will **increase risk of wildfires that may trigger vegetation changes including transformation and emergence of novel vegetation communities** (including elements from British Columbia).

Scenario 3

Increased precipitation will favor persistence of coastal forests, wetlands, and species; however, it will also lead to **substantially increased rot and disease, flooding, avalanches, and landslides that reduce forested areas**. Increased temperatures and precipitation will lead to **substantial upslope expansion** of coastal forests into alder shrub fields and may lead to emergence of novel and **potentially invasive vegetation and pest communities** (including elements from British Columbia).

Vegetation: Subalpine shrublands / woodlands

Scenario 1

Subalpine shrublands / woodlands will expand moderately due to warmer temperatures and increased precipitation that drives (spatially-variable) soil moisture, which in turn will lead to upslope expansion of subalpine shrublands / woodlands and encroachment from boreal forest, alder, and poplar (particularly in primary successional areas). **Increased erosion and landslides** due to increased precipitation and extreme precipitation events will reduce subalpine shrublands / woodlands habitat, however post-disturbance regeneration may rebound the populations.

Critical uncertainties:

- Degree to which increased and longer lasting snowpack counteract upslope expansion and forest encroachment.
- Degree to which invasive species establish in eroded areas and lead to competition.

Scenario 2

Subalpine shrublands / woodlands may expand slightly due to warmer temperatures and permafrost thaw that drives (spatially variable) increases in soil moisture, although drought and drier areas will constrain this expansion. Increased wildfires may cause shrubland / woodland loss.

Critical uncertainties:

- Degree to which warmer temperatures cause encroachment by boreal forest, alder, and poplar.

Scenario 3

Subalpine shrublands / woodlands will expand substantially due to warmer temperatures and increased precipitation that drives (spatially-variable) soil moisture, which in turn will lead to upslope expansion of subalpine shrublands / woodlands and encroachment from boreal forest, alder, and poplar (particularly in primary successional areas). **Increased erosion and landslides** due to increased precipitation and extreme precipitation events will reduce subalpine shrublands / woodlands habitat, however post-disturbance regeneration may rebound the populations.

Critical uncertainties:

- Degree to which increased snowpack counteract upslope expansion and forest encroachment.
- Degree to which **invasive species establish in eroded areas and lead to competition.**

Vegetation: Alpine tundra

Scenario 1

Alpine tundra will shrink slightly due to increased shrubification and boreal forest encroachment, however increased snowpack and freeze-thaw events may slow encroachment and promote continued presence of tundra.

Scenario 2

Alpine tundra will shrink moderately due to increased shrubification and boreal forest encroachment and may experience shifts toward **drier alpine tundra plant communities.**

Scenario 3

Alpine tundra will shrink substantially due to decreased snowpack as insulation and significantly increased shrubification and boreal forest encroachment. **Increased slides and slumps will occur from widespread slope instability due to thermokarst.**

Vegetation: Berry production (i.e., berries as a food source for animals and subsistence)

Scenario 1

General: Phenological mismatches with both wildlife and subsistence (traditional gathering times). Upward elevational shift of distributions, however shift will be starkly limited by soil type, which could lead to overall reduction of distributions.

Non-tundra: Modest but uncertain abundance, distribution, and productivity changes of all berries. Positive effects on productivity from modest warming, possibly counteracted by negative effects of increased precipitation. Increased precipitation will cause fungal issues in raspberries.

Tundra: Some declines in distribution (especially of cloudberry) due to some decline of tundra/permafrost habitat.

Critical uncertainties:

- *Non-tundra:* How positive effects of modest warming and negative effects of increased precipitation will interact to drive changes in berry-producing species.
- *Tundra:* Degree to which the loss of berry tundra habitat at lower-elevation margins may be compensated for by gains at higher-elevation margins.

Scenario 2

General: Phenological mismatches with both wildlife and subsistence (traditional gathering times). Upward elevational shift of distributions, however shift will be starkly limited by soil type, which could lead to overall reduction of distributions.

Non-tundra: Modest, likely-heterogeneous abundance, distribution, and productivity changes, with frequent fires and drought reducing the distribution and abundance of ericaceous berry-producing species (blueberry, cranberry) but not necessarily of soapberry and raspberry, which both occur in early-successional situations and are drought-tolerant.

Tundra: Modest declines in distribution (especially of cloudberry) due to modest decline of tundra/permafrost habitat.

Critical uncertainties:

- *Non-tundra:* Details about how change in fire regime and drought will influence berry-producing species
- *Tundra:* Degree to which the modest loss of berry tundra habitat at lower-elevation margins may be compensated for by gains at higher-elevation margins

Scenario 3

General: Phenological mismatches with both wildlife and subsistence (traditional gathering times). Upward elevational shift of distributions, however shift will be starkly limited by soil type, which could lead to overall reduction of distributions.

Non-tundra: Large abundance, distribution, and productivity changes of all berries. Non-linear productivity patterns for some sites/species over time, possibly counteracted by negative effects of

increased precipitation. Strong declines in blueberries (subalpine dominant) due to tall shrub/tree competition. Increased precipitation will cause fungal issues in raspberries. Arrival of new berry species into the park from further south.

Tundra: Large declines in distribution (especially of cloudberry) due to large decline of tundra/permafrost habitat.

Critical uncertainties:

- *Non-tundra*: How positive effects of substantial warming and negative effects of substantially increased precipitation will interact to drive changes in berry-producing species.
- *Tundra*: Degree to which the large loss of berry tundra habitat at lower-elevation margins may be compensated for by gains at higher-elevation margins.

Shared critical uncertainties:

- *General*: How phenology (relevant for wildlife and subsistence) and pollinators/pollination (relevant for productivity) may change.



Caribou herd on the Goat Trail. NPS photo.

Wildlife: Caribou

Scenario 1

The Chisana and Mentasta caribou herds are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, caribou abundance will likely not change drastically. However, caribou abundance could experience modest increases or decreases depending on the relative magnitude of negative (i.e., deeper snow) and positive climate change impacts (i.e., increased vegetation productivity). Specifically, caribou will decline due to increased prevalence of deeper snow in the shoulder season affecting calf survival and increasing rain-on-snow events limiting access to vegetation during critical seasons. Declines could be offset by increasing summer herbaceous vegetation, however increased vascular plant growth reduces tundra lichen which caribou rely on.

Scenario 2

The Chisana and Mentasta caribou herds are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, caribou abundance will likely not change drastically. However, caribou abundance could experience modest increases or decreases depending on the relative magnitude of negative (i.e., phenological mismatch) and positive climate change impacts (i.e., increased summer vegetation productivity). Specifically, caribou will decline due to loss of winter thermal cover as a result of increased fire frequency, forage as a result of drought-stressed vegetation, and phenological mismatch between vegetation emergence and energetic demands of reproduction.

Scenario 3

The Chisana and Mentasta caribou herds are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, caribou abundance will likely not change drastically. However, caribou herds could experience modest decreases depending on the relative magnitude of negative climate change impacts (i.e., rain-on-snow events, decreased wintering habitat, phenological mismatch). Specifically, caribou will decline due to loss of late-successional spruce-dominated forests, declines in lichen availability driven by increasing wildfires, increasing rain-on-snow events limiting access to vegetation during critical seasons, and phenological mismatch between vegetation emergence and energetic demands of reproduction. Declines could be offset by increasing summer herbaceous vegetation, however increased vascular plant growth reduces tundra lichen.

Shared critical uncertainties:

- Caribou abundance may not change drastically overall but there may be regional forcings that change the equilibrium.

Wildlife: Moose

Scenario 1

Moose are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, moose abundance will likely not change drastically. However, moose abundance could experience modest increases or decreases depending on the

relative magnitude of negative climate change impacts (i.e., deeper snow, increased snowmachine use, and more disease) and positive climate change impacts (i.e., increase in favored early-successional and wetland vegetation).

Critical uncertainties:

- Moose abundance may not change drastically overall but there may be regional forcings that change the equilibrium (e.g., deeper snow and crusting over may result in declines in relation to predator/prey relationships and browse access).

Scenario 2

Moose are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, moose abundance will likely not change drastically. However, moose abundance could experience modest increases or decreases depending on the relative magnitude of negative climate change impacts (i.e., more disease) and positive climate change impacts (i.e., increase in favored early-successional vegetation).

Critical uncertainties:

- Moose abundance may not change drastically overall but there may be regional forcings that change the equilibrium.

Scenario 3

Moose are limited by top-down versus bottom-up drivers; therefore, unless there are drastic changes in predator population size or composition, moose abundance will likely not change drastically. However, moose abundance could experience modest increases or decreases depending on the relative magnitude of negative climate change impacts (i.e., more disease) and positive climate change impacts (i.e., increase in favored early-successional vegetation).

Critical uncertainties:

- Moose abundance may not change drastically overall but there may be regional forcings that change the equilibrium (e.g., deeper snow and crusting over may result in declines in relation to predator/prey relationships and browse access).

Shared critical uncertainties:

- Incidence of disease is a wild card. If conditions change enough to allow establishment of a novel parasite or pathogen the population-level response could be dramatic (e.g., winter ticks in western Canada and moving north).

Wildlife: Dall's sheep

Scenario 1

Dall's sheep abundance will decline substantially due to 1) increased rain-on-snow and icing events reducing fall, winter, and spring forage availability in the Wrangell and Coastal mountains, 2) increased snow depth reducing winter forage and movement and lamb survival, and 3) loss of alpine habitat due to upward shrub encroachment.

Scenario 2

Dall's sheep abundance will decline substantially due to 1) loss of alpine habitat due to upwards shrub encroachment, 2) reduced summer lamb survival due to decreased summer forage from wildfires, and 3) potential heat stress driving sheep into higher elevations for available forage.

Scenario 3

Dall's sheep abundance will decline substantially due to 1) loss of alpine habitat due to upwards shrub encroachment, 2) increased summer vegetation possibly negated by overall loss of alpine habitat, and 3) potential heat stress driving sheep into higher elevations for available forage.

Shared critical uncertainties:

- Balance between habitat lost and gained is unknown and likely will exhibit heterogeneity.

Wildlife: Wolves

Scenario 1

Large wolf abundance changes are unlikely, but populations may shift in the direction of changes in prey abundance.

Scenario 2

Large wolf abundance changes are unlikely, but populations may shift in the direction of changes in prey abundance.

Critical uncertainties:

- Potential increase to wolf abundance due to wildfire effects on small mammals and meso-carnivores.

Scenario 3

Large wolf abundance changes are unlikely, but populations may shift in the direction of changes in prey abundance (caribou may decline).

Wildlife: Brown bears

Scenario 1

Large brown bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including increased vegetation in most habitats (except the alpine tundra) and potentially increased berries in most habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and reduced growing season length affecting the ability to gain fat reserves.

Scenario 2

Large brown bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including potentially increased vegetation in some habitats (except the alpine tundra) and potentially increased berries in some habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and increased likelihood of wildfires.

Scenario 3

Large brown bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including increased vegetation in most habitats (except the alpine tundra) and potentially increased berries in most habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and loss of winter impacting hibernation (increased amount of prey required and lower survival rate).

Wildlife: Black bears

Scenario 1

Large black bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including overall increased vegetation in most habitats (except the alpine tundra) and potentially overall increased berries in most habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and reduced growing season length affecting the ability to gain fat reserves.

Scenario 2

Large black bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including potentially increased vegetation in some habitats (except the alpine tundra) and potentially increased berries in some habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and increased likelihood of wildfires.

Scenario 3

Large black bear changes in abundance are unlikely but may shift in the direction of prey abundances and habitat availability.

Critical uncertainties:

- The interaction between positive abundance drivers including increased vegetation in most habitats (except the alpine tundra) and potentially increased berries in most habitats (except the alpine tundra), and negative abundance drivers including uncertain salmon abundance and loss of winter impacting hibernation (increased amount of prey required and lower survival rate).

Wildlife: Bald eagles

Scenario 1

Bald eagle abundance will decline due to loss of habitat from flooding and increased egg/chick mortality from weather extremes.

Scenario 2

Bald eagle abundance will decline due to loss of habitat from wildfires, increased egg/chick mortality from weather extremes, and increased energetic costs of thermoregulation (adults and young).

Scenario 3

Bald eagle abundance will decline due to loss of habitat from flooding and wildfires, increased egg/chick mortality from weather extremes, and increase energetic costs of thermoregulation (adults and young).

Shared critical uncertainties:

- Abundance of salmon

Wildlife: Harbor seals

Scenario 1

Seal distribution and abundance may increase or remain stable if ice habitat increases.

Scenario 2

Seal distribution and abundance may decrease as ice habitat decreases.

Critical uncertainties:

- Glacial retreat may happen faster and even lead to grounding, which would expedite seal abundance decline, however seals may then use terrestrial land more often.

Scenario 3

Seal distribution and abundance may decrease more (relative to scenario 2) as ice habitat decreases.

Critical uncertainties:

- Glacial retreat may happen faster and even lead to grounding, which would expedite seal abundance decline, however seals may then use terrestrial land more often.

Shared critical uncertainties:

- Calving dynamics of tidewater glaciers over short and long timescales and spatial scales.

- How the availability of ice habitat balances out with contrasting glacial dynamics is highly uncertain—distribution and abundance of seals will be highly dependent on retreat and expansion of individual glaciers.
- Migration and changes of prey species outside of the park will influence health upon arrival in the park and ensuing fitness.
- Access of cruise ships to the area (targeting tidewater glaciers, which are gradually disappearing).



Sockeye salmon congregating to spawn in Alaska's glacial watersheds. NPS photo.

Aquatics: Chinook/Coho Salmon that rear in glacially influenced watersheds

Scenario 1

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions.

Critical uncertainties:

- Changing glacial melt season and how this matches salmon life history.

Scenario 2

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative effects to return migrations resulting in reduced food production and more challenging return migrations.

Scenario 3

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative effects due to loss of side channel habitat and positive effects on rearing conditions (milder winters, buffered stream warming by glacial melt).

Critical uncertainties:

- Changing glacial melt season and how this matches salmon life history.

Shared critical uncertainties:

- Climate change effects on rearing habitat.
- Population-level effects of ocean condition changes.

Aquatics: Chinook/Coho Salmon that rear in NON-glacially influenced watersheds

Scenario 1

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative impacts from increased heat stress and increased heavy rain events and positive effects of reduced winter severity and enhanced rearing conditions (earlier ice out).

Critical uncertainties:

- Degree to which reduced winter severity and enhanced rearing conditions (earlier ice out) offset effects of slight heat stress and increased rain events.

Scenario 2

Population-level responses are uncertain, but increasing variability is likely due to complex interactions including negative impacts from increased heat stress, increased dry conditions in the fall, and interactions of climate change with infection/diseases.

Critical uncertainties:

- Degree to which reduced winter severity and enhanced rearing conditions (earlier ice out) offset effects of heat stress.

Scenario 3

Population-level response is uncertain, but increasing variability is likely due to complex interactions including negative impacts from increased heat stress, increased heavy precipitation events, and interactions of climate change with infection/diseases. Aquatic food web changes could further negatively impact these populations, but such impacts are difficult to predict. Reduced winter severity and enhanced rearing conditions associated with beaver dams could offset some losses in Chinook and Coho productivity.

Critical uncertainties:

- Degree to which reduced winter severity and enhanced rearing conditions (earlier ice out) offset effects of significant heat stress and increased heavy rain events.

Shared critical uncertainties:

- Population-level effects of ocean condition changes.
- Aquatic food web change effects on productivity.

Aquatics: Sockeye Salmon

Scenario 1

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative effects from migration-related challenges particularly associated with heavy precipitation events, positive effects from potential enhancement of rearing conditions (earlier ice out), and mixed effects from changes in beaver populations—dams blocking in- or out-migration and dams creating beneficial rearing habitat.

Scenario 2

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative effects from migration-related challenges particularly associated with drought, positive effects from potential enhancement of rearing conditions (earlier ice out), and mixed effects from changes in beaver populations—dams blocking in- or out-migration and dams creating beneficial rearing habitat.

Scenario 3

Population-level responses are uncertain, but increasing variability is likely due to numerous complex interactions including negative effects from migration-related challenges particularly associated with heavy precipitation events, positive effects from potential enhancement of rearing conditions (earlier ice out), and mixed effects from changes in beaver populations—dams blocking in- or out-migration and dams creating beneficial rearing habitat.

Shared critical uncertainties:

- Population-level effects of ocean conditions, which are a critical driver of species condition (e.g., marine heat waves could lead to food web shifts in either direction).
- Changes in beaver populations and effects on Sockeye.

Aquatics: Other fish species

Scenario 1

Warming temperatures increase thermocline depth and reduce habitat for species such as lake trout and burbot, but also increase productivity. A longer ice-free period increases winter survivorship by increasing dissolved oxygen (a major mortality factor in many smaller and shallower water bodies that contain lake trout, burbot, and grayling).

Scenario 2

Warming temperatures increase thermocline depth and reduce habitat for species such as lake trout and burbot, but also increase productivity. A longer ice-free period increases winter survivorship by increasing dissolved oxygen (a major mortality factor in many smaller and shallower water bodies that contain lake trout, burbot, and grayling).

Scenario 3

Rapidly warming temperatures increase thermocline depth and reduce habitat for species such as lake trout and burbot, but also increase productivity. A longer ice-free period increases winter survivorship by increasing dissolved oxygen (a major mortality factor in many smaller and shallower water bodies that contain lake trout, burbot, and grayling).

Shared critical uncertainties:

- Degree to which warming expands extent of beaver-created pond habitat, which benefits rainbow trout, grayling, and cutthroat in coastal areas.



Kennecott Machine Shop and Mill building, an iconic remnant of mining operations in WRST. Although it has withstood 20 years of modifications, additions, and serving as a hub for processing heavy ore and machinery, future climate conditions will likely compromise the integrity of this historic site. NPS photo by Matthew Yarbrough.

Cultural resources: Archaeological resources

Scenario 1

Riverine: Sites along rivers will be degraded or destroyed due to flooding and erosion from increased precipitation and early and large snowmelt, precluding future research and interpretation. Human landscape use patterns will change due to flooding, which will impact previously buffered resources.

Coastal: Integrity of coastal sites will be reduced due to melting of glaciers, sea-water intrusion, and flooding (with expansion of pro-glacial lakes facilitating/accelerating subsurface glacial melting, leading to threshold-like saltwater intrusion events). Sites along coastlines will be inundated due to sea-level rise or rapid, dramatic coastal change (e.g., tsunami) involving total loss of coastline.

Mountains: Moderately accelerated melting of ice patch sites will reveal archeological resources and disintegrate organic artifacts due to warming temperatures. Artifacts will be buried or destroyed due to increasing landslides from loss of soil ice.

Other: Shoreline and landscape-level changes will affect the integrity, setting, feeling, and association at archeological sites. Archeological sites will be inundated due to formation of proglacial lakes at termini of glacial retreat. Archeological resources will suffer stratigraphic-integrity impacts (i.e., to their subsurface context) by permafrost thaw/formation of thermokarst areas and suffer degradation of organic artifacts. Human landscape use will change (including expansion into new areas).

Scenario 2

Riverine: Sites along rivers will be degraded or destroyed due to increased landslides and erosion following wildfires, as well as potential flooding from early snowmelt, precluding future research and interpretation. Human landscape use patterns will change (including expansion into new areas) due to wildfire, and to a lesser degree, flooding, which will impact previously buffered resources.

Coastal: Integrity of coastal sites will be reduced due to melting of glaciers, sea-water intrusion, and flooding (with expansion of pro-glacial lakes facilitating/accelerating subsurface glacial melting, leading to threshold-like saltwater intrusion events). Sites along coastlines will be inundated due to sea-level rise or rapid, dramatic coastal change (e.g., tsunami) involving total loss of coastline.

Mountains: Accelerated melting of ice patch sites will reveal archeological resources and disintegrate organic artifacts at faster rates than in the past due to warming temperatures. Artifacts will be buried or destroyed due to increasing landslides from loss of soil ice and increased wildfires.

Other: Shoreline and landscape-level changes will affect the integrity, setting, feeling, and association at archeological sites. Archeological sites will be inundated due to formation of proglacial lakes at termini of glacial retreat. Archeological resources will suffer stratigraphic-integrity impacts (i.e., to their subsurface context) by accelerated permafrost thaw due to increasing wildfires/formation of thermokarst areas. Human landscape use will change (including expansion into new areas).

Scenario 3

Riverine: Sites along rivers will be severely degraded or destroyed due to flooding and erosion from increased precipitation and early and large snowmelt, precluding future research and interpretation. Human landscape use patterns will change due to flooding (and possibly wildfire), which will impact previously buffered resources.

Coastal: Integrity of coastal sites will be reduced due to melting of glaciers, sea-water intrusion, and flooding (with expansion of pro-glacial lakes facilitating/accelerating subsurface glacial melting, leading to threshold-like saltwater intrusion events). Sites along coastlines will be greatly inundated due to sea level rise or rapid, dramatic coastal change (e.g., tsunami) involving total loss of coastline.

Mountains: Substantially accelerated melting of ice patch sites will reveal archeological resources and disintegrate organic artifacts at much faster rates than in the past due to warming temperatures. Artifacts will be buried or destroyed due to increases in frequency and severity (wildfire + flooding) of landslides from loss of soil ice and soil saturation and wildfire.

Other: Shoreline and landscape-level changes will affect the integrity, setting, feeling, and association at archeological sites. Archeological sites will be inundated due to formation of proglacial lakes at termini of glacial retreat. Archeological resources affected will suffer stratigraphic-integrity impacts (i.e., to their subsurface context) by accelerated permafrost thaw due to higher severity fires, and also suffer degradation of organic artifacts. Human landscape use will change (including expansion into new areas).

Shared critical uncertainties:

- Effects on sites near Malaspina glacier (inundated due to glacial melt or uplifted due to isostatic rebound).
- Degree to which changing invasive species management may affect sites.
- Sites that may exist that have not yet been identified.

Cultural resources: Cultural landscapes

Scenario 1

Riverine: Vegetation growth from increased precipitation will lead to impacts (e.g., rot) on historic structures, impede viewshed characteristics, and obscure associated circulation patterns. Sites along rivers will be harmed or destroyed by flooding, erosion, or landslides. Increased snow accumulation will likely continue to impact associated structures or lead to collapse.

Coastal: Vegetation growth from increased precipitation will lead to impacts (e.g., rot) on historic structures, impede viewshed characteristics (including of Malaspina glacier), and obscure associated circulation patterns.

Mountains: Structural damage/collapse will continue from increased snow loads. Features and viewsheds will be lost due to larger avalanches or large-scale landslides from increased precipitation and shoulder-season snow. Structures associated with mining landscapes will be affected by partial

or total loss of sites near glaciers due to glacial melt. Increased precipitation will lead to increased structural rot.

Scenario 2

Riverine: Increased wildfires will result in more altered cultural landscapes and impacts on associated structures (including destruction). Erosion and landslides following wildfires will bury or destroy resources in riverine areas.

Coastal: Increased wildfires will result in more altered cultural landscapes (including viewshed characteristics of Malaspina glacier) and impacts on associated structures including destruction). Erosion and landslides following wildfires will bury or destroy resources along coastal areas.

Mountains: Increased wildfires will result in more altered cultural landscapes and impacts on associated structures (including destruction). Erosion and landslides following wildfires will bury or destroy resources along mountain areas. Structures associated with mining landscapes will be affected by partial or total loss of sites near glaciers due to glacial melt.

Scenario 3

Riverine: Vegetation growth from significantly increased precipitation will lead to severe impacts (e.g., rot) on historic structures, impede viewshed characteristics, and obscure associated circulation patterns. Sites along rivers will be harmed or destroyed by flooding erosion, or (flood or fire-driven) landslides. Increased snow accumulation will likely continue to impact associated structures or lead to collapse. Increased wildfires will result in more altered cultural landscapes and associated structures.

Coastal: Vegetation growth from significantly increased precipitation will lead to severe impacts (e.g., rot) on historic structures, impede viewshed characteristics (including of Malaspina glacier), and obscure associated circulation patterns.

Mountains: Structural damage/collapse will continue from increased snow loads. Features and viewsheds will be lost due to larger avalanches or large-scale landslides from increased precipitation and shoulder-season snow. Structures associated with mining landscapes will be affected by partial or total loss of sites near glaciers due to glacial melt. Significantly increased precipitation will lead to severe structural rot.

Shared critical uncertainties:

- Impacts to cultural landscapes that have not yet been identified.

Cultural resources: Historic & prehistoric structures

Scenario 1

Overall: Increases in invasive species and pest infestations from increased temperatures will lead to partial or total loss of structures.

Riverine: Vegetation growth from increased precipitation will lead to impacts (e.g., rot) on historic structures and obscure associated circulation patterns. Sites along rivers will be harmed or destroyed

by flooding, erosion, or landslides. Increased snow accumulation will impact structures or lead to collapse.

Coastal: Vegetation growth from increased precipitation will lead to impacts (e.g., rot) on historic structures. Integrity of coastal sites will reduce due to changes in sea ice, isostatic rebound, and erosion. Increased snow accumulation will continue to impact structures or lead to collapse.

Mountains: Structural damage/collapse will occur from increased snow loads. Features will be lost due to large-scale landslides from increased precipitation and shoulder-season snow. Structures associated with mining landscapes will be affected by partial or total loss of sites near glaciers due to glacial melt.

Scenario 2

Overall: Increases in invasive species and pest infestations from increased temperatures (and particularly ants from drying) will lead to partial or total loss of structures.

Riverine: There will be an **increased likelihood of wildfire-caused destruction of historic structures**. Erosion and landslides following wildfires will bury or destroy structures in riverine areas.

Coastal: There will be an **increased likelihood of wildfire-caused destruction of historic structures**. Erosion and landslides following wildfires will bury or destroy structures in coastal areas.

Mountains: There will be an **increased likelihood of wildfire-caused destruction of historic structures**. Erosion and landslides following wildfires will bury or destroy resources along mountain areas. Structures associated with mining landscapes will be affected by partial or total loss of sites near glaciers due to glacial melt.

Scenario 3

Overall: Increases in invasive species and pest infestations from increased temperatures will lead to partial or total loss of structures.

Riverine: Vegetation growth from significantly increased precipitation will lead to severe impacts (e.g., rot) on historic structures and obscure associated circulation patterns. Sites along rivers will be harmed or destroyed by flooding, erosion, or landslides. Increased snow accumulation will impact structures or lead to collapse. There will be an **increased likelihood of wildfire-caused destruction of historic structures**.

Coastal: Vegetation growth from significantly increased precipitation will lead to severe impacts (e.g., rot) on historic structures. Integrity of coastal sites will reduce due to changes in sea ice, isostatic rebound, and erosion. Increased snow accumulation will continue to impact structures or lead to collapse. Sites along coastlines will be inundated due to sea level rise.

Mountains: Structural damage/collapse will occur from increased snow loads. Features and viewsheds will be lost due to large-scale landslides from increased precipitation and shoulder-season snow. Structures associated with mining landscapes will be affected by partial or total loss of sites near glaciers due to glacial melt.

Cultural resources: Kennecott Mines National Historic Landmark (NHL)

Scenario 1

The integrity of materials and workmanship of historic structures will face an increased and high risk of impacts due to increased temperatures, precipitation, and humidity, including destruction from increased snow loads, damage from rot, sinking of structures from the melting of Root Glacier, seasonal flooding (especially on frozen ground where water may divert to buildings), increased pests, potential pollutant discharge from mine tailings, and increased vegetation that is not managed. Landscape-level changes, including loss of the glacier, from increased temperatures can also affect the setting, feeling, and association for visitors. Visitor-use impacts and activities will increase due to warmer and longer summers.

