



Greater Yellowstone Climate-Aquatics Workshop

Report from the April 27–29, 2021, Climate-Smart Conservation Workshop

Natural Resource Report NPS/YELL/NRR—2022/2479





ON THIS PAGE

Monitoring amphibians in Grand Teton National Park.

NPS/ANDY RAY

ON THE COVER

Spawning Yellowstone cutthroat trout.

NPS/JAY FLEMING

Greater Yellowstone Climate-Aquatics Workshop

Report from the April 27–29, 2021, Climate-Smart Conservation Workshop

Natural Resource Report NPS/YELL/NRR—2022/2479

Tom Olliff,¹ David Thoma,¹ Molly Cross,² Ann Rodman,³ Patrick Barry,⁴ David Lawrence,⁵ Scott Barndt,⁶ Andrew Ray,¹ Mike Tercek,⁷ Janelle Christensen,⁵ Justin Peterson,⁴ David Diamond⁶

¹National Park Service
Bozeman, MT

²Wildlife Conservation Society
Bozeman, MT

³National Park Service
Yellowstone National Park, WY

⁴U.S. Forest Service
Jackson, WY

⁵National Park Service
Fort Collins, CO

⁶U.S. Forest Service
Bozeman, MT

⁷Walking Shadow Ecology
Gardiner, MT

November 2022

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Olliff, T., D. Thoma, M. Cross, A. Rodman, P. Barry, D. Lawrence, S. Barndt, A. Ray, M. Tercek, J. Christensen, J. Peterson, and D. Diamond. 2022. Greater Yellowstone climate-aquatics workshop: Report from the April 27–29, 2021, climate-smart conservation workshop. Natural Resource Report NPS/YELL/NRR—2022/2479. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2294895>

Contents

	Page
Figures.....	v
Appendices.....	v
Executive Summary	vi
Acknowledgments.....	viii
Introduction.....	1
Climate Change in the Greater Yellowstone Ecosystem.....	2
Aquatic Resources and Management in the GYE—General Overview.....	2
Workshop Objectives	3
Methods.....	4
Workshop Support and Planning.....	4
Pre-Workshop Interviews.....	4
Climate Data Analysis.....	4
Overview of Climate-Smart Conservation	4
Case Studies.....	5
Adaptation Strategies and Options	6
Greater Yellowstone Aquatic Conservation Projects Database	6
Post-Workshop Follow-up.....	8
Case Studies	9
Case Study 1: Restoring Native Biodiversity to the Blacktail Ponds Wetland Complex in Yellowstone National Park	9
1) Management Goals.....	10
2) Vulnerability Assessment.....	10
3) Climate Aligned Goals.....	11
4) Identify Potential Management Options	11
5) Select Feasible Adaptation Actions for Implementation.....	12
6) Implement Management Actions	13

Contents (continued)

	Page
Case Study 2: Conserving and Restoring Yellowstone Cutthroat Trout in Buffalo Creek, Lamar and Yellowstone rivers	13
1) Management Goals.....	15
2) Vulnerability Assessment.....	15
3) Climate Aligned Goals.....	17
4) Identify Potential Management Options	17
5) Select Feasible Adaptation Actions for Implementation.....	18
6) Implement Management Actions	19
7) Monitoring.....	19
Case Study 3: Protecting or Restoring Resilient Riparian Areas Through Fire Management on the East Side Drainages of the Gallatin River on the CGNF	19
1) Management Goals.....	20
2) Vulnerability Assessment.....	20
3) Climate Aligned Goals.....	21
4) Identify Potential Management Options	21
5) Select Feasible Adaptation Actions for Implementation.....	23
6) Implement Management Actions	23
7) Monitoring.....	23
Discussion and Next Steps.....	24
Priority 1	25
Priority 2.....	25
Priority 3.....	25
Priority 4.....	25
Conclusion	27
Literature Cited	29

Figures

	Page
Figure 1. The Climate-Smart Conservation Planning Cycle (from Stein et al. 2014).	5
Figure 2. Distribution of project habitat and project type in the Greater Yellowstone Aquatic Conservation Projects database.	7
Figure 3. Screen capture from the Greater Yellowstone Aquatic Conservation Projects database.	7
Figure 4. Map of the Buffalo Creek watershed where a Yellowstone cutthroat trout project has been proposed.	14

Appendices

	Page
Appendix A. Agenda	31
Appendix B. Workshop Participants and Planning Team.....	33
Appendix C. Water Balance Reports	36
Appendix D. Cold Water Fisheries Adaptation Approaches and Strategies.....	46
Appendix E. History of Federal Climate Change Activities in the GYE	49
Appendix F. Climate Summaries	56

Executive Summary

The Greater Yellowstone Coordinating Committee's (GYCC) Climate Change, Fisheries, and Hydrology subcommittees hosted a virtual Climate-Smart Conservation workshop, April 27–29, 2021, focused on aquatic resources. Fifty people attended the plenary sessions; over 30 people participated in the breakout sessions. Molly Cross, Climate Change Adaptation Scientist for the Wildlife Conservation Society, facilitated the workshop.

Climate change is arguably the most pervasive conservation threat to the Greater Yellowstone Ecosystem (GYE)—preparing for it will require a well-informed shared understanding of impacts at both project and ecosystem scales. Fish kills in the Yellowstone River; the spread of aquatic invasive species; rapidly increasing invasive grasses; shrinking wetland resources; and extreme wildfire behavior with impacts to aquatic resources have all been linked to a warmer, drier climate. Since 1950, average temperature increased by 2.3°F in the GYE; peak precipitation shifted from May/June to April/May; average snowfall declined by 3.5 inches; and the timing of peak flow now occurs about 8 days earlier. Warming trends are projected to continue by +0.5°F to +1.2°F per decade; water stored in the snowpack is expected to continue to decrease; and a further decline in soil moisture of 5–7% is projected by mid-century (Hostetler et al. 2021).

The workshop opened with plenary sessions that included the inspirational photography of Jeremy Monroe from Freshwaters Illustrated, perspectives on climate change from senior agency managers, results from the recently completed Greater Yellowstone Area (GYA) Climate Assessment, and presentations on linking science to action. Dr. Clint Muhlfeld, Aquatic Ecologist with the USGS Northern Rockies Science Center, provided the closing keynote.

The majority of the workshop focused on applying a Climate-Smart Conservation planning process to three case studies: (a) Restoring native biodiversity (amphibians, plants, aquatic macroinvertebrates, birds, and bats) to the Blacktail Ponds wetland complex in Yellowstone National Park (YNP); (b) Conserving and restoring Yellowstone cutthroat trout (YCT) in Buffalo Creek, Lamar and Yellowstone rivers; and (c) Protecting or restoring resilient riparian areas through fire management on the east side drainages of the Gallatin River on the Custer Gallatin National Forest (CGNF).

The case study breakout groups: (1) reviewed the project purpose and scope; (2) assessed climate impacts and vulnerabilities; (3) reviewed and revised, where necessary, the project goals using the Resist-Accept-Direct (RAD) framework; (4) identified possible climate adaptation actions; and (5) began to evaluate and select adaptation actions. Each breakout group had site-specific historic and projected future climate data and was supported by a scientist with expertise in the topic. The Buffalo Creek YCT project identified adaptation actions that will be incorporated into the on-going project. The Gallatin group will continue to meet to develop adaptation actions that could be implemented by the CGNF and that could serve as a model for managing fire and fuel treatment in riparian areas. The Blacktail Ponds project is a model for identifying actions with broad biodiversity benefits (improving habitat conditions for multiple taxonomic groups) at a site determined to be relatively insensitive to projected changes in runoff.

To close the workshop, participants brainstormed several recommendations for motivating climate-smart conservation across the GYE. In addition, we followed the workshop with a survey of both participants and invitees who identified a subset of those actions as especially high-priority next steps, including:

- Build “menus” of adaptation strategies, actions, and checklists of climate-related issues to help project managers incorporate climate change into projects started during the April 2021 workshop.
- Develop a GYCC climate adaptation communications strategy, with agency Public Affairs Offices (PAOs), to tell stories of climate adaptation work to the public, link current conservation efforts to climate adaptation, and take advantage of the ‘buzz’ resulting from the public release of the GYA Climate Assessment, include clear communication from leadership that climate response is a priority.
- Develop GYE-level goals for climate-smart management and conservation that individual unit goals can fit underneath and support. Leverage GYCC goal of ecosystem health.
- Invest in capacity to support climate adaptation work and identify funding sources that could be used to support climate-informed conservation in the GYE.

Acknowledgments

Many individuals provided input and inspiration for the workshop. We greatly appreciate your help. Special thanks to Keynote speakers Jeremy Monroe, Freshwaters Illustrated, and Dr. Clint Muhlfeld, US Geological Survey (USGS); Speakers Mary Erickson, U.S. Forest Service, Paul Dey, Wyoming Game and Fish, Steve Hostetler, USGS, Adam Sepulveda, USGS, Charles Luce, U.S. Forest Service, Robert Al-Chochachy, USGS, and Kate Dwyer, U.S. Forest Service. The National Park Service (NPS) Greater Yellowstone Inventory and Monitoring Program provided staff time and support for the workshop. The NPS Climate Change Response Program provided funding for the workshop. The GYA Climate Assessment greatly informed our understanding of climate exposure in the ecosystem. We particularly thank Jana Cram for creating the breakout rooms and running the Teams meeting and Jeff Mitzelfelt for creating the GYE Aquatic Project Database. Thanks to Amanda Babson, Pam Benjamin, and one anonymous reviewer for their informative and helpful suggestions resulting from peer-review.



Sunrise over Lamar River, Yellowstone National Park. NPS/JACOB FRANK

Introduction

The Greater Yellowstone Ecosystem (GYE) is a unique and special place. The 15 million acres of federal lands of the GYE are geographically contiguous and ecologically interdependent. The GYE is managed by four federal agencies, the National Park Service, the US Forest Service, the US Fish and Wildlife Service and the Bureau of Land Management, each with differing missions and organizational structures. The Greater Yellowstone Coordinating Committee (GYCC; <https://www.fedgycc.org/>) allows the federal land managers of the GYE to pursue opportunities for voluntary cooperation and coordination at the landscape scale. The GYCC is formed through a Memorandum of Understanding that documents the desire of all parties to cooperate fully in matters relating to responsible land management throughout the GYE. The GYCC priorities are management for ecosystem health and to connect people to the land. The GYCC is not a regional decision-making body.

The Greater Yellowstone Coordinating Committee's Climate Change, Fisheries, and Hydrology subcommittees hosted a virtual Climate-Smart Conservation workshop, April 27–29, 2021, focused on aquatic resources (see Agenda, Appendix A). This workshop follows on a similar workshop held at the AMK Ranch in Grand Teton National Park in 2018 and other climate change efforts in the GYE (Appendix E). Fifty people attended the plenary sessions; over 30 people participated in the breakout sessions (Appendix B). Molly Cross, Climate Change Adaptation Scientist for the Wildlife Conservation Society, facilitated the workshop.

We focused on aquatic resources because they are highly vulnerable to climate change and are actively managed by federal and state agencies in the GYE. In addition, we were able to take advantage of the latest historical climate analysis and climate projections reported in the recently published GYA Climate Assessment. This analysis looked at two different potential climate futures: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 (IPCC 2014). The workshop focused on applying steps in the Climate-Smart Conservation Planning Cycle (Stein et al. 2014) to three case studies: (a) Restoring native biodiversity (amphibians, plants, aquatic macroinvertebrates, birds, and bats) to the Blacktail Ponds wetland complex in Yellowstone National Park (YNP); (b) Conserving and restoring Yellowstone cutthroat trout (YCT) in Buffalo Creek, Lamar and Yellowstone rivers; and (c) Protecting or restoring resilient riparian areas through fire management on the east side drainages of the Gallatin River on the Custer-Gallatin National Forest (CGNF).

The case study breakout groups: (1) reviewed the project purpose and scope; (2) assessed climate impacts and vulnerabilities; (3) reviewed and revised, where necessary, the project goals using the Resist-Accept-Direct (RAD) framework; (4) identified possible climate adaptation actions; and (5) began to evaluate and select adaptation actions. Each breakout group had site-specific historical and projected future climate data and was supported by a scientist with expertise in the topic. The Buffalo Creek YCT project identified adaptation actions that will be incorporated into the on-going project. The Gallatin group will continue to meet to develop adaptation actions that could be implemented by the CGNF and that could serve as a model for managing fire and fuel treatment in riparian areas. The Blacktail Ponds project identified actions with broad biodiversity benefits (improving habitat

conditions for multiple taxonomic groups) at a site determined to be relatively insensitive to projected changes in runoff.

Climate Change in the Greater Yellowstone Ecosystem

Climate change is arguably the most pervasive conservation threat to the GYE—preparing for it will require a well-informed shared understanding of impacts at both project and ecosystem scales. Fish kills in the Yellowstone River; the spread of aquatic invasive species; rapidly increasing invasive grasses; shrinking wetland resources; and extreme wildfire behavior with impacts to aquatic resources have all been linked to a warmer, drier climate. Since 1950, average temperature increased in the GYE 2.3°F; peak precipitation shifted from May/June to April/May; average snowfall declined by 3.5 inches; and the timing of peak flow now occurs about 8 days earlier (Hostetler et al. 2021). Warming trends are projected to continue by +0.5°F to +1.2°F per decade; water stored in the snowpack is expected to continue to decrease; and a further decline in soil moisture of 5–7% is projected by mid-century (Hostetler et al. 2021).

Aquatic Resources and Management in the GYE—General Overview

Three mighty rivers—the Missouri, Snake, and Green—flow from GYE mountains. The GYE is also the headwaters of the Gallatin, Madison, Yellowstone, Clarks Fork, and Wind/Bighorn rivers. These headwaters are significant sources to the much larger Mississippi, Columbia and Colorado River basins. The watersheds of the area provide vital water supplies for agriculture, human use, natural vegetation, and wildlife that extend outside the GYE. As the twenty-one counties of the GYE continue to be some of the faster growing areas in the United States, water resources of the GYE will realize unprecedented importance and pressure to satisfy human needs. Furthermore, with changing climate becoming a greater ecological concern in the region, the implications for water resources in the GYE will gain more prominence. Thus, water may very well be the most valuable natural resource in the GYE, much as it is across all of the arid western states.

In addition to flowing water, wetlands—areas covered by standing water or where the water table is at or near the surface—host extraordinary biological diversity and productivity. For example, while wetlands cover only 6.4% of the planet’s surface, they produce a quarter of the plant and animal species (Marcus et al. 2012). Small, palustrine wetlands cover only about 3% of Yellowstone National Park (YNP) and Grand Teton National Park (GTNP) (Gould et al. 2012). The wetlands in the Beartooth Mountains of the northern Shoshone National Forest have high botanical significance, representing the widest known array of wetland fen types in Wyoming, and are among the highest known concentrations of fen sites and rare plant species in Wyoming (Heidel and Rodemaker 2008). YNP has more than 90 species of aquatic plants; GTNP has over 70 species. Many species documented represent new records or range extensions and highlight the growing understanding of the biodiversity of GYE wetlands (Hellquist et al. 2014).

Following the last glacial period, 12 species/subspecies of fish recolonized the GYE. These fish, including the iconic cutthroat trout, adapted and evolved to become specialists in the Yellowstone environment, underpinning a natural food web that includes magnificent animals: ospreys, bald eagles, river otters, black bears, and grizzly bears all feed upon cutthroat trout. Fish from outside the ecosystem were first introduced in 1889, including brook trout, brown trout, rainbow trout and lake

trout. GTNP and YNP are home to five native amphibians: the Columbia spotted frog (*Rana luteiventris*), boreal chorus frog (*Pseudacris maculata*), western tiger salamander (*Ambystoma mavortium*), western toad (*Anaxyrus boreas*), and plains spadefoot (*Spea bombifrons*).

Aquatic resources management by the federal agencies in the GYE includes: Protecting and restoring water quality; Protecting fish through regulations; Fish surveys, genetics evaluations and restoration actions; Protecting and restoring streams, watersheds, wetlands, and riparian areas; Restoring beaver; Monitoring amphibians; and Prevention, early detection, eradication, and control of aquatic invasive species.