Scenario 2

The integrity of materials and workmanship of historic structures will face an increased and high risk of impacts due to increased temperatures and drier conditions, including destruction from wildfires, damage from increased pests, and sinking of structures from the thaw of Root Glacier. Landscape-level changes, including loss of the glacier, from wildfires and increased temperatures can also affect the setting, feeling, and association for visitors. Visitor-use impacts and activity will increase due to warmer temperatures and decreased precipitation, which can lead to increased risk of human-caused ignition (by visitors and residents).

Scenario 3

The integrity of materials and workmanship of historic structures will face an increased and severe risk of impacts due to increased temperatures, precipitation, and humidity, including destruction from increased snow loads, damage from rot, sinking of structures from the melt of Root Glacier, seasonal flooding (especially on frozen ground where water may divert to buildings), destruction from wildfires, increased pests, potential pollutant discharge from mine tailings, and increasing vegetation that is not managed. Landscape-level changes, including loss of the glacier, from increased temperatures and wildfires can also affect the setting, feeling, and association for visitors. Visitor-use impacts and activities will increase substantially due to hotter and longer summers.

Shared critical uncertainties:

- Mechanisms underlying pollutant discharge and degree of discharge from mine tailings, and how discharge might change in response to changes in climate.

Cultural resources: Museum collections

Scenario 1

Collections face a high risk of damage, degradation, and destruction due to increased temperatures, precipitation, and humidity without controlled environment, as well as destruction from increased snow loads on facilities that are structurally vulnerable. Increased temperatures may also result in additional threats to collections if there is a corresponding increase in museum pests. Access to Kennecott and objects on the landscape may be restricted or blocked due to increased snow and longer winters. At Kennecott, continued sinking of the landscape will occur from the melting of Root Glacier, putting the collections at an increased risk to flooding from structural damage to the facility.

At Bremner, objects will be directly impacted by an increase in mold and rust because there is no enclosing facility, which will ultimately destroy them.

Critical uncertainties:

- Degree that Copper Center may be at risk to climate changes.

Scenario 2

Collections face a high risk of damage, degradation, and destruction due to an increased likelihood of wildfires and increased pests from warmer temperatures. At Kennecott, continued sinking of the landscape will occur from the melting of Root Glacier, putting the collections at an increased risk to flooding from structural damage to the facility.

Scenario 3

Collections face a severe risk of damage, degradation, and destruction due to increased temperatures, precipitation, and humidity without a controlled environment and increased likelihood of wildfires, as well as destruction from increased snow loads on facilities that are structurally vulnerable. Increased temperatures may also result in additional threats to collections if there is a corresponding increase in museum pests. At Kennecott, continued sinking of the landscape will occur from the melting of Root Glacier, putting the collections at an increased risk to flooding from structural damage to the facility. At Bremner, objects will be directly impacted by an increase in mold and rust because there is no enclosing facility, which will ultimately destroy them.

Critical uncertainties:

- Degree that Copper Center may be at risk to climate changes.

Shared critical uncertainties:

- Better understand the nature of effects from pollutant exposure, and how they might change in response to changes in climate.



Landing a plane in the snowy forests of Chisana. NPS photo.

Human Systems: Snowmachine, off-road vehicle, watercraft use

Scenario 1

Winter

Snowmachine use opportunities will increase due to increased snowfall, however snowmachine season length will decrease from overall warmer temperatures and fewer below-freezing days. Snowmachine use in mid-winter (DJF) will increase due to warmer temps (i.e., less harsh conditions) in conjunction with daylight hours, however risk of accidents will increase due to more unstable conditions due to warmer shoulder-season temperatures (i.e., increased freeze-thaw events, warmer temperatures, increased precipitation) that lead to unstable ice conditions on rivers and possibly shifting windows of avalanche danger.

Summer

Jetboat and non-motorized watercraft use opportunities will expand in glacial and non-glacial streams and glacial drainages due to higher water levels from increased precipitation, runoff from snowmelt, and glacial melt, however hazards will increase from higher and more erratic water levels. Off-road vehicle (ORV) use opportunities will decrease due to increased rainfall, swollen streams, trail washouts, and thawing permafrost. ORVs may become more amphibious (i.e., all-terrain).

Critical uncertainties:

- Specific details regarding how increased snowfall will govern when the snowpack can really be “driven on” (e.g., snow takes time to settle, so more snowfall can mean LESS accessibility at times).
- Specific details about how risk of accidents will change, both seasonally and spatially (different drivers in different places and times).

Scenario 2

Winter

Snowmachine use opportunities will decrease due to warmer winters, lack of snowfall and freeze up in fall, and earlier snowmelt and ice out in spring, however snowmachine use in mid-winter (DJF) will increase due to less harsh conditions.

Summer

Jetboat use opportunities will increase in glacial systems due to more glacial melt and overall easier boating conditions. Non-motorized watercraft use opportunities will be lost in non-glacial streams as they will be too low for pack rafts. Off-road vehicle (ORV) use opportunities will increase, particularly in the north side of the park, due to overall drier (less boggy) conditions and reduced barrier streams/rivers in the fall.

Scenario 3

Winter

Snowmachine use opportunities will decrease due to warmer winters, lack of snowfall and freeze up in fall, and earlier snowmelt and ice out in spring, as well as across major rivers due to shorter periods of reliable ice. However, snowmachine use in mid-winter (DJF) will increase due to less harsh conditions. Moreover, **risk of accidents will increase** due to more unstable conditions due to warmer shoulder-season temperatures (i.e., hotter temperatures, increased and extreme precipitation) that lead to unstable ice conditions on rivers.

Summer

Jetboat and non-motorized watercraft use opportunities will expand significantly in glacial and non-glacial streams and glacial drainages due to higher water levels from increased precipitation, runoff from snowmelt, and glacial melt however **hazards will significantly increase** from higher and more erratic water levels. Off-road vehicle (ORV) use opportunities will decrease due to increased rainfall, swollen streams, trail washouts, and thawing permafrost. ORVs may become more amphibious (i.e., all terrain). ORV use will increase impacts (i.e., mass wasting events) to trails.

Critical uncertainties:

- Specific details about how risk of accidents will change, both seasonally and spatially (different drivers in different places and times).

Shared critical uncertainties:

- Details about how avalanche danger windows may shift.

- How changes in watercraft accessibility may vary spatially (not just a simple expansion—new hazards).
- Details regarding how ORV use opportunities will change seasonally due to changing climate.

Human Systems: Aviation use

Scenario 1

Winter

Variable temperatures above and below freezing with more frequent snowfall will help the interior winter ski flying. Dry light snow and extreme cold will make operations difficult and hazardous, but it will also make strong hard ice which makes waterbodies safer to utilize. High moisture and denser snow, deposited more frequently, generally produce a more useable and stable snowpack and support the aircraft much better. Warmer winter temps could make aircraft operations and skiing safer and easier if it means a higher proportion of ski-season days are below freezing but above zero Fahrenheit. Warmer temperatures could also make some of the areas on water bodies unusable due to lower ice thickness.

Summer

A longer summer season will increase tourism and associated flying and lengthen mineral extraction season and associated flying. Shrubification, already a reality at most of the more common fixed wing landing sites, will get moderately more aggressive, needing more frequent maintenance or use of helicopters. Increased snow during winter, although shorter in duration, will help slow shrubification into higher tundra areas that are currently used. Large precipitation events will take away some landing areas and open others. Floatplanes may need to be utilized more to get into the backcountry.

Scenario 2

Winter

There will be shorter ski seasons for flyers and skiers. Ski landings on snow-covered terrestrial areas will improve due to deeper snow coverage over brush and rocks and other obstacles below the snowpack. Warmer winter temps could make aircraft operations and skiing safer and easier if it means a higher proportion of ski-season days are below freezing but above zero. Long drying periods in winter will form unstable snow layers and reduce snowpack due to wind displacement and sublimation, but at this latitude dry winter days are usually cold. Long dry spells in winter, accompanied by high winds will make snow landings difficult or impossible in unprotected areas due to drifting of the wind affected snow. Warmer temperatures will also make some of the areas on water bodies unusable due to lower ice thickness.

Summer

Long hot dry spells will **increase fire potential, which drastically disrupts all flying except for fire suppression / monitoring / detection flying**. A longer summer season will increase tourism and associated flying and lengthen mineral extraction season and associated flying. Shrubification, already a reality at most of the more common fixed wing landing sites, will get slightly more

aggressive, needing more frequent maintenance or use of helicopters. Increased winter snowpack will partially compensate for dry summers by the increased spring snow melt charging the water table and lakes and rivers in spring, which may allow for use of float planes.

Scenario 3

Winter

There will be much shorter ski seasons for flyers and skiers, if at all. Ski landings on lakes or rivers, where warm water is introduced from subsurface or tributaries will be more difficult or impossible all winter, with a shorter season on others. Warmer winter temperatures could make aircraft operations and skiing safer and easier, but only if it means a higher proportion of ski-season days are below freezing but above zero, which is less likely in this scenario. Hotter temperatures will also make most of the areas on water bodies unusable due to lower ice thickness.

Summer

Increased fire potential will drastically disrupt all flying except for fire suppression / monitoring / detection flying. A longer summer season will increase tourism and associated flying and lengthen mineral extraction season and associated flying. **Shrubification, already a reality at most of the more common fixed wing landing sites a, will get severely more aggressive,** needing more frequent maintenance or use of helicopters. Large precipitation events will take away some landing areas and open others. Floatplanes may need to be utilized more to get into the backcountry.

Shared critical uncertainties:

- Degree of management on airstrips—will airstrips be maintained from shrubification, or will alternative access be required, or will access otherwise decline?

Human Systems: Recreating / backcountry use

Scenario 1

Winter

Mountaineering season—and therefore emergency response needs—will shift to earlier in spring, necessitating earlier staff onboarding and gearing up for emergency response. Mountaineering routes will change as glaciers melt / recede / change, but fewer incidents will occur due to increased snowpack.

Summer

The **need for trails will intensify due to changing vegetation/shrubification.** Backcountry river crossings will become more difficult/dangerous at certain times of the year due to high levels of spring run-off and increased rainfall. There will be declines in fixed-wing access and a changing brushline will **focus visitor use into smaller areas.**

Scenario 2

Winter

Mountaineering season—and therefore emergency response needs—will shift to earlier in spring, necessitating earlier staff onboarding and gearing up for emergency response. Mountaineering routes will change as glaciers melt / recede / change.

Summer

Visitor-use seasonality will shift to avoid wildfire impacts. Backcountry river crossings will become easier earlier in the season (relative to other scenarios) in many locations, particularly later in the season given glacially-fed streams and rivers will return to base flow earlier in the year, which will expand travel routes.

Scenario 3

Winter

Mountaineering season—and therefore emergency response needs—will shift much earlier in spring, necessitating earlier staff onboarding and gearing up for emergency response. Mountaineering routes will change as glaciers melt / recede / change, increasing incidents as new routes are established and past information becomes less reliable.

Summer

The need for trails will intensify due to changing vegetation/shrubification. Backcountry river crossings will become more difficult/dangerous due to high water levels due to increased rainfall. There will be declines in fixed-wing access and a changing brushline will focus visitor use into smaller areas.

Shared critical uncertainties:

- Degree of management on airstrips—will airstrips be maintained from shrubification, or will alternative access be required, or will access otherwise decline?

Human Systems: Hunting, trapping, fishing

Scenario 1

General access implications: Nabesna District ORV trails will degrade due to increased summer precipitation. River and stream crossing will become more difficult/dangerous in many locations due to higher water levels. Fixed-wing access will decline due to shrubification of non-riverine airstrips. Winter river crossings will be negatively affected by ice conditions.

Resource-specific harvest implications: 1) *Moose*—ease of harvest will be negatively impacted by degraded ORV trails and warmer and wetter weather that makes meat care more difficult; 2)

Caribou—ease of harvest will be negatively impacted by degraded ORV trails and warmer and wetter weather that makes meat care more difficult, snow-machine access issues will come into play (new season winter); 3) *Dall's sheep*—harvest will be more difficult because of degraded ORV trails and there will be increased exposure of Dall's sheep to hunting due to increased jetboat use; 4)

Salmon—harvest ease implications are uncertain; 5) *Non-salmon fishes*—there will be a small shift in safe and comfortable ice-fishing conditions towards mid-winter and away from spring; 6)

Furbearers—trapping season will contract and trap-check frequency will increase.

Critical uncertainties:

- Salmon—the relative influences (on ease of harvest) of higher water levels 1) reducing salmon density (by water volume) while also 2) potentially affecting in-river migration

behavior, 3) increased bank erosion will reduce ease of access for fish wheel-based harvest (which generally occurs off park lands).

- Whether hunters might be able to use jet boats to get closer to harvest areas due to more abundant water under this scenario.

Scenario 2

General access implications: Nabesna District ORV trail conditions will improve due to decreased summer and fall precipitation. River and stream crossing will become easier in many locations due to lower water levels during summer months. Fixed-wing access will decline due to shrubification of both non-riverine and river-bar airstrips. Winter river crossings will be negatively affected by ice conditions.

Resource-specific harvest implications: 1) *Moose*—ease of harvest will improve from improved ORV trail conditions, which will reduce the negative impact of warmer weather on meat care; 2) *Caribou*—ease of harvest will improve from improved ORV trail conditions, which will reduce the negative impact of warmer weather on meat care; 3) *Dall's sheep*—harvest will become easier because of improved ORV trails and there will be increased exposure of Dall's sheep to hunting due to increased jetboat use; 4) *Salmon*—harvest ease implications are uncertain; 5) *Non-salmon fishes*—there will be a small shift in safe and comfortable ice-fishing conditions towards mid-winter and away from spring; 6) *Furbearers*—trapping season will contract and trap-check frequency will increase.

Critical uncertainties:

- Whether and to what degree drying conditions may create new landing areas.
- Salmon—the relative influences (on ease of harvest) of higher water levels 1) reducing salmon density (by water volume) while also 2) potentially affecting in-river migration behavior, 3) decreased or unchanged bank erosion may increase/not change ease of access for fish wheel-based harvest (which generally occurs off parks lands).

Scenario 3

General access implications: Nabesna District ORV trail conditions will degrade due to increased summer precipitation. River and stream crossing will become more difficult/dangerous in many locations due to higher water levels. Fixed-wing access will decline due to shrubification of non-riverine airstrips. Winter river crossings will be negatively affected by ice conditions.

Resource-specific harvest implications: 1) *Moose*—ease of harvest will be negatively impacted by degraded ORV trails and much warmer and wetter weather that makes meat care more difficult; 2) *Caribou*—ease of harvest will be negatively impacted by degraded ORV trails and much warmer and wetter weather that makes meat care more difficult, snow-machine access issues will come into play (new season winter); 3) *Dall's sheep*—harvest will be more difficult because of degraded ORV trails and there will be increased exposure of Dall's sheep to hunting due to increased jetboat use; 4) *Salmon*—harvest ease implications are uncertain; 5) *Non-salmon fishes*—there will be a very large

shift in safe and comfortable ice-fishing conditions towards mid-winter and away from spring; 6) *Furbearers*—trapping season will contract and trap-check frequency will increase.

Critical uncertainties:

- Salmon—the relative influences (on ease of harvest) of higher water levels 1) reducing salmon density (by water volume) while also 2) potentially affecting in-river migration behavior, 3) increased bank erosion will reduce ease of access for fish wheel-based harvest (which generally occurs off park lands).
- Whether hunters might be able to use jet boats to get closer to harvest areas due to more abundant water under this scenario.

Shared critical uncertainties:

- Potential range expansions associated with climatic warming may make available harvest of species that currently do not have harvestable numbers (e.g., mule deer & mountain lion).
- Shifting rut seasonality.
- Degree of shrubification management on airstrips.

Human Systems: Wood & berry harvest

Scenario 1

Wood: Increasing availability for recreation (downed) due to increasing spruce bark beetle infestations in boreal forests from warmer conditions.

Berries: Access issues same as those for hunting and backcountry recreation.

Critical uncertainties:

- Wood harvest: Influence of increasing wildfire and tree mortality on wood availability.

Scenario 2

Wood: Reduced availability for recreation (downed) due to increasing wildfire in boreal forests.

Berries: Access issues same as those for hunting and backcountry recreation.

Scenario 3

Wood: Increasing availability for recreation (downed) due to increasing spruce bark beetle infestations in boreal forests from warmer conditions.

Berries: Access issues same as those for hunting and backcountry recreation.

Critical uncertainties:

- Wood harvest: Influence of increasing wildfire and tree mortality on wood availability.

Shared critical uncertainties:

- Berry harvest: Access uncertainties same as for hunting and backcountry recreation.



A fishwheel on the Copper River. Subsistence harvesting of fish is a central part of Alaska Native cultural identity and a major component of subsistence in Wrangell-St. Elias. Changes in resource availability may reshape this traditional practice. NPS photo by Barbara Cellarius.

Subsistence: Salmon

Scenario 1

Resource availability may change, perhaps dramatically, in terms of both greater temporal variability and strong trends (complex system—change likely but difficult to predict). Harvest opportunities will shift in space as bank erosion (as a result of high water) on the Copper River will result in the loss of some fish wheel sites. For some subsistence users this will mean additional time and effort in order to find a different location for their wheels. Others may elect to try to harvest their fish with a dip net instead, potentially adding additional travel time to reach sites where dip netting is effective (on average, dipnetters harvest fewer fish per permit than do fishwheel users, so this could reduce overall harvest levels). ***Warmer weather (and potentially warmer water) will pose a challenge to the preservation of salmon.***

Critical uncertainties:

- Degree to which fish wheel efficiency changes due to high water levels.

Scenario 2

Resource availability may change, perhaps dramatically, in terms of both greater temporal variability and strong trends (complex system—change likely but difficult to predict). Harvest opportunities will shift in space as bank erosion (during spring high water due to glacial melt) on the Copper River will result in the **loss of some fish wheel sites and subsequent low water will potentially reduce fish wheel effectiveness** in some sites. For some subsistence users this will mean additional time and effort in order to find a different location for their wheels. Others may elect to try to harvest their fish with a dip net instead, potentially adding additional travel time to reach sites where dip netting is effective (on average, dipnetters harvest fewer fish per permit than do fishwheel users, so this could reduce overall harvest levels). Warmer weather (and potentially warmer water) will pose a challenge to the preservation of salmon.

Critical uncertainties:

- Degree to which fish wheel efficiency changes due to low water levels.

Scenario 3

Resource availability may change, perhaps dramatically, in terms of both greater temporal variability and strong trends (complex system—change likely but difficult to predict). Harvest opportunities will shift in space as bank erosion (as a result of high water) on the Copper River will result in the loss of some fish wheel sites. For some subsistence users this will mean additional time and effort in order to find a different location for their wheels. Others may elect to try to harvest their fish with a dip net instead, potentially adding additional travel time to reach sites where dip netting is effective (on average, dipnetters harvest fewer fish per permit than do fishwheel users, so this could reduce overall harvest levels). **Warmer weather (and potentially warmer water) will pose a challenge to the preservation of salmon.**

Critical uncertainties:

- Degree to which fish wheel efficiency changes due to high water levels.

Shared critical uncertainties:

- Manner and degree to which salmon responses to changing marine conditions may affect salmon responses to changing freshwater conditions (inclusive of river flow and aquatic food webs).
- Degree to which changing climate may influence the current trend of declining salmon body size and increased parasites, etc., which may reduce calories/nutrition per salmon harvested.
- Degree to which reduced winter severity and enhanced rearing conditions offset effects of heat stress and increased heavy rain events.
- Aquatic food web change effects on productivity.
- Changing glacial melt season and how this matches salmon life history (could be very strongly impactful).

Subsistence: Freshwater fishes

Scenario 1

Resource availability will shift and generally improve across the landscape—to a moderate degree—as contrasting (but largely positive) impacts of moderate warming will expand habitat (but increase thermocline depth) and increase productivity and winter survivorship. Ice-fishing harvesting opportunities (i.e., safe and comfortable conditions) will continue to steadily shift towards mid-winter and away from late spring.

Scenario 2

Resource availability will shift and generally improve across the landscape—to a moderate degree—as contrasting (but largely positive) impacts of moderate warming will expand habitat (but increase thermocline depth) and increase productivity and winter survivorship. Ice-fishing harvesting opportunities (i.e., safe and comfortable conditions) will continue to steadily shift towards mid-winter and away from late spring.

Scenario 3

Resource availability will shift and generally improve across the landscape—rapidly—as contrasting (but largely positive) impacts of moderate warming will expand habitat (but increase thermocline depth) and increase productivity and winter survivorship. Ice-fishing harvesting opportunities (i.e., safe and comfortable conditions) will shift rapidly towards mid-winter and away from late spring.

Shared critical uncertainties:

- Degree to which warming increases extent of beaver-created pond habitat.
- Freshwater fish assemblage changes, particularly for species such as lake trout that will experience contrasting influences (increased dissolved oxygen but also increased thermocline depth).

Subsistence: Moose

Scenario 1

Resource availability will persist largely unchanged unless a changing climate allows arrival of a new pathogen that reduces population size or meat or hide quality. **Harvest opportunities and ease will decline substantially** due to reduced access (soggy trails, high water at stream crossings, and shrubification), which will exacerbate **growing meat care challenges** in this moderately warming scenario, leading to a shift towards more road-, boat-, or aviation-based harvesting.

Scenario 2

Resource availability will persist largely unchanged unless a changing climate allows arrival of a new pathogen that reduces population size or meat or hide quality. Harvest opportunities will persist largely unchanged because trails remain dry, although 1) stream crossings will become more difficult due to enhanced glacial melt, which will exacerbate **growing challenges of meat care** in this moderately warming scenario, and 2) modest competition issues with sport hunters will arise as harvest shifts towards later, cooler part of the season.

Scenario 3

Resource availability will persist largely unchanged unless a changing climate allows arrival of a new pathogen that reduces population size or meat or hide quality. **Harvest opportunities and ease will decline substantially** due to 1) reduced access (soggy trails and widespread permafrost thaw, high water at stream crossings, and shrubification), which will exacerbate **severe meat care challenges** in this dramatically warming scenario, leading to a major shift towards more road-, boat-, or aviation-based harvesting, and 2) strong competition with sport hunters as harvest shifts dramatically towards the later, cooler part of the season.

Shared critical uncertainties:

- Likelihood of arrival and nature of impact of new pathogens brought by a changing climate.
- Whether and how timing of rut may shift due to a changing climate, impacting the hunting season.
- Changing temperature effects on animal movement patterns (connected to changes in rut).

Subsistence: Dall's sheep

Scenario 1

Resource availability (abundance) will decline substantially. Harvest opportunities and ease will decline substantially due to reduced access (soggy trails, high water at stream crossings, and shrubification), which will exacerbate growing challenges of meat care in this moderately warming scenario, leading to a shift (to the degree that the populations can continue to sustain a harvest) towards more boat-based harvesting that takes advantage of higher waters and the fact that high waters expand the reach of boat-based harvest.

Scenario 2

Resource availability (abundance) will decline substantially. Harvest opportunities and ease will persist largely unchanged because trails will remain dry (increasing access to some populations relative to current levels), although stream crossings will become more difficult due to enhanced glacial melt. There will be a shift towards more boat-based harvesting that takes advantage of (spatially heterogeneous) higher waters and the fact that high waters expand the reach of boat-based harvest.

Scenario 3

Resource availability (abundance) will decline substantially. Harvest opportunities and ease will decline substantially due to reduced access (soggy trails, widespread permafrost thawing, high water at stream crossings, and shrubification), which will exacerbate growing challenges of meat care in this rapidly warming scenario, leading to a shift (to the degree that the populations can continue to sustain a harvest) towards more boat-based harvesting that takes advantage of higher waters and the fact that high waters expand the reach of boat-based harvest.

Shared critical uncertainties:

- Likelihood of arrival and nature of impact of new pathogens or diseases (e.g., brought by the expansion of ranges of other species due to a changing climate).

- Changing temperature effects on animal movement patterns.

Subsistence: Caribou

Scenario 1

Resource availability (abundance) will persist largely unchanged. ***Harvest opportunities and ease will decline substantially*** due to reduced access (soggy trails, high water at stream crossings, and shrubification), which will exacerbate growing challenges of meat care in this moderately warming scenario.

Scenario 2

Resource availability (abundance) will persist largely unchanged. Harvest opportunities and ease will persist largely unchanged because trails remain dry, although access to some areas becomes more difficult due to peripheral permafrost thaw, which will exacerbate growing challenges of meat care in this moderately warming scenario.

Scenario 3

Resource availability (abundance) will persist largely unchanged. ***Harvest opportunities and ease decline very substantially*** due to 1) reduced access (soggy trails and widespread permafrost thawing, high water at stream crossings, and shrubification), which will exacerbate severe challenges of meat care in this dramatically warming scenario, leading to a major shift towards more road-, boat-, or aviation-based harvesting.

Subsistence: Harbor seals

Scenario 1

Resource availability (abundance) will increase in response to increased ice habitat. Harvest opportunities will increase due to reduced boat travel distances.

Scenario 2

Resource availability (abundance) will decline in response to reduced ice habitat. ***Harvest opportunities will decline*** due to increased boat travel distances (because seals group at a distance from the glacier terminus) and cruise ship-driven impacts to access, unless seals move to and use terrestrial sites in Yakutat Bay or thereabouts.

Critical uncertainties:

- Degree to which, as ice declines, seals move to and use terrestrial sites in Yakutat Bay or surrounding areas.

Scenario 3

Resource availability (abundance) will decline in response to reduced ice habitat. ***Harvest opportunities will decline*** due to increased boat travel distances (because seals group at a distance from the glacier terminus) and cruise ship-driven impacts to access, unless seals move to and use terrestrial sites in Yakutat Bay or thereabouts.

Critical uncertainties:

- Degree to which, as ice declines, seals move to and use terrestrial sites in Yakutat Bay or surrounding areas.

Shared critical uncertainties:

- Whether the Malaspina Glacier becomes a tidewater glacier and, if so, how this change impacts seal habitat and abundance.
- Degree to which changes to tidewater glaciers elsewhere in the region affect cruise ship traffic in/near WRST.
- Degree to which marine processes influence seal condition and ultimately abundance (e.g., via potential changes in prey availability).

Subsistence: Wolves

Scenario 1

Resource availability (abundance) will persist largely unchanged. Harvest opportunities and ease will decline due to a shorter snowmachine season, less stable ice on water crossings, and increasing trap-check frequency. Fewer extreme cold conditions will slightly reduce fur quality (not preserved between trap checks) and cause loss of trapping participation.

Scenario 2

Resource availability (abundance) will persist largely unchanged. Harvest opportunities and ease will decline due to a shorter season when fur is in prime condition, less stable ice on water crossings, and increasing trap-check frequency. Fewer extreme cold conditions will moderately reduce fur quality (not preserved between trap checks) and cause loss of trapping participation.

Scenario 3

Resource availability (abundance) will persist largely unchanged. Harvest opportunities and ease will decline substantially due to a shorter snowmachine season, much less stable ice on water crossings, and increasing trap-check frequency. Fewer extreme cold conditions will drastically reduce fur quality (not preserved between trap checks) and cause loss of trapping participation.

Subsistence: Brown bears

Scenario 1

Resource availability (abundance) changes are uncertain but unlikely to be large. Hibernation length will be slightly impacted by warming temperatures. ***Harvest opportunities and ease will decline*** due to soggy trails, but higher water levels will make boat-based harvest easier.

Scenario 2

Resource availability (abundance) changes are uncertain but unlikely to be large. Hibernation length will be moderately impacted by warming temperatures. Harvest opportunities and ease will remain good due to dry trails, but permafrost thaw will constrain access in some areas.

Scenario 3

Resource availability (abundance) changes are uncertain but may trend downward due to strong negative climate impacts. Hibernation length will be drastically impacted by warming temperatures. ***Harvest opportunities and ease will decline substantially*** due to soggy trails, widespread permafrost thawing, and shrubification but higher water levels will make boat-based harvest easier.

Subsistence: Black bears

Scenario 1

Resource availability (abundance) changes are uncertain but unlikely to be large. Hibernation length will be slightly impacted by warming temperatures. ***Harvest opportunities and ease will decline*** due to soggy trails, but higher water levels will make boat-based harvest easier.

Scenario 2

Resource availability (abundance) changes are uncertain but unlikely to be large. Hibernation length will be moderately impacted by warming temperatures. Harvest opportunities and ease will remain good due to dry trails, but permafrost thaw will constrain access in some areas.

Scenario 3

Resource availability (abundance) changes are uncertain but may trend downward due to strong negative climate impacts. Hibernation length will be drastically impacted by warming temperatures. ***Harvest opportunities and ease will decline substantially*** due to soggy trails, widespread permafrost thawing, and shrubification but higher water levels will make boat-based harvest easier.

Subsistence: Wood & berries

Scenario 1

Wood: Increased availability for subsistence (standing dead) due to increased spruce bark beetle infestations in boreal forests from warmer conditions.

Berries: Phenological mismatch with subsistence (traditional gathering times). Upward shift of distributions, however shifts will be starkly limited by soil type, which could lead to overall reduction of distributions. Overall resource availability (abundance) will persist with modest but uncertain changes in all non-tundra species (blueberry, cranberry, raspberry, soapberry) and some declines in tundra species (cloudberry) due to some permafrost thaw. Harvest opportunities and ease will decline due to soggy trails, higher water at stream crossings, causing some changes in where berries are harvested.

Scenario 2

Wood: Reduced availability for subsistence (standing dead) due to increased wildfire in boreal forests.

Berries: Phenological mismatch with subsistence (traditional gathering times). Upward shift of distributions, however shifts will be starkly limited by soil type, which could lead to overall reduction of distributions. Overall resource availability (abundance) changes will include 1) declines in some non-tundra species (blueberry, cranberry) due to drought, 2) no change or increases in other

non-tundra species (raspberries, soapberries) due to drought-tolerance, and 3) modest declines in tundra species (cloudberry) due to modest permafrost thaw. Harvest opportunities and ease will continue or even improve due to dry trails and easier stream crossings.

Critical uncertainties:

- Wood harvest: Influence of increasing wildfire and tree mortality on wood availability.

Scenario 3

Wood: Increased availability for subsistence (standing dead) due to increased spruce bark beetle infestations in boreal forests from warmer conditions, but subsistence harvest may become more difficult in spring due to warmer boreal conditions reducing snow cover (which allows use of snow machines, the easiest means of harvest) during periods when daylight hours allow harvest.

Berries: Phenological mismatch with subsistence (traditional gathering times). Upward shift of distributions, however shifts will be starkly limited by soil type, which could lead to overall reduction of distributions. Overall resource availability (abundance) will change substantially, including 1) large declines in all non-tundra species (cranberry, raspberry, soapberry) but especially blueberries due to tall shrub/tree competition, 2) substantial declines in tundra species (cloudberry) due to substantial permafrost thaw, and 3) arrival of new (regionally native) species from outside the park. Harvest opportunities and ease will decline due to soggy trails, higher water at stream crossings, causing some changes in where berries are harvested.

Critical uncertainties:

- Wood harvest: Influence of increasing wildfire and tree mortality on wood availability.



Backpackers taking in the view from Skookum Volcano Trail. NPS photo.

Wilderness: Solitude

Scenario 1

Opportunities for solitude and remoteness will decrease (in some areas) due to increased visitor concentration from warmer weather and fewer sunny flying days, changing visitation routes from altered vegetation communities and waterways, more concentrated snowmachine and watercraft use, potentially increased overflights (see critical uncertainty below), and increased and changing technologies. Wetter conditions will result in greater demand for existing public use cabins, which would degrade solitude through increasing visitor numbers.

Scenario 2

Opportunities for solitude and remoteness will decrease due to increased visitor concentration on smoke-free days, more concentrated ORV and watercraft use, potentially increased overflights (see critical uncertainty below), and increased and changing technologies.

Scenario 3

Opportunities for solitude and remoteness will decrease due to increased visitor concentration from warmer weather, changing visitation routes from changing vegetation communities and waterways, more concentrated watercraft use, potentially increased overflights (see critical uncertainty below), and increased and changing technologies. Wetter and more extreme conditions will result in greater

demand for existing public use cabins, which would degrade solitude through increasing visitor numbers.

Shared critical uncertainties:

- Aviation use overall will vary (increase/decrease) depending on activity, season, and individual weather days.
- Change in flightseeing (possibly driven by cruise ship volume changes).

Wilderness: Night skies

Scenario 1

Star and northern lights viewing opportunities will decrease parkwide (but particularly in Coastal Mountains) due to increasing cloud cover and brighter photic environments from increasing snow cover duration.

Scenario 2

Changes to star and northern lights viewing opportunities are uncertain because decreased cloud cover and darker photic environments (from decreased snow cover extent) may improve viewing, but increased wildfire smoke may decrease opportunities.

Scenario 3

Star and northern lights viewing opportunities will decrease parkwide (but particularly in Coastal Mountains) due to increasing cloud cover and increasing wildfire smoke.

Wilderness: Natural soundscape

Scenario 1

Acoustic environments will change due to increased precipitation and glacial melt (increasing streamflow), reducing the volume that listeners interact with and thereby having the effect of making anthropogenic noise less evident.

Human: Natural soundscapes will degrade due to spatially and temporally dependent increases in aviation, snowmachine, and watercraft use. Increasing visitor numbers will drive pressure for additional infrastructure.

Natural: Acoustic environments will become more energetic but shrubification will dampen wind, altering soniferous communities. Changing geophysical processes will lead to dramatic soundscape changes.

Scenario 2

Acoustic environments will change during late summer and fall due to decreased precipitation (reduced streamflow), increasing the volume that listeners interact with and thereby having the effect of making anthropogenic noise more evident.

Human: Natural soundscapes will degrade due to spatially- and temporally-dependent increases in aviation, snowmachine, and ORV use, especially from firefighting activities during fire season. Winter soundscapes will remain more intact due to generally decreased snowmachine activity.

Increased length of high visitation season will increase length of anthropogenic noise and increasing visitor numbers will drive pressure for additional infrastructure.

Natural: Acoustic environments will become more energetic but shrubification will dampen wind, altering soniferous communities. Changing geophysical processes will lead to dramatic soundscape changes.

Scenario 3

Acoustic environments will change due to increased precipitation and glacial melt (increasing streamflow), reducing the volume that listeners interact with and thereby having the effect of making anthropogenic noise less evident.

Human: Natural soundscapes will degrade due to spatially- and temporally-dependent increases in aviation, snowmachine, and watercraft use. Winter soundscapes will remain more intact due to generally decreased snowmachine activity. Increasing visitor numbers will drive pressure for additional infrastructure.

Natural: Acoustic environments will become more energetic but shrubification will dampen wind, altering soniferous communities. Changing geophysical processes will lead to transformational soundscape changes.

Shared critical uncertainties:

- Aviation use will vary (increase/decrease) depending on activity, season, and individual weather days
- Degree to which greater demand for visitor infrastructure leads to management decisions to construct additional infrastructure.

Wilderness: Wilderness character

Scenario 1

Natural: Changes to biophysical resources will change the natural quality of wilderness character.

Undeveloped: Undeveloped quality will be degraded due to spatially- and temporally-dependent increases in aviation, snowmachine, and watercraft use, and there will be increased demand for construction to support increased visitor use (e.g., wetter weather will result in increased demand for existing public use cabins; the park might develop more airstrips and trails in response to shrubification and flooding). Undeveloped quality will be degraded by additional monitoring instruments.

Unconfined Recreation: Increasing hazards due to biophysical changes (flooding, glacial melt, etc.) and flooding will lead to pressures to develop additional visitor rules/restrictions.

Scenario 2

Natural: Changes to biophysical resources will change the natural quality of wilderness character.

Undeveloped: Undeveloped quality will be degraded due to spatially- and temporally-dependent increases in aviation, snowmachine, and ORV use, especially from firefighting activities during fire season, and there will be increased demand for construction to support increased visitor use (e.g., the park might develop more facilities like airstrips and trails in response to shrubification and flooding). Increased length of high visitation season will increase length of anthropogenic noise. Undeveloped quality will be degraded by additional monitoring instruments.

Unconfined Recreation: Increasing hazards due to biophysical changes (wildfire, glacial melt, etc.) and (glacial melt-driven) flooding will lead to pressure to develop additional visitor rules/restrictions.

Scenario 3

Natural: Changes to biophysical resources will significantly change the natural quality of wilderness character.

Undeveloped: Undeveloped quality will be degraded due to spatially- and temporally-dependent increases in aviation, snowmachine, and watercraft use, and there will be increased demand for construction to support increased visitor use (e.g., wetter weather will result in increased demand for existing public use cabins; the park might develop more facilities like airstrips and trails in response to shrubification and flooding). Winter soundscapes will remain more intact due to decreased snowmachine activity. Undeveloped quality will be degraded by additional monitoring instruments.

Unconfined Recreation: Increasing hazards due to biophysical changes (flooding, glacial melt, wildfire, etc.) and flooding will lead to pressures to develop additional visitor rules/restrictions.

Shared critical uncertainties:

- Aviation use will vary (increase/decrease) depending on activity, season, and individual weather days.

Operationalizing climate-resource scenarios

Climate change and other global change stressors challenge land managers' abilities to protect natural areas and demand that we re-think conservation concepts, goals, and actions (activities) in a continuously changing world (Hobbs et al. 2010, NPS AB 2012, Fisichelli et al. 2016). Climate change adaptation is, in simple terms, adjustment to changing conditions. It is, more formally, “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007).

The next step in the climate change adaptation process was translating insights derived from scenario planning into climate-informed management plans for implementation. To develop adaptation options, the process included a step of identifying “critical implications” for each resource, i.e., implications identified as common to all scenarios (Table 3, Common to all scenarios), or “highly consequential” implications relevant to a subset of resources and requiring special consideration (Table 3, Not common to all scenarios) (Miller et al. 2022). All implications presented here are critical and warrant a management response, but this “two-track” presentation maintains clarity regarding which implications are likely to occur because they are associated with all scenarios and those that may only occur in a subset but are highly consequential. Both types require anticipatory adaptation but with potentially differing strategies. Under this process, park staff focused both on outcomes of the implications common to all scenarios, and on those that appear only in a subset of scenarios but are highly consequential to priority resources.

In a subsequent adaptation workshop, participants reviewed and refined candidate critical implications identified by the climate change team for each resource (see Figure 2; Schuurman et al. 2024). In a few cases, participants made changes to critical implications at this stage for clarity or completeness, and therefore WRST critical climate change implications in this report are the most current (Table 3).

In the two-day adaptation workshop, participants (park staff and other SMEs) used critical implications for each resource—along with the characterization of how climate might affect non-climate resource stressors (Appendix 5)—to develop actions that the park can take to address ongoing and plausible future climate change impacts. Details and outcomes of that process are fully described in Schuurman et al. (2024).

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Appendix 1. Scenario planning meetings timeline

The climate-resource scenarios for WRST were developed through a series of meetings, each focused on one of eight “priority resources.” Priority-resource groups were strategically sequenced (Table A1) so cumulative information could be used to generate fully integrated, consistent scenarios. Generally, each priority-resource group met twice (except for Vegetation and Wildlife⁶). The initial meeting began with an introductory call where the climate change team explained the use of scenario planning in an RSS, steps for creating scenarios, and desired outcomes. The climate change team then facilitated a discussion to develop the best framework for classifying resources to elicit scenarios (e.g., Historic Structures were clustered into categories by ecosystems where structures were located; salmon were clustered by species and whether they spawned in glacially fed systems).

Table A1. Priority-resource group meeting dates in 2021.

Resource Group	Meeting 1 Date	Meeting 2 Date
Vegetation	26-Aug	–
Hydrology	30-Sep	25-Oct
Wildlife	29-Sep	13-Oct*
Aquatics	01-Oct	27-Oct
Human systems	12-Oct	25-Oct
Wilderness values	12-Oct	17-Nov
Cultural resources	15-Oct	27-Oct
Subsistence	28-Oct	15-Nov

The rest of the meeting focused on eliciting climate change implications for each of the scenarios. Participants were encouraged to use a variety of materials targeting their specific resource group: climate futures packets (Appendix 4), a worksheet of non-climate stressors developed for each climate future (Appendix 5), and implications worksheets for other priority-resource groups. Participants used this information to identify potential implications for each priority-resource component under each climate future.

The climate change team facilitated discussion through as many priority-resource components as possible during Meeting 1, with participants encouraged to continue filling in implications independently after the meeting (usually for a period of one week). The climate change team then summarized the draft implications and flagged any questions or inconsistencies between priority

⁶ In response to participant feedback and requests for more guidance, the process for developing scenarios was modified following the vegetation group. This resource group had a single meeting with subsequent online review. The Wildlife group met a third time on 20 October to finalize ungulate implications.

resources. In Meeting 2, participants reviewed the summaries for completeness and accuracy and finalized the implications for all resource components.

Appendix 2. Scenario planning participants

Table A2. Subject-matter experts involved in developing climate-resource scenarios for WRST.

Name	Affiliation	Priority resource group
Mark Miller	NPS, WRST	All
Jennifer Barnes	NPS, AKRO	Vegetation
Fleur Nicklen	NPS, CAKN	Vegetation
Peter Neitlich	NPS, AKRO	Vegetation
Carl Roland	NPS, CAKN	Vegetation
Sarah Stehn	NPS, CAKN	Vegetation
Kate Baer	USDA	Vegetation
Grant Hilderbrand	NPS, AKRO	Wildlife
Melanie Flamme	NPS, YUCH	Wildlife
John Jansen	NOAA	Wildlife
Seth Danielson	U Alaska - Fairbanks	Wildlife
Josh Schmidt	NPS, CAKN	Wildlife
Mary Hake	NPS, AKRO	Wildlife
Scott Gende	NPS, GLBA	Wildlife
Mathew Sorum	NPS, YUCH	Wildlife
Judy Putera	NPS, WRST	Wildlife, Subsistence
Jamie Womble	NPS, SEAN	Wildlife, Subsistence
Heidi Hatcher	AK Dept Fish and Game	Wildlife
David Payer	NPS, AKRO	Wildlife
Jeff Wells	AK Dept Fish and Game	Wildlife
Jeff Gross	AK Dept Fish and Game	Wildlife
Trey Simmons	NPS, CAKN	Glaciers & Hydrology, Aquatics
Amy Larsen	NPS, CAKN	Glaciers & Hydrology
Andrew Bliss	NPS, SEAN	Glaciers & Hydrology
Paul Burger	NPS, AKRO	Glaciers & Hydrology
Mike Loso	NPS, WRST	Glaciers & Hydrology
David Sarafin	NPS, WRST	Glaciers & Hydrology, Aquatics, Human systems, Subsistence
Melissa Valentin	2100 Consulting Public Benefit Corporation	Glaciers & Hydrology
Jeremy Littell	USGS, AK CASC	Glaciers & Hydrology
Dana Brown	U Alaska - Fairbanks	Glaciers & Hydrology, Human systems, Subsistence
Dave Lawrence	NPS, CCRP	Aquatics
Kristen Gorman	U Alaska - Fairbanks	Aquatics

Table A2 (continued). Subject-matter experts involved in developing climate-resource scenarios for WRST.

Name	Affiliation	Priority resource group
Pete Rand	Prince William Sound Science Center	Aquatics
Rachel Mason	NPS, AKRO	Human Systems, Cultural resources
Nyssa Landres	NPS, WRST	Human Systems, Wilderness values
Don Welty	NPS, WRST	Human Systems
Jesse Heinbaugh	NPS, WRST	Human Systems
Joshua Scott	NPS, WRST	Human Systems
Barbara Cellarius	NPS, WRST	Human Systems, Cultural resources, Subsistence
Timothy Mullet	NPS, KEFJ	Wilderness values
Davyd Betchkal	NPS, AKRO	Wilderness values
Adrienne Lindholm	NPS, AKRO	Wilderness values
Heather Feil	NPS, AKRO	Cultural resources
Lee Reininghaus	NPS, WRST	Cultural resources
Desiree Ramirez	NPS, WRST	Cultural resources
Kelsey Lutz	NPS, AKRO	Cultural resources
Shina duVall	NPS, AKRO	Cultural resources
Grant Crosby	NPS, AKRO	Cultural resources
Odin Miller	Ahnta Intertribal Resource Commission	Subsistence
Caroline Ketron	BLM	Subsistence
Gregor Schuurman	NPS, CCRP	Climate change team
Amber Runyon	NPS, CCRP	Climate change team
Brecken Robb	NPS, CCRP; USGS, NC CASC	Climate change team
Garrett Knowlton	NPS, CCRP	Climate change team
Joel Reynolds	NPS, CCRP	Climate change team

Appendix 3. Climate metrics and development of climate futures

Table A3.1. Climate sensitivity scores of seventeen variables for components of the eight priority resources. Climate sensitivity scores were developed through SME interviews and surveys. For components that appear under more than one priority resource group, the sensitivities identified in the Subsistence group refer specifically to sensitivity of subsistence uses and the sensitivity listed under the primary priority resource refers to the biotic sensitivity. Numbers identify the proportion of SMEs who reported the metric to be a climate sensitivity of each component. The top metrics that were used for selecting climate futures (indicated by “Y” in top row) were identified by averaging the responses then ranking them. Park SME’s responses were given double weight and the final list was validated by park managers.

Priority Resource	Component	Winter tempera- ture	Spring tempera- ture	Summer tempera- ture	Fall tempera- ture	Winter precipita- tion	Spring precipita- tion	Summer precipita- tion	Snow depth	Shoulder season snow	Clim water deficit / water balance	Avg annual tempera- ture	Seasonal mean tmax	Seasonal mean tmin	Freeze- thaw cycles	Seasonal freeze events	Growing season length / degree days	Freq of hot days
–	Top metrics	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N
Hydrologic Systems	Glaciers	0.8	0.7	1.0	0.7	0.8	0.7	0.5	1.0	1.0	0.7	0.5	0.5	0.5	0.3	0.3	0.7	0.8
	Rivers	1.0	1.0	1.0	0.8	1.0	0.8	1.0	0.8	0.6	0.8	0.6	0.4	0.6	0.2	0.6	0.4	0.2
	Non-glacial streams	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	0.8	0.8	0.5	0.3	0.5	0.5	0.5	0.5	0.5
	Lakes	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0
	Wetlands	0.7	1.0	1.0	0.7	1.0	1.0	1.0	0.3	0.3	0.7	0.7	0.3	0.7	0.7	0.7	0.3	0.7
Subsistence	Salmon	0.3	0.3	0.5	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.0	0.0	0.2	0.0	0.5
	Freshwater fish	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Moose	0.7	0.5	0.5	0.8	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.3
	Dall’s sheep	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Caribou	0.8	0.7	0.5	0.8	0.7	0.5	0.5	0.7	0.7	0.3	0.5	0.3	0.3	0.5	0.5	0.5	0.6
	Harbor seals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Wolves	0.8	0.7	0.5	0.7	0.2	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0
	Brown bears	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Black bears	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Berries	0.0	0.3	0.4	0.4	0.3	0.3	0.4	0.0	0.5	0.3	0.3	0.0	0.0	0.3	0.5	0.3	0.3
	Users & stakeholders	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Human Systems	Hunting, trapping, fishing	1.0	0.9	1.0	1.0	0.8	0.6	0.8	1.0	0.8	0.6	0.8	0.8	0.6	1.0	0.8	0.9	0.8
	Wood & berry harvest	0.5	0.6	0.4	0.4	0.5	0.5	0.8	0.8	0.8	0.4	0.5	0.3	0.3	0.8	0.4	0.5	0.8
	Active mining	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Recreating / backcountry use	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	1.0	0.7	0.7	0.7	1.0	0.7	1.0
	Research	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Aviation use	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.5	0.5	0.5	0.3	0.8	0.8	0.5	0.5
	Snowmachine, ATV, jetboat use	0.8	0.8	0.8	1.0	0.8	0.6	0.6	0.8	0.8	0.6	0.4	0.4	0.4	0.8	1.0	0.4	0.6
	Complex spatial patterns of land tenure/access	1.0	0.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	Ethnography	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0

Table A3.1 (continued). Climate sensitivity scores of seventeen variables for components of the eight priority resources. Climate sensitivity scores were developed through SME interviews and surveys. For components that appear under more than one priority resource group, the sensitivities identified in the Subsistence group refer specifically to sensitivity of subsistence uses and the sensitivity listed under the primary priority resource refers to the biotic sensitivity. Numbers identify the proportion of SMEs who reported the metric to be a climate sensitivity of each component. The top metrics that were used for selecting climate futures (indicated by “Y” in top row) were identified by averaging the responses then ranking them. Park SME’s responses were given double weight and the final list was validated by park managers.

Priority Resource	Component	Winter tempera- ture	Spring tempera- ture	Summer tempera- ture	Fall tempera- ture	Winter precipita- tion	Spring precipita- tion	Summer precipita- tion	Snow depth	Shoulder season snow	Clim water deficit / water balance	Avg annual tempera- ture	Seasonal mean tmax	Seasonal mean tmin	Freeze- thaw cycles	Seasonal freeze events	Growing season length / degree days	Freq of hot days
Cultural Resources	Archeological resources	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0	0.0	0.8
	Cultural landscapes	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.0	0.6	0.0	0.0	0.0	0.5	0.0	0.8	0.6
	Historic & prehistoric structures	0.5	1.0	0.5	0.5	1.0	1.0	1.0	0.6	0.5	0.8	0.5	0.5	0.5	0.7	0.4	0.8	0.6
	Kennecott Mines NHL	0.5	1.0	0.5	0.5	0.8	1.0	0.8	0.6	0.5	0.8	0.5	0.5	0.5	0.7	0.4	0.8	0.6
	Museum collections (all)	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0
	Museum collections - Kennecott	–	–	–	–	–	1.0	–	–	–	–	–	0.7	–	0.7	–	–	0.7
	Museum collections - Copper Center	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Museum collections - Glennallen Conex	–	–	–	–	–	0.7	–	–	–	–	–	0.7	–	0.7	–	–	0.7
Aquatics	Salmon	1.0	1.0	1.0	1.0	0.7	0.7	0.7	0.7	0.7	0.7	1.0	1.0	1.0	1.0	1.0	0.7	0.7
	Other	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Focal Wildlife Species	Caribou	0.7	0.8	0.8	0.7	0.8	0.6	0.3	1.0	0.5	0.5	0.4	1.0	1.0	0.8	0.4	0.8	0.6
	Moose	0.5	0.5	0.8	0.2	0.7	0.3	0.3	0.8	0.5	0.0	0.7	0.7	0.0	0.5	0.0	0.8	0.8
	Dall’s sheep	0.4	0.5	0.0	0.0	0.8	0.5	0.5	0.9	0.6	0.5	0.4	0.3	0.0	0.8	0.0	0.9	0.3
	Wolves	1.0	1.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
	Brown bears	0.7	0.7	0.3	0.5	0.0	0.7	0.7	0.3	0.5	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3
	Black bears	–	–	–	–	–	0.7	0.7	–	0.7	–	–	–	–	–	–	–	–
	Bald eagles	0.3	1.0	0.5	0.3	0.8	0.8	0.7	0.7	0.8	0.5	0.3	0.8	0.5	0.0	0.0	0.3	0.0
	Harbor seals	0.3	0.7	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.7	0.3	0.7	0.7	0.7	1.0	0.3	0.7
	Sea otters	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	2.0	3.0	1.0	2.0
Wilderness Values	Solitude	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5	1.0	0.5	0.0	0.0	0.0	0.5	1.0
	Night skies	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Natural soundscape	1.0	1.0	1.0	1.0	0.5	0.5	0.5	1.0	1.0	0.5	0.5	0.0	0.0	0.0	0.0	0.5	0.5
Vegetation Dynamics	Soils & permafrost	0.8	0.8	0.8	0.6	0.9	0.4	0.4	1.0	0.8	0.2	1.0	0.2	0.2	0.0	0.0	0.7	0.0
	Lichen	0.0	0.5	0.5	0.5	1.0	1.0	1.0	0.5	0.0	0.5	0.5	0.5	0.5	0.5	0.0	1.0	0.5
	Berry production	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
	Boreal forests	0.3	1.0	1.0	1.0	0.3	0.7	0.7	0.7	0.7	0.7	1.0	0.3	0.0	0.3	0.0	0.7	0.3
	Subalpine shrublands / woodlands	0.3	0.8	1.0	0.8	0.0	0.5	0.5	1.0	0.5	0.5	1.0	0.8	0.3	0.0	0.0	0.8	0.5
	Alpine tundra	0.7	0.7	1.0	0.7	0.7	0.3	0.3	1.0	0.7	0.3	1.0	0.7	0.7	0.3	0.3	0.7	0.3
	Coastal forests	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3.2. Climate sensitivity scores of sixteen variables for components of the eight priority resources. Climate sensitivity scores were developed through SME interviews and surveys. For components that appear under more than one priority resource group, the sensitivities identified in the Subsistence group refer specifically to sensitivity of subsistence uses and the sensitivity listed under the primary priority resource refers to the biotic sensitivity. Numbers identify the proportion of SMEs who reported the metric to be a climate sensitivity of each component. The top metrics that were used for selecting climate futures (indicated by “Y” in top row) were identified by averaging the responses then ranking them. Park SME’s responses were given double weight and the final list was validated by park managers.

Priority Resource	Component	Days under 32	Days under 0	Non-sum- mer days over 0	Winter thaw events	Heat index	Annual precipita- tion	Fall precipita- tion	Extreme precipita- tion intensity	Extreme precipita- tion frequency	Snow:rain ratio	Rain-on- snow events	Drought	Fire risk	Runoff	Soil moisture	Humidity
–	Top metrics	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hydrologic Systems	Glaciers	0.7	0.0	0.3	0.5	0.0	0.7	0.7	0.5	0.5	1.0	0.7	0.5	0.0	0.5	0.3	0.3
	Rivers	1.0	0.2	0.2	0.8	0.2	0.6	0.8	0.8	0.8	0.8	0.8	0.6	0.2	0.4	0.6	0.2
	Non-glacial streams	1.0	0.3	0.5	1.0	0.0	0.5	0.8	1.0	1.0	0.8	0.8	1.0	0.3	0.5	0.3	0.3
	Lakes	1.0	1.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	Wetlands	0.7	0.7	0.3	0.7	0.3	0.7	0.7	0.7	0.7	0.7	0.3	1.0	0.3	0.7	0.3	0.3
Subsistence	Salmon	0.3	0.2	0.0	0.3	0.0	0.3	0.3	0.8	0.8	0.2	0.2	0.5	0.0	0.7	0.2	0.2
	Freshwater fish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Moose	0.0	0.0	0.0	0.0	0.2	0.3	0.7	0.5	0.5	0.5	0.5	0.3	0.4	0.5	0.3	0.0
	Dall's sheep	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
	Caribou	0.3	0.4	0.0	0.5	0.7	0.5	0.4	0.5	0.3	0.3	0.5	0.5	0.4	0.0	0.0	0.0
	Harbor seals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Wolves	0.3	0.3	0.2	0.3	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Brown bears	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Black bears	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Berries	0.3	0.3	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.3	0.3	0.4	0.3	0.3	0.0
	Users & stakeholders	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5
Human Systems	Hunting, trapping, fishing	0.4	0.6	0.8	0.6	0.6	0.4	0.8	0.6	0.6	0.4	0.6	0.8	1.0	0.4	0.8	0.2
	Wood & berry harvest	0.5	0.3	0.3	0.5	0.5	0.8	0.8	0.6	0.6	0.3	0.3	1.0	0.8	0.6	0.7	0.5
	Active mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	Recreating / backcountry use	0.7	0.7	1.0	1.0	0.7	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7
	Research	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Aviation use	0.3	0.3	0.5	0.8	0.5	0.8	0.8	1.0	1.0	0.5	0.8	0.5	0.5	1.0	0.8	0.3
	Snowmachine, ATV, jetboat use	0.8	0.8	0.6	1.0	0.4	0.8	0.8	0.8	0.8	0.8	0.8	0.4	0.6	0.8	0.6	0.2
	Complex spatial patterns of land tenure/access	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0
	Ethnography	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3.2 (continued). Climate sensitivity scores of sixteen variables for components of the eight priority resources. Climate sensitivity scores were developed through SME interviews and surveys. For components that appear under more than one priority resource group, the sensitivities identified in the Subsistence group refer specifically to sensitivity of subsistence uses and the sensitivity listed under the primary priority resource refers to the biotic sensitivity. Numbers identify the proportion of SMEs who reported the metric to be a climate sensitivity of each component. The top metrics that were used for selecting climate futures (indicated by “Y” in top row) were identified by averaging the responses then ranking them. Park SME’s responses were given double weight and the final list was validated by park managers.