Workshop Objectives

The purpose, scope and expected outcomes of the workshop included:

- Increase understanding of potential climate impacts to select aquatic resources in the GYE, including uncertainty in potential impacts.
- Understand and map current GYE water resources management and native aquatic species conservation projects.
- Identify management actions that can be applied at the project or unit level to adapt to climate change impacts.
- Identify how individual unit actions fit into a broader conservation effort. Are strategies aligned across boundaries? Are they sufficient to achieve climate informed conservation goals?
- Build a community-of-practice to engage in on-going climate adaptation for aquatic resources in the GYE, including on-going support for one or more project.

The purpose of this report is to (a) capture the workshop outcomes for the three case studies; (b) share unique products that were developed for this workshop, such as water balance reports (Appendix C) and site-specific climate summaries (Appendix F); (c) record the workshop process for shared learning as other land management agency staff design and carry out similar workshops; and (d) articulate next steps, and how we hope to achieve them, as we continue to understand and address climate change impacts in the GYE.

Methods

Workshop Support and Planning

The GYCC Climate Change Subcommittee proposed and the GYCC Executive Committee approved this workshop in 2019. Funding to The NPS Climate Change Response Program (CCRP) funded the workshop. The NPS Future Park Leaders Intern program provided an intern to assist with pre-workshop interviews and to summarize historical and projected biophysical environmental conditions at the three case study locations. Staff from the National Park Service, the U.S. Forest Service, and the Wildlife Conservation Society planned and conducted the workshop.

Pre-Workshop Interviews

We interviewed nine resource managers from four federal agencies (USFS (4); NPS (3); BLM (1); USGS (1)) in the GYE to better understand how they manage resources, including how managers take climate change into account in their planning, how vulnerable the resources they manage are, and what concerns them about the future for those resources. Our interview objectives were to: identify common aquatic resource themes/goals; identify levels of climate vulnerability understanding; identify management actions and opportunities; and generate enthusiasm, interest and support for ecosystem scale aquatic conservation. Knowing what concerns managers and where they are in the process of incorporating climate change into their plans allowed us to better understand how to tailor the focus and emphasis of the workshop.

Climate Data Analysis

Future Park Leader Intern Janelle Christensen used the water balance model maintained by the National Park Service (developed by Mike Tercek, David Thoma and John Gross) to summarize historical and projected biophysical environmental conditions from 1980–2100 at the single grid cell level (gridMET = 4km; projections = 1km) for each of the case study areas. The water balance data provides a useful set of individual graphs for 8 water balance variables, including soil water, rain, runoff, actual evapotranspiration, potential evapotranspiration, accumulated growing degree days, accumulated snow water equivalent, and deficit. The graphs display the variables in an easily understood format and provide basic interpretation of the variables for people who aren't familiar with hydrology to understand how they apply to their projects. Additionally, the data were summarized in tables for quantitative sensitivity and vulnerability assessments which can help identify management actions aligned with plausible changes in climate.

Overview of Climate-Smart Conservation

Climate-Smart Conservation (Stein et al. 2014) is an approach to incorporating climate change into natural resource management that was developed by representatives from federal and state agencies and non-governmental organizations. Climate-Smart Conservation is the intentional and deliberative consideration of climate change in resource management, realized through forward-looking goals and linking actions to key climate impacts and vulnerabilities (Stein et al. 2014). The Climate-Smart Conservation Planning Cycle depicts how the various parts of the adaptation planning process fit together. This useful framework is being adopted by managers across the region and its common use can facilitate cross-jurisdictional collaborations (Figure 1). In 2018, the GYCC Climate Change

Subcommittee (CCSC) sponsored a Climate-Smart Conservation training class for members from other GYCC subcommittees. That course provided the foundation for incorporating Climate-Smart principles into resource management planning activities. This workshop was designed as a follow-on effort to help put this training into practice in the GYE.

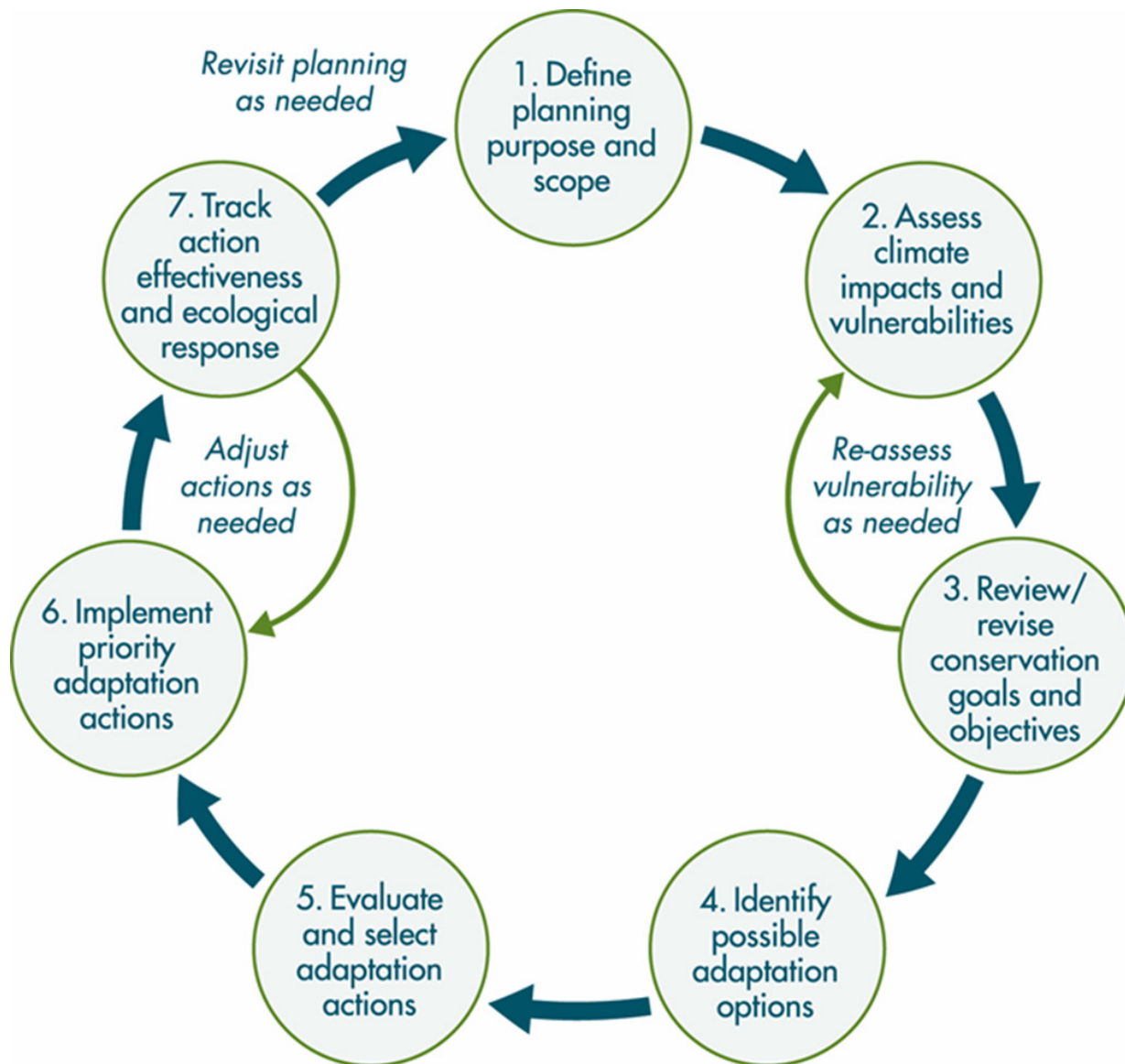


Figure 1. The Climate-Smart Conservation Planning Cycle (from Stein et al. 2014).

Case Studies

The workshop focused on applying steps from the Climate-Smart Conservation Planning Cycle to three case studies: (a) Restoring native biodiversity (amphibians, plants, aquatic macroinvertebrates, birds, and bats) to the Blacktail Ponds wetland complex in YNP; (b) Conserving and restoring Yellowstone cutthroat trout (YCT) in Buffalo Creek, Lamar and Yellowstone rivers; and (c) Protecting or restoring resilient riparian areas through fire management on the east side drainages of

the Gallatin River on the CGNF. The breakout groups used custom-designed worksheets to (1) review the project purpose and scope; (2) assess climate impacts and vulnerabilities; (3) review and revise, where necessary, the project goals using the Resist-Accept-Direct (RAD) framework; (4) identify possible climate adaptation actions; and (5) begin to evaluate and select adaptation actions. Each breakout group had site-specific historic and projected future climate data and was supported by a scientist with expertise in the topic. Case studies provide focused on-the-ground projects so participants don't get overwhelmed, can make tangible progress on applying climate-smart principles and practices, and help participants understand climate-smart principles to apply to other projects.

Adaptation Strategies and Options

In Climate-Smart Conservation Step 4, participants brainstormed adaptation strategies and options, then winnowed those down to the most feasible in Step 5. In addition to ideas offered by workshop participants, we also consulted a wide range of reports and peer-reviewed publications on climate change adaptation as well as input from scientists and project managers to develop “menus” of adaptation actions that are relevant to aquatic resources in the GYE. This approach follows the guidance suggested by the Northern Institute of Applied Climate Science (Swanston et al. 2016). These menus were shared with workshop participants during the breakout sessions to augment their brainstorming efforts.

Greater Yellowstone Aquatic Conservation Projects Database

The Greater Yellowstone Aquatic Conservation Projects (Figures 2 and 3) database is a crowd-sourced web map that helps federal and state agencies and organizations plan more strategically, identify opportunities for collaboration, and raise the profile of what's happening on-the-ground to support conservation. Our aim is to show and collect information about aquatic related GYE monitoring, management, and research projects that facilitates researchers and project managers sharing information about their projects and to see other research in the area that might be pertinent for collaboration or comparison. The map (<http://gyccscience.org>) is available for editing by registered users and for viewing by the public. This database helps fulfill the workshop goal to understand and map current GYE water resources management and native aquatic species conservation projects.

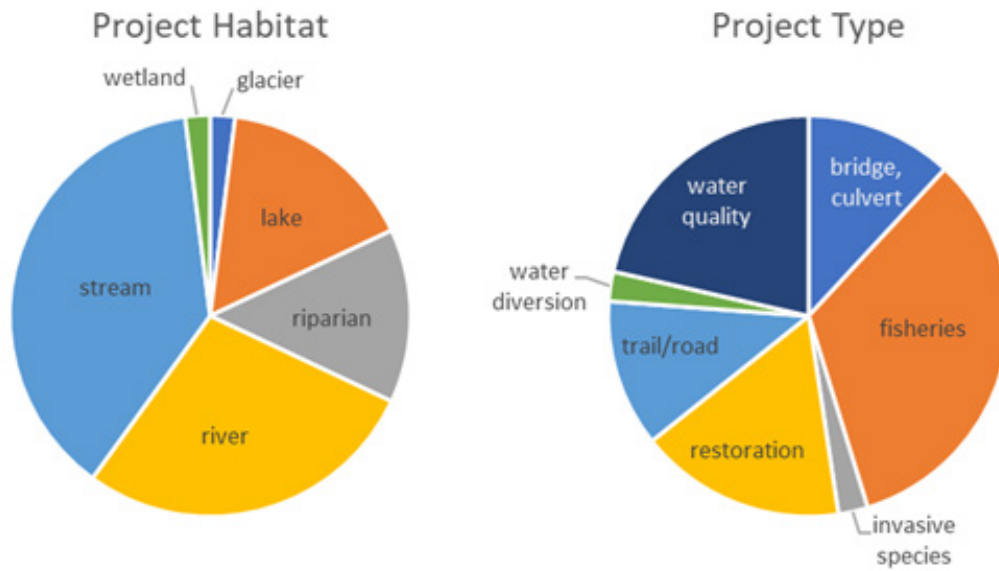


Figure 2. Distribution of project habitat and project type in the Greater Yellowstone Aquatic Conservation Projects database.

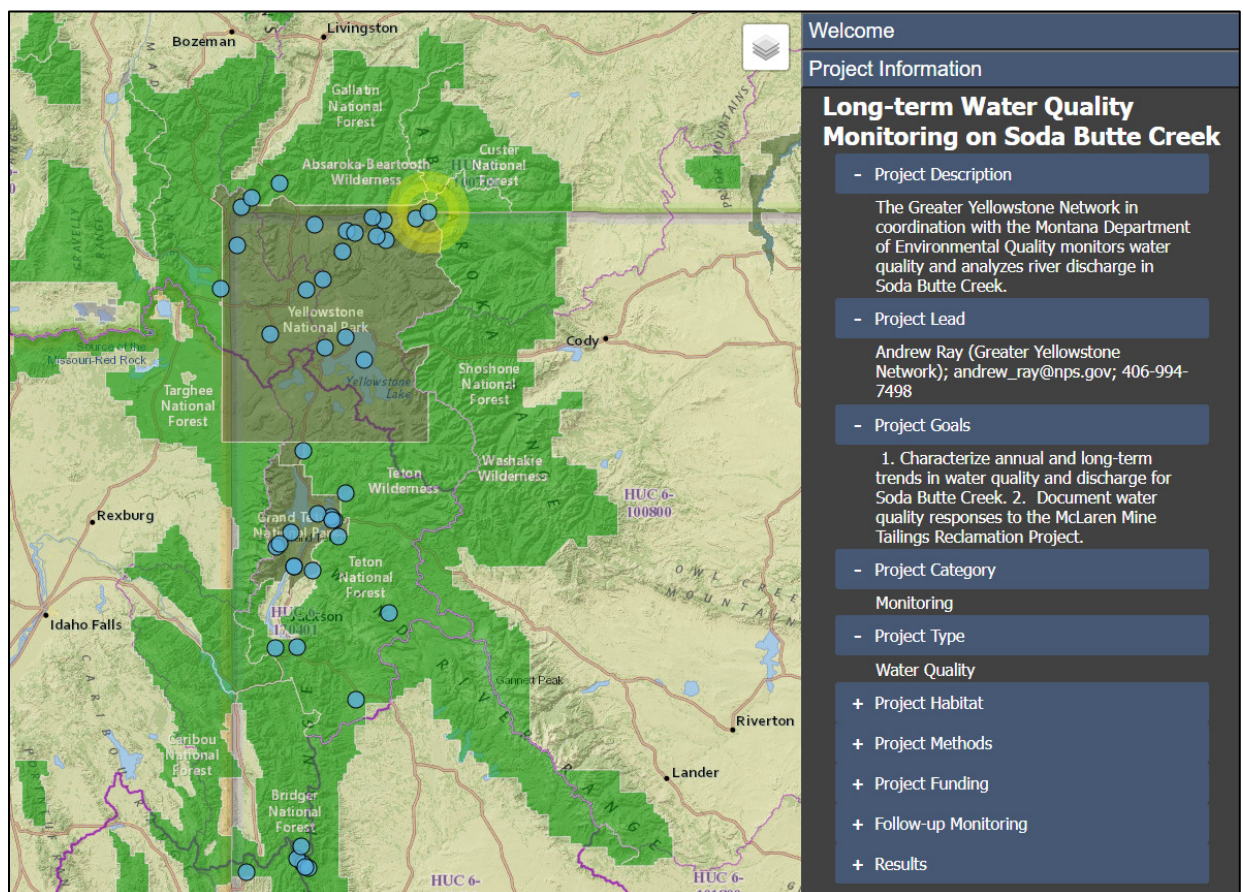


Figure 3. Screen capture from the Greater Yellowstone Aquatic Conservation Projects database.

Post-Workshop Follow-up

One projected outcome of the workshop was to build a community of practice to engage in climate change adaptation within the GYE. The Planning Team has continued to meet bi-weekly to follow up on high-priority actions identified by workshop participants and invitees and to seek opportunities to scale adaptation projects to larger areas in the GYE.