Priority Resource	Component	Days under 32	Days under 0	Non-sum- mer days over 0	Winter thaw events	Heat index	Annual precipita- tion	Fall precipita- tion	Extreme precipita- tion intensity	Extreme precipita- tion frequency	Snow:rain ratio	Rain-on- snow events	Drought	Fire risk	Runoff	Soil moisture	Humidity
Cultural Resources	Archeological resources	1.0	1.0	0.0	1.0	0.8	0.0	0.0	1.0	1.0	0.0	0.0	0.8	0.0	1.0	0.3	0.0
	Cultural landscapes	0.0	0.0	0.0	0.5	0.0	0.8	0.8	1.0	1.0	0.4	0.4	0.8	0.6	0.8	0.6	0.0
	Historic & prehistoric structures	0.5	0.5	0.5	0.4	0.6	1.0	1.0	1.0	1.0	0.6	0.6	0.8	0.8	1.0	0.8	1.0
	Kennecott Mines NHL	0.5	0.5	0.5	0.4	0.6	0.8	0.8	1.0	1.0	0.6	0.6	0.8	0.8	1.0	0.8	0.8
	Museum collections (all)	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0
	Museum collections - Kennecott	–	–	–	–	0.7	–	–	0.7	0.7	–	–	–	1.0	0.3	–	0.7
	Museum collections - Copper Center	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Museum collections - Glennallen Conex	–	–	–	–	1.0	–	–	0.7	0.7	–	–	–	0.3	0.3	–	0.7
Aquatics	Salmon	0.7	0.7	0.7	1.0	0.7	0.7	0.7	1.0	1.0	0.7	0.7	1.0	0.7	0.7	0.7	0.7
	Other	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Focal Wildlife Species	Caribou	0.4	0.4	0.0	0.8	0.4	0.4	0.0	0.0	0.0	0.8	1.0	0.6	1.0	0.0	0.5	0.0
	Moose	0.3	0.0	0.0	0.5	0.8	0.3	0.0	0.0	0.0	0.5	0.7	0.7	0.8	0.0	0.0	0.3
	Dall's sheep	0.0	0.0	0.0	0.6	0.3	0.4	0.0	0.0	0.3	0.6	0.9	0.3	0.3	0.0	0.0	0.0
	Wolves	1.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	Brown bears	0.0	0.0	0.0	0.3	0.5	0.5	0.0	0.0	0.0	0.3	0.0	0.7	0.3	0.7	0.0	0.0
	Black bears	–	–	–	0.7	1.0	0.7	–	–	–	–	–	1.0	0.7	–	–	–
	Bald eagles	0.3	0.0	0.0	0.0	0.5	0.7	0.5	0.8	0.8	0.3	0.3	0.5	0.3	1.0	0.3	0.3
	Harbor seals	0.3	0.3	0.3	0.7	0.0	0.3	0.0	0.0	0.0	0.7	0.3	0.7	0.0	0.3	0.0	0.0
	Sea otters	1.0	1.0	1.0	2.0	0.0	1.0	0.0	0.0	0.0	2.0	1.0	2.0	0.0	1.0	0.0	0.0
Wilderness Values	Solitude	0.0	0.0	0.0	0.0	0.5	1.0	1.0	1.0	1.0	0.5	0.0	0.5	0.5	0.5	0.0	0.5
	Night skies	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	Natural soundscape	0.5	0.5	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	0.5	1.0	0.0	0.5
Vegetation Dynamics	Soils & permafrost	0.4	0.3	0.0	0.0	0.0	0.6	0.4	0.5	0.5	0.5	0.2	0.3	0.8	0.3	0.8	0.0
	Lichen	0.5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.5	0.5
	Berry production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0
	Boreal forests	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.3	0.0	0.0	0.7	0.7	0.0	0.7	0.3
	Subalpine shrublands / woodlands	0.3	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.0	0.5	0.3	0.0	0.3	0.0	0.8	0.0
	Alpine tundra	0.3	0.0	0.0	0.7	0.0	0.7	0.3	0.0	0.0	0.7	0.3	0.3	0.7	0.0	0.7	0.0
	Coastal forests	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3.3. Loading values and variance of principal components (PC) PC1 and PC2 for the 20 projections used in this study. Use of the two PCs accounts for 68% of the cumulative variance of the 10 key climate metrics identified in Tables A3.1 and A3.2. The minimum and maximum projections for PCs 1 and 2 were selected to capture the most divergent climate futures for this process.

Climate projection	Principal component 1	Principal component 2	Selected climate futures
ACCESS1-3.rcp45	-4.41	-1.29	Climate Future 2
HadGEM2-ES.rcp45	-2.48	-2.20	–
ACCESS1-3.rcp85	-2.32	-2.28	–
MIROC5.rcp45	-1.66	-1.35	–
GFDL-ESM2M.rcp45	-1.39	2.95	–
MPI-ESM-MR.rcp45	-1.23	0.80	–
CSIRO-Mk3-6-0.rcp45	-0.98	0.45	–
GFDL-ESM2M.rcp85	-0.92	1.60	–
inmcm4.rcp45	-0.55	2.25	–
MRI-CGCM3.rcp85	-0.51	1.19	–
CCSM4.rcp85	-0.47	-1.80	–
CCSM4.rcp45	-0.25	-1.43	–
MIROC5.rcp85	0.38	0.48	–
HadGEM2-ES.rcp85	0.64	-1.35	–
MRI-CGCM3.rcp45	0.87	2.19	–
inmcm4.rcp85	1.39	3.37	Climate Future 1
CSIRO-Mk3-6-0.rcp85	2.24	0.76	–
CanESM2.rcp45	2.86	-2.46	–
MPI-ESM-MR.rcp85	3.31	0.63	–
CanESM2.rcp85	5.48	-2.49	Climate Future 3

Appendix 4. Example climate future packet

This packet is an example of the climate futures packet that was used to develop resource implications.

Introduction

Plausible climate futures for Wrangell-St. Elias National Park & Preserve (WRST) are expressed in terms of future (2025–2055) change relative to late-20th-century conditions (1950–1999). The climate information summarized here is specific to WRST, developed in collaboration with the Alaska Climate Adaptation Science Center, using projected, gridded data that are specifically downscaled (12km, BCSD) for Alaska (Mizukami et al. 2021). Due to the size and complex geography of the park, climate futures are presented spatially, with timeseries of the spatial means across each area shown to characterize the dynamics. The four geographic areas are distinct climate and ecological zones in WRST (Figure A4.1).

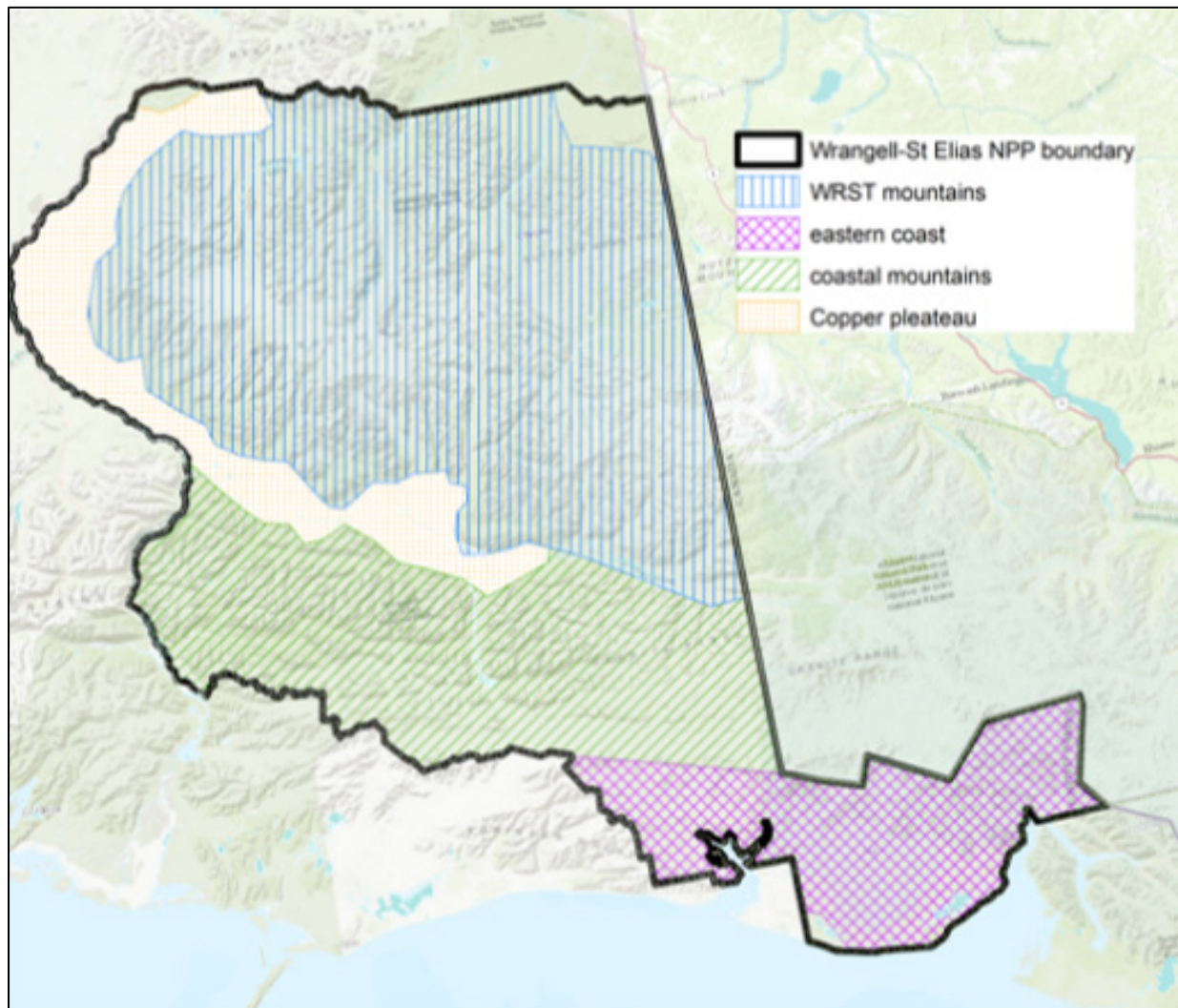


Figure A4.1. Geographic areas in WRST used for climate analysis.

Climate futures are from projections from ten global climate model (GCMs), run under two contrasting greenhouse gas emissions scenarios (RCP4.5 and RCP8.5). The GCMs were selected due to their use in previous CMIP5 hydrologic downscaling, independence, and representativeness in Alaska and Hawaii (Mizukami et al. 2022) and represent a range of plausible future climates for the park over the coming decades. From these 20 projections (10 GCMs x 2 emissions scenarios), three divergent climate futures were chosen that characterized a substantial range of uncertainty across all trajectories. The uncertainty was measured across the climate metrics that park and subject-matter experts expressed as the most consequential for resources at WRST (Figure 3). Those *consequential* climate metrics are listed in Table 1, below. See ([Runyon et al. 2021](#)) and ([Lawrence et al. 2021](#)) for details on model selection methodology.

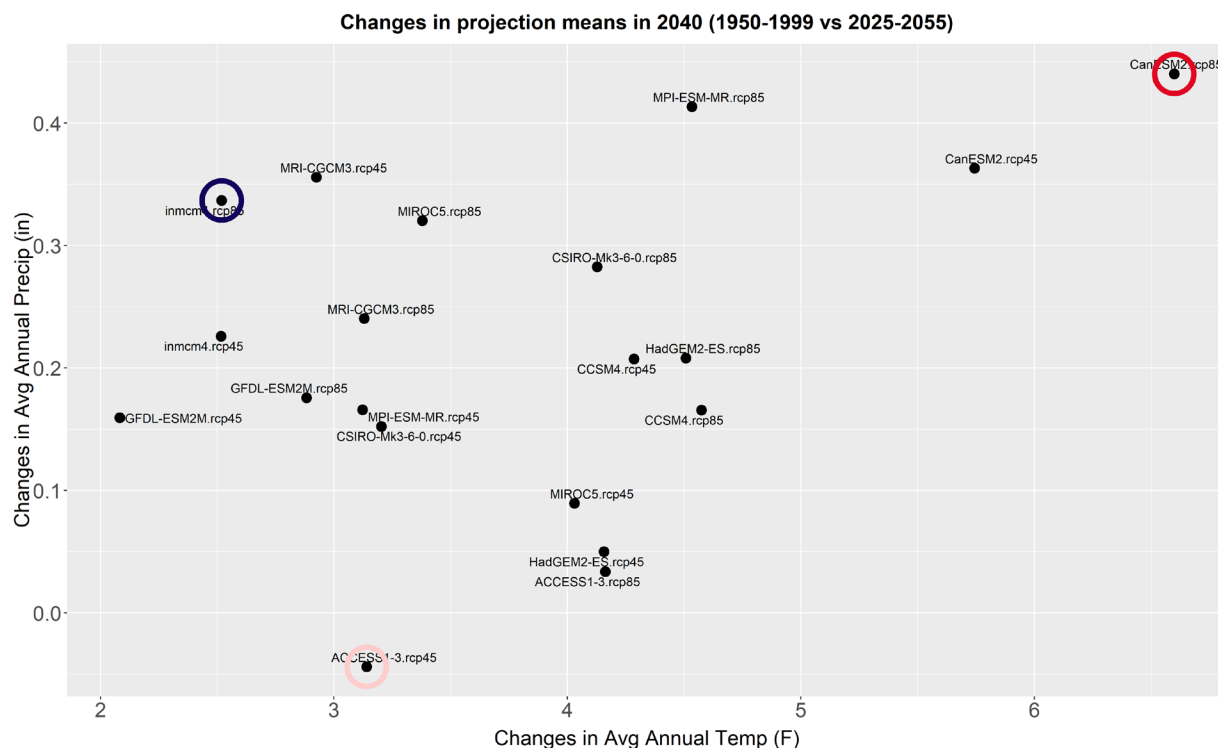


Figure A4.2. Projected changes in average annual temperature and precipitation for the 20 projections. Points represent differences between average values for the 3-decade period 2025–2055 and 1950–1999 for each GCM. Circled GCM/RCP combinations are projections selected for climate futures. Circle color corresponds with the color of the climate futures and scenarios used throughout this document.

Climate metrics representing most challenging climate sensitivities for resources at WRST:

- Seasonal (DJF, MAM, JJA, SON) average temperature
- Seasonal (DJF, MAM, JJA, SON) average precipitation
- Maximum annual snow depth
- Shoulder season (MAM & SON) snow
- Water balance

Table A4.1. GCMs selected as climate futures. Climate future colors are consistent throughout this document.

CF	GCM
Climate Future 1	inmcm4.rcp85
Climate Future 2	ACCESS1-3.rcp45
Climate Future 3	CanESM2.rcp85

Hydrology and glacial systems

Park and subject matter experts identified the following metrics as sensitivities for hydrology and glacial systems in WRST (Table 1). These metrics are evaluated for each of the three climate futures in the subsequent sections of this packet. Use this table when determining implications of each of the climate futures on each resource to identify metrics to review.

Table A4.2. Climate sensitivities for hydrology and glacial systems resources. An “X” indicates a sensitivity.

Climate Sensitivity	Glaciers	Rivers	Non-glacial streams	Lakes	Wetlands
Avg annual temperature	X	X	X	X	X
Winter temperature	X	X	X	X	X
Spring temperature	X	X	X	X	X
Summer temperature	X	X	X	X	X
Fall temperature	X	X	X	X	X
Seasonal mean tmax	X	X	X	–	X
Seasonal mean tmin	X	X	X	X	X
Freeze-thaw cycles	X	X	X	X	X
Seasonal freeze events	X	X	X	X	X
Growing degree days	X	X	X	–	X
Freq of hot days	X	X	X	–	X
Days under 32	X	X	X	X	X
Non-summer days over 0	X	X	X	–	X
Winter thaw events	X	X	X	X	X
Annual precipitation	X	X	X	X	X
Winter precipitation	X	X	X	X	X
Spring precipitation	X	X	X	X	X
Summer precipitation	X	X	X	X	X
Fall precipitation	X	X	X	X	X
Extreme precipitation intensity	X	X	X	X	X
Extreme precipitation frequency	X	X	X	X	X
Snow depth	X	X	X	–	X
Shoulder season snow	X	X	X	–	X
Snow:rain ratio	X	X	X	–	X
Fire risk	–	X	X	–	X
Climatic water deficit / water balance	X	X	X	–	X
Runoff	X	X	X	–	X
Soil moisture	X	X	X	–	X

Climate futures summary

The following table summarizes key climate features for hydrologic resources that are illustrated in figures and tables in this document.

Table A4.3. Commonalities and differences among the climate futures.

Metric	Climate Future 1: Warm wet; cool, rainy summers; increasing snow	Climate Future 2: Dry; early snowmelt and drying summers and falls	Climate Future 3: Hot wet; loss of winter, hot summers; rainy	Common across
Temperature	- Least change in annual tmean (+2 °F) with lowest interannual variability - Low (+1–2 °F) tmax inc. in DJF and SON; less warming in mountains. 3 more days tmax >68 per year - Lowest warming across most seasons (+1–3.5 °F) with lowest in JJA. SON warming concentrated in mountains. 20 fewer days below freezing and 3 fewer freezing DJF days +6 freeze-thaw events per year	- Annual tmean increasing +3 °F with less warming in mountains, but high interannual variability (some years lowest tmean of all CFs, other years highest) - Lowest (+1 °F) DJF tmax increase with no winter change in WRST mountains, moderate (+2–4 °F) inc in other seasons. 10 more days tmax >68 per year - Moderate warming. Lowest in MAM (+2.5 °F) with little change in mountains during that season. 30 fewer days below freezing and 2 fewer freezing DJF days - Slight decline (–0.6/year) in freeze-thaw events	- Hottest CF with annual tmean increasing +6. Less warming in eastern coastal and most warming in coastal mountain areas. - Highest (>+8 °F) tmax inc in JJA; +4–6 °F inc in other seasons. Highest rates of warming in Coastal Mountains, particularly in DJF and JJA with little change in eastern coastal areas during those time periods. 20 more days tmax >68 per year - Highest tmin increase in all seasons. +10 °F in DJF, about +6 °F in other seasons. Warming most concentrated in Coastal Mountains. 40 fewer days below freezing and 7 fewer freezing DJF days –2 freeze-thaw events per year	- Average annual temperature warming in all seasons 20–40 fewer days tmin < 32 °F and increasing DJF thaw events (tmin>32) - Increasing tmax >68
Precipitation	- Increasing (+9 in/yr) annual precip. Highest rates of change in mountain and coastal areas. - Little change in MAM precip; DJF +7 in, JJA +10, SON +17. Increases most heavily concentrated in coastal and mountain areas - Large precipitation events (daily precip>0.5 increasing) by 14%	- Slightly decreasing (–0.4 in/yr) annual precip with some very dry years. WRST mountains greatest precip declines. - Slight increase (+2 in) in DJF precip, concentrated in eastern coastal area. Little change in MAM precip but slight drying in eastern coastal area. Declines in JJA (–2 in) and SON (–6) precip, concentrated in mountains. - Large precipitation events (daily precip>0.5 decreasing) by –6%	- Increasing (+10 in/yr) but highly variable annual precip. Highest rates of change in mountain and coastal areas. - Increasing precip across all seasons, most heavily in coastal areas in SON (+12 in) and in WRST mountains in DJF and JJA (+12 and +10) - Large precipitation events (daily precip>0.5 increasing) by 17%	–

Table A4.3 (continued). Commonalities and differences among the climate futures.

Metric	Climate Future 1: Warm wet; cool, rainy summers; increasing snow	Climate Future 2: Dry; early snowmelt and drying summers and falls	Climate Future 3: Hot wet; loss of winter, hot summers; rainy	Common across
Water balance	Water balance increasing (+8 in/yr), with most increases in mountain areas	Water balance declining (−0.9 in/yr) across WRST with some years half of historical average.	Water balance increasing (+10 in/yr), with most increases in mountain areas but high degree of interannual variability.	Water balance increasing (+8 in/yr), with most increases in mountain areas
Snow	- Slight increase (8%) in proportion of precip falling as snow with increased variability from year-to-year. 20% increase in mean annual SWE. Increasing (22%) shoulder season (MAM/SON) SWE	- Slight increase (10%) in proportion of precip falling as snow with increased variability from year-to-year. 5% increase in mean annual SWE. Slight decrease (−2%) in shoulder season (MAM/SON) SWE	- Slight decline in proportion of precip falling as snow (−5%) with increased variability from year-to-year. Declines in WRST mountains with increasing snow in Copper plateau 15% increase in mean annual SWE - Slight increase (3%) in shoulder season (MAM/SON) SWE	Slightly increasing mean annual SWE, but declining in coastal areas

Climate futures

Fundamental climate metrics

The following figures illustrate seasonal change (1950–1999 vs 2025–2055) in basic climate metrics. Seasons are characterized as yearly quarters: DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November.

Unless specified, average values displayed as change values in dotplots or annual averages in timeseries plots are averaged across all grid cells in the geographies represented in each map. Maps are high resolution so zoom can be used to view specific areas more closely.

Table A4.4. WRST climate futures (average for 3-decade period 2025–2055), expressed in terms of change relative to the historical period (1950–1999), with negative values indicating declines. The “Historical” column represents the 1950–1999 average value for each metric.

CF	Average annual temperature (°F)				Average annual max temperature (°F)				Average annual min temperature (°F)				Average annual precipitation (in)			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Climate Future 1	3	3.3	1.2	2.6	2.3	3.4	0.9	1.9	3.7	3.1	1.5	3.2	7	–0.5	10	13.8
Climate Future 2	2.8	2.2	3.7	3.9	1	2.1	3.7	3.9	4.6	2.3	3.7	3.9	2.2	0.5	–1.1	–5.5
Climate Future 3	9.4	5.6	5.9	5.5	8.1	5	5.9	4.4	10.6	6.2	6	6.6	12.4	4.9	9.6	12.8
Historical	2.5	23.3	45.3	20.9	12.2	35.9	58.2	31.5	–7.3	10.6	32.4	10.2	10.7	5.9	19.4	17.7

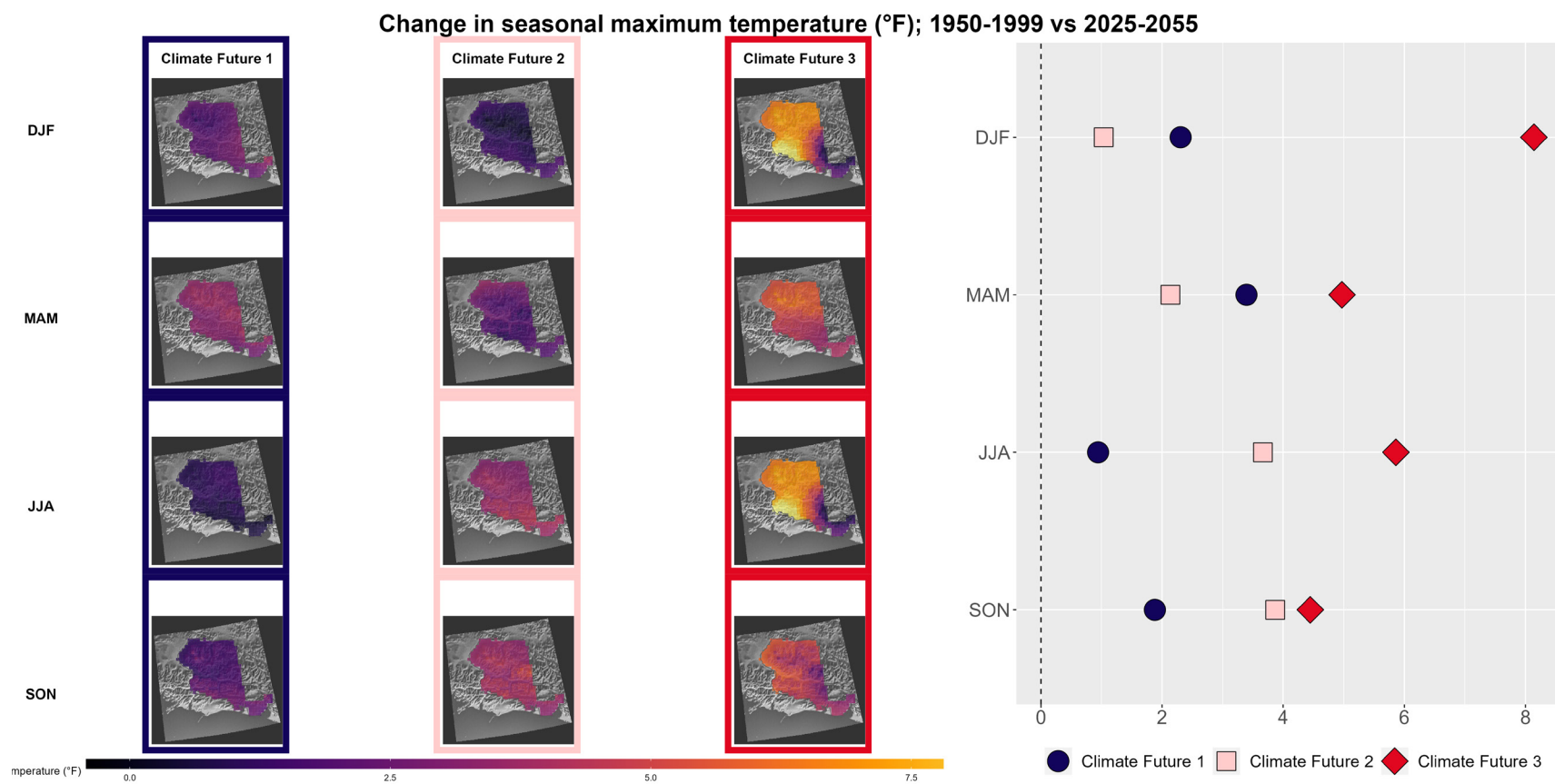


Figure A4.3. Seasonal change in maximum temperature (°F).

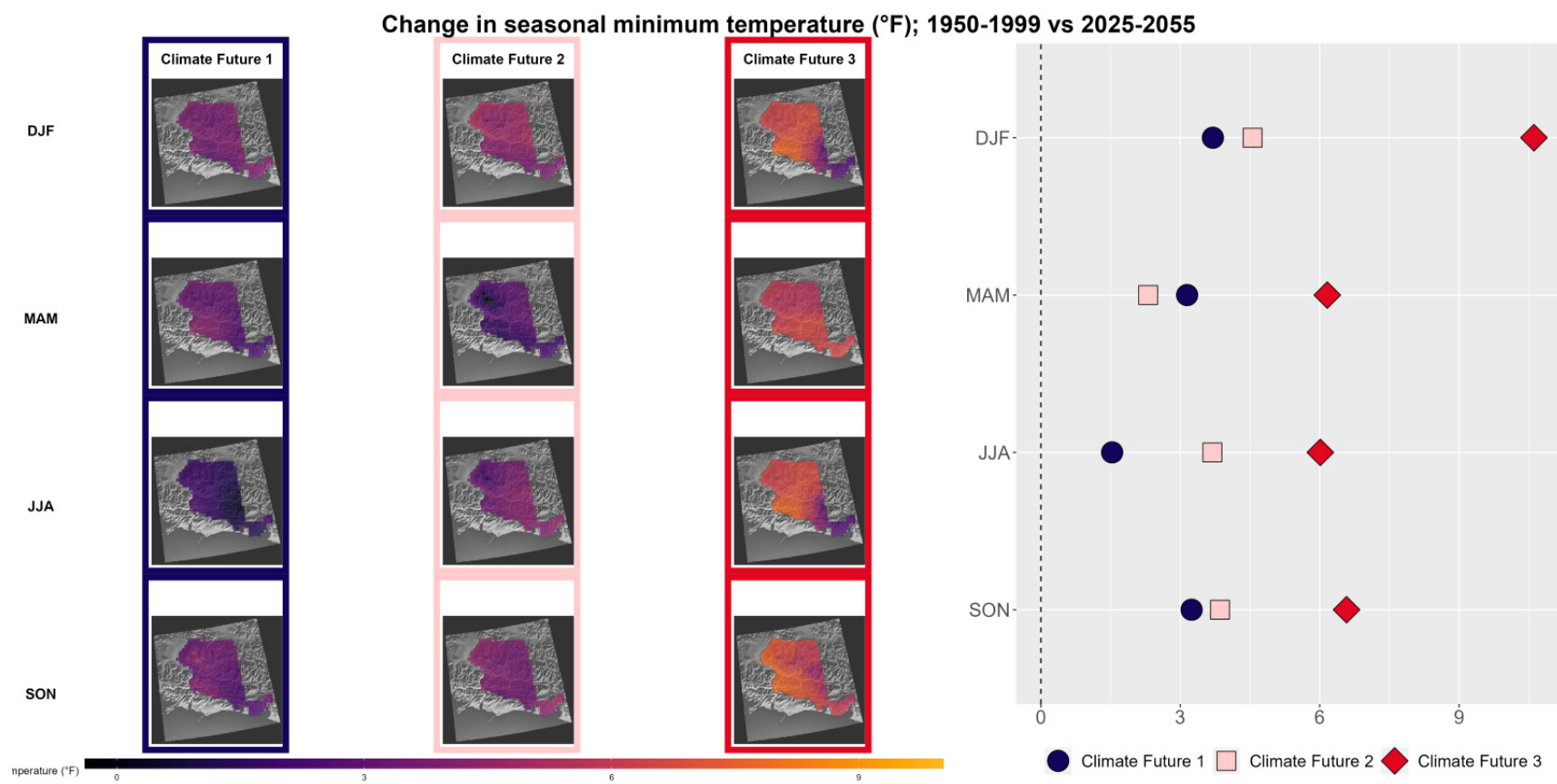


Figure A4.4. Seasonal change in minimum temperature (°F).

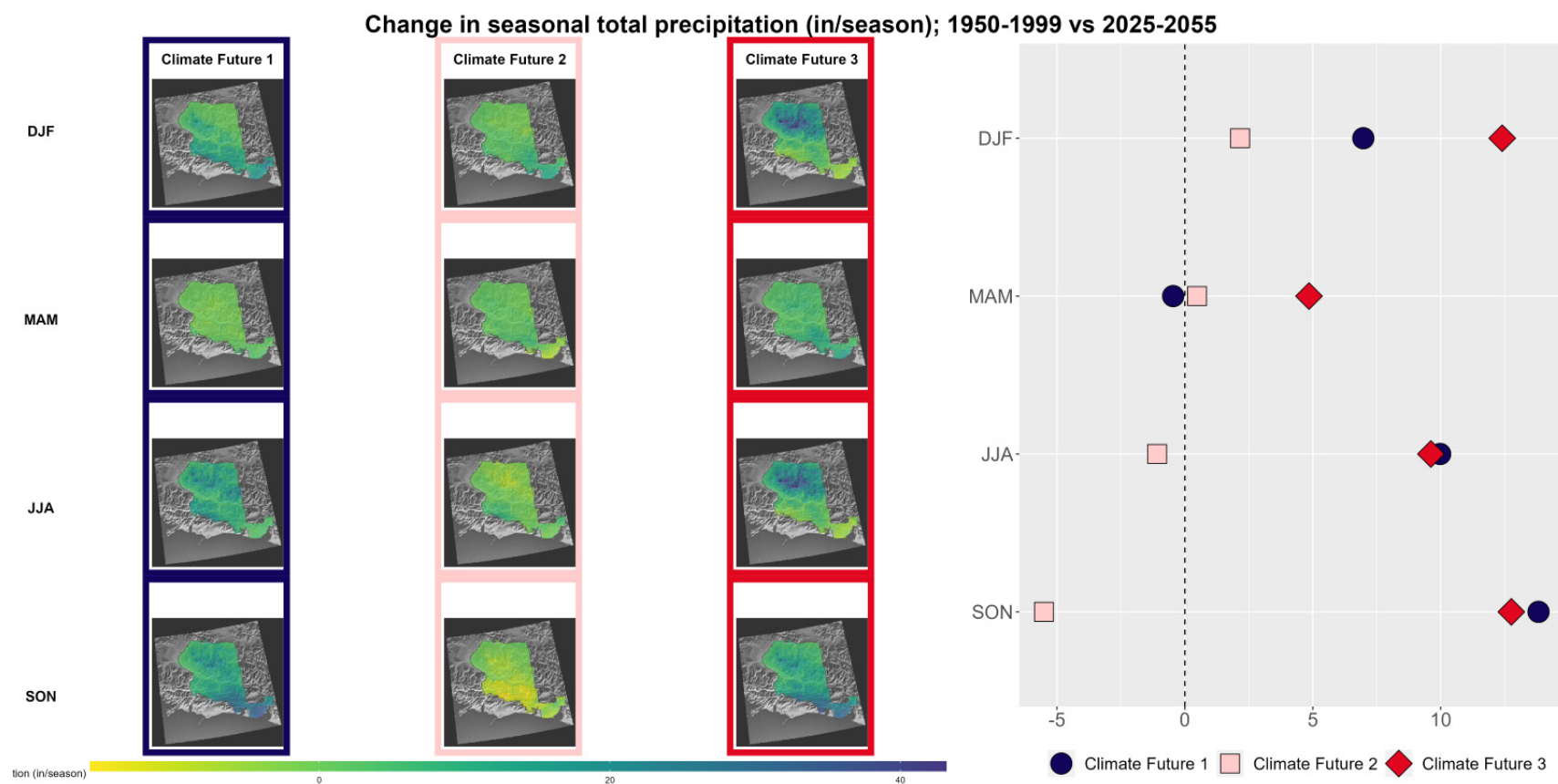


Figure A4.5. Seasonal change in total precipitation (inches).

The following figure panels illustrate change in the specified metric between the historical period (1950–1999) and each climate future (2025–2055). Timeseries plots compare recent climate trends using observed, gridded climate data (Daymet) from 1980–2016 to climate futures. The bottom-right tables summarize the mean annual values for the historical period (Daymet) and each climate future. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

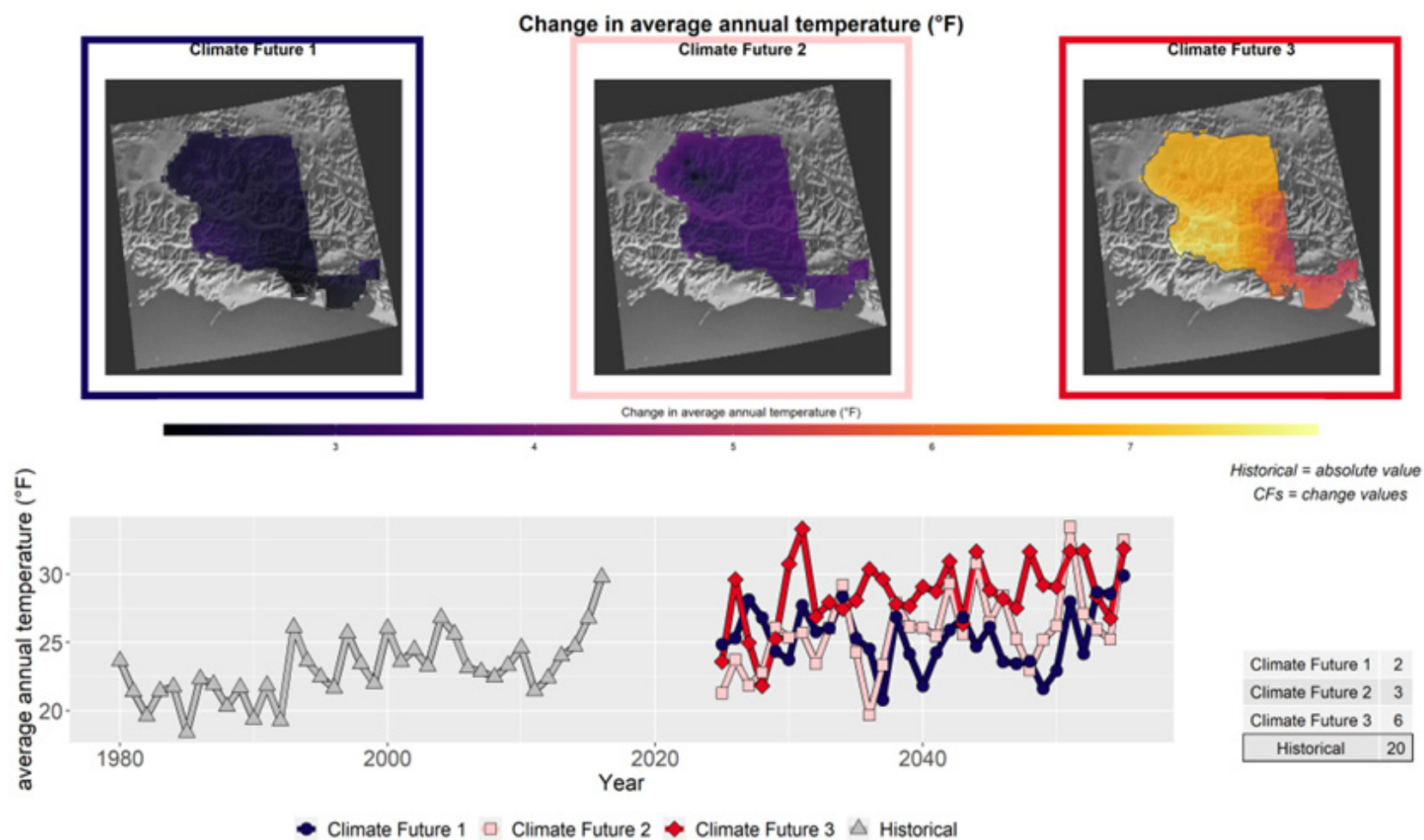


Figure A4.6. Average annual temperature.

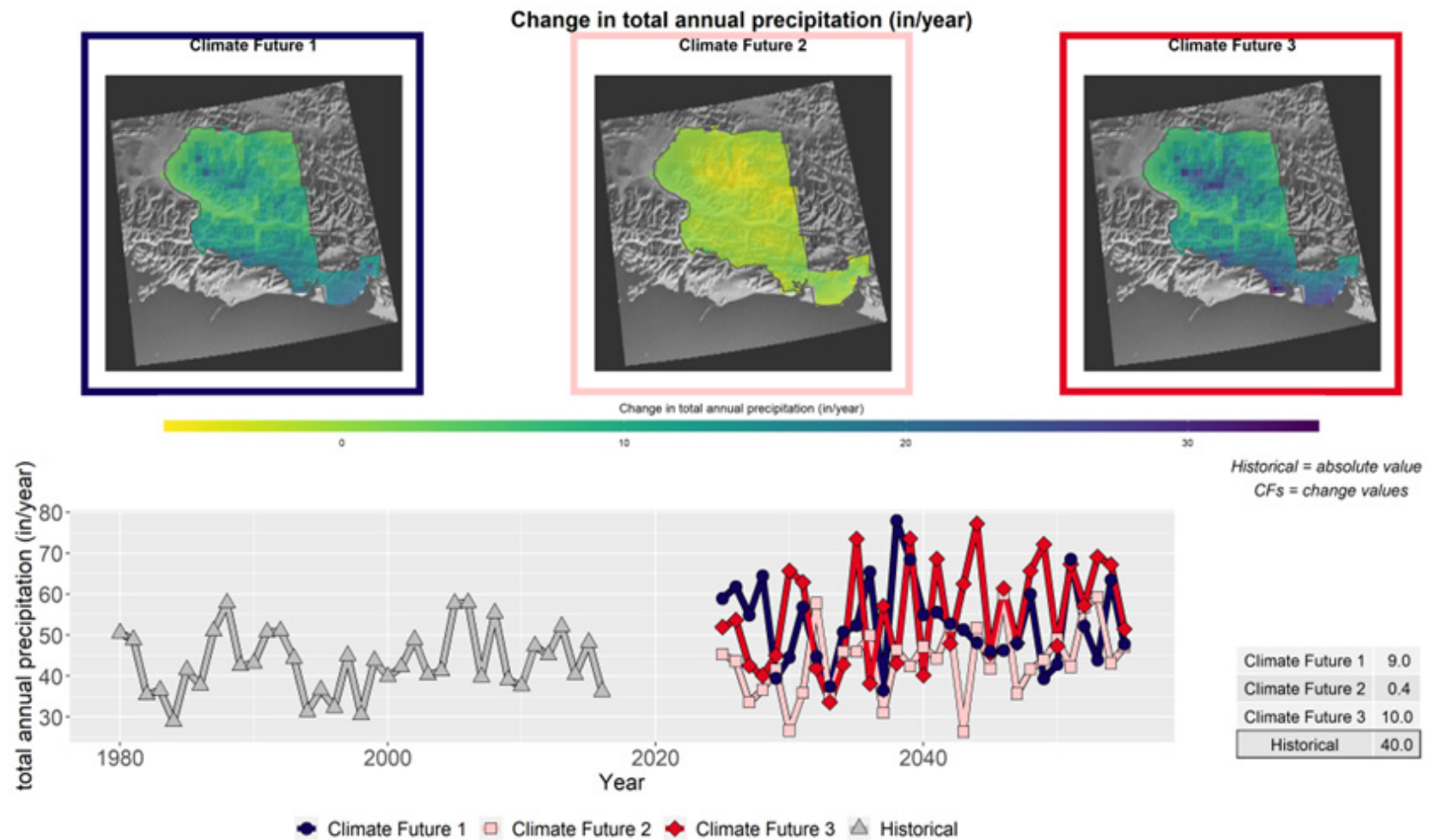


Figure A4.7. Average annual precipitation.

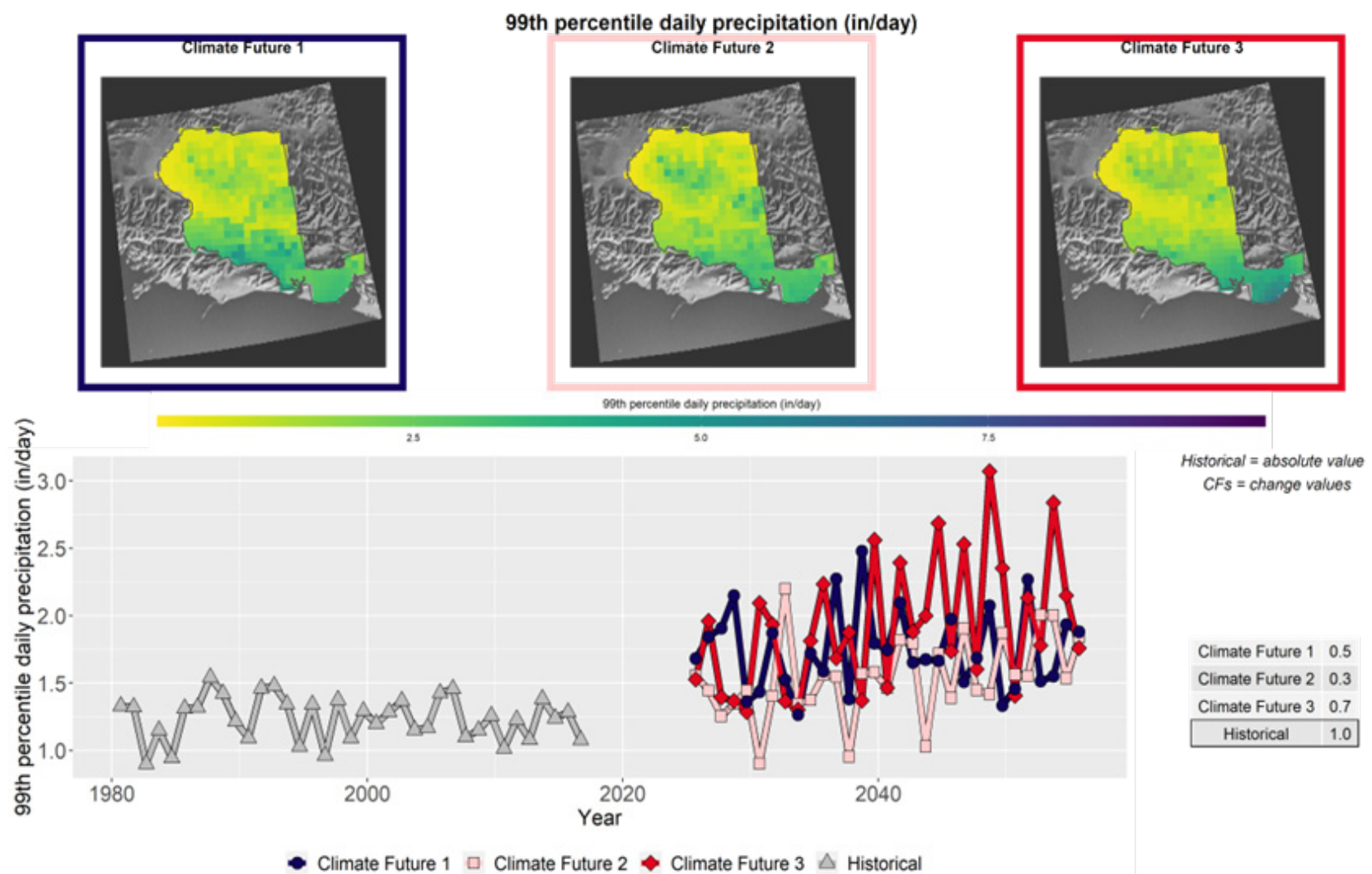


Figure A4.8. Average high precipitation events (calculated as average annual 99th percentile daily precipitation).

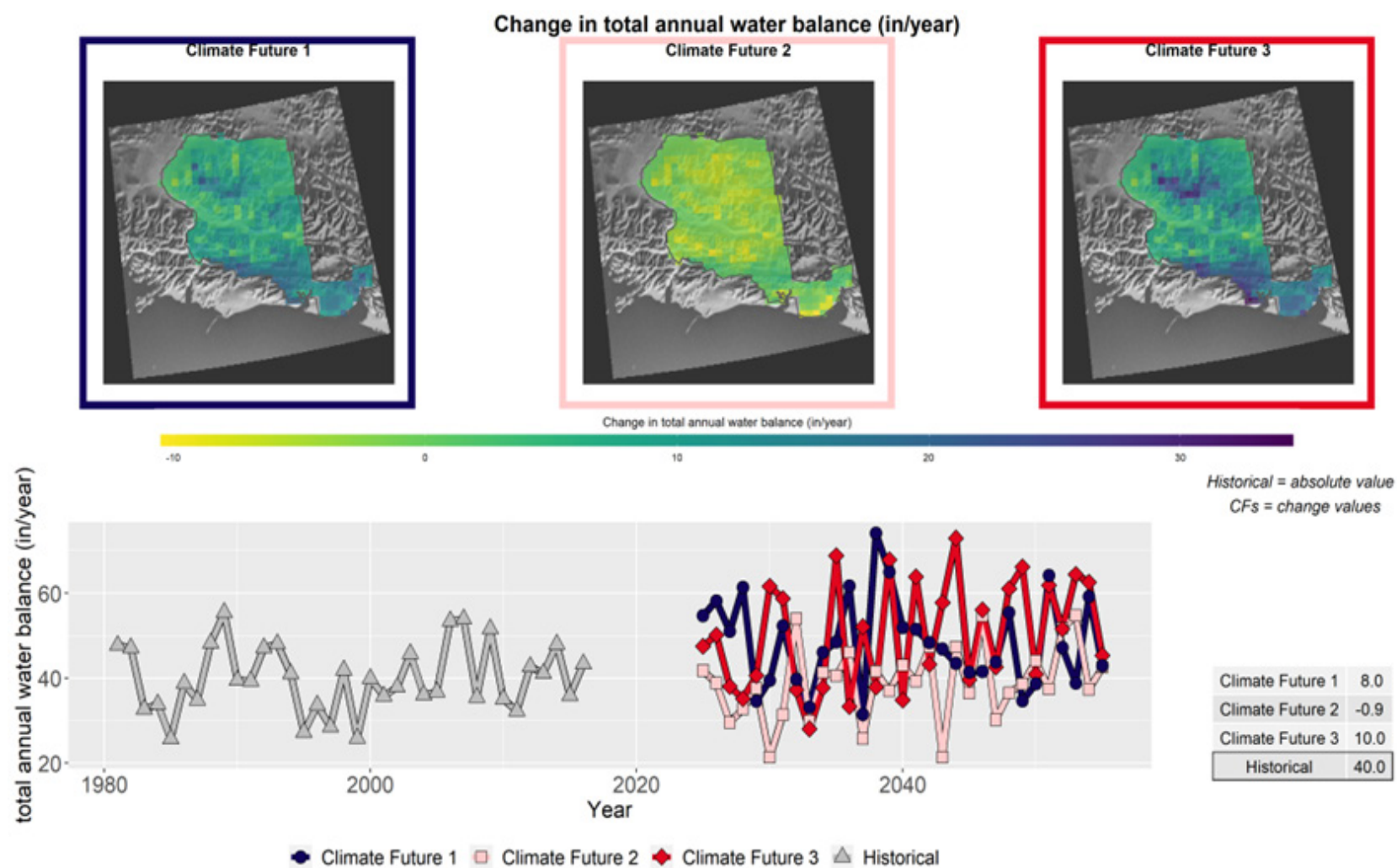


Figure A4.9. Average annual water balance, calculated as precipitation minus total evapotranspiration (ET).

Threshold metrics

The following plots represent annual averages for threshold exceedance metrics in different regions of WRST (see Figure A4.1). The values represent the average of all 15-km grid cells within each region. Timeseries plots compare recent climate trends using observed, gridded climate data (Daymet) from 1980–2016 to climate futures. The bottom-right tables summarize the mean annual values for the historical period (Daymet) and each climate future. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

Freeze-thaw is the number of freeze-thaw cycles per year, calculated as days when the maximum temperature $>34^{\circ}$ and the minimum temperature $<28^{\circ}$.

$T_{min} < 32^{\circ}$ () is the number of days per year when the minimum temperature is below 32° .

$T_{max} > 68^{\circ}$ () is the number of days per year when the maximum temperature is above 68° .

$T_{min} > 32^{\circ}$ in DJF is the number of days per year during December–February when the minimum temperature is above 32° .

Precip > 0.5 inches is the number of days per year when precipitation is greater than 0.5 inches.

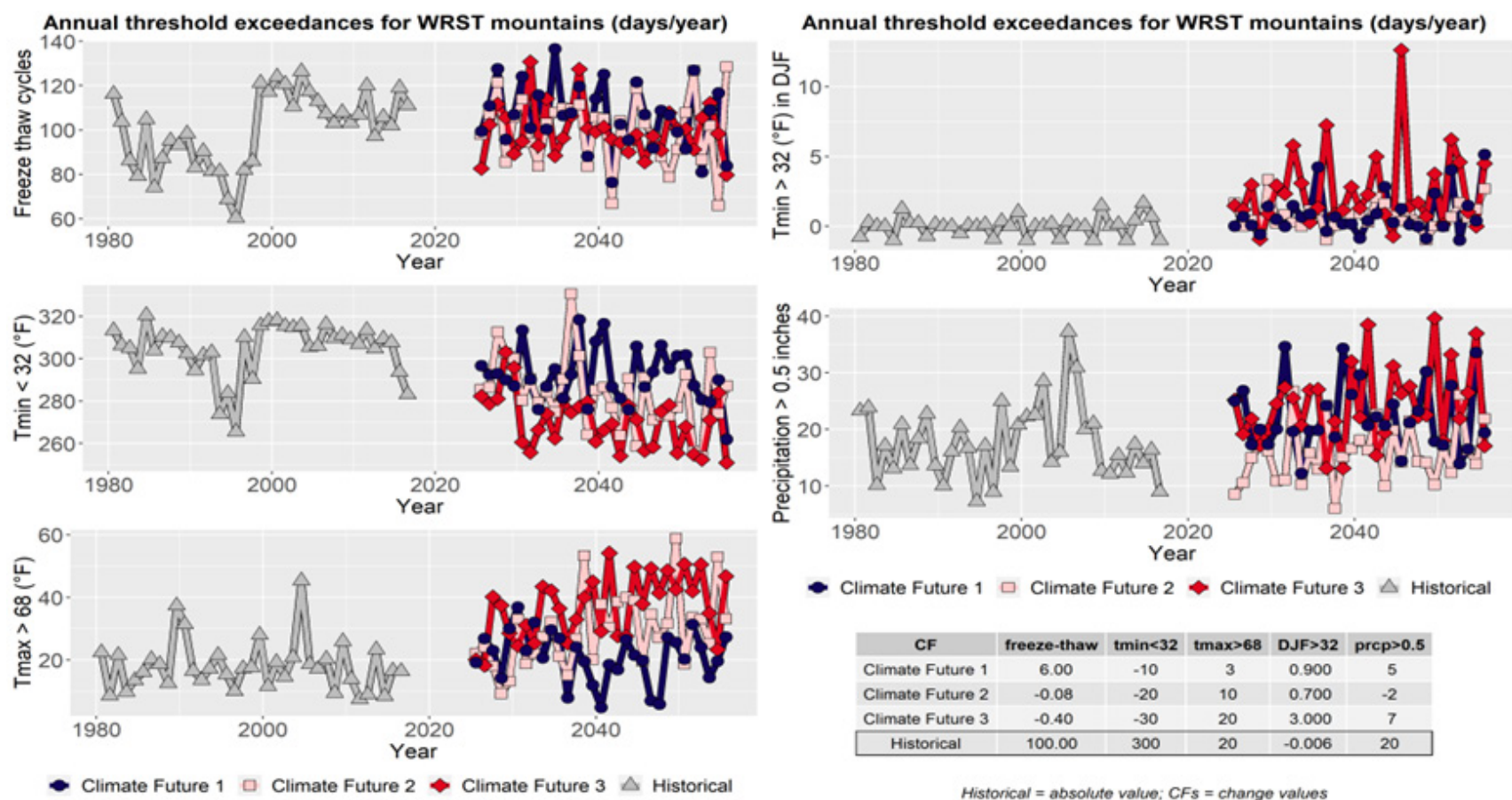


Figure A4.10. Threshold exceedance values for the WRST Mountains region.