Case Studies

The bulk of the workshop was spent on three case studies. The case study groups used a series of five worksheets and breakout sessions to: (1) review the project purpose and scope; (2) assess climate impacts and vulnerabilities; (3) review and revise, where necessary, the project goals using the Resist-Accept-Direct (RAD) framework; (4) identify possible climate adaptation actions; and (5) begin to evaluate and select adaptation actions. Each breakout group had site-specific historic and projected future climate data and was supported by a scientist with expertise in the topic and a group facilitator. The notes in this section came directly from the worksheets thus can be a bit choppy.

Case Study 1: Restoring Native Biodiversity to the Blacktail Ponds Wetland Complex in Yellowstone National Park

The Blacktail Ponds wetland complex lies in an open sagebrush and sedge glacial basin on the north side of the road between Mammoth Hot Springs and Tower Junction, six miles east of Mammoth Hot Springs. Blacktail ponds is nutrient rich; the ponds' water supply comes from underground springs and the outlet empties into Blacktail Deer Creek. Brook, cutthroat, and rainbow trout were planted in Blacktail Deer Creek between 1909 and 1943. Blacktail Pond was stocked with brook trout, cutthroat trout, and cutthroat-rainbow hybrids 1939–1957. This pond is a popular fishery particularly among brook trout anglers; it ranks third in angler use among Yellowstone ponds (Pierce 1987). Focal features of this case study included native biodiversity (plants, aquatic macroinvertebrates, amphibians, birds, and bats) in wetlands and natural wetland processes and intact aquatic-terrestrial linkages (e.g., insect emergence, amphibian breeding). Dr. Andrew Ray, NPS Greater Yellowstone Inventory and Monitoring Network, facilitated this case study, served as the supporting scientist, and was the project proponent.



Sunrise at Blacktail Pond, Yellowstone National Park. NPS/NEAL HERBERT

1) Management Goals

- Restore native biodiversity (plants, aquatic macroinvertebrates, amphibians, birds, and bats) to Blacktail Ponds wetland complex impacted by introduced fish.
- Remove process barriers and restore lost linkages (e.g., insect emergence and amphibian breeding) to Blacktail Ponds wetland complex through introduced fish removal.

2) Vulnerability Assessment

Exposure

- Decline in annual runoff will reduce the habitats available to wetland dependent species on the landscape (plants, macroinvertebrates, amphibians).
- Number of hot days in the summer will stress terrestrial life stages (for amphibians).
- Unknown effects of climate on neighboring habitats; small/shallow habitats likely to be lost (need to do a formal analysis of neighboring wetlands).
- Seasonal wetlands are highly sensitive to climate (data shown in background materials), so vulnerability is high at the landscape level
- Evapotranspiration is expected to increase which will increase probability of drying, especially for shallow wetlands across the Northern Range.
- *Opportunity*: Blacktail Ponds appear less sensitive to climate changes than other wetlands; groundwater support likely contributes to this insensitivity—there is a documented history of less surface area variability.

Sensitivity

- Studies show that all four amphibian species reproduction vary with runoff and water availability.
- Boreal chorus frogs most sensitive; similar datasets needed for other taxonomic groups.
- Blacktail Ponds wetland area relatively insensitive to changes in runoff; many wetlands in Northern Range are more sensitive.
- Concentration of populations can increase disease transmission (amphibians specific).
- Fewer wetlands across northern range landscape can also reduce terrestrial predator food opportunities, potentially concentrating them.
- Water conservation will help adult amphibians; higher metabolic rates mean higher caloric demands (adult amphibians sensitive to changes in terrestrial habitats).

Adaptive Capacity

- The adaptive capacity of amphibians is low when fish are present; Amphibian numbers are impacted by predatory fish.
- Breeding adjustments possible—some species will breed earlier if temperatures warmer and water is available, but potential fitness consequences and susceptibility to false springs followed by hard freezes.

- Warmer waters in Blacktail Ponds could increase productivity overall and improve conditions for larval growth and development.
- Amphibians could rely on semi-permanent or intermittent habitats without fish, but amphibians are even more vulnerable to climate change when fish are introduced to ponds.
- Longer-lived species can opt out of breeding during multi-year droughts; shorter-lived species cannot.
- Amphibians generally have low capacity: they desiccate relatively easily and require wetland habitats for reproduction which are increasingly vulnerable to drying.

Vulnerability

- Amphibians are highly vulnerable to climate change because they rely on wetland habitats that may dry out. Furthermore, some of the more stable (i.e., permanent) habitats have predatory fish that hinder reproduction.
- Wetlands in general are vulnerable to climate change; deeper wetlands, those with larger groundwater inputs, and higher elevation wetlands may be less vulnerable (Copeland et al. 2011).
- Warmer water may be beneficial to larval life stages; warmer waters tend to be more productive habitat for amphibians and therefore favorable to amphibian reproduction in the absence of predatory fish.

3) Climate Aligned Goals

- Restore regular native amphibian recruitment within 10 years and maintain Blacktail Ponds as breeding habitat for amphibians in perpetuity.

4) Identify Potential Management Options

A brainstorming session identified a wide range of management options, including:

- Remove introduced fish (poison, netting, electroshock, dynamite, drying etc.).
- Add fish barrier at outlet to ponds and between Blacktail Deer Creek.
- Translocate amphibians from proximal breeding sites.
- Beaver dam analog to outlet.
- Ban fishing at the ponds.
- Launch public outreach effort.
- Close ponds to public access.
- Review options for amphibian disease mitigation; evaluate using onsite trials.
- Add large wood and other cover objects extending from pond margins.
- Exclude fire from this area.
- Excavate and expand the ponds so it creates more/larger area of resilient habitat.
- Fence off the ponds (people exclosures).
- Reduce habitat loss in nearby sites. Protect proximal sites with artificial water storage.

- Pump water from Lava/Blacktail Creek to maintain water in Blacktail Ponds and nearby wetlands.
- Partner with Association of Zoos and Aquariums certified zoo on a captive breeding program for releasing eggs or head-starting larvae.
- Introduce natural cover to ponds to deter avian predators.
- Seed clouds to increase summer precipitation.
- Monitor amphibians.
- Introduce and maintain trout predators (any known that won't eat amphibians? Use sound as a fish deterrent?).
- Temporarily drain ponds through pumping to kill fish and introduce at 10 year frequency to prevent future fish establishment.
- Introduce Plains spadefoots (or species that are more drought tolerant).
- Dig, line, and artificially manage water levels in an adjacent created wetland.
- As needed, increase water supply to wetlands that lack fish.

5) Select Feasible Adaptation Actions for Implementation

The entire range of potential management options were vetted to identify feasible or highest priority actions, which include:

- Remove introduced fish:
 - Coordinate with existing plans/priorities with the Native Fish Program.
 - Develop a GYE Strategic Plan for Amphibian Conservation.
 - Make the case for action at this site using existing datasets (Landsat, climate, GRYN monitoring).
 - National Environmental Policy Act (NEPA)/permitting conversations; conversations with staff from the Yellowstone Center for Resources including the Wildlife Disease Program.
 - Identify funding—conversations with NPS Water Resources Division; working with other parks/people that have a history of similar projects (Yosemite; North Cascades; Great Sand Dunes).
- Launch public outreach effort that includes a fishing ban to help people understand and support the importance of amphibian restoration.
 - Engaging Yellowstone's Strategic Communications Division and partners such as Yellowstone Forever and Trout Unlimited.
- Add fish barrier/water control structure between ponds and Backtail Deer Creek
 - Engage the National Technology & Development Program to support fish barrier design and installation.
- Add large wood and other cover objects extending from pond margins to assist amphibian migration.

6) Implement Management Actions

- The workshop was not designed to implement projects. YNP staff will have to review the recommendations and determine if they will be implemented at Blacktail Ponds.

7) Monitoring

- Monitoring will continue after project implementation.

The Blacktail Ponds project can serve as a model for improving wetland biodiversity through targeted fish removal (Ryan et al. 2014). This would require a decision-making National Environmental Policy Act (NEPA) process.

Case Study 2: Conserving and Restoring Yellowstone Cutthroat Trout in Buffalo Creek, Lamar and Yellowstone rivers

This project proposes to remove nonnative rainbow trout from the Buffalo Creek watershed (Figure 4) within the Absaroka-Beartooth Wilderness to its confluence with Slough Creek in Yellowstone National Park. Slough Creek is a highly valued Yellowstone cutthroat trout (YCT) fishery; however, rainbow trout and hybrids have been found with increasing frequency over the past decade. The primary goal of this project is to protect the genetic integrity of YCT in the Lamar River basin. A secondary benefit of the proposed action is that it would establish a secure population of nonhybridized YCT in Buffalo Creek. Climate change is constricting the amount of habitat suitable for Yellowstone cutthroat trout within their historic range. The project area is at high elevation and predicted to remain thermally suitable for YCT for the foreseeable future (Appendix F). This project would be a collaboration among Montana Fish, Wildlife & Parks (FWP), the CGNF, and the NPS. The project is consistent with each agency's established strategies for conserving YCT trout and their legal obligations to conserve native trout. Dr. David Lawrence, National Park Service Climate Change Response Program (NPS CCRP), facilitated this case study. Dr. Robert Al-Chockhachy, USGS, served as the supporting scientist. Brian Ertel, YNP fisheries biologist, was the project proponent.

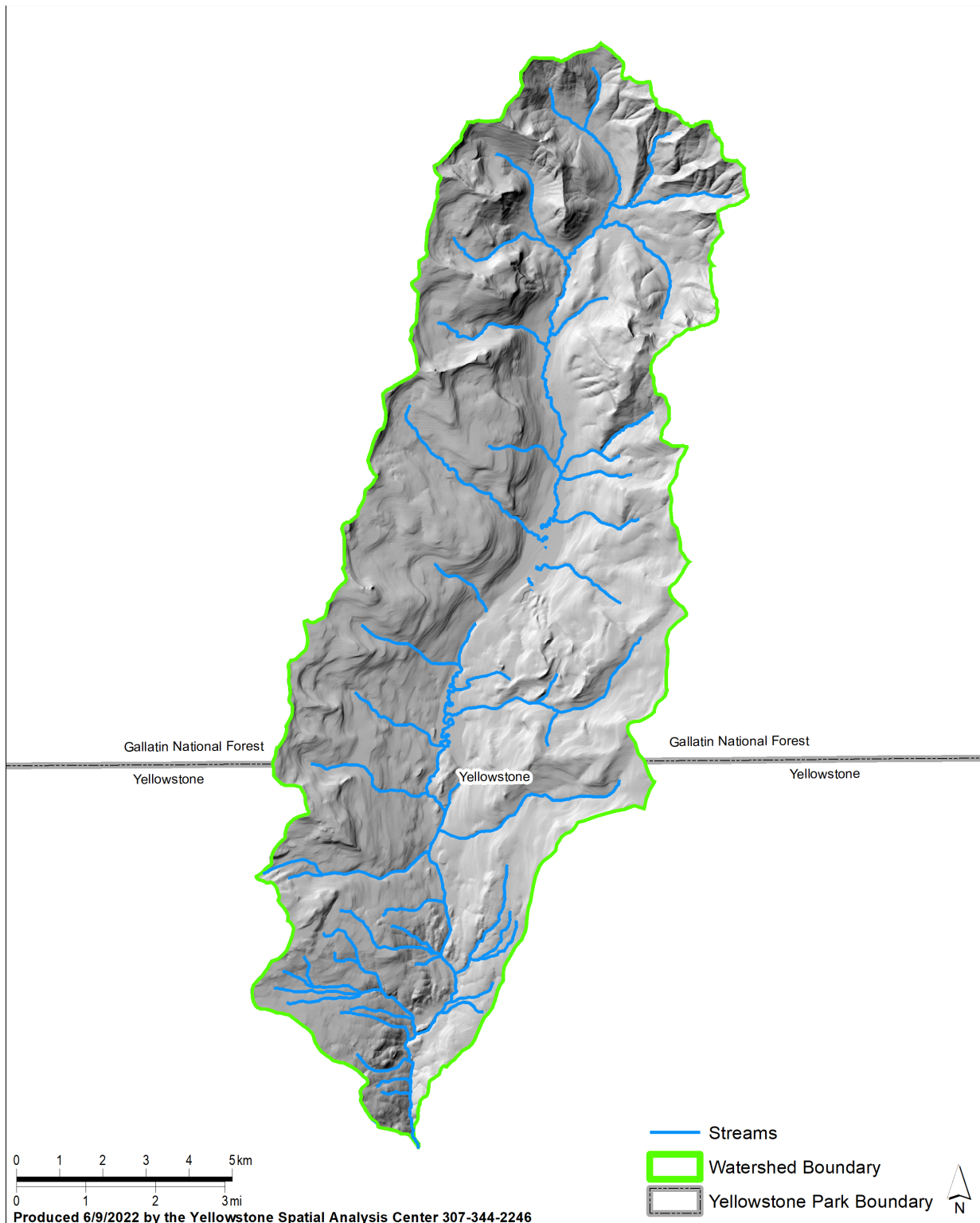


Figure 4. Map of the Buffalo Creek watershed where a Yellowstone cutthroat trout project has been proposed. This project is a partnership between Yellowstone National Park, Montana Fish, Wildlife, and Parks, and the Custer-Gallatin National Forest.

1) Management Goals

Goals

- Conservation of the YCT in Buffalo Creek, Lamar River Drainage, and Yellowstone River.
- Conservation of historic stream hydrology, thermal regime, YCT habitat availability, and riparian plant communities.
- Conservation of intact beaver population in Buffalo Creek.
- Understand and mitigate the likely expansion of non-native smallmouth bass in the lower-Yellowstone River.

Proposed Actions

- Identify habitat suitability and climate alterations projected for Buffalo Creek and Lamar River drainage.
- Mitigate rainbow trout genetic introgression in the Lamar River drainage originating from Buffalo Creek by removing rainbow trout from Buffalo Creek and restoring non-introgressed YCT to Buffalo Creek.
- Establish a YCT population in Buffalo Creek (YCT fluvial stocks should be prioritized).
- Install beaver dam analogs.
- Ground water monitoring and enhancement (piezometer installation).

2) Vulnerability Assessment

Exposure

Annual maximum and minimum air temperatures in the Buffalo Fork Creek drainage are forecast to increase 3 to 5°F relative to current averages by 2040, with the greatest seasonal increases expected during spring and summer. Maximum (daytime) temperatures in the drainage during the summer are predicted to increase 4 to 6°F from the historic average of 67.7°F. To put this in context, consider that the total increase since the start of the industrial revolution until present has been about 1°F. The amount of warming required to end the last ice age and melt the continental glaciers was about 5–11°F. By 2040, the number of days below freezing is expected to decrease by ~130 days per year in the Buffalo Fork Creek drainage, a roughly 50% reduction. Some mid-elevation locations in the Yellowstone area have already lost up to 90 days below freezing in the last 30 years.

Sensitivity

Cutthroat trout have relatively narrow thermal tolerances (Bear et al. 2007), and migration timing and life-history expressions are strongly tied to thermal and hydrologic regimes (DeRito et al. 2010). Trout are most successful in water temperatures ranging from 32–68°F. They can survive in warmer temperatures but do not thrive. Warming summer temperatures coupled with changes in the magnitude and timing of precipitation and snowmelt runoff are likely to create more stressful summer conditions for YCT in some areas.

Adaptive Capacity

- Buffalo Creek will have no immigration, but emigration, and gene flow upstream will be non-existent due to a natural waterfall barrier. Picking genetic stock for reintroduction is important.
- Introduced cutthroat genetics will dictate adaptive capacity, and a fluvial stock should be considered.
- Consider genetic supplementation over time in Buffalo Creek.
- Over-winter habitat availability is likely to decrease (groundwater dependent).
- The success of piscicide probability in eradicating rainbow trout is uncertain (logistic challenges of beaver complexes when applying treatment and working in wilderness).
- Where you get fish for reintroduction affects how they do with regard to warming (pick warm adapted population; Consider conducting a range wide assessment of YCT to better understand their genetics).