Table A4.5. Table from Figure A4.10 above. Mean annual values for the historical period (Daymet) and each climate future in the WRST Mountains region. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

CF	Freeze-thaw	Tmin<32	Tmax>68	DJF>32	Prcp>0.5
Climate Future 1	6	-10	3	0.9	5
Climate Future 2	-0.08	-20	10	0.7	-2
Climate Future 3	-0.4	-30	20	3	7
Historical	100	300	20	-0.006	20

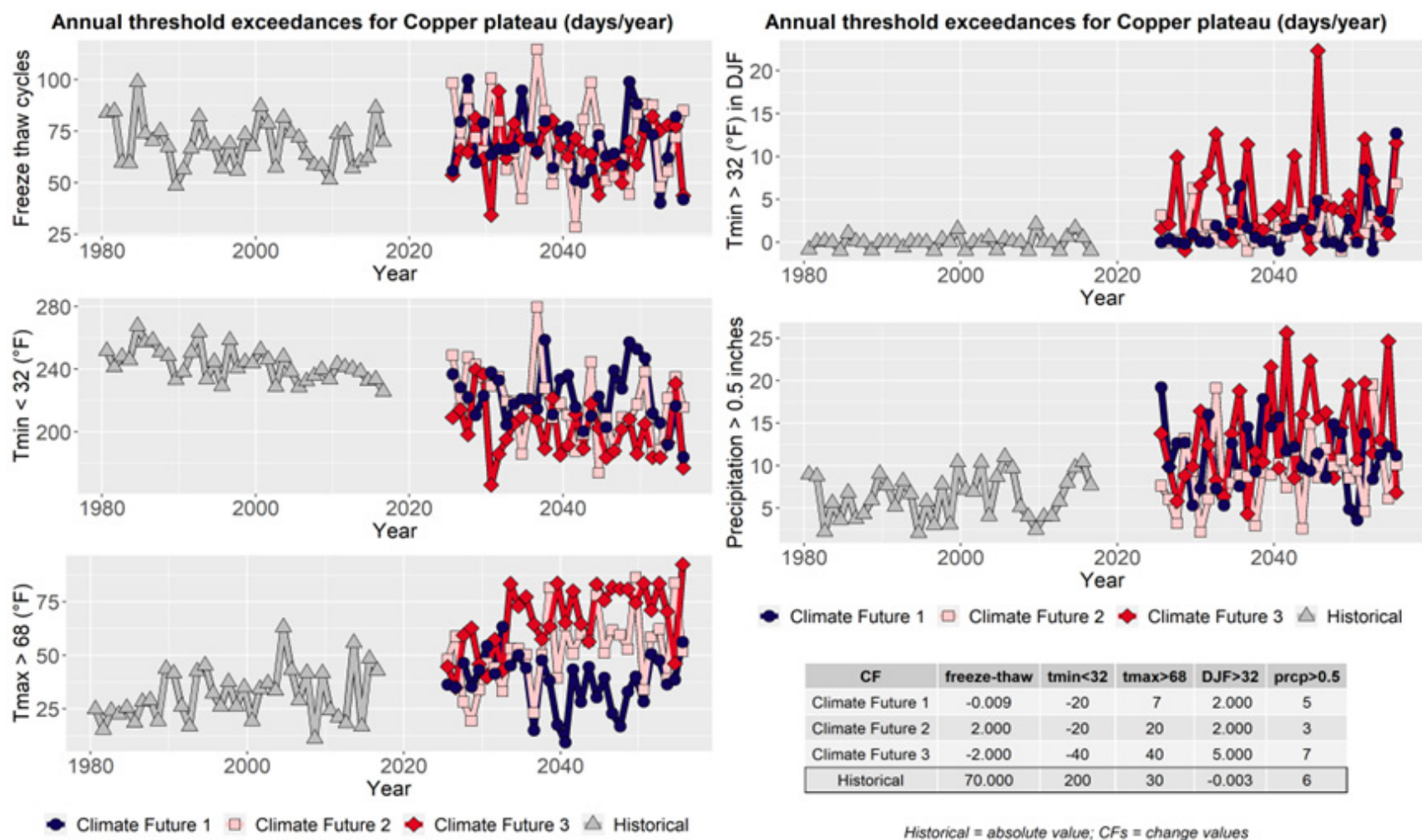


Figure A4.11. Threshold exceedance values for the Copper plateau region.

Table A4.6. Table from Figure A4.11 above. Mean annual values for the historical period (Daymet) and each climate future in the Copper Plateau region. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

CF	Freeze-thaw	Tmin<32	Tmax>68	DJF>32	Prcp>0.5
Climate Future 1	-0.009	-20	7	2	5
Climate Future 2	2	-20	20	2	3
Climate Future 3	-2	-40	40	5	7
Historical	70	200	30	-0.003	6

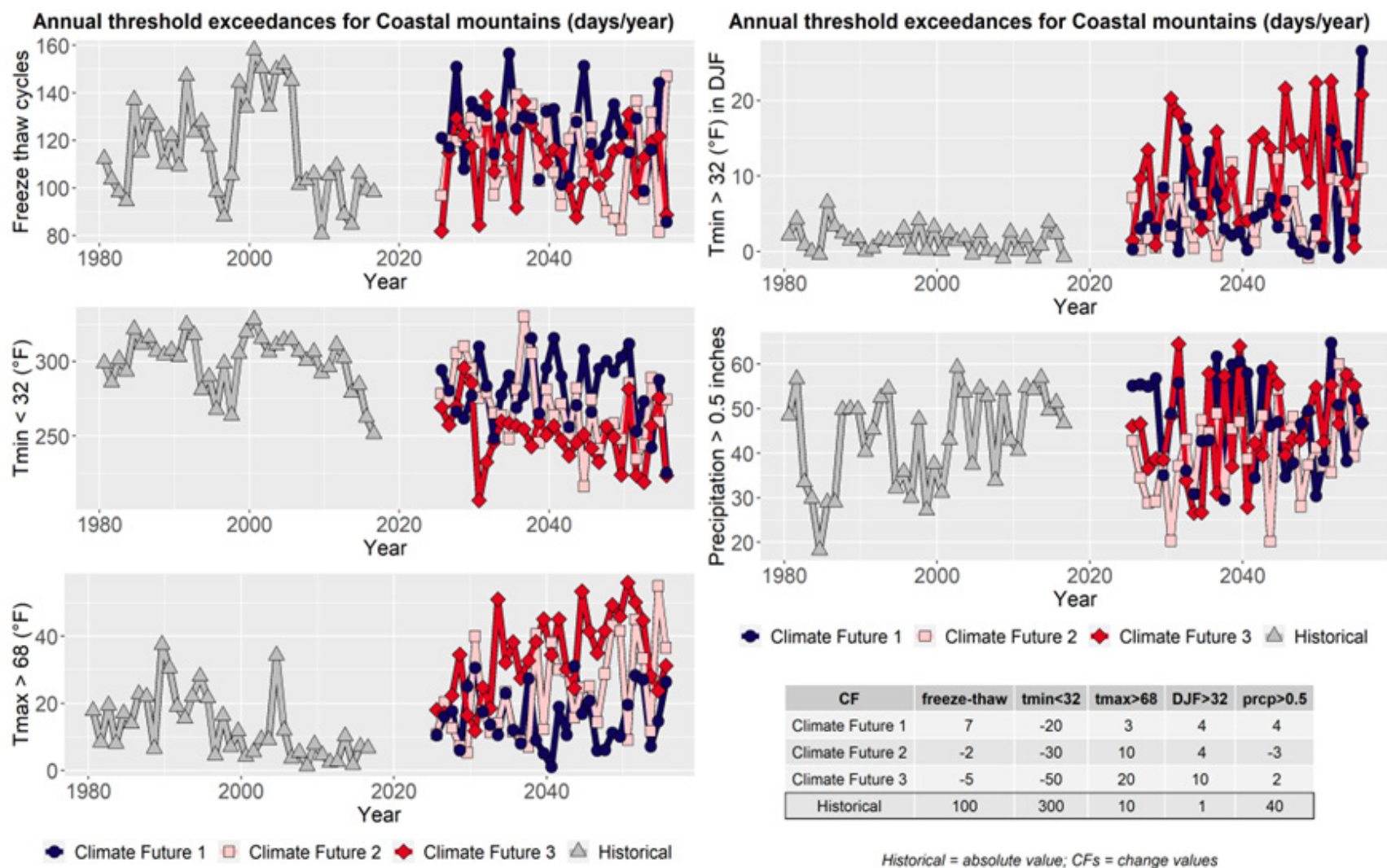


Figure A4.12. Threshold exceedance values for the Coastal Mountains region.

Table A4.7. Table from Figure A4.12 above. Mean annual values for the historical period (Daymet) and each climate future in the Coastal Mountains region. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

CF	Freeze-thaw	Tmin<32	Tmax>68	DJF>32	Prcp>0.5
Climate Future 1	7	-20	3	4	4
Climate Future 2	-2	-30	10	4	-3
Climate Future 3	-5	-50	20	10	2
Historical	100	300	10	1	40

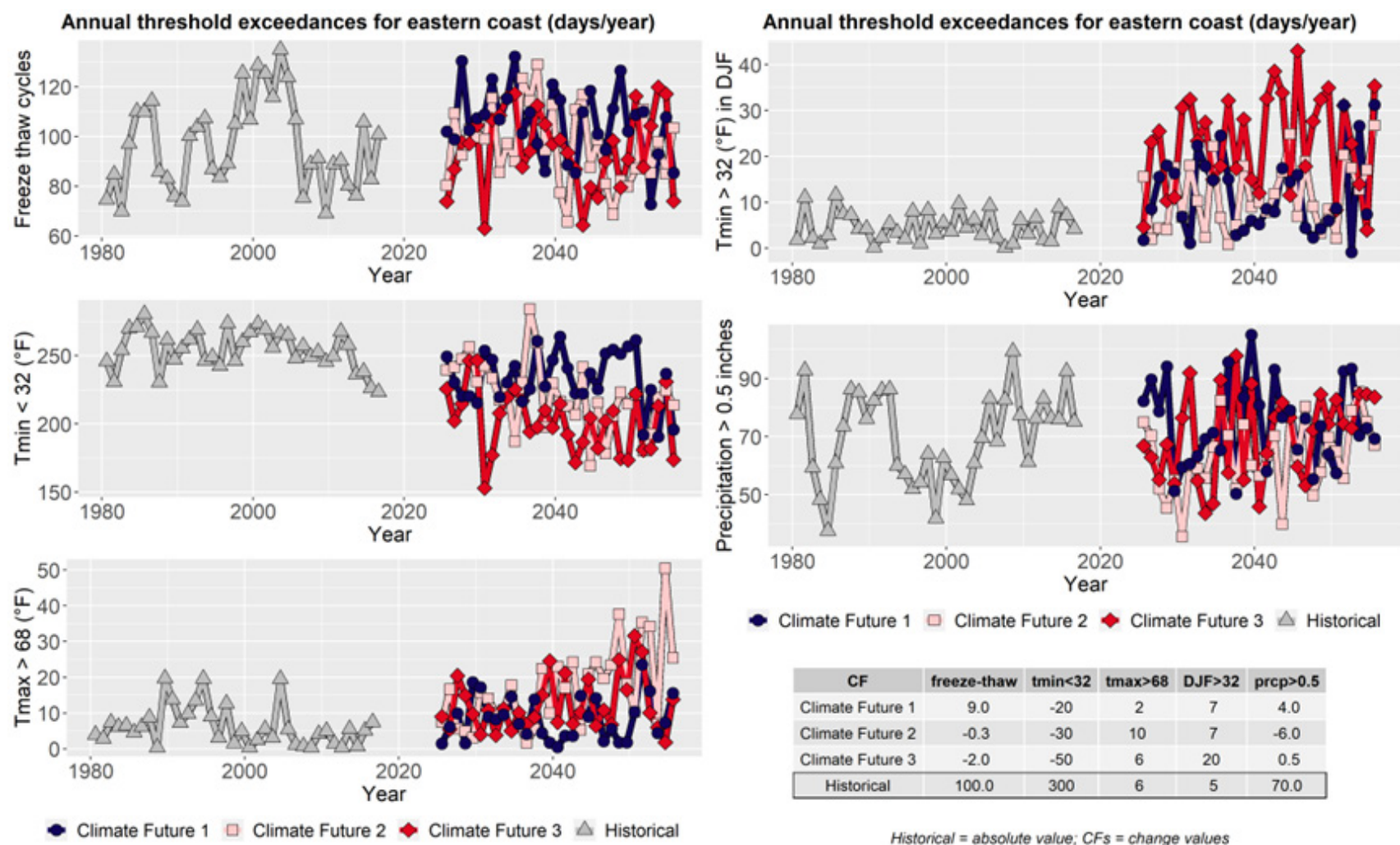


Figure A4.13. Threshold exceedance values for the eastern coast region.

Table A4.8. Table from Figure A4.13 above. Mean annual values for the historical period (Daymet) and each climate future in the Eastern Coast region. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

CF	Freeze-thaw	Tmin<32	Tmax>68	DJF>32	Prctp>0.5
Climate Future 1	9.0	-20	2	7	4.0
Climate Future 2	-0.3	-30	10	7	-6.0
Climate Future 3	-2.0	-50	6	20	0.5
Historical	100.0	300	6	5	70.0

Snow metrics

The following figure panels illustrate change in the specified metric between the historical period (1950–1999) and each climate future (2025–2055). Timeseries plots compare recent climate trends using observed, gridded climate data (Daymet) from 1980–2017 to climate futures. The bottom-right tables summarize the mean annual values for the historical period (Daymet) and each climate future. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

The snow metrics were calculated using a variable infiltration capacity (VIC) model on the same 15-km grid, provided by NCAR Mizukami et al. (20212).

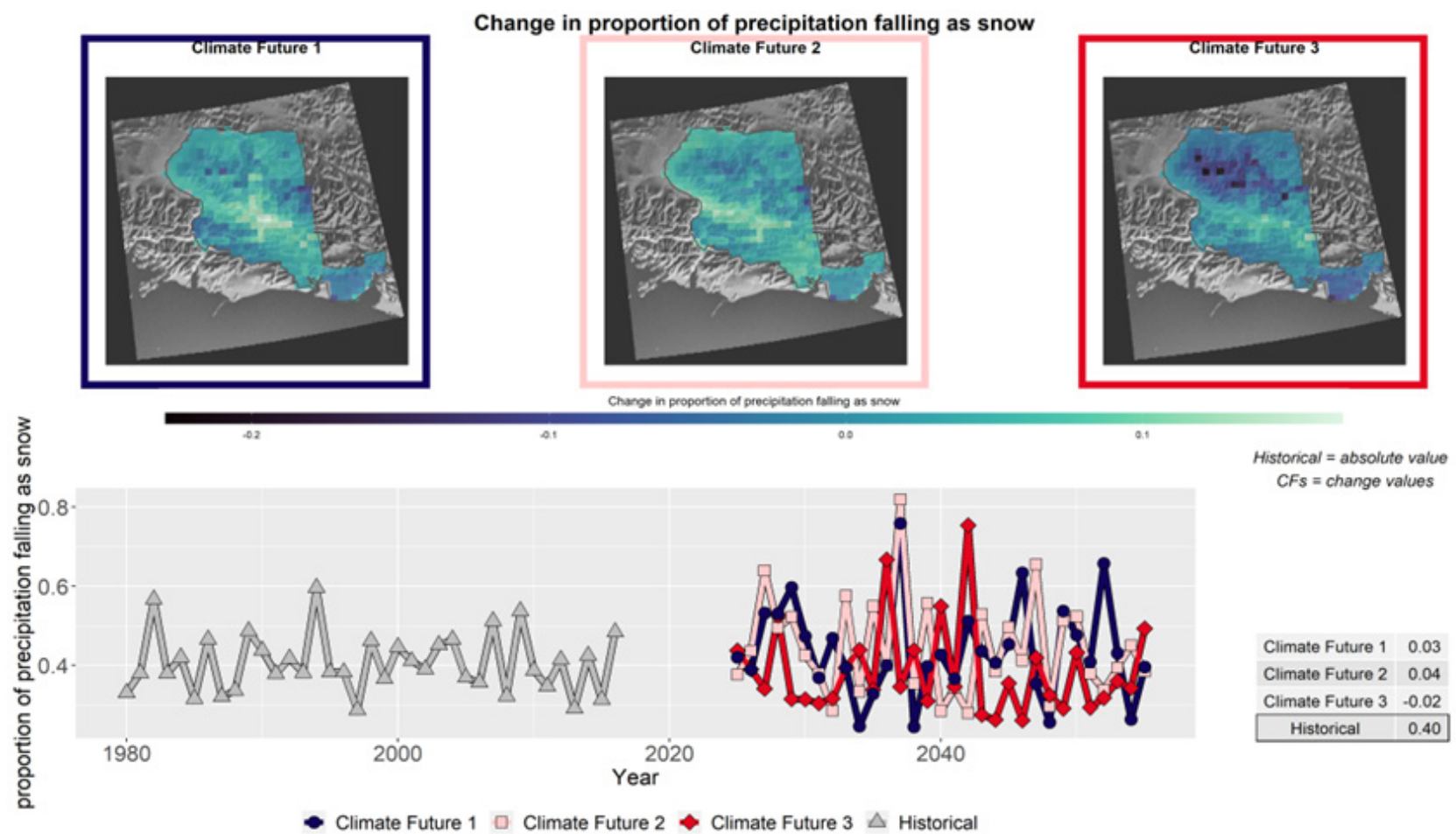


Figure A4.14. Change in average annual proportion of precipitation falling as snow.

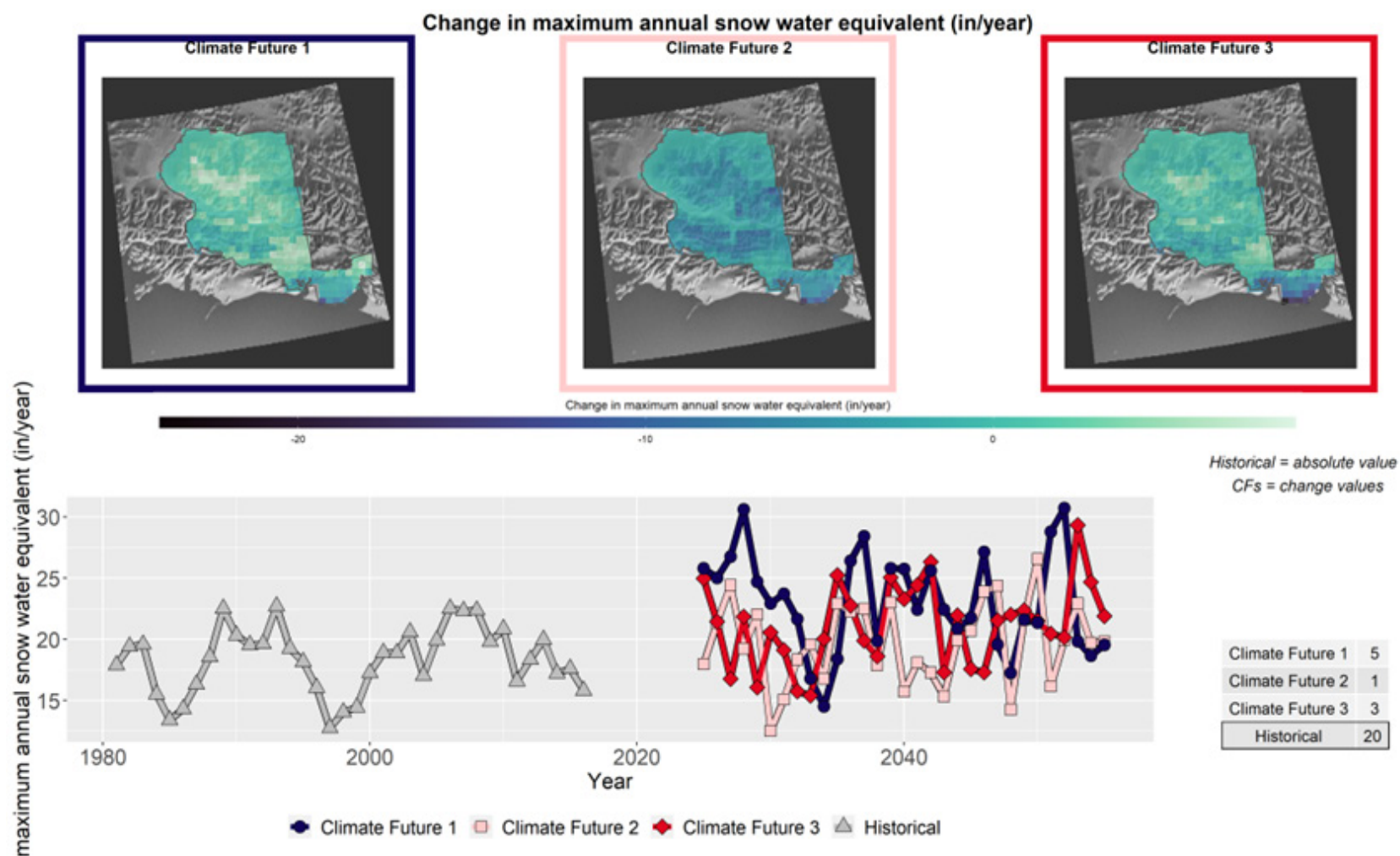


Figure A4.15. Change in average annual snow water equivalent (in/year).

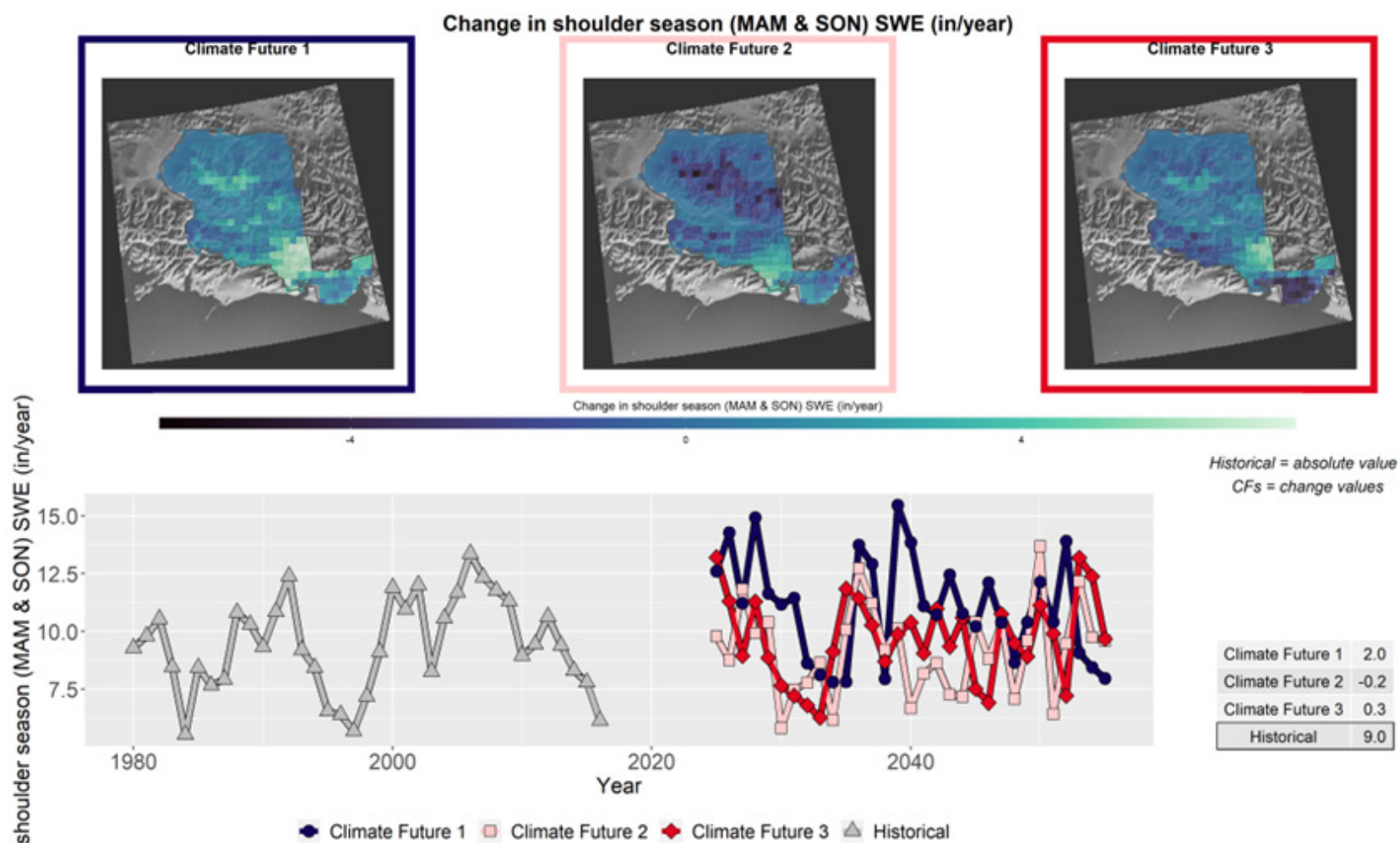


Figure A4.16. Change in average shoulder-season (MAM & SON) SWE (in/year).

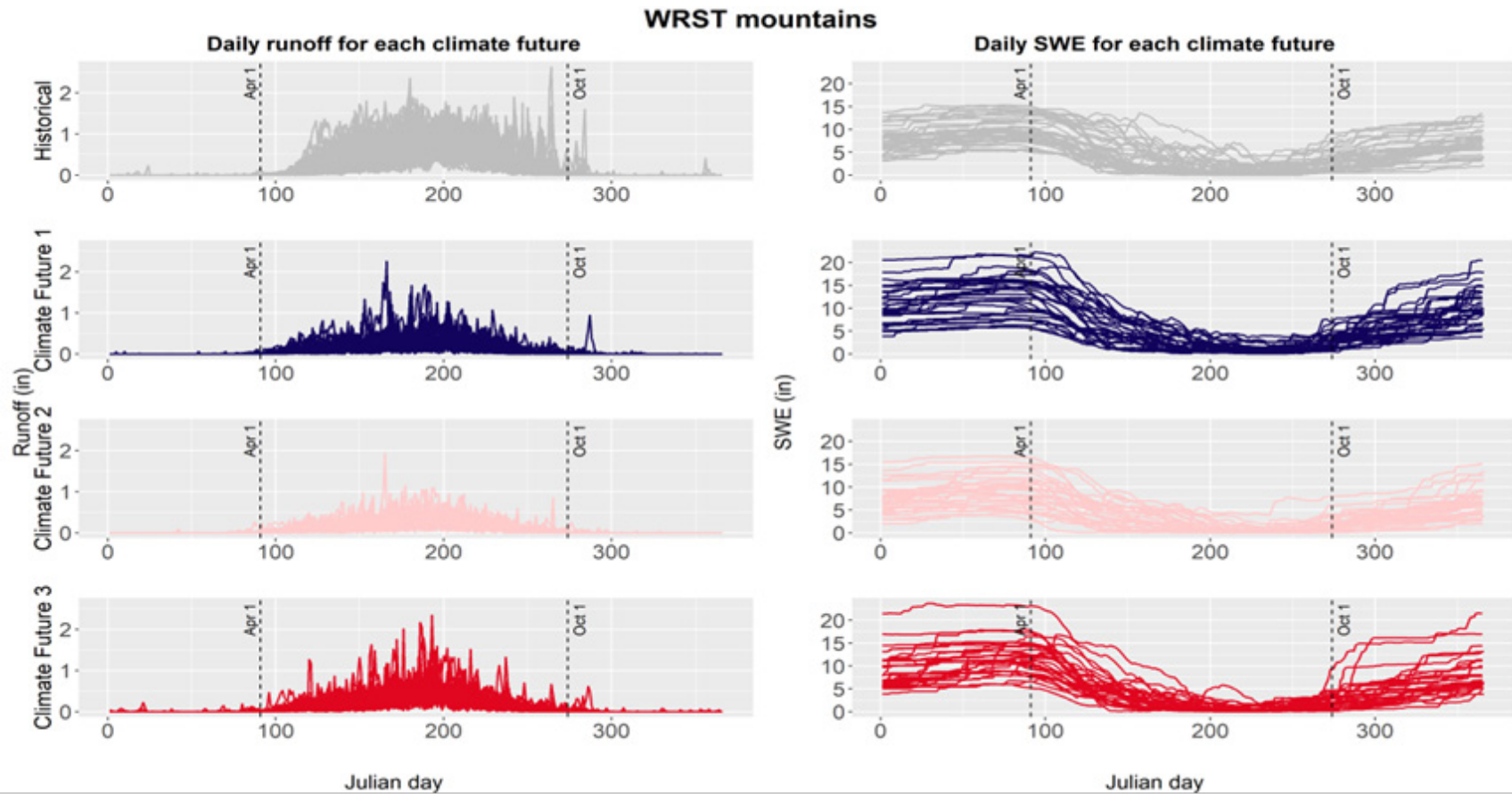


Figure A4.17. Daily runoff and SWE for the historical period and each climate future for the Wrangell Mountains.

The following plots show yearly daily runoff and snow water equivalent (SWE) values for each year. The historical period is observed, gridded climate data (Daymet) from 1980–2016; climate future are from 2025–2055. Figures are produced for the different regions of WRST (see Figure A4.1) and values are averages of all 15-km grid cells within each region. These metrics were calculated using a variable infiltration capacity (VIC) model on the same 15-km grid, provided by NCAR Mizukami et al. (2022).

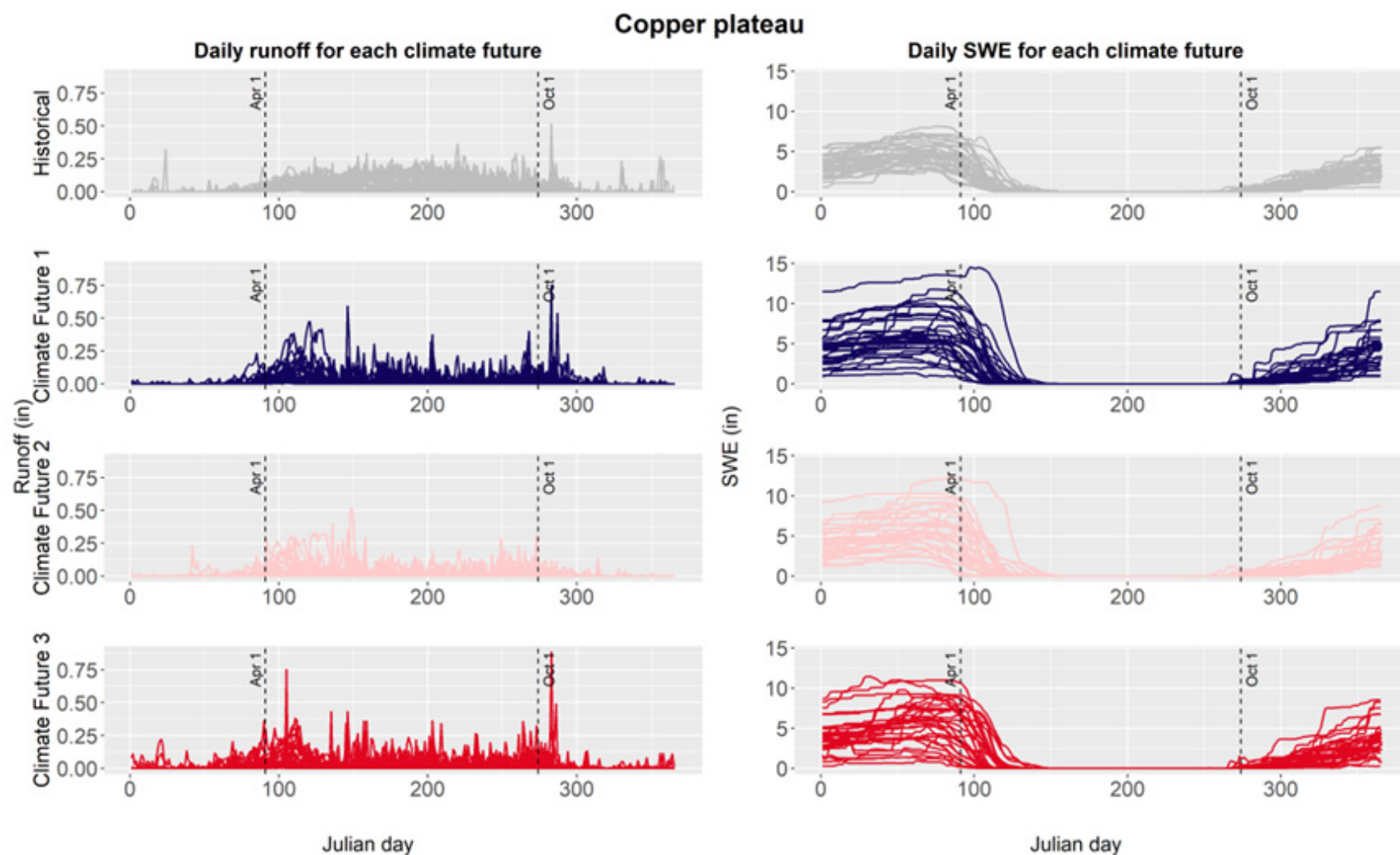


Figure A4.18. Daily runoff and SWE for the historical period and each climate future for the Copper Plateau.

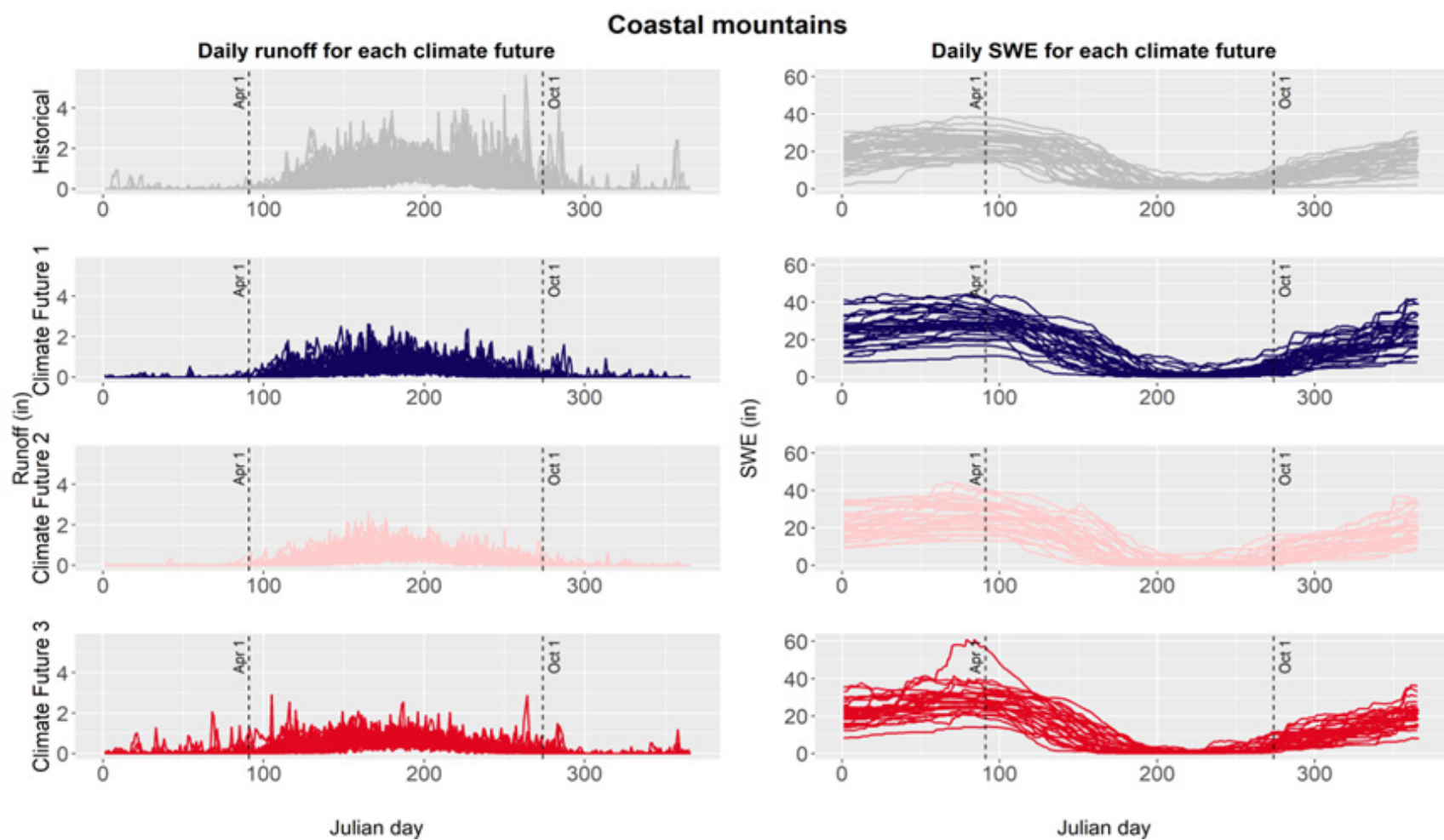


Figure A4.19. Daily runoff and SWE for the historical period and each climate future for the Coastal Mountains.

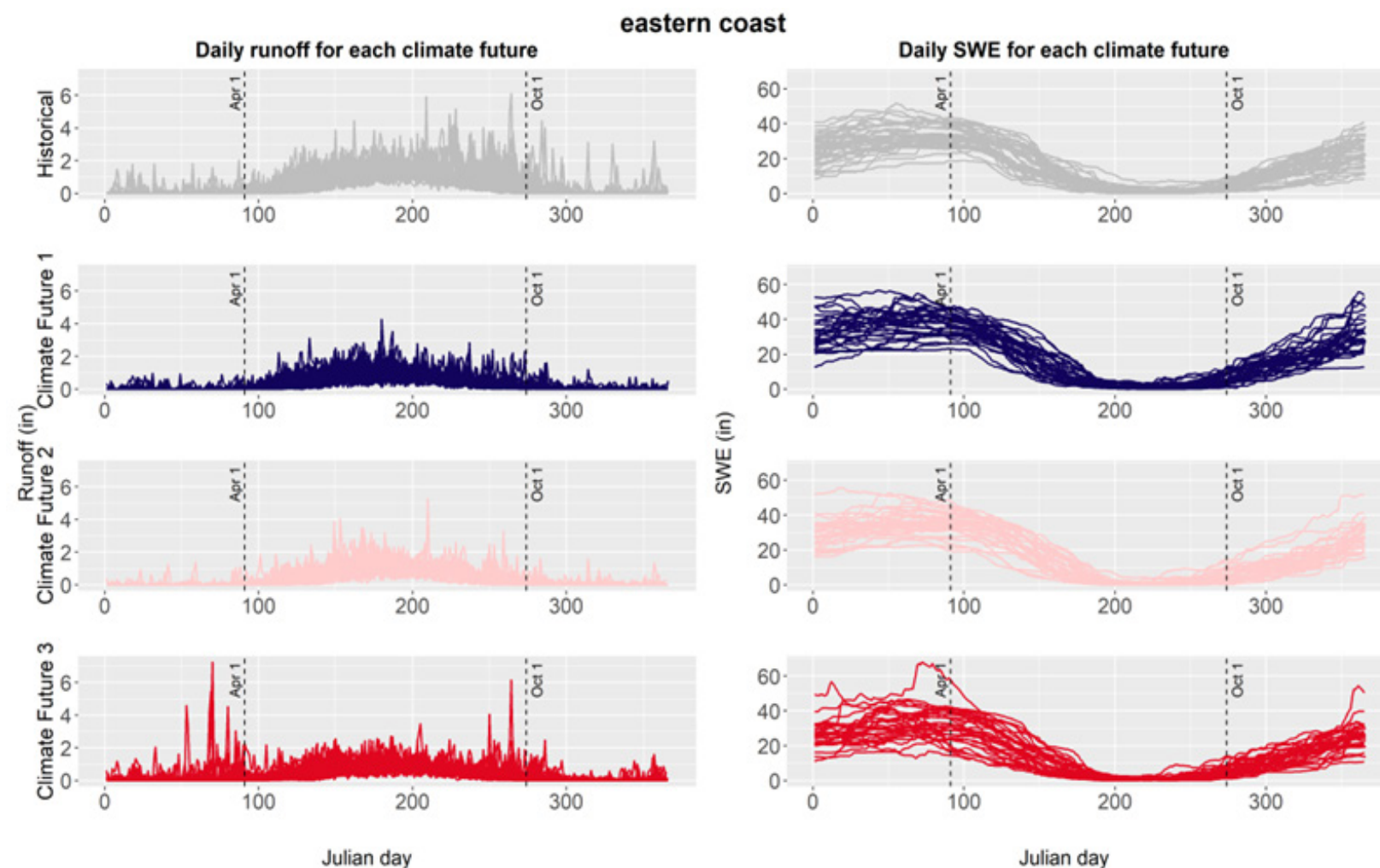


Figure A4.20. Daily runoff and SWE for the historical period and each climate future for the eastern coast.

Soils and permafrost metrics

The following figure panels illustrate change in the specified metric between the historical period (1950–1999) and each climate future (2025–2055). Timeseries plots compare recent climate trends using observed, gridded climate data (Daymet) from 1980–2016 to climate

futures. The bottom-right tables summarize the mean annual values for the historical period (Daymet) and each climate future. The historical period is represented as an absolute value and climate futures are change values, so negative values indicate a decline in the metrics.

The soil metrics were calculated using a variable infiltration capacity (VIC) model on the same 15-km grid, provided by NCAR Mizukami et al. (2021).

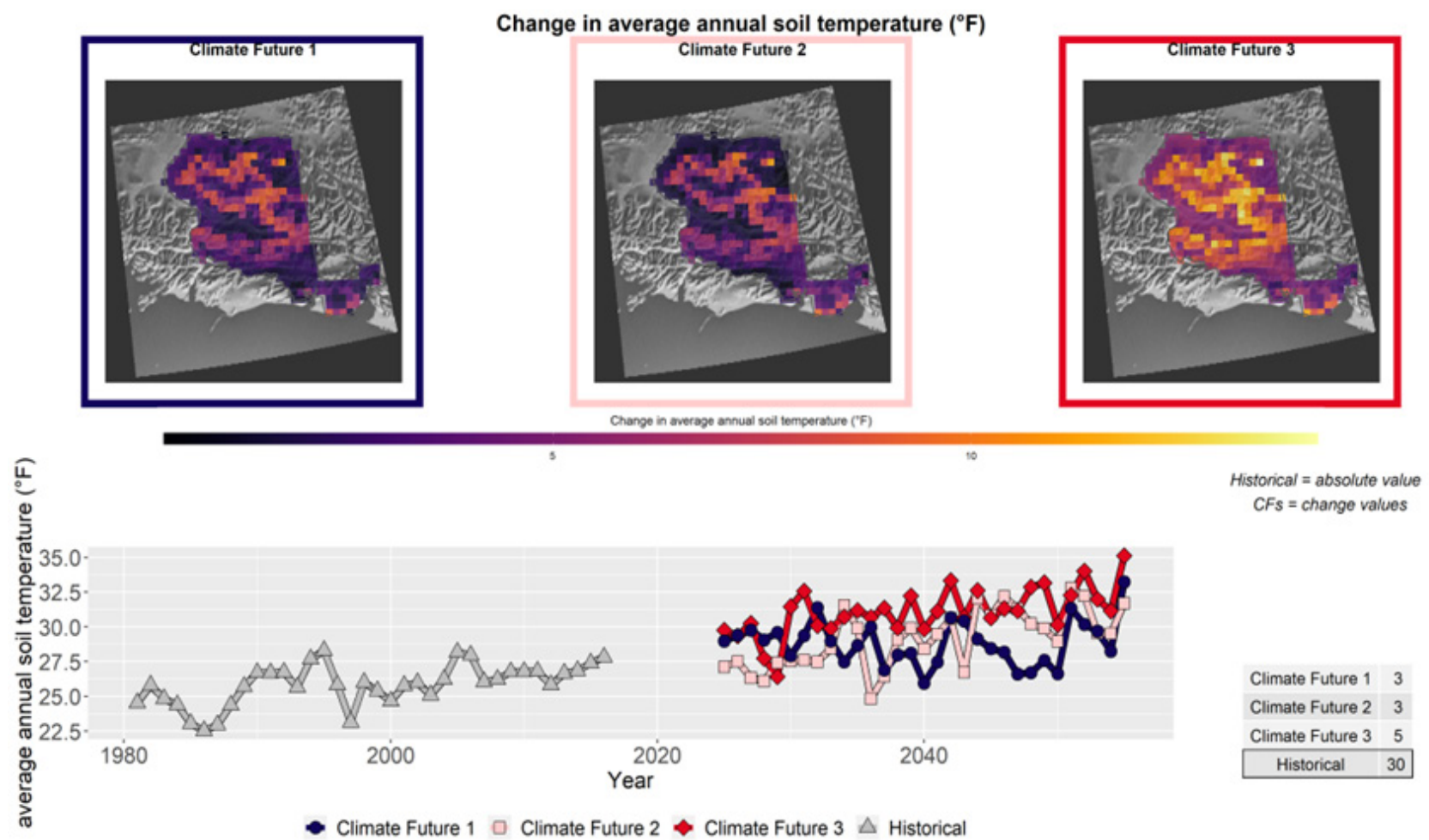


Figure A4.21. Average soil temperature calculated as the average of the first two soil temperature layers from the VIC energy balance model.

References

- Lawrence, David J, Amber N Runyon, John E Gross, Gregor W Schuurman, and Brian W Miller. 2021. “Divergent , plausible , and relevant climate futures for near- and long-term resource planning.” *Climatic Change* 167: 38. <https://doi.org/https://doi.org/10.1007/s10584-021-03169-y>
- Mizukami, N., AJ Newman, JS Littell, AW Wood, ED Gutmann, TW Giambelluca, JJ Hamman, B Nijssen, MP Clark, and JR Arnold. 2022. “21st century hydrologic projections for Alaska and Hawai’i.” *In Review at Climate Services*.

Additional Notes

Email [Amber Runyon](#) with questions about material in this document

Code available at [WRST GitHub repository](#)

Climate information developed in collaboration with [Jeremy Littell](#), U.S.G.S. Alaska Climate Adaptation Science Center

Downscaled climate projections provided by Andrew Newman, National Center for Atmospheric Research Mizukami et al. (2021)

Appendix 5. Non-climate stressors

Table A5. Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Flooding	• Vegetation communities next to waterways shift towards more disturbance-tolerant species. • More erosion of banks and bluffs along rivers (dry bluffs contain unique plant communities), washouts, and sedimentation. • Higher nutrient inputs. • Open terrain, flood plains and banks for opportunistic and invasive plant species. • Tree and shrub loss, due to white spruce, poplars and shrubs along river flood plains being washed out/scoured by floods. • Increase in permafrost thaw facilitated by precipitation heat transfer to permafrost. • Moderate increase in flooding could maintain early successional veg communities on the landscape, favoring moose forage availability. • Enhanced formation of proglacial lakes at termini of retreating glaciers will lead to larger lakes and an increased possibility of catastrophic failure of moraine dams, leading to catastrophic flooding. • Loss of bald eagle nest trees in riparian zones to flooding and erosion could negatively impact eagle populations, at least at the local level. • Moderate increase in meteorologically driven flooding can damage roads, ATV trails, pedestrian trails, airstrips, and public use cabins, leading to changes in use patterns and/or higher maintenance costs. • Glacial melt patterns will overlay the precipitation patterns making it difficult to predict what the surface water conditions in WRST will be under any of the three climate scenarios. • Water levels often drop after earthquakes. • Early season rainfall on still-frozen ground leads to rapid runoff, flash flooding, and landslides; risk lessens over time as early-season ice persistence diminishes; particular risk to Nabesna Road at stream crossings. • Changes may affect food sources for herbivores (e.g., increased flooding may increase willow availability). • Increases in precipitation may increase flooding, runoff and promote erosion of archeological and historic sites. • Increases in snow may increase spring melt/runoff may cause increased erosion to historic and archeological sites. • Glacial outburst flooding may impact archeological and historic sites alongside rivers and streams. • Accelerated permafrost thaw can cause thermokarst areas and subsidence, which affects archeological and historic sites in myriad ways. • Formation of proglacial lakes at termini of retreating glaciers could cause inundation at archeological and historic sites. • Increasing loss of glaciers and ice patches can reveal archeological resources. • Change in use patterns resulting from flooded roads, trails, airstrips, cabins, etc. can impact archeological sites previously buffered from these use areas. • Large landscape-level changes resulting from flooding can affect the integrity of setting, feeling, and association at archeological and historic sites. • Increased risk of spring flooding could threaten Gulkana Hatchery (nearly washed away in 2013).	• Enhanced formation of proglacial lakes at termini of retreating glaciers will lead to larger lakes and an increased possibility of catastrophic failure of moraine dams, leading to catastrophic flooding. • Based on a modeled approximation of CF2: Although P decreases slightly, increased snow melt and glacier ice melt from higher temperatures will increase runoff in all seasons, especially in MAM (spring); flooding risks for CF2 are therefore similar to CF1 and CF3. • Glacial melt patterns will overlay the precipitation patterns making it difficult to predict what the surface water conditions in WRST will be under any of the three climate scenarios; will lead to increased erosion. • Water levels often drop after earthquakes. • Early season rainfall on still-frozen ground leads to rapid runoff, flash flooding, and landslides; risk lessens over time as early-season ice persistence diminishes; particular risk to Nabesna Road at stream crossings. • Increased wildfire occurrence or severity will accelerate permafrost thaw, increasing soil water storage capacity and winter base flow of rivers. • Early season snowmelt on frozen ground may lead to runoff/flooding that may impact historic resources. • Formation of proglacial lakes at termini of retreating glaciers could cause inundation at archeological and historic sites. • Increasing loss of glaciers and ice patches can reveal archeological resources. • Change in use patterns resulting from flooded roads, trails, airstrips, cabins, etc. can impact archeological sites previously buffered from these use areas. • Large landscape-level changes resulting from flooding can affect the integrity of setting, feeling, and association at archeological and historic sites.	• Dramatic increase in flooding changes floodplain vegetation patterns. • Vegetation communities next to waterways shift towards more disturbance-tolerant species. • More erosion, washouts, and sedimentation along rivers, dry bluffs. • Higher nutrient inputs. • Tree and shrub loss, due to white spruce, poplars and shrubs along river flood plains being washed out/scoured by floods. • Accelerate permafrost thaw. • Bald eagles use traditional nest sites within riparian zones; Excessive flooding and erosion with loss of poplars and other mature trees would reduce availability of traditional nest sites, with unknown implications at the population level. • Enhanced formation of proglacial lakes at termini of retreating glaciers will lead to larger lakes and an increased possibility of catastrophic failure of moraine dams, leading to catastrophic flooding. • Substantial increase in meteorologically driven (and glacier runoff augmented) flooding can damage roads, ATV trails, pedestrian trails, airstrips, and public use cabins, leading to changes in use patterns and/or higher maintenance costs. • Glacial melt patterns will overlay the precipitation patterns making it difficult to predict what the surface water conditions in WRST will be under any of the three climate scenarios. • Water levels often drop after earthquakes. • Early season rainfall on still-frozen ground leads to rapid runoff, flash flooding, and landslides; risk lessens over time as early-season ice persistence diminishes; particular risk to Nabesna Road at stream crossings. • Increased wildfire occurrence or severity will accelerate permafrost thaw, increasing soil water storage capacity and winter base flow of rivers. • Increases in precipitation may increase flooding, runoff and promote erosion of archeological and historic sites. • Accelerated permafrost thaw can cause thermokarst areas and subsidence, which affects archeological and historic sites in myriad ways. • Formation of proglacial lakes at termini of retreating glaciers could cause inundation at archeological and historic sites. • Increasing loss of glaciers and ice patches can reveal archeological resources. • Change in use patterns resulting from flooded roads, trails, airstrips, cabins, etc. can impact archeological sites previously buffered from these use areas. • Large landscape-level changes resulting from flooding can affect the integrity of setting, feeling, and association at archeological and historic sites. • Increased flooding and high-water events may decrease the feasibility and effectiveness of fish-wheels as a method of harvesting salmon (they often cannot be run during high water and are likely to be washed away or destroyed during high water and erosion events). • Loss of native allotments and other private lands on the riverbanks due to increased erosion. • Increased flooding could cause increased sedimentation impacts on salmon-spawning bed habitat.

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Wildfires	N/A	- Increased wildfire frequency/intensity may shift vegetation towards deciduous-dominated forests due to permafrost degradation. - More frequent fires results in a more open/deciduous canopy, but over time results in (perhaps) less ‘catastrophic’ fire regime. - Shorter fire return intervals cause more deciduous trees/shrub establishment and poorer black spruce regeneration. - Potential boreal-to-grasslands conversion. - More likely that deciduous forests and shrublands will burn. - Potential for more fires in the coastal areas, unique fire revegetation. - Higher severity fires will result in thermokarsting in permafrost-underlain places. - Erosion potential along bluffs, slopes etc. - More trees (spruce, birch, aspen, polar) will fall, post-fire, due to deep duff consumption; adds to the coarse woody debris load for future fires. - Coarse woody debris adds structure to forest understory and favors many species of small mammals and meso-carnivores; increased small mammal abundance will favor large carnivores. - More fire ignitions from lightning (high temps—storms) and human caused fires (dry conditions). - Drier vegetation, mosses, and lichens - more susceptible to fires. - Decreased area of late successional spruce forest will reduce winter forage (arboreal lichens) for caribou, but increased area of early successional habitats may favor moose initially. - A modest increase in JJA (summer) temperature in the forested river valley (Copper Plateau), with no increase in precipitation but with earlier snowmelt, may slightly lengthen hot and dry conditions in this region. - Wildfire may reduce vegetation and lead to soil erosion and flooding/landslide events that may impact archeological and historic resources. - Dry summers increase risk of wildfire which will threaten to burn/impact historic structures. - Thermokarst areas and accelerated permafrost thaw resulting from higher severity fires can result in inundation and subsidence at archeological sites. - Large landscape-level changes resulting from wildfires can affect the integrity of setting, feeling, and association at archeological and historic sites. - Increased fire in subalpine and alpine tundra (due to drier conditions) could drive shrubline and treeline advance. This may contribute to a decline in caribou habitat, both due to loss of alpine vegetation that forms important caribou forage and because caribou tend to avoid shrubby areas (which can hide predators). - Increased wildfire may hasten the advance of lodgepole pine (Pinus contorta) into Alaska (currently the westernmost extent of its range is in the western Yukon Territory); lodgepole pine forests are fire-dependent, so this may in turn drive increasing wildfire.	- Hotter temperatures and variable precipitation in Coastal Mountains may increase fire frequency, which may favor a shift towards more disturbance-tolerant vegetation communities. - Increased effective evapotranspiration with warmer temperatures offsets effects of higher precipitation. - Sporadic large fire events during brief dry periods or drier summers. - Potential conversion to grasslands, more deciduous trees or shrub establishment, poorer black spruce regeneration. - Spruce forests still predominant fuel load. - High temps and unstable air masses lead to thunderstorms and lightning, and therefore ignitions (more likely wet t-cells). - Increased forest growth with warm, wet conditions may increase fuel loads during drought. - As with CF2, conversion from late-successional spruce-dominated landscapes to early and mid-successional deciduous forests and shrublands would favor moose over caribou. - High JJA (summer) temperature in the forested river valley, paired with increased evaporative deficit, will extend the hot and dry season by two months, from July to June, July, and August. - Wildfire may reduce vegetation and lead to soil erosion and flooding/landslide events that may impact archeological and historic resources. - Dry summers increase risk of wildfire which will threaten to burn/impact historic structures. - Thermokarst areas and accelerated permafrost thaw resulting from higher severity fires can result in inundation and subsidence at archeological sites. - Significantly increased temperatures, along with precipitation and humidity can affect the integrity of materials and workmanship for historic structures. - As in CF2, advancing treelines and loss of alpine tundra may decrease caribou habitat. - As in CF2, may hasten lodgepole pine advance into the CR valley.