Vulnerability

As stream temperatures warm, the amount of thermally suitable habitat for YCT may be reduced considerably in some populations (Al-Chokhachy et al. 2013, Isaak et al. 2015). Mean August stream temperatures in northern YNP are predicted to increase 1.4–1.7°F. In addition to the direct effects of changing thermal regimes, YCT may suffer increased mortality from catch-and-release angling. Most fish managers in the region restrict opportunities for angling when water temperatures reach critical levels, and these restrictions will likely become more frequent as the climate warms (Al-Chokhachy et al. 2017).

High-elevation headwater stream reaches may become critically important cold water refugia for salmonids, including YCT (Isaak et al. 2015). Furthermore, the spread of hybridization may be exacerbated as flow and temperature conditions become more favorable for rainbow trout (Ertel et al. 2017).

Additional vulnerabilities brainstormed at the workshop include:

- Non-native fish interactions (smallmouth bass (SMB)/rainbow trout (RBT)), exacerbated by climate change (introgression, competition, etc.)
- Loss of access to suitable spawning habitat (can YCT shift spawn timing in relation to advancing stream melt? Seasonal barriers that limit access to spawning habitat may increase severity/length due to changing hydrology; Drought causing drying of redds).
- Loss of fish numbers during disturbance events (all life stages; no immigration due to natural barrier), downstream flushing out of young of the year (YOY), direct mortality.
- Spring snowmelt variability may impact YOY recruitment.
- Smaller overall adult body size of YCT & reduced fecundity in Buffalo Creek upstream of barrier (small body size results in fewer eggs).
- High disturbance frequency will imperil fish population upstream of barrier.
- There are a lot of small ~ 9 inch rainbows in system currently.

- Lower flow conditions will lead to more terrestrial predation (wolves, bears, birds).

3) Climate Aligned Goals

Preservation of redundant (multiple isolated and non-isolated populations), resilient (large enough patch size to persist through disturbance) and representative (life history and genetic diversity) YCT populations to the end-of-the-century in those areas predicted to remain thermally/hydrologically suitable across the Lamar River drainage.

4) Identify Potential Management Options

A brainstorming session identified a wide range of potential management options, including:

- Beaver (re)establishment (exclude ungulates in Lamar Valley to, increase forage for beavers in the system); shift over 20 years from 20K elk to 3400 elk on northern range, 400–500 bison (currently there are around 4500 bison).
- Install beaver dam analogs in Buffalo and Lamar (especially in upper portion of drainage).
- Incentivize RBT retention; program w/ coded wire tags (but issues with locating where fish where caught, don't want to promote a new non-native fisheries); coded wire tags in South Fork Snake is an example of this program; other examples include brown trout incentives program in Glen Canyon (but double bounty issue); Idaho fish and game tried incentivizing RBT retention (not as effective as non-native removal; now focused on non-native removal but politically contentious).
- Non-native fish removal efforts in Buffalo Creek and other Lamar tributaries, e.g. from Rose Creek (middle of Lamar Valley, west side of valley, flows by old Buffalo Ranch), used by Lamar River mainstem fish, plus resident fish that are hybrids (employing mechanical removal), not yet seeing recovery of pure YCT; Cache Creek (upstream of Lamar/Soda Butte Creek), heat barrier kept the system mostly pure YCT but slight introgression—head to Buffalo Creek to spawn; not a lot of additional habitats that can be established as 'restored' YCT habitat.
- Place snow fencing in strategic portions of drainage to prevent ungulates from grazing (dual benefit).
- Snow making machines to create heavier snowpack. Snow fencing with white insulation to cover them up.
- Pump water from elsewhere? Solar operated groundwater pumps to send 55°F water down channel.
- Intensive shade tree planting on creek to reduce stream temperatures (especially Lamar Valley where it is currently open); plus grazer exclosure (Elk Creek, put in beaver dam analogs, fenced stream where vegetation has recovered; outside of that area sage brush, crested wheat grass); jackstrawing trees—disincentivize cattle from grazing near stream.
- Track distribution of non-native fish in the watershed; eg, track upstream expansion of SMB using eDNA; conduct watershed-wide eDNA sweep of non-natives (RBT, brown trout, northern pike, pickeral, brook trout, SMB, large-mouth bass (LMB), bluegill, etc.); Interagency rapid response plan for newly detected invaders.

- YCT exhibit in Yellowstone airport (encourage native fish conservation).
- Interagency rapid response plan for newly detected invaders.
- Fish lineage assessment, assisted by the public (help them understand native fish conservation); anglers get info back about fin clip re genetics (hybridization); cut-slam (receive print out describing fishes caught for anglers); fly fishing program to get fin clips, scale, weights (was a successful program 50–100 anglers involved / year; but slowdown because of funding constraints).
- Monitor smallest tributaries in Buffalo Creek to understand flow intermittency, could become target for beaver dam analog if flow intermittent streams are identified.
- Select for thermally adapted YCT when choosing genetics to reintroduce to Buffalo Creek; include diverse life histories when reintroducing YCT to Buffalo Creek; take advantage of range-wide YCT genetics assessment; Maintain and enhance genetic diversity.
- Prescribed fire in Buffalo drainage to prevent catastrophic wildfire; strategic fuel breaks.

5) Select Feasible Adaptation Actions for Implementation

- Install beaver dam analogs (BDA) in Buffalo and Lamar (especially in upper portion of drainage).
- Installation of monitoring devices (stream temperature, pressure transducers, shade evaluation/baseline), evaluate locally and downstream (Slough Creek and Lamar/Yellowstone USGS stream monitoring site).
- Estimate required number of BDAs to be installed (longitudinal profiling of streams that have had beaver activity; add and remove dynamically based on BDA success).
- Non-native fish removal efforts in Buffalo Creek and other Lamar tributaries, e.g. from Rose Creek (middle of Lamar Valley, west side of valley, flows by old Buffalo Ranch), used by Lamar River mainstem fish, plus resident fish that are hybrids (employing mechanical removal), not yet seeing recovery of pure YCT; Cache Creek (upstream of Lamar/Soda Butte Creek), heat barrier (a naturally occurring thermal barrier that cutthroat and/or rainbow trout would not voluntarily cross (e.g. water warmer than ~66°F), thus preventing introgression of non-native rainbow trout with native YCT) kept the system mostly pure YCT but slight introgression—head to Buffalo Creek to spawn; not a lot of additional habitats that can be established as ‘restored’ YCT habitat.
- Monitor for RBT emergence timing.
- Track distribution of non-native fishes in the watershed; e.g., track upstream expansion of SMB using eDNA; employ watershed wide eDNA sweep of non-natives (RBT, brown trout, northern pike, pickeral, brook trout, SMB, LMB, bluegill, etc.); Interagency rapid response plan for newly detected invaders
- Identify funding sources.
- Complete planning and compliance.
- Conversations with WY Fish and Game about developing rapid response plan.
- YCT exhibit in Yellowstone airport (encourage native fish conservation).

- Select for thermally adapted YCT when choosing genetics to reintroduce to Buffalo Creek; include diverse life histories when reintroducing YCT to Buffalo Creek; take advantage of range-wide YCT genetics assessment; Maintain and enhance genetic diversity.
- Expand temperature loggers into those streams selected for genetic samples.
- Add stream temperature monitoring to Antelope Creek (not currently monitored).
- Evaluate stream temperature data for Pebble Creek, LeHardy Rapids (Yellowstone River near Fishing Bridge) for possible YCT source population.
- Add thermal evaluation of potential stocking sources (Pebble Creek adapted to <11°C, may want to also consider other stocks adapted to warmer waters).

6) Implement Management Actions

- Restoration of native cutthroat trout is a cooperative project between Yellowstone National Park, Montana Fish, Wildlife, and Parks, and the Custer-Gallatin National Forest. This project is currently in the design phase. Information from the workshop will be used to help design a successful project.

7) Monitoring

- Monitoring will continue after project implementation.

Case Study 3: Protecting or Restoring Resilient Riparian Areas Through Fire Management on the East Side Drainages of the Gallatin River on the CGNF

Gallatin River East (the area south/southwest of Bozeman, MT, including tributaries on east side of West Gallatin River from Big Bear Creek south to the drainage divide south of Levinski Creek) is approximately 100,000 acre area (1–3% riparian). About 40,000 acres have potential for active vegetation treatments. This case study explored how climate change might affect this drainage (Appendix F) and how we might best treat riparian areas with either fuel reduction or prescribed fire. Tom Olliff, NPS Intermountain Region, facilitated this case study. Dr. Kate Dwyer, USFS, served as the supporting scientist. Scott Barndt, CGNF Ecosystem Officer, was the project proponent.



Moose on the Gallatin River. NPS/NEAL HERBERT

1) Management Goals

- Fully functioning, resilient riparian areas delivering the full array of ecosystem services, in a changing climate.
- Restore riparian areas departed from desired condition or trend.
- Reduce vulnerability of riparian areas and their ecosystem services to climate change, using whatever tools may be appropriate for the riparian area in question (e.g., prescribed fire, thinning, fuel reduction, etc.)

2) Vulnerability Assessment

Exposure

- Rising temperature, declining snow water equivalent, declining soil moisture and increasing water deficit in spite of increasing precipitation, increased rain/snow ratio (i.e. transition to more mixed precipitation). Earlier timing of runoff hydrograph/earlier start to baseflow period. Because of these, duration and length of base flow will be extended (riparian areas likely have less water for a longer period, maybe July–Sept). Reduction in summer runoff by about 50% by mid-century. Need to store water for later in the year if we want to retain water later in the year since snowpack will be reduced and melting earlier in the future.
- Important aspects of exposure not captured that affect fire severity: Fire weather, wind.
- Do focal resource have equal exposure? No, exposure depends on type of riparian area, slope gradient and aspect of the surrounding country.

Sensitivity

- According to Westerling et al. 2011, in the northern Rockies high fire activity occurred during periods of warmer-than-average temperatures. In addition to temperature, moisture deficit and

summer precipitation also influenced fire during warm years. The increase in temperature at which increased fire activity occurred was only 0.9°F above the 1961–1990 average.

- Multi model average mid-century mean projections indicate summer temperature increase by 4.2–6.7°F. This indicates a high potential for fire in the future.
- Spring runoff is projected to increase 11%, but summer decrease by 51% mid-century. Earlier runoff equates to lower summer base flow.
- Topography, stream gradient and channel width/shape make some riparian areas more or less exposed to a given level of dryness.

Adaptive Capacity

- Riparian areas are inherently resilient due to the relative abundance of water, but they are also highly vulnerable when the hydrologic cycle is dramatically altered due to fire or drought.
- In some riparian areas can we confer additional adaptive capacity through storing more water; e.g., beaver reintroduction, beaver dam analogs? Especially in areas that have acted as fire breaks in the past.
- Deciduous vegetation, or areas adapted to it, are likely more adaptable than conifer dominated areas. Most cottonwood and willow species respond well to low to moderate severity wildfire. Willows resprout vigorously following prescribed fire.

Vulnerability

- Vulnerability of riparian areas in the Gallatin is related to fire risk. Wildfire Hazard estimates are available from the Landfire Data set.
- Shifting baselines—those that used to be more resistant to fire behavior will now be more likely to burn, or those that burned in the past may burn more severely.
- Assume shifts are/have/will happen. We need to be careful to avoid thinking in the context of a static state as we plan this project or we will miss climate impacts, potentially increasing vulnerability of riparian areas.
- Vulnerability increases with drying in all riparian types.
- Projections for extended low base flow could lead to a long-term decrease in areal extent of riparian areas (especially shrub-dominated) and possibly some species shifts in riparian vegetation.
- Are warmer temperatures conducive to riparian vegetation such as aspen and willows? Occurrence of these species is more related to water availability at the lower elevations. Water, flow, and soil moisture are the most important factors.

3) Climate Aligned Goals

- Fully functioning, resilient riparian areas delivering the full array of ecosystem services, in a changing climate.

4) Identify Potential Management Options

A brainstorming session identified a wide range of potential management options, including:

- Increase water storage in reaches where that's possible (BDA, beaver, Large Woody Debris (LWD) inputs, etc.).
- Block flow with boulders to increase storage and slow flow.
- Reduce fuels in steep "chimney drainages," or at least try to match fuel load to surrounding uplands (Riparian Fuel Treatments).
- Putting in a mix of native plants—blend of local and some w/ genetic resilience to higher temperatures (from lower elevations).
- Restore aspen.
- Ensure channel complexity in reaches where water storage is less possible (e.g., by adding LWD), either actively or passively.
- Respond to or prepare for high spring water levels and excessive surface runoff. May include adding floodplain structure/roughness.
- Wildlife management: predator reintroductions (in the vein of wolves and moose/elk imbalances); could also be addressed with tall fences, but preferring to restore natural processes that don't require future re-engagement.
- Prioritize introductions of native fish to potential climate refugia. Remove all non-natives from climate refugia.
- Adjust riparian grazing; Fencing, livestock removal, inundation etc.
- Reduce livestock numbers & re-evaluate timing (cows on/ off); identify allotments with riparian pastures that could be 'closed.'
- Increase fuel treatments in riparian areas that burn more frequently than adjacent areas to reduce fire severity.
- Consider habitat work/fuels treatments for narrow niched endemic plant species.
- Work with surrounding communities to reduce nutrient inputs to water bodies as they warm.
- Riparian Timber Harvest.
- Manage recreation, especially. dispersed camping, ATV/UTV use.
- Incorporate the idea of riparian fire classification into wildfire response (e.g., work with Incident Commanders, Planning, and Operations chiefs to help them understand how this concept might impact firefighting tactics).
- Large scale watershed prescribed fire to reduce fire severity, post fire runoff and erosion that blows out water storage structures.
- Focused thinning to reduce both fire risk but also potentially increase flows.
- Chase down additional in-stream flow opportunities; this may require legislation, improving existing diversion/irrigation efficiency.
- Create inventory of water rights that might become available.
- Build or plant high elevation snow fences that can augment late season base flow in areas that feed trout streams.

- Move facilities out of riparian areas.
- Remove roads from floodplains
- Evaluate road impacts on hydrology and channel function where roads are near streams, reduce sedimentation from anywhere in watershed.
- Evaluate stem and canopy density relative to precipitation/runoff ratio and adjust timber harvest and prescribed fire to optimize production/runoff relationships that are designed to slow snowmelt to sustain flow and minimize evapotranspiration losses that create late season drought.
- Weather modification (e.g. cloud seeding) post runoff, late-summer, baseflow and/or low-groundwater season.
- Sediment delivery to sediment-starved, incised reaches—BDA, bank blasters, gravel augmentation, road/culvert blow outs, prescribed fire paired with in-stream work.
- Improve floodplain connectivity by removing artificial (or natural?) barriers (e.g., levees, mine tailings, road prisms).
- Remove roads and campgrounds post fire when opportunity to do so presents itself.
- Install post-fire BDAs in incised channels to take advantage of post-fire sediment supply to reactivate floodplains.
- Envisioning a riparian evolution model where a riparian system could be managed to become more resilient to fire, moving through burn patterns outlined by Kate Dwyer. Past land management, like trapping, timber, grazing, fire suppression, etc. would be replaced in the future by active and passive restoration, shifts in land management, water allocation, and climate change in the future.

5) *Select Feasible Adaptation Actions for Implementation*

- Increase water storage and channel complexity in reaches where that's possible (BDA, beaver, LWD inputs, etc). Channel complexity also increases stability.
- Fuel treatments both mechanical and prescribed fire. Fuel treatments in riparian zones might be challenged by the public; however, stem densities for fuels need to be connected to uplands. Frame: vegetation treatment for the benefit of riparian zones.
- Manage recreation, especially. dispersed camping, ATV/UTV use.
- Adjust riparian grazing; Fencing, livestock removal, inundation, etc.
- Reduce livestock numbers and re-evaluate timing (cows on/ off); identify allotments with riparian pastures that could be 'closed.'

6) *Implement Management Actions*

- The Gallatin group will continue to meet to develop adaptation actions that could be implemented by the CGNF that could serve as a model for managing fire and fuel treatment in riparian areas.

7) *Monitoring*

- Monitoring will occur after actions are implemented.

Discussion and Next Steps

We met or exceeded many of the workshop objectives, including:

- Increase understanding of potential climate impacts to aquatic resources in the GYE, including uncertainty in potential impacts.
 - Dr. Steve Hostetler, USGS, presented the findings of the GYA Climate assessment to workshop participants on Day 1, including historic and projected changes in temperature, precipitation, snowpack abundance and timing, streamflow, and decreases in water availability in the six sub-basins of the GYE.
 - Site-specific water balance reports (Appendix C) and climate summaries (Appendix F) were developed for the three case studies.
 - Each breakout group worked with a case study scientist and experienced land managers to discuss and understand potential impacts from climate change to the three case studies.
- Understand and map current GYE water resources management and native aquatic species conservation projects.
 - We created the Greater Yellowstone Aquatic Conservation Projects database so managers in the GYE can enter their projects and discover other projects that might inform their efforts.
- Identify management actions that can be applied at the project or unit level to adapt to climate change impacts.
 - Created ‘Adaptation Strategies and Approaches’ background documents, based on the Northern Institute of Applied Climate Science model, to help managers consider a full suite of management actions that can be applied (Appendix D).
 - Each breakout group brainstormed adaptation (management) actions in Step 4 and determined whether or which brainstormed actions were feasible (Step 5). In each case study, the project goal was feasible (with some modification) and several potential management actions were identified.
- Identify how individual unit actions fit into a broader conservation effort. Are strategies aligned across boundaries? Are they sufficient to achieve climate informed conservation goals?
 - We began this process but did not complete it at the workshop. To date, we have not yet articulated goals and strategies at the GYE level.
- Build a community-of-practice to engage in on-going climate adaptation for aquatic resources in the GYE, including on-going support for one or more project.
 - The workshop planning team has evolved into this community of practice and continues to meet bi-weekly to address the next steps outlined below. In addition, several new members have joined the team, including staff from other federal agencies and non-governmental organizations.

To close the workshop, participants brainstormed how to motivate climate-smart conservation across the GYE and made several recommendations. In a follow up survey, participants and invitees

identified a subset of those actions as especially high-priority next steps, informed both by the number of responses and how feasible the action is to implement. Next steps include:

Priority 1

Task 1.1: Build menus of adaptation strategies, actions, and checklists of climate-related issues to help project managers incorporate climate change into projects started in April 2021 workshop, including:

- Develop fisheries project checklist (Lead: Patrick Barry; Facilitator: Tom Olliff/David Thoma)
- Gallatin River East project: re-engage workshop project team after 2021 fire season (Lead: Scott Barndt; Facilitator: Tom Olliff; Science Lead: Kate Dwyer).
- Blacktail Ponds checklist complete: awaiting YNP management engagement (Lead: Andy Ray).

Task 1.2: Develop a GYCC climate adaptation communications strategy, with agency Public Affairs Officers (PAOs), to tell stories of climate adaptation work to the public, link current conservation efforts to climate adaptation, and take advantage of the ‘buzz’ resulting from public release of the GYA Climate Assessment, include clear communication from leadership that climate response is a priority.

Task 1.3: Develop GYE-level goals for climate-smart management and conservation that individual unit goals can fit underneath and support. GYCC articulated climate change as a priority in 2022.

Task 1.4: Invest in capacity to support climate adaptation work and identify funding sources that could be used to support climate-informed conservation in the GYE.

Priority 2

Task 2.1: Explore ways to support more monitoring that is specifically designed to track the effectiveness (or lack thereof) of climate adaptation projects so that we can learn more about whether these approaches and strategies are working. Incorporate learning into adaptive management over time.

Priority 3

Task 3.1: Develop Climate-Smart Community of Practice. Identify and work with partner agencies, tribes, NGO’s and units, University of Wyoming, Montana State University, but also different programs within agencies, such as NEPA staff and planners to expand scope and scale of climate-smart planning and management actions. GYCC Climate Change Subcommittee serves as an umbrella group and incorporate climate-smart planning discussions into all GYCC Subcommittees.

Priority 4

Task 4.1: Create a forum where people can post climate-related questions to other GYE researchers and practitioners (e.g., “Can someone point me to water balance (or drought projections, fire risk, stream flow, etc.) datasets?”).

Task 4.2: Develop a Climate Fellows Program to integrate climate science and endemic land manager knowledge. Include agency staff, agency science partners, tribes, and universities to raise

the level of conversation about climate change and encourage adoption of climate adaptation practices.

Conclusion

This cooperative approach could not come at a better time—2021 was a remarkable year. The COVID-19 pandemic entered its second year and the effects of climate change made news almost daily, from extreme heat to drought to fires and flash floods. July 2021 was Earth’s hottest month on record. In the GYE, expansive drought brought rivers and soil moisture to alarmingly low levels, a series of heat waves set temperature records across the region, and a fast and furious start to a wildfire season in Montana and beyond resulted in a haze of smoke that lasted most of the summer. Preparing for these changes and adapting to them will dominate the next decade or more of resource management.

Managers in the GYE have a decade-long history of working toward understanding and addressing climate change (Appendix E). This workshop builds on the history, takes advantage of the recently published GYA Climate Assessment, as well as recent climate events and endeavors to start a new era of cooperative management across federal, state, and private organizations. Still, there is more work to do. In the future, we will need similar deep dives into other resources to explore on-the-ground viable management options to respond to a continuing changing climate.

Staff from national parks, national forests, Bureau of Land Management and Fish and Wildlife Service lands will continue to have these types of workshops in the future to understand how climate change is impacting resources and what, if any, management actions we can take to resist or direct those changes, or whether accepting change is our best course of action. We hope that by detailing the methods and results of this workshop others can learn from both our successes and challenges and improve our collective ability to manage for climate change impacts to our natural and cultural resources and facilities on federal lands.



Snake River Overlook in Grand Teton National Park. NPS/JOHN TOBIASON.

Literature Cited

- Al-Chokhachy, R., J. Alder, S. Hostetler, R. Gresswell, and B. Shepard. 2013. Thermal controls of Yellowstone cutthroat trout and invasive fishes under climate change. *Global Change Biology* 19: 3069–3081.
- Al-Chokhachy, R., B. Shepard, J. Burckhardt, S. Opitz, Scott, D. Garren, T. Koel, Todd and M. Nelson., 2017. Status & Conservation of Yellowstone Cutthroat Trout in the Greater Yellowstone Area. *Yellowstone Science*. v25:1, p. 12–17.
- Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protection standards. *Transactions of the American Fisheries Society* 136:1113–1121.
- Copeland, H.E., S.A. Tessman, E.H. Girvetz, L. Roberts, C. Enquist, A. Orabona, S. Patla, and J. Kiesecker. 2010. A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands. *Ecological Indicators* 10:869–879.
- DeRito, J.N., A.V. Zale, and B.B. Shepard. 2010. Temporal reproductive separation of fluvial Yellowstone cutthroat trout from rainbow trout and hybrids in the Yellowstone River. *North American Journal of Fisheries Management* 30:866–886.
- Endicott, C. 2021. Restoration of Buffalo Creek for Yellowstone cutthroat trout conservation. Draft Environmental Assessment. Montana Fish, Wildlife, and Parks, Livingston, MT. 84 p.
- Ertel B. 2017. Preservation of Native Cutthroat Trout in Northern Yellowstone, *Yellowstone Science*. v25:1, p. 35–41.
- Gould, W. R., D. A. Patla, R. Daley, P. S. Corn, B. R. Hossack, R. Bennetts, and C. R. Peterson. 2012. Estimating occupancy in large landscapes: evaluation of amphibian monitoring in the Greater Yellowstone Ecosystem. *Wetlands* 32:379–389.
- Heidel, B. and Rodemaker, E. 2008. Inventory of peatland systems in the Beartooth Mountains, Shoshone National Forest. <http://www.uwyo.edu/wynddsupport/docs/Reports/WYNDDRReports/U08HEI02WYUS.pdf>
- Hellquist, C.E., C.B. Hellquist, and J.J. Whipple. 2014. New records for rare and under-collected aquatic vascular plants of Yellowstone National Park. *Madroño* 61:159–176.
- Hostetler S, Whitlock C, Shuman B, Liefert D, Drimal C, Bischke S. 2021. Greater Yellowstone climate assessment: past, present, and future climate change in greater Yellowstone watersheds. Bozeman MT: Montana State University, Institute on Ecosystems. 260 p. <https://doi.org/10.15788/GYCA2021>
- IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 p.

- Isaak, D.J., M.K. Young, D.E. Nagel, D.L. Horan, and M.C. Groce. 2015. The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century. *Global Change Biology* 21:2540–2553.
- Marcus, W.A., J.E. Meacham, A.W. Rodman, and A.Y. Steingisser. 2012. *Atlas of Yellowstone*. University of California Press, Berkeley and Los Angeles, CA. 274 p.
- Pierce, S. 1987. *The lakes of Yellowstone: a guide for hiking, fishing, and exploring*. The Mountaineers. Seattle, Washington, 199 p.
- Ryan, M. E., W. J. Palen, M. J. Adams, and R. M. Rochefort. 2014. Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US. *Frontiers in Ecology and the Environment* 12:232–240.
- Stein, B. A., P. Glick, N. Edelson, and A. Staudt, eds. 2014. *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. National Wildlife Federation, Washington, D.C.
http://www.nwf.org/pdf/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.pdf
- Swanston, Christopher W.; Janowiak, Maria K.; Brandt, Leslie A.; Butler, Patricia R.; Handler, Stephen D.; Shannon, P. Danielle; Derby Lewis, Abigail; Hall, Kimberly; Fahey, Robert T.; Scott, Lydia; Kerber, Angela; Miesbauer, Jason W.; Darling, Lindsay; Parker, Linda; St. Pierre, Matt. 2016. *Forest Adaptation Resources: climate change tools and approaches for land managers*, 2nd ed. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. <http://dx.doi.org/10.2737/NRS-GTR-87-2>
- Westerling, A. L., M. G. Turner, E. A. Smithwick, W. H. Romme, and M. G. Ryan. 2011. Continued warming could transform greater Yellowstone fire regimes by mid-21st century. *Proceedings of the National Academy of Sciences* 108(32):13165–13170.

Appendix A. Agenda

April 27, 2021—Day 1. Anticipating the Future: Climate Science, Impacts & Vulnerabilities

9:00am: Welcome & Introductions, *Ann Rodman, Molly Cross*

9:20am: Keynote Address, *Jeremy Monroe (Freshwaters Illustrated)*

10:00am: Senior Management Perspectives, *Cam Sholly (NPS), Mary Erickson (USFS), Paul Dey (WY Game and Fish Department)*

11:00am: GYE Aquatic Climate Assessment, *Cathy Whitlock, Steve Hostetler*

11:30am: Linking Science and Action, *Adam Sepulveda, Charles Luce*

LUNCH

1:00pm: Introduction to Climate-Smart Conservation, *David Lawrence*

1:15pm: GYE Activity Aligned With Climate-Smart Conservation, *David Thoma*

1:30pm: Overview of workshop exercises and Climate-Smart Cycle Steps #1 & #2, *Molly Cross*

2:00pm: BREAKOUT GROUPS: Climate-Smart Cycle Steps #1 & #2

3:30pm: Plenary: Climate-Smart Cycle Step #2 report-out

April 28, 2021—Day 2. Adapting to the Future: Climate-Informed Goals and Actions

9:00am: Review Agenda for Day 2, *Molly Cross*

9:15am: Climate-Informed Goals: Resist-Accept-Direct (RAD) framework & BAU-Retrofit-Rebuild, *David Lawrence*

9:45am: Overview of Climate-Smart Cycle Step #3, *Molly Cross*

10:15am: BREAKOUT GROUPS: Climate-Smart Cycle Step #3

11:30am: PLENARY: Climate-Smart Cycle Step #2 and Step #3 Report-Out

LUNCH

1:00pm: “What’s Different?” About Climate-Smart Conservation, *Molly Cross*

1:15pm: Adaptation Options Menu, *Tom Olliff*

1:30pm: Overview of workshop exercises and Climate-Smart Cycle Step #4, *Molly Cross*

2:00pm: BREAKOUT GROUPS: Climate-Smart Cycle Steps #4

3:30pm: Plenary: Climate-Smart Cycle Step #4 report-out

April 29, 2021—Day 3. Coordinated Climate Action in the GYE

9:00am: Review Agenda for Day 3, *Molly Cross*

9:15am: Overview of Climate-Smart Cycle Step #5, *Molly Cross*

10:00am: BREAKOUT GROUPS: Climate-Smart Cycle Step #5

11:00am: Scaling up to the GYE

11:30am: Round Robin Report Outs

11:45am: Climate-Smart Cycle Wrap-Up, *Molly Cross*

LUNCH

1:00pm: Review Afternoon Agenda, *Molly Cross*

1:15pm: GYE Project Map, *Ann Rodman*

1:30pm: What's Needed to Advance Climate-Smart Conservation in the GYE? *Molly Cross and the Workshop organizing team*

2:30pm: What Are Our Next Steps? *David Thoma and Tom Olliff*

3:15pm: Workshop Conclusion, *David Thoma, Tom Olliff, Ann Rodman*

6:00pm: Trout in a Changing Climate, *Dr. Clint Muhlfeld*

Appendix B. Workshop Participants and Planning Team

Table B-1. Workshop participants, affiliations, and roles.

Last Name	First Name	Affiliation	Role
Al-Chokhachy	Robert	USGS	Participant
Barndt	Scott	USFS	Planning Team
Barry	Patrick	USFS	Planning Team
Beckworth	Lesley	Teton County WY	Participant
Berberman	Monica	USFS	Participant
Caskey	Simeon	NPS	Participant
Chaffin	Jake	USFS	Participant
Chin	Susan	USFS	Participant
Christensen	Janelle	NPS	Participant
Conley	Kimberly	USFS	Participant
Cox	Michelle	USFS	Participant
Cram	Jana	NPS	Planning Team
Cross	Molly	WCS	Participant
Cruz	Ryan	GYC	Participant
Dey	Paul	WYGFD	Participant
Diamond	David	USFS	Planning Team
Dodd	Hope	NPS	Participant
Drimal	Charles	GYC	Participant
Dwire	Kate	USFS	Participant
Erickson	Mary	USFS	Participant
Ertel	Brian	NPS	Participant
Finley	Nancy	NPS	Participant
Gerber	Gwen	USFS	Participant
Hancock	Kenneth	USFS	Participant
Healy	Brian	NPS	Participant
Hostetler	Steve	USGS	Participant
Lawrence	David	NPS	Planning Team
Legg	Kristin	NPS	Participant

Table B-1 (continued). Workshop participants, affiliations, and roles.

Last Name	First Name	Affiliation	Role
Lewis	Max	Friends of the Teton River	Participant
Lien	Mike	Friends of the Teton River	Participant
Locatelli	Mike	NPS	Participant
Luce	Charles	USFS	Participant
Mickelson	Jennifer	USFS	Participant
Mills	Sue	NPS	Participant
Mitzelfelt	Jeff	NPS	Planning Team
Monroe	Jeremy	Freshwater Illustrated	Participant
Muhlfeld	Clint	USGS	Participant
Nosal	Johanna	USFS	Participant
Olliff	Tom	NPS	Planning Team
Olsen	Kate	USFS	Participant
Owens	Kelly	USFS	Participant
Peterson	Justin	USFS	Planning Team
Quistorff	Cassidy	NPS	Participant
Ray	Andy	NPS	Planning Team
Robison	Hillary	NPS	Participant
Rodman	Ann	NPS	Planning Team
Rowell	Gareth	NPS	Participant
Schook	Derek	NPS	Participant
Seagle	Gene	NPS	Participant
Sepulveda	Adam	USGS	Participant
Sestrich	Clint	USFS	Participant
Stringer	Allison	USFS	Participant
Tercek	Mike	Walking Shadow Ecology	Planning Team
Thoma	David	NPS	Planning Team
White	Christina	NPS	Participant
White	Erin	NPS	Participant
Whitlock	Cathy	MSU	Participant
Williams	Howard	NPS	Participant

Acronyms

GYC: Greater Yellowstone Coalition

MSU: Montana State University

NPS: National Park Service

USFS: U.S. Forest Service

USGS: U.S. Geological Survey

WCS: Wildlife Conservation Society

Appendix C. Water Balance Reports

Historical and Projected Water Balance Report for Blacktail Ponds

Janelle Christensen, David Thoma, Mike Tercek, John Gross

July 1, 2021

Location: (44.96, -111.6)

Water balance is the mathematical accounting of water input and movement through the environment. It accounts for water storage in different phases (ice, liquid) and loss to the atmosphere (gas) via evapotranspiration. Through integrating the interactions of temperature and precipitation, it allows us to estimate water availability, movement to streams, and ground water and use by plants. It also accounts for heat load on different aspects and slopes in complex terrain, as well as water holding capacity of different soil types. Local site characteristics such as slope, aspect, soil properties are represented by the modification of regional weather and climate and depict the biophysical conditions at local scales that plants and animals “experience.” For these reasons, water balance is usually more strongly correlated with natural resource response (plant growth, stream flow, fire danger) than temperature or precipitation. More information about water balance and links to studies that have used water balance to improve understanding of natural resources response to climate change can be found at <https://www.nps.gov/subjects/climatechange/waterbalance.htm>. The water balance model is maintained by the National Park Service (Mike Tercek, David Thoma and John Gross). Collectively this report summarizes historical and projected biophysical environmental conditions from 1980–2100 at the single grid cell level (gridMET = 4km; projections = 1km). A link to the NPS water balance gridded products can be found at <http://www.yellowstone.solutions/thredds/catalog.html>.

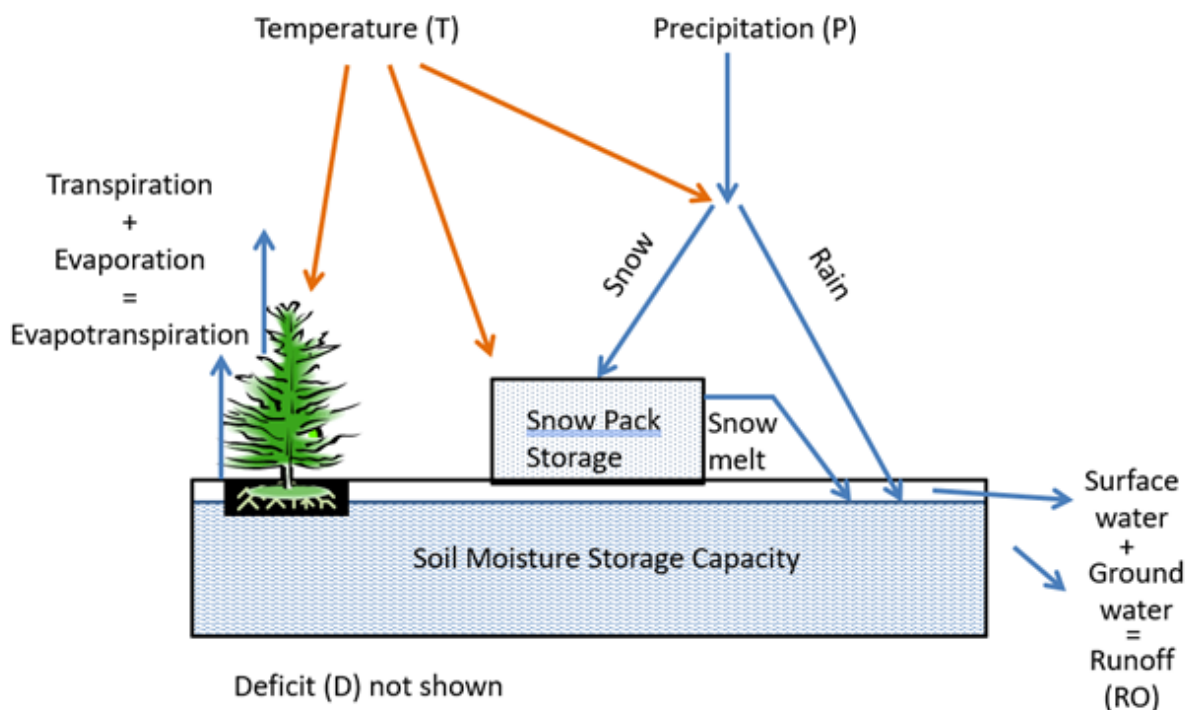


Figure C-1. Schematic of water balance model, adapted from McCabe and Markstrom 2007.

This report is created from temperature and precipitation data that is input to a water balance model. The historical temperature and precipitation data are from gridMET (<https://www.climatologylab.org/gridmet.html>). The future climate projections, MRI-CGCM3 RCP 8.5 and HadGEM2-CC365 RCP 8.5, used in this report are from the CMIP5 experiments (<https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip5>).

Future Model Selection

The models used in this analysis were chosen based on two climate futures that bracket a wide range of plausible future climate conditions represented by the Global Circulation Models (GCM) in the CMIP5 experiments. The experiments include the effects of anthropogenic warming caused by changes in carbon dioxide concentration in the atmosphere. Representative Concentration Pathways (RCP) describe scenarios of carbon dioxide emission, where RCP 8.5 is the high-emission scenario and RCP 4.5 is a lower emission scenario. Model selection for this report is based on a temperature v. precipitation scatterplot of future climate models and scenarios at mid-century. Users are cautioned that the two models presented in this report are intended to represent a range of conditions, but other projections are available and may need to be considered for a full accounting of possible futures. The spatial resolution of climate data used in the water balance model may not be representative of site-specific conditions, especially in areas of high relief or high topographic complexity, and high variation in soil water holding capacity.

Projected water balance conditions presented in this report were selected based on the scatter in projected temperature and precipitation in the future. The latitude and longitude of the site is used to build a scatterplot visualization of future projections from the MACA website of all modeled future conditions of temperature and precipitation. Models from the scatterplot are selected to represent a drier and hotter climate future (the bottom right of the scatterplot) and a wetter and hotter climate future (the upper left of the scatterplot).

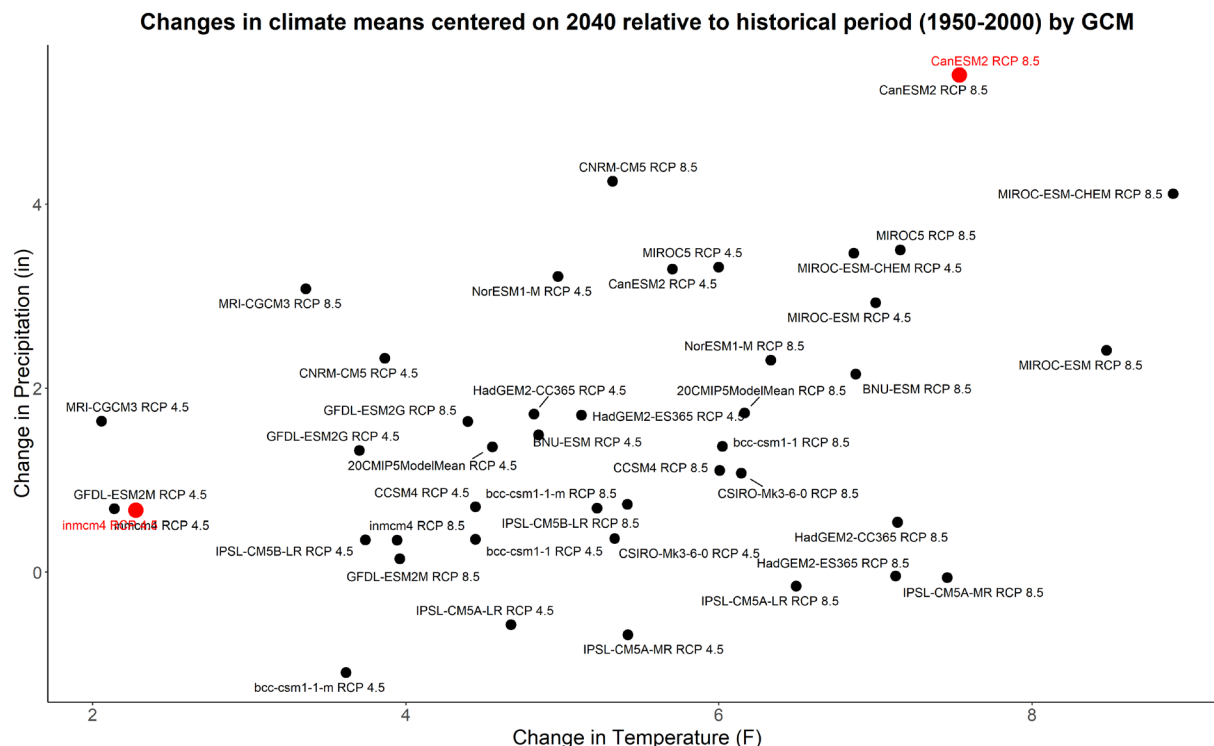


Figure C-2. This graph shows how 45 future climate models project changes in precipitation and changes in temperature for the year 2040.

Change in Annual Values Through Time

Runoff, rain, potential evapotranspiration (PET), actual evapotranspiration (AET), and deficit are summed to show annual values through time. Peak snow water equivalent (SWE) is the max value for the year regardless of the month in which it occurs. Soil water is the mean annual water content in the top meter soil profile. Additionally, it is important to note that precipitation includes rain plus snow, whereas rain is only liquid precipitation. Rain is specifically precipitation that does not fall as snow. If total precipitation stayed the same but temperatures increased, the data here would display that as an increase in rain.

The reason for the different summary statistics is because water variables that don't have an upper limit like rain, runoff, evapotranspiration and deficit can accumulate indefinitely within a calendar year, whereas soil moisture is limited by the soil water holding capacity, so it is averaged on an annual basis. Temperature variables are averaged by convention and growing degree days are summed to account for the seasonal accumulation of heat that controls biological metabolism and

thus growth rates and phenology when water is available. Snow water equivalent is reported as a maximum value because snow accumulates during winter and the maximum water content of the snowpack is useful for predicting stream flow rate and reservoir storage needs.

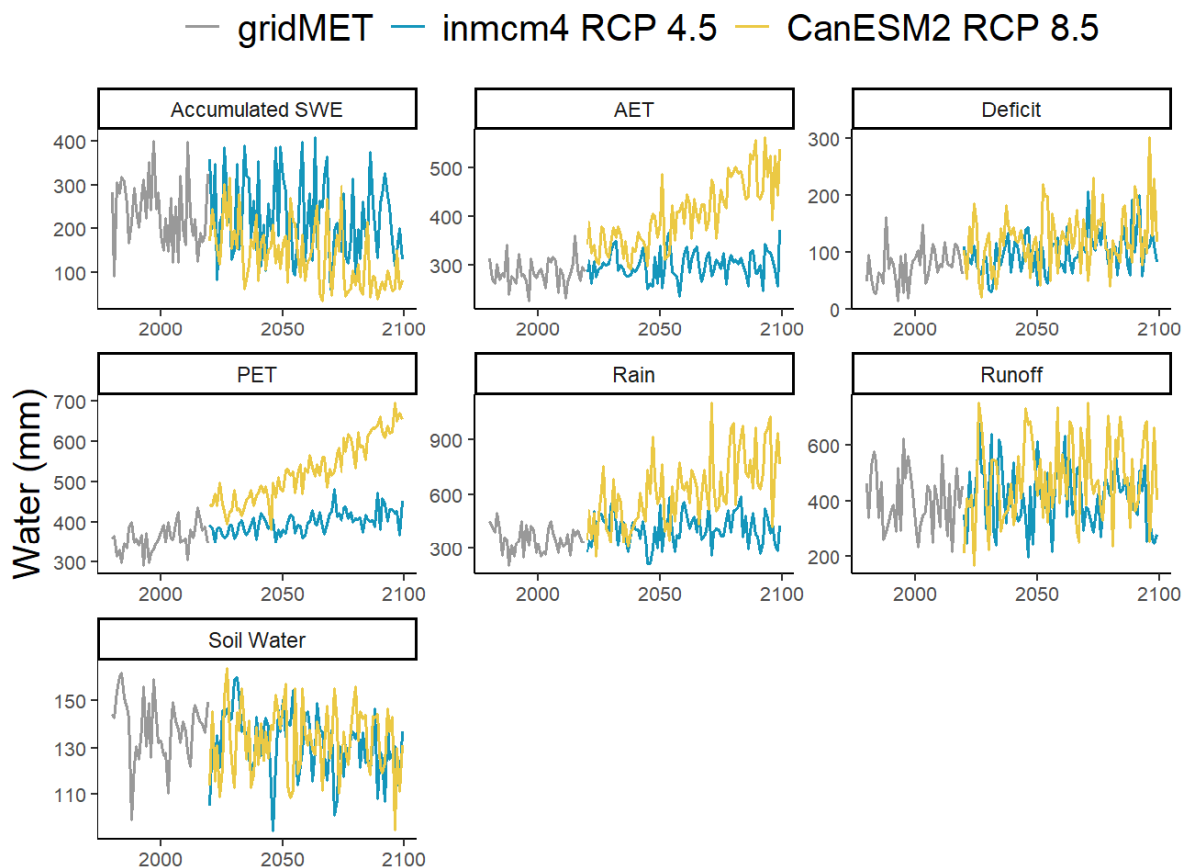


Figure C-3. Annual values over time. The gray line represents historical data modeled from gridMET, the turquoise line represents MRI-CGCM3 rcp85 and the yellow line represents HadGEM2-CC365 rcp85.

Deficit v. Actual Evapotranspiration

Actual evapotranspiration (AET) is an estimate of soil water used by plants plus evaporation. Deficit (D) is an estimate of unmet water need. That is, it represents the amount of water vegetation would use if the water was available and hence is an estimate of vegetation drought stress. Together, AET and D are good predictors of vegetation condition and are useful variables for understanding climate stress on vegetation and how vegetation may transition in the future (Stephenson, 1998). If the clustering of AET and D change in climate space, vegetation assemblages will respond and changes in assemblages will eventually reflect the new climate space. The figure below (Tercek et al., 2021) shows how AET v. D, calculated using the water balance model used for this report, differs across bioregions in the U.S.

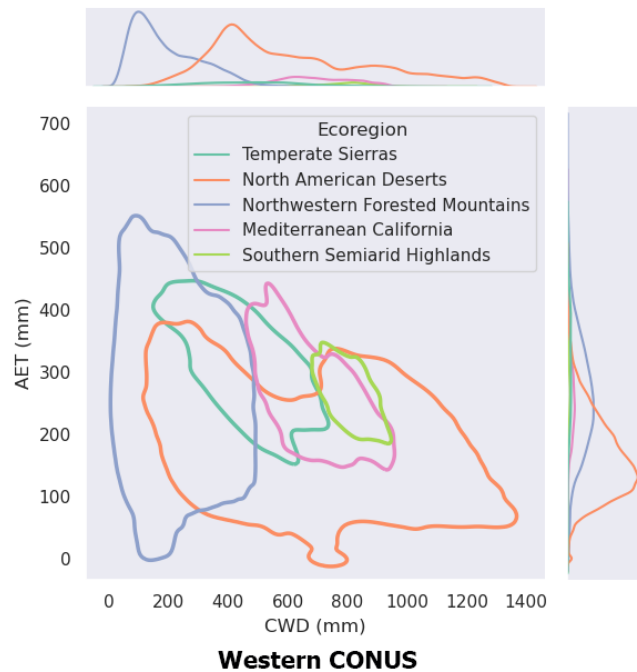


Figure C-4. Ecoregions in the Western United States based on AET and Deficit (CWD). (Tercek et al., 2021)

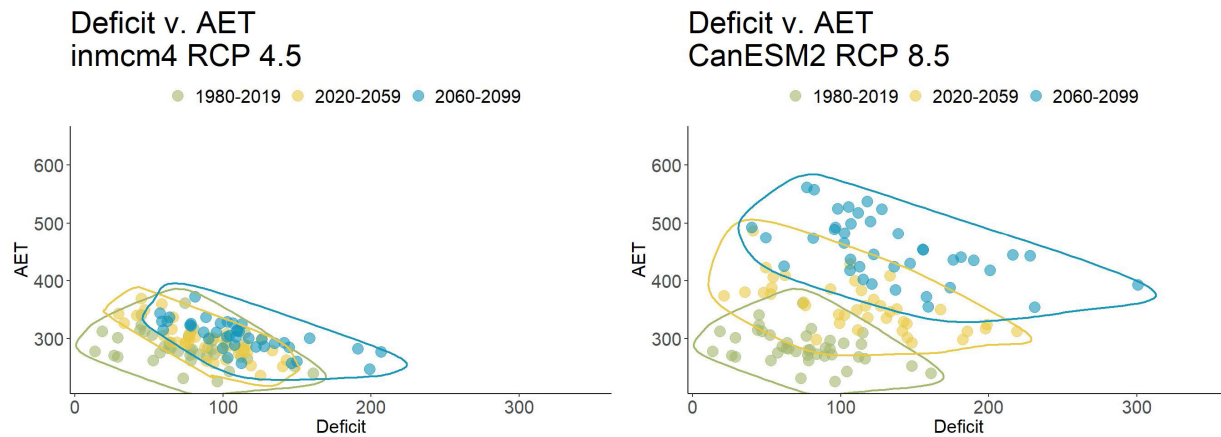


Figure C-5. Modeled Deficit vs. AET. The points are annual sums of daily observations in each year. The green points represent 1980–2019; the yellow points 2020–2059; and the turquoise points 2060–2099. The contours around each set of points delineate shifts in climate space over time.

Water Balance Projections

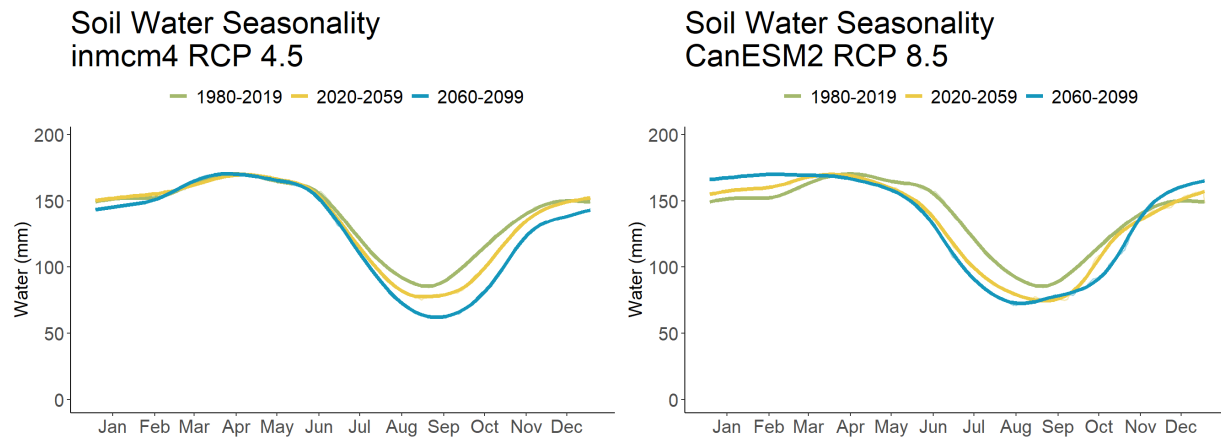


Figure C-6. Modeled soil water seasonality for scenario RCP 4.5 (left) and RCP 8.5 (right) The green line represents the time period 1980–2019; yellow line the time period 2020–2059; blue line time period 2060–2099.

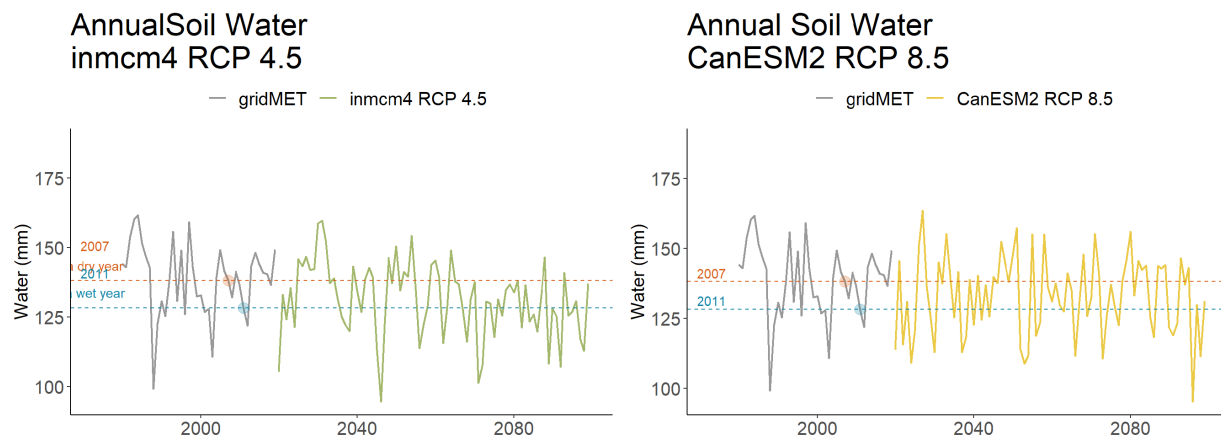


Figure C-7. Modeled annual soil water for scenario RCP 4.5 (left) and RCP 8.5 (right) The gray line represents historic data from gridMET. The green line (left) represents projections from the climate model inmc4 (RCP4.5). The yellow line (right) represents projections from the climate model CanESM2 (RCP8.5).

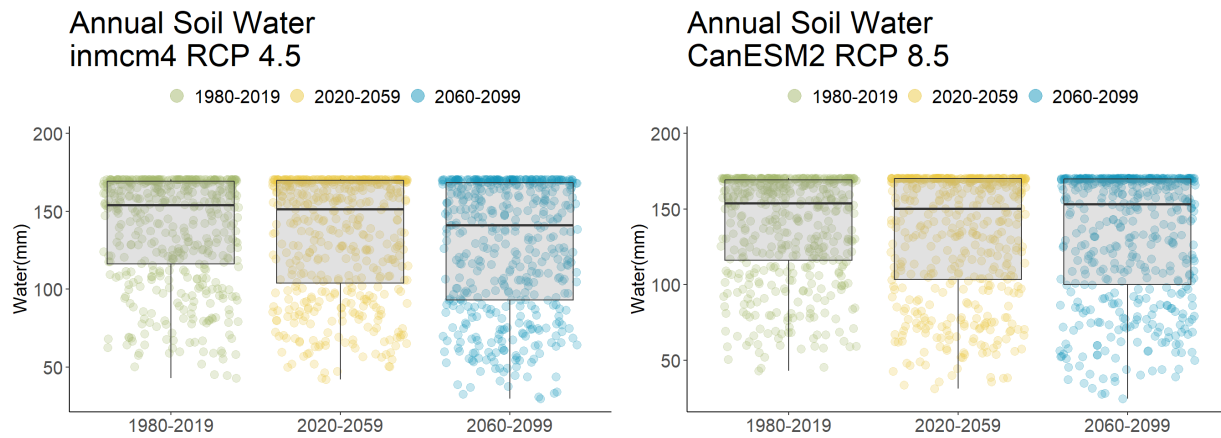


Figure C-8. Modeled annual soil water for scenario RCP 4.5 (left) and RCP 8.5 (right) The green dots represent the time period 1980–2019; yellow dots the time period 2020–2059; blue dots time period 2060–2099.

Runoff

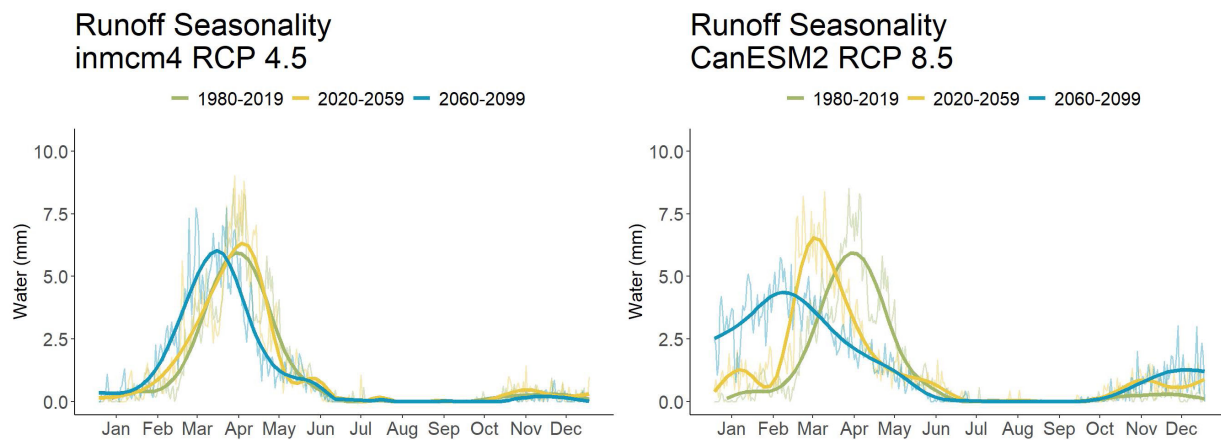


Figure C-9. Modeled runoff seasonality for scenario RCP 4.5 (left) and RCP 8.5 (right) The green line represents the time period 1980–2019; yellow line the time period 2020–2059; blue line time period 2060–2099.

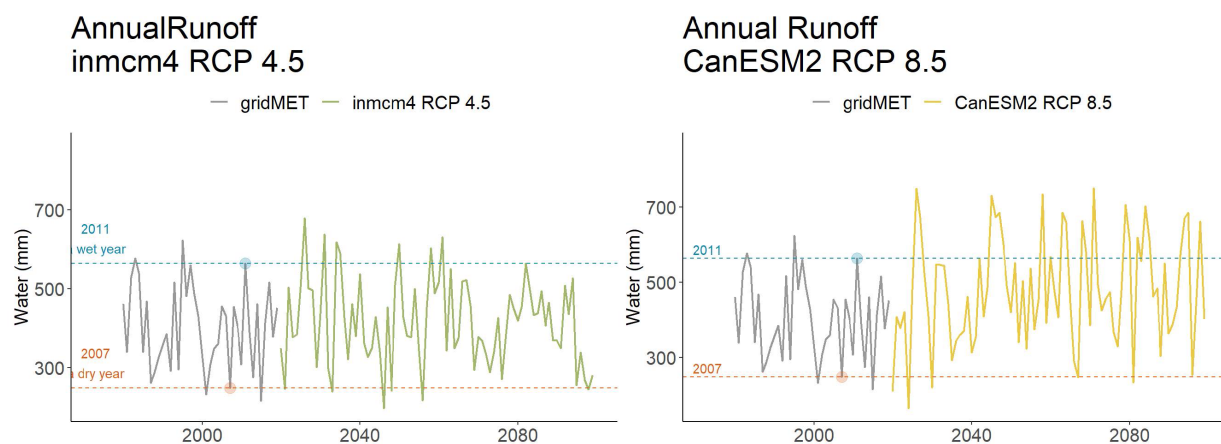


Figure C-10. Modeled annual runoff for scenario RCP 4.5 (left) and RCP 8.5 (right) The gray line represents historic data from gridMET. The green line (left) represents projections from the climate model inmc4 (RCP4.5). The yellow line (right) represents projections from the climate model CanESM2 (RCP8.5).

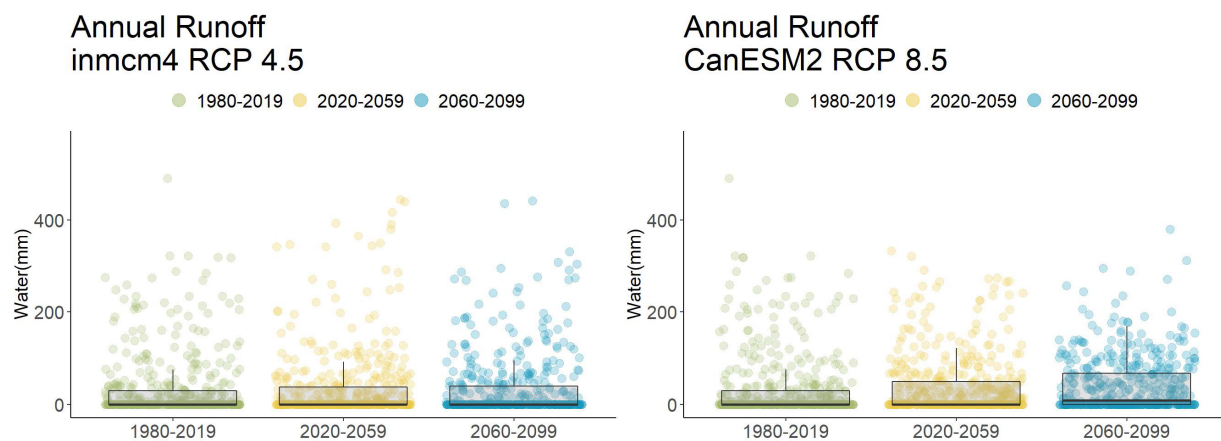


Figure C-11. Modeled annual runoff for scenario RCP 4.5 (left) and RCP 8.5 (right) The green dots represent the time period 1980–2019; yellow dots the time period 2020–2059; blue dots time period 2060–2099.

Rain

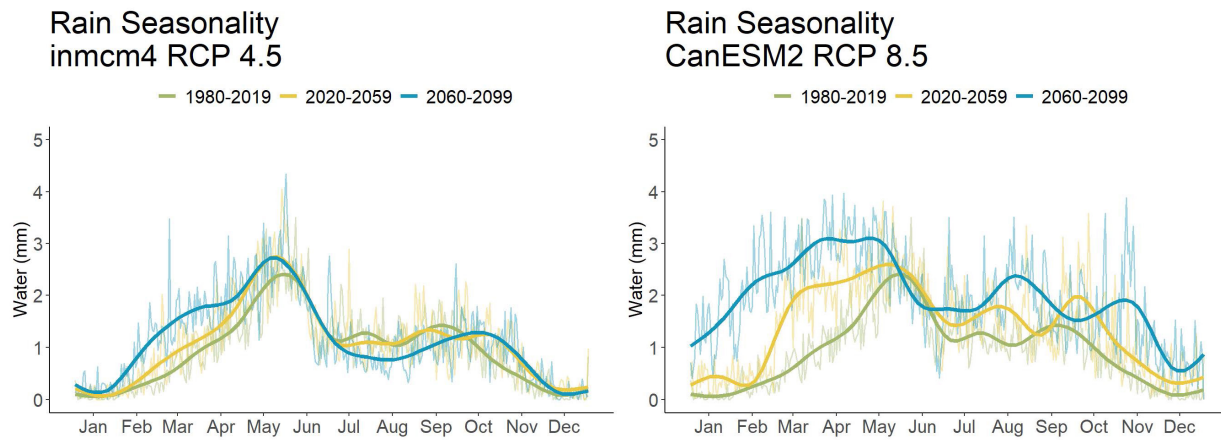


Figure C-12. Modeled rain seasonality for scenario RCP 4.5 (left) and RCP 8.5 (right) The green line represents the time period 1980–2019; yellow line the time period 2020–2059; blue line time period 2060–2099.

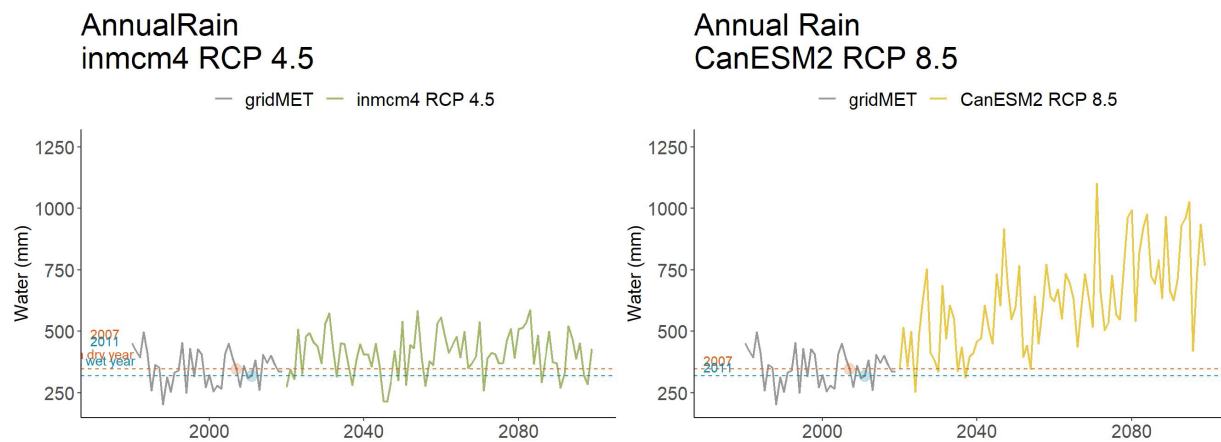


Figure C-13. Modeled annual rain for scenario RCP 4.5 (left) and RCP 8.5 (right) The gray line represents historic data from gridMET. The green line (left) represents projections from the climate model inmcm4 (RCP4.5). The yellow line (right) represents projections from the climate model CanESM2 (RCP8.5).

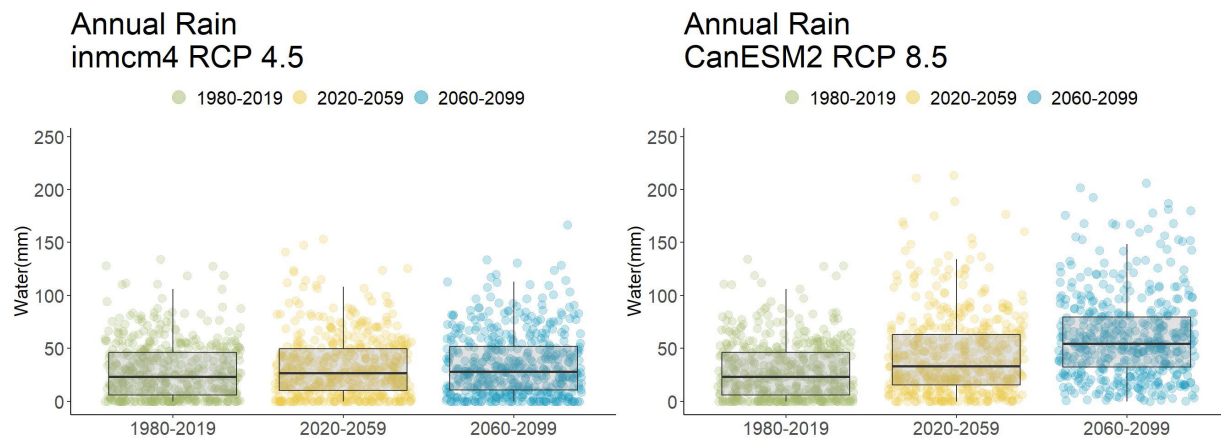


Figure C-14. Modeled annual rain for scenario RCP 4.5 (left) and RCP 8.5 (right) The green dots represent the time period 1980–2019; yellow dots the time period 2020–2059; blue dots time period 2060–2099.

Literature Cited

McCabe, G.J., and Markstrom, S.L., 2007, A monthly water-balance model driven by a graphical user interface: U.S. Geological Survey Open-File report 2007-1088, 6 p.

Tercek, M, Thoma, D. Gross, J., Sherrill, K., Kagone, S. and Senay, G. 2021. Historical changes in plant water use and need in the continental United States. PloS one. 16.

<https://doi.org/10.1371/journal.pone.0256586>

Appendix D. Cold Water Fisheries Adaptation Approaches and Strategies

Adaptation approaches and strategies were developed for each case study. The cold water fisheries approaches are included here as an example.

Strategy 1: Increase Habitat Resilience by Restoring Structure and Function of Streams

- 1.1 Reduce impacts to water quality
- 1.2 Improve watershed function through restoration and expansion of wetlands, riparian areas, wet meadows, and floodplains
- 1.3 Restore natural channel and floodplain form and function
- 1.4 Increase streamflows and moderate changes in in-stream flow. For example: pulse flows from regulated streams during critical times of high temperatures; reduce water withdrawal; secure water rights for instream flow
- 1.5 Reintroduce beaver where beaver and fish management are compatible
- 1.6 Improve watershed resiliency to disturbances by improving culverts, bridges, and other stream/road crossings
- 1.7 Identify and map where ground water inputs provide cold water

Strategy 2: Reduce the Impact of Biological Stressors

- 2.1 Prevent introduction of aquatic invasive species
- 2.2 Remove aquatic invasive species
- 2.3 Remove non-native species through increased take, manual or chemical removal, or excluding with physical barriers

Strategy 3: Reduce the Risk and Long-Term Impact of Severe Disturbances

- 3.1 Implement fuel treatments to reduce wildfire severity and size
- 3.2 Install erosion control structures following wildfires

Strategy 4: Maintain or Create Refugia

- 4.1 Prioritize and maintain unique sites
- 4.2 Prioritize and maintain sensitive or at-risk species or communities
- 4.3 Establish artificial reserves for at-risk and displaced species

- 4.4 Increase cold-water refuge habitats by adding large wood structure, increasing channel complexity, and narrowing and deepening stream channels

Strategy 5: Maintain and Enhance Species and Enhance Species and Structural Diversity

- 5.1 Promote diverse age classes
- 5.2 Maintain and restore diversity of native species
- 5.3 Retain biological legacies
- 5.4 Increase stream shading and reduce stream siltation by increasing riparian habitats and their native plant species
- 5.5 Establish reserves to maintain ecosystem diversity

Strategy 6: Increase Ecosystem Redundancy Across the Landscape

- 6.1 Manage habitats over a range of sites and conditions
- 6.2 Expand the boundaries of preserves to increase diversity

Strategy 7: Promote Aquatic Connectivity

- 7.1 Reduce fragmentation
- 7.2 Identify, prioritize, and remove barriers to trout movements
- 7.3 Maintain functional stream channel morphology with adequate width:depth ratios, pool frequency, and healthy riparian vegetation
- 7.4 Increase stream connectivity by removing instream barriers and replacing poorly designed culverts

Strategy 8: Maintain and Enhance Genetic Diversity

- 8.1 Favor existing genotypes that are better adapted to future conditions
- 8.2 Use fish from a greater geographic area for restoration

Strategy 9: Facilitate Community Adjustments Through Species Transitions

- 9.1 Favor or restore native species that are expected to be adapted to future conditions
- 9.2 Move at-risk species to locations that are expected to provide habitat

Strategy 10: Monitor for Climate Impact and Management Effectiveness

- 10.1 Identify trout spawning/rearing distributions, and create a monitoring network across the GYE that can efficiently monitor if/when these distributions shift or are lost

Literature Cited

- Al-Chokhachy, Robert & Shepard, Bradley & Burckhardt, Jason & Garren, Dan & Optiz, Scott & Koel, Todd & Nelson, Lee & Gresswell, Robert. (2018). A Portfolio Framework for Prioritizing Conservation Efforts for Yellowstone Cutthroat Trout Populations. Fisheries. 43. <https://doi.org/10.1002/fsh.10137>.
- Al-Chokahachy, R., A. Ray, D. Thoma, M. Tercek. 2017. Evaluating species-specific changes in hydrologic regimes: an iterative approach for salmonids in the Greater Yellowstone Area (USA). Reviews in Fish Biology and Fisheries. <https://doi.org/10.1007/s11160-017-9472-3>.
- Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. <http://dx.doi.org/10.2737/NRS-GTR-87-2>.
- Williams, Jack & Isaak, Daniel & Imhof, Jack & Hendrickson, Dean & Mcmillan, John. (2015). Cold-Water Fishes and Climate Change in North America. Reference Module in Earth Systems and Environmental Sciences. <https://doi.org/10.1016/B978-0-12-409548-9.09505-1>.

Appendix E. History of Federal Climate Change Activities in the GYE

Climate change adaption on federal lands in the GYE is coordinated by the GYCC through the Climate Change Adaptation Subcommittee (Subcommittee) The mission of the Subcommittee is to integrate land managers, scientists, and other subject matter experts across multiple disciplines to facilitate discussion and encourage efforts to understand, manage and assist adaptation to changes associated with a changing climate. The Subcommittee consists of interdisciplinary agency program managers and specialists from the GYCC units as well as from the NPS Inventory and Monitoring Program, the USGS, the Forest Service Rocky Mountain Research Station, and Forest Service and NPS Regional Offices. The subcommittee's also worked with partners (Montana State University, The Wildlife Conservation Society, Wilderness Society) working with project funding.

Workshops

Efforts to understand and manage the impacts of climate change on federal lands in the GYE have been going on for over a decade, starting with *Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A Workshop to Identify Priority Science and Implementation Strategies* in November 2009 (Olliff et al. 2010) closely followed in May 2010 by *Monitoring Ecological Response to Climate Change in High Elevation Parks in the Great Northern Landscape Conservation Cooperative* (Bingham et al. 2010, NPS 2010). Other workshops include: *The Aquatics Decision Support Framework for Climate Adaptation* (2012) helped managers document how they have incorporated information on climate change into their management decisions and prioritization of limited resources (Nelson et al. 2012); the 2018 Custer-Gallatin National Forest Climate Change for Forest Planning to assess vulnerability of the portion of the Custer Gallatin National Forest (CGNF) within the GYE to climate change and identify potential adaptation strategies that could be incorporated into the forest plan revision of the CGNF (Hansen et al. 2018); and the 2018 Climate-Smart Conservation Training, to help GYE managers understand the Climate-Smart process, walk through the decision steps to arrive at climate-informed management actions, through case studies in wildland fire, invasive terrestrial species and hydrology/aquatic resources (Thoma et al. 2018). Over 200 federal managers and partners have participated in these workshops to inform understanding of climate science, historical and projected climate metrics, the Climate-Smart process, and management activities robust to a changing climate.

Vulnerability Assessment Projects with Workshops Attended by Agency Staff

GYE managers have benefitted from vulnerability assessments funded and managed by partner scientists. From 2011–2015 Dr. Andrew Hansen, Montana State University, supported by the NASA Applied Sciences Program in cooperation with the NPS I &M Program, the Great Northern Landscape Conservation Cooperative, and the USGS North Central Climate Science Center, led the Landscape Climate Change Vulnerability Project to work with federal land managers to develop decision support tools to assess vulnerability of ecosystems and species to climate and land use change and evaluate management options. (Hansen et al. 2016, Chang and Hansen 2014).

The Northern Rockies Adaptation Partnership (2014–2018) documented the sensitivity of resources to climate change across the USFS Region 1 and the Greater Yellowstone. The assessment serves as a science foundation for developing adaptation options on federal lands to reduce negative consequences and transition resources to a warmer climate. Over 80 resource specialists and researchers from federal agencies and other organizations participated in a science-management partnership that encompasses vegetation, wildlife, water, fisheries, recreation, and ecosystem services (Halofsky et al., 2018, 2018b)

The Montana Climate Assessment (including portions of Montana in the GYE) synthesized, evaluated, and shared credible and relevant scientific information about climate change in Montana with the citizens of the state (Whitlock et al. 2017).

Assessments

In addition to those mentioned above, several climate change vulnerability assessments have been commissioned, conducted, or used by GYCC managers to understand climate projections and impacts to resources, including:

- *Observed and projected ecological response to climate change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature* (Ashton, I.W. 2010).
- *Climate and ecosystem change in the US Rocky Mountains and Upper Columbia Basin: Historic and future perspectives for natural resource management* (McWethy et al. 2010).
- *The Middle Rockies Rapid Ecoregional Assessment* (BLM 2012).
- *Climate change on the Shoshone National Forest, Wyoming: a synthesis of past climate, climate projections, and ecosystem implications* (Rice et al. 2012).

Interactive climate analysis systems

Several interactive systems help managers understand historic and projected climate metrics for counties, HUC6 watersheds and site-specific locations in the GYE.

The Climate Analyzer (<http://www.climateanalyzer.org/>) creates custom graphs and tables from weather station data, satellite imagery, stream gaging stations, and other climate data sources. The data are updated at least every 24 hours—more often in some cases. These summaries are calculated dynamically, when requested by a user. Managers can tell the system which years or months they are interested in and it calculates averages, totals, or other summaries.

The USGS National Climate Change Viewer (<https://www2.usgs.gov/landresources/lcs/nccv.asp>) includes the historical and future climate projections from 30 of the downscaled models for two of the RCP emission scenarios, RCP4.5 and RCP8.5, and allows users to visualize projected changes in climate (maximum and minimum air temperature and precipitation) and the water balance (snow water equivalent, runoff, soil water storage and evaporative deficit) for any state, county and USGS Hydrologic Units (HUC) (<https://water.usgs.gov/GIS/huc.html>). The viewer provides a number of useful tools for characterizing climate change including maps, climographs (plots of monthly averages), histograms that show the distribution or spread of the model simulations, monthly time series spanning 1950–2099, and tables that summarize changes in the quantiles (median and

extremes) of the variables. The application also provides access to comprehensive, summary reports in PDF format and CSV files of the temperature and precipitation data for each geographic area.

A consortium of academic, and government agencies created the [Climatetoolbox.org](https://climatetoolbox.org) website. It produces on-demand charts of historic and future scenarios for agriculture, climate, fire and water resources from downscaled climate models. It allows users to map conditions as well as create point-based charts of time series for variables that affect natural resources, and human activities affected by climate.

The USFS NorWeST system (<https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>) hosts stream temperature data and climate scenarios in a variety of user-friendly digital formats for streams and rivers across the western U.S. The temperature database was compiled from hundreds of biologists and hydrologists working for >100 resource agencies and contains >200,000,000 hourly temperature recordings at >20,000 unique stream sites. Those temperature data were used with spatial statistical network models to develop 36 historical and future climate scenarios at 1-kilometer resolution for >1,000,000 kilometers of stream (Isaak et al. 2017).

Adaptation Strategies and Tactics

Many GYE managers have participated in these workshops, partnered in the assessments, participated in training, and have used this knowledge to insert climate-informed actions into strategies or projects. Specific examples include:

Whitebark pine (*Pinus albicaulis*) is a keystone species of high elevation ecosystems in the Greater Yellowstone area (GYA), and is currently at significant risk from the combined effects of insects, the introduced disease white pine blister rust, climate change and successional replacement throughout its range. The GYCC Whitebark Pine Subcommittee is actively implementing the Whitebark Pine Strategy for the Greater Yellowstone Area (2011) (https://f1c59591-81c4-4f48-b9c5-25880bae0b0d.filesusr.com/ugd/a0f00b_a5e0ef096eba4cbbbbb1f18c61250b648.pdf) with its associated Adaptive Action Plan – Whitebark Pine in the Greater Yellowstone Area (2015) (https://f1c59591-81c4-4f48-b9c5-25880bae0b0d.filesusr.com/ugd/a0f00b_5ea01c12470f49c98426e6ff49b570ea.pdf). Ongoing actions include extensive protection and restoration efforts, such as cone collection from blister rust resistant trees and planting across the GYE, and the establishment of a GYGT seed orchard and clone bank on the Custer-Gallatin NF.

The Custer Gallatin National Forest is in the process of revising its land and resource management plans (“forest plan” or “land management plan” or “land and resource management plan”) to, among other things, comply with the 2012 Forest Planning rule.

https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd567788.pdf. Climate change is recognized as a stressor and is integrated into the discussion of affected environment and environmental consequences in the final EIS. Specifically, the section “Climate Change Considerations and Assumptions” in the Terrestrial Vegetation section of the EIS explains, in detail, the major anticipated effects of climate change as well as the Best Available Scientific Information used to inform the analysis process. Vegetation modeling incorporated future climate scenarios that

reflected best estimates of climatic trends over the next five decades. Most notably, modeling of future vegetation dynamics includes a doubling in the amount of wildfire expected to occur (Erdody and Carnwath 2018). In addition, the effects of climate change on regeneration in dry forest ecosystems was accounted for (including regeneration challenges in dry forest ecosystems