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Shoreline disturbance processes	- River shoreline: increased precipitation and flooding may strongly favor disturbance-tolerant species and may allow for their expansion further away from currently established waterways, more partial submerged aquatic community potential. - Coastal shoreline: unpredictable. - Likelihood of substantial change at the Malaspina Glacier foreland (Pacific Ocean margin) under any scenario, leading to loss of park land and likely loss of coastal forest habitat. - Erosion of banks and bluffs along large rivers, dry bluffs contain unique plant communities. - Increased availability of submerged aquatic vegetation or expansion of riparian zones with early successional vegetation would favor moose. - Fens and lakes may be maintained or expanded. - Changes may affect food sources for herbivores (e.g., increased flooding may increase willow availability). - Increased precipitation will increase flooding and will impact historic and prehistoric sites (specifically Ahtna village sites) located along rivers and streams. - Changes along shorelines and coastal areas can affect archeological and historic sites both through inundation and erosion. - Large landscape-level changes resulting from shoreline changes can affect the integrity of setting, feeling, and association at archeological and historic sites.	- River shoreline: Lower river flow may allow for colonization of less disturbance-tolerant vegetation. - Higher temperatures may lead to greater glacial melting and more consistent (less variable) flow through area rivers. - Coastal shoreline: unpredictable. - Drying of shorelines – will result in different vegetation communities, more forest encroachment. - Forest encroachment and reduced early successional vegetation would reduce available habitat and forage for moose. - Enhanced formation of proglacial lakes at termini of retreating glaciers will lead to larger lakes and an increased possibility of catastrophic failure of moraine dams, leading to catastrophic flooding. - Lakes/fens would decline. - Early snowmelt may increase seasonal flooding events on frozen ground and impact sites located along rivers and streams. - Formation of proglacial lakes at termini of retreating glaciers could cause inundation at archeological and historic sites. - Large landscape-level changes resulting from shoreline changes can affect the integrity of setting, feeling, and association at archeological and historic sites.	- River shoreline: Increased precipitation and flooding may strongly favor disturbance-tolerant species and may allow for their expansion further away from currently established waterways. - Coastal shoreline: unpredictable. - Sporadic annual and inter annual increase and decrease in shoreline of lake margins – change in vegetation communities. - Enhanced formation of proglacial lakes at termini of retreating glaciers will lead to larger lakes and an increased possibility of catastrophic failure of moraine dams, leading to catastrophic flooding. - As with CF1, increased availability of submerged aquatic vegetation or expansion of riparian zones with early successional vegetation would favor moose. - Increased flooding in rivers may alter or reduce terrestrial habitats used by seals. - Significant erosion events that rework these large, braided river networks especially if the melting glaciers cause large lakes or Jokulhlaups to form. - Increased precipitation will increase flooding and will impact historic and prehistoric sites (specifically Ahtna village sites) located along rivers and streams. - Changes along shorelines and coastal areas can affect archeological and historic sites both through inundation and erosion. - Formation of proglacial lakes at termini of retreating glaciers could cause inundation at archeological and historic sites. - Large landscape-level changes resulting from shoreline changes can affect the integrity of setting, feeling, and association at archeological and historic sites.
Ungulate herbivory	- Changes may affect food sources (e.g., increased flooding may increase willow availability). - Increased snow depth could restrict of moose and caribou movement in winter months. - Deeper snow causes snowshoe hare herbivory on deciduous shrubs and trees to be higher on the boles of trees. - More snow could reduce the browsing on small spruce seedling/saplings that are covered by the snow in deeper snowpack. - Deeper snowpack and increased ice from rain-on-snow and freeze-thaw events result in poor browsing of lichen and other forage by caribou, Dall's sheep, and bison during fall/winter/early spring. - Warm wet summers will increase willow and deciduous tree growth (beneficial to moose) and increased herbaceous growth (grasses, sedges, and forbs) will benefit hares, caribou, voles, etc. - Deeper snow insulates the ground and protects low vegetation, possibly leading to shrubification of tundra areas as had been documented in the arctic; this will affect avian communities - positive for some species and negative for others depending on life history; also, may favor expansion of beaver populations, with implications for hydrologic regimes and fisheries. - For all climate futures, changes in temperature and/or precipitation, and especially earlier snowmelt and spring warm-up could result in phenological mismatch between development of vegetation and energetic demands of reproduction; this could affect ungulates and many species of birds.	- Changes in vegetation community composition may have impacts to ungulate food sources (e.g., increased wildfire disturbance may favor willow species during secondary succession or impact lichen availability in coniferous forest understories). - Fires increase deciduous browse for ungulates and hares. - Fires increase abundance of graminoid and herbaceous plants that are browsed/eaten by caribou, hares, and voles. - Fire that results in net loss of mature spruce forests will reduce winter range and forage (arboreal lichens) for caribou. - Mule deer become more established in the park, and resultant browsing pressure changes plant communities. - If mule deer become more abundant and interact with other ungulates, they could introduce pathogenic organisms such as winter tick and Parelaphostrongylus tenuis (brain worm), which are a threat to moose and caribou. - Potential increase in wildfires will promote early seral vegetation preferred by moose. - Drier summers could lead to a reduction in Dall sheep lamb survival via a reduction in herbaceous growth (see point at least – reduction in NDVI).	- Changes in disturbance regimes due to wildfires and flooding may impact ungulate food sources (e.g., willows are positively associated with disturbance; lichen understories may be disrupted by wildfires). - More fires lead to more deciduous veg for ungulates and hares, more graminoid for caribou, hare, and voles. - Icing events result in poor browse conditions of lichens and graminoids throughout fall, winter, and spring, negatively affecting Dall's sheep, caribou, and bison, among other species. - Mule deer become more established in the park, and resultant browsing pressure changes plant communities. - If mule deer become more abundant and interact with other ungulates, they could introduce pathogenic organisms such as winter tick and Parelaphostrongylus tenuis (brain worm), which are a threat to moose and caribou. - Potential for decrease in caribou, decline in herbivory, however caribou ranges can likely sustain much higher abundance of caribou than what is there now, so you would have to see caribou habitat virtually go away to cause a significant decrease in caribou. - Dall sheep populations would likely shift to higher elevation and perhaps result in concentration of sheep herbivory in smaller footprints, thereby increasing impacts in localized areas. - On the other hand, reduced winter severity could result in winter habitat expanding for Dall's sheep. - More productive boreal vegetation due to warmth and wetness could perhaps support larger moose populations per unit area than at present.

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Non-native plains bison & domestic livestock	- Increased herbaceous growth (grasses, sedges, and forbs) will benefit bison and livestock. - Warm wet summers will increase willow and deciduous tree growth, which will provide more forage for bison. - Bison are primarily grazing animals, eating grasses, sedges, and forbs. They will also browse willow and dwarf birch, unsure about other browse species. - Flooding along rivers will cause different travel patterns of bison during the summer months, including potentially pushing them out of river flood plain areas. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and livestock (e.g., designated grazing areas, watering holes, invasive species removal activities, etc.)	- Increase in grassland communities could benefit bison and livestock. - If too dry, less annual production/biomass of graminoids. - Dry summers may increase grass environments which may lead to an increase in bison grazing ranges and bedding areas; bison bedding areas may cause impacts to archeological sites. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and livestock (e.g., designated grazing areas, watering holes, invasive species removal activities, etc.)	- Increase in grassland communities (increased graminoid production/biomass) could benefit bison and livestock. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and livestock (e.g., designated grazing areas, watering holes, invasive species removal activities, etc.)
Invasive species	- Increased flooding may facilitate invasions by providing disturbed areas that can be colonized by invasive species (easier spread of seeds - e.g., sweet clover). - Invasive species that can survive under change in new climate regime. - If dependent on pollination by insects for seed dispersal, could have less seeds with rainy summers. - Increased snowpack will keep soils warmer and make it more conducive for some non-native plants. - May impact vegetation characteristic of cultural landscapes. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species (e.g., invasive species removal activities, etc.)	- Increased fire disturbance may allow for invasive species establishment in burned areas (e.g., Mediterranean weed species such as Melilotus). - Increase in invasive plant species due to warmer temperatures and soils. - Potential for cheat grass and other invasive plant species that have low palatability for ruminants and crowd out native species. - Lodgepole pine (not an invasive) expands into interior and future fire regime shifts. - May impact vegetation characteristic of cultural landscapes. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species (e.g., invasive species removal activities, etc.)	- Increase in invasive plant species (especially disturbance-tolerant) due to warmer temperatures and soils, disturbed floodplains/shorelines, and/or wildfire disturbances, may cause tree mortality or defoliation of trees and shrubs. - Potential for cheat grass. - Lodgepole pole (not an invasive) expands into interior and future fire regime shifts. - Increased potential for plant diseases and rots with warmer temps. - Southern species expanding northward. - May impact vegetation characteristic of cultural landscapes. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species (e.g., invasive species removal activities, etc.)
Insect pests and diseases	- Contrasting potential impacts (uncertainty): 1) Lower risk of drought stress may render trees less susceptible to mortality via insect attack, but 2) warming will increase potential for invasive insects and native insects (bark beetle, leaf minors, sawflies) that can cause tree mortality (bark beetles) and defoliation of trees and shrubs. - Greater levels of rot due to fungal pathogens. - Warmer winters will increase brood size and survivorship of spruce bark beetles and likely other insects. - High snowpack keeps warmer soils and bark beetles overwinter in the duff in the ground - Warmer winters could allow establishment of ectoparasites such as ticks, lice, and fleas, which can directly cause disease (e.g., hair loss in moose from winter tick) or may act as disease vectors. - Expansion of mule deer could result in increased risk to moose of parasites and diseases (e.g., winter ticks). - Warmer climate and increased precipitation may lead to Increase of insect pests such as ants which will impact historic structures. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and pest management (e.g., removal and mitigation activities, etc.)	- Drought-stressed trees and vegetation are often more susceptible to attack by insect pests. - Higher temperatures may augment overwinter larval survival, leading to larger insect pest outbreaks. - Less chance of increasing rot. - Increased drought stress and warming may increase trees' susceptibility to insects and disease (bark beetle, leaf minors, sawflies). - Extensive spruce mortality could reduce winter range and forage for caribou, would alter avian communities, and may lead to greater competitive advantage for other plant species (grasses, alders, etc.) - Expansion of mule deer could result in increased risk to moose of parasites and diseases (e.g., winter ticks). - Dry climate and lack of winter may lead to increase of insect pests such as ants which will impact historic structures. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and pest management (e.g., removal and mitigation activities, etc.)	- Where water is increasingly limited, trees may be more susceptible to attack by insect pests. - Where water is more abundant, they may be less susceptible. - Vegetation in areas receiving greater precipitation coupled with higher temperatures may be more susceptible to rot. - Longer growing seasons for more pest reproductive cycles. - Fewer cold winters may promote pest and disease increase. - Expansion of mule deer could result in increased risk to moose of parasites and diseases (e.g., winter ticks). - Hot climate may lead to increase of insect pests such as ants which will impact historic structures. - Archeological and historic sites are often affected by the activities associated with the management of non-native/invasive species and pest management (e.g., removal and mitigation activities, etc.)

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Threats from pollutants	- Increased precipitation of contaminants from places like Russia/China impacts lichens and other sensitive plants. - Warmer conditions lead to increased melt from glaciers with potential for increased transport of contaminants from glaciers. - Pollutants may increase melt of high alpine ice patches which may impact ice patch archeological sites. - Depending on the severity and scope of the pollutant, rock art panels and similar resources can experience accelerated erosion from accumulated particulates. - Increased high water and flooding may threaten contaminated areas near rivers, such as village dump sites.	- Drier conditions may make long-range transport of pollutants less of an issue, however many pollutants transport by wind currents. - Increase in smoke (PM2.5) from fires. - Loss of wetlands reduces system’s natural capacity to biomediate pollutants. - Pollutants may increase melt of high alpine ice patches which may impact ice patch archeological sites. - Depending on the severity and scope of the pollutant, rock art panels and similar resources can experience accelerated erosion from accumulated particulates.	- Wetter conditions make long-range transport of pollutants an important issue. - Much higher PM2.5 air quality issues due to fires in Alaska, Canada, and everywhere. - Warmer conditions lead to increased melt from glaciers with potential for increased transport of contaminants from glaciers. - Greater possibility of hydrocarbon spills from failed attempts to cross glacial rivers by miners, others (see below under “active mining”). - Pollutants may increase melt of high alpine ice patches which may impact ice patch archeological sites. - Depending on the severity and scope of the pollutant, rock art panels and similar resources can experience accelerated erosion from accumulated particulates. - An increased risk of hydrocarbon spill incidents can adversely affect both archeological and historic resources, both from the spill itself as well as from response/mitigation activities following the spill. - As in CF1, increased high water and flooding may threaten contaminated areas near rivers, such as village dump sites.
Visitor-use impacts (i.e., impacts from climate change-driven changes in visitation)	- Warmer temperatures (more people out recreating), but more rain (unhappy visitors). - Wetter conditions cause more trail erosion and vegetation damage. - Snow machine access better due to more snow coverage; could see more snow machine use. - If increased snowmachine use, increased potential to disturb wildlife (caribou, moose, Dall’s sheep, bison) during energetically demanding times of year. - Shift in visitor patterns as best places to access and see glaciers change with continued glacier retreat; need for adjustments to roads, trails, facilities. - Eastern coastal areas may see increased visitation by vessels, particularly if other areas in state lose desirable, accessible tidewater glaciers. - Glacial melt and higher flows cause dangerous summertime conditions for watersports, hunters, and motorized traffic on the Copper River and other rivers. - Increased asynchrony with users, timing of floating no longer corresponds to good water conditions, either too low water or too high. - Less snowpack – fewer opportunities for winter visitor use (mushing, skiing, snowmobiling). - A potentially narrow window of drier weather in the summer may cause the same number of cruise ships to schedule visits over fewer days resulting in greater daily disturbance to ice-hauling seals. - Flooding and other climate changes may necessitate new/modified infrastructure (roads, trails, cabins); natural sounds would be impacted from construction and maintenance. - Changes in visitor use (more snow-go use, more and/or concentrated use along coastal areas) would reduce opportunities for solitude in those locations. - Increase in visitor use because of warm summers may increase vandalism to historic and archeological sites; increases in visitor use will also benefit resource as people will be able to enjoy them more. - Increased rain may increase use of historic structures by visitors which may result in impacts; increase in use will also benefit the resource as people will enjoy it.	- Warmer/drier conditions may increase visitation (including longer season) and damage to vegetation. - Improved trail conditions where not located on permafrost. - Increased potential for human-caused wildfire. - Areas that maintain snowpack see more concentrated snow machine access. - Eastern coastal areas may see increased visitation by vessels, particularly if other areas in state lose desirable, accessible tidewater glaciers. - Shift in visitor patterns as best places to access and see glaciers change with continued glacier retreat; need for adjustments to roads, trails, facilities. - Climbing season on glaciated peaks shifts earlier in spring, and potential for crevasse falls is enhanced on traditional routes. - Warmer, drier summers may extend the cruise ship season in Icy and Disenchantment Bays causing higher levels of disturbance to ice-hauling seals. - Glacial melt and higher flows cause dangerous summertime conditions for watersports, hunters, and motorized traffic on the Copper River and other rivers. - Increased asynchrony with users, timing of floating no longer corresponds to good water conditions, either too low water or too high. - Less snowpack – fewer opportunities for winter visitor use (mushing, skiing, snowmobiling). - Early season rainfall on still-frozen ground leads to landslides and are special concern along McCarthy Road; risk lessens over time as early-season ice persistence diminishes. - Shift in timing of visitor use to avoid peak fire season (to before and after the peak) and its limitations to visibility and impacts to air quality; increased asynchrony for backcountry visitation. - Firefighting activities impact natural soundscapes due to increased activity from aircraft and motorized equipment. - Flooding and other climate changes may necessitate new/modified infrastructure (roads, trails, cabins); natural sounds would be impacted from construction and maintenance. - Increase in visitor use as a result of dry summers may increase vandalism to historic and archeological sites; increases in visitor use will also benefit resource as people will be able to enjoy them more.	- Warmer conditions may increase visitation (including longer season), resulting in more trampling, social trails, tree cutting – damage to vegetation. - Wetter conditions cause more trail erosion and vegetation damage. - With variable snowpack, see more damage to vegetation – shrubs and tundra damage. - Areas that maintain snowpack see more concentrated snow machine access. - Eastern coastal areas may see increased visitation by vessels, particularly if other areas in state lose desirable, accessible tidewater glaciers. - Even more rapid shift in visitor patterns as best places to access and see glaciers change with continued glacier retreat; need for adjustments to roads, trails, facilities. - Climbing season on glaciated peaks shifts earlier in spring, and potential for crevasse falls is enhanced on traditional routes. - A potentially narrow window of drier weather in the summer may cause the same number of cruise ships to schedule visits over fewer days resulting in greater daily disturbance to ice-hauling seals. - Glacial melt and higher flows cause dangerous summertime conditions for watersports, hunters, and motorized traffic on the Copper River and other rivers. - Increased asynchrony with users, timing of floating no longer corresponds to good water conditions, either too low water or too high. - Less snowpack – fewer opportunities for winter visitor use (mushing, skiing, snowmobiling). - Early season rainfall on still-frozen ground leads to landslides and are special concern along McCarthy Road; risk lessens over time as early-season ice persistence diminishes. - Wetter conditions increase likelihood of slope failure on steep roadcuts along McCarthy road and may affect vehicle access. - Consistent wet conditions would lead to more constant high-water issues on the Nabesna Road stream crossings and exacerbate already difficult erosion/maintenance issues. - Substantial increase in meteorologically driven (and glacier runoff augmented) flooding can damage roads, ATV trails, pedestrian trails, airstrips, and public use cabins, leading to changes in use patterns and/or higher maintenance costs. - Flooding and other climate changes may necessitate new/modified infrastructure (roads, trails, cabins); natural sounds would be impacted from construction and maintenance.

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Visitor-use impacts (i.e., impacts from climate change-driven changes in visitation) (continued)	- Increased visitor use from warm climate will benefit historic trails, airstrips historic structures and other resources that are threatened from neglect/encroaching vegetation as people will clear vegetation during use; conversely, new trails may be developed that could have impacts to historic and archeological resources. - Changes in visitor use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions. - Adjustments to roads, trails, facilities due to changes in visitor traffic patterns (pedestrian or otherwise) can affect archeological and historic sites.	- Increased visitor use from warm climate will benefit historic trails, airstrips historic structures and other resources that are threatened from neglect/encroaching vegetation as people will clear vegetation during use; conversely, new trails may be developed that could have impacts to historic and archeological resources. - Increase in visitor use due to dry climate may increase human-caused fire which will directly impact historic structures. - Changes in visitor use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions. - Adjustments to roads, trails, facilities due to changes in visitor traffic patterns (pedestrian or otherwise) can affect archeological and historic sites. - With variable snowpack, more visitor-impact damage to vegetation – shrubs and tundra.	- Increase in visitor use as a result of hot summers may increase vandalism to historic and archeological sites; increases in visitor use will also benefit resource as people will be able to enjoy them more. - Increased visitor use from hot climate will benefit historic trails, airstrips historic structures and other resources that are threatened from neglect/encroaching vegetation as people will clear vegetation during use; conversely, new trails may be developed that could have impacts to historic and archeological resources. - Increase in visitor use due to hot climate may increase human-caused fire which will directly impact historic structures. - Changes in visitor use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions. - Adjustments to roads, trails, facilities due to changes in visitor traffic patterns (pedestrian or otherwise) can affect archeological and historic sites. - Increase in high-water events may result in fewer good fishing days in Chitina personal-use dipnet fishery, and CR basin sport fisheries, with potential impact on number of participants.
Off-road vehicle use	- Increased ORV damage (braided trails) to wetlands as riders avoid expanding wet areas, especially where rapid soil warming coincides with permafrost soils (e.g., Nabesna Road area), making it more dangerous to travel. - Increased ORV damage leads to increased stream channel initiation, increased surface runoff, sediment inputs to downstream channels. - Increase in ORV use on existing trails during wet climates may impact archeological sites through increased ground disturbance from creation of additional braided trails to avoid wet areas, rutting, etc. - Changes in visitor ORV use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions.	- Increased usage due to drier conditions, vegetation damage to more side trails created. - Increased need for brushing along ORV and other trails as vegetation becomes more woody. - Dry climates may increase off-trail ORV use which may impact archeological resources because of ground disturbance/trail-making. - Changes in visitor ORV use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions. - Increased wildfire leads to more downed trees and erosion, blocking or damaging ORV trails and causing them to require more intensive maintenance.	- Increased ORV damage (braided trails) to wetlands as riders avoid expanding wet areas, especially where rapid soil warming coincides with permafrost soils (e.g., Nabesna Road area), making it more dangerous to travel. - Increased ORV damage leads to increased stream channel initiation, increased surface runoff, sediment inputs to downstream channels. - Substantial increase in meteorologically driven (and glacier runoff augmented) flooding can damage roads, ATV trails, pedestrian trails, airstrips, and public use cabins, leading to changes in use patterns and/or higher maintenance costs. - Hot climates may increase off-trail ORV use which may impact archeological resources because of ground disturbance/trail-making. - Increase in ORV use on existing trails during wet climates may impact archeological sites through increased ground disturbance from creation of additional braided trails to avoid wet areas, rutting, etc. - Changes in visitor ORV use may have effects on traditional use areas/sacred sites that were previously protected due to seasonal or public use-area restrictions. - As in CF2, increased wildfire is likely to cause more damage to ORV trails.
Active mining and abandoned mine lands	- Potential erosion factors with increased rain. - With increased run-off and flooding, contaminants may more readily move downstream or across landscapes. - More summer spring-fed streamflow in Gold Hill area could lengthen viable placer mining season. - More glacier runoff and enhanced spring-fed streamflow could routinely challenge access across Nizina River for Dan Creek-area miners, and potentially lead to more accidents en route. - Archeological and historic sites are often affected by the activities associated with the management of active mines and AMLs (e.g., closures, mitigation activities, etc.).	- Minimal changes, except drier summer conditions may lead to less leaching of contaminants. - Less summer spring-fed streamflow in Gold Hill area could shorten viable placer mining season. - More glacier runoff could sometimes challenge access across Nizina River for Dan Creek-area miners, and potentially lead to more accidents en route. - Archeological and historic sites are often affected by the activities associated with the management of active mines and AMLs (e.g., closures, mitigation activities, etc.)	- Potential erosion factors with increased rain. - With increased run-off and flooding, contaminants may more readily move downstream or across landscapes. - More, and more volatile, spring-fed summer streamflow in Gold Hill area could lengthen, but make more challenging, viable placer mining season. - More glacier runoff and enhanced spring-fed streamflow could routinely challenge access across Nizina River for Dan Creek-area miners, and potentially lead to more accidents en route. - Archeological and historic sites are often affected by the activities associated with the management of active mines and AMLs (e.g., closures, mitigation activities, etc.)
Slope stability	- Loss of soil ice would destabilize slopes and increase magnitude and frequency of landslides and debris flows. - Increased soil moisture would allow shallower slopes to fail, increasing the magnitude and frequency of landslides and debris flows. - Slope failures into streamways would cause increases in stream turbidity; failures creating temporary dams could lead to flooding; failures along roadways would adversely impact visitor access and increase maintenance costs.	- Loss of soil ice would destabilize slopes and increase magnitude and frequency of landslides and debris flows. - Slope failures into streamways would cause increases in stream turbidity; failures creating temporary dams could lead to flooding; failures along roadways would adversely impact visitor access and increase maintenance costs.	- Loss of soil ice would destabilize slopes and increase magnitude and frequency of landslides and debris flows. - Increased soil moisture would allow shallower slopes to fail, increasing the magnitude and frequency of landslides and debris flows. - Slope failures into streamways would cause increases in stream turbidity; failures creating temporary dams could lead to flooding; failures along roadways would adversely impact visitor access and increase maintenance costs.

Table A5 (continued). Non-climate stressors identified by SMEs with implications for each of the three scenarios. An initial list of non-climate stressors was created by the climate change team and participants were asked to use the climate futures packet (Appendix 4) to review the stressors relevant to the resource(s) for which they were a SME and add content about how the stressor will change under each climate future. Development of this table was iterative with the addition of relevant non-climate stressors and comments on and modifications of content where there was disagreement.

Non-Climate Stressor	Scenario 1	Scenario 2	Scenario 3
Permafrost thaw (see Vegetation: soils and Permafrost)	–	–	–
Rapid expansion of vegetation as a result of rapidly receding glaciers	• Periglacial areas expand. • Significant increase in habitat for early successional plant species at glacier margins (Dryas spp., alders, poplars, etc.) • Many wetland areas are supported by ice on otherwise well-drained gravels; loss of this persistent ice layer would allow wetlands to drain, and those areas would be succeeded by more woody vegetation.	• More vegetation in previously unvegetated areas attracting more avian predators and loss of nesting habitat for ground/cliff nesting birds. • On the other hand, newly vegetated areas may provide expanded habitat for a variety of avian and mammalian species. • Significant increase in habitat for early successional plant species at glacier margins (Dryas spp., alders, poplars, etc.) • Many wetland areas are supported by ice on otherwise well-drained gravels; loss of this persistent ice layer would allow wetlands to drain, and those areas would be succeeded by more woody vegetation.	• More vegetation in previously unvegetated areas attracting more avian predators and loss of nesting habitat for ground/cliff nesting birds. • Significant increase in habitat for early successional plant species at glacier margins (Dryas spp., alders, poplars, etc.) • Many wetland areas are supported by ice on otherwise well-drained gravels; loss of this persistent ice layer would allow wetlands to drain, and those areas would be succeeded by more woody vegetation.
Receding and potential grounding of glaciers	• Expansion of glacial habitat; more glacial ice available for harbor seals.	• Loss of ice bergs and area covered by ice resulting in less substrate for resting and pupping harbor seals and increased access by predators and human hunters.	• Loss of ice bergs (or increase in melt rate of icebergs) and area covered by ice resulting in less substrate for resting and pupping harbor seals and increased access by predators and human hunters (important to consider timescale here as availability of ice habitat will vary depending upon stage of glacier retreat).

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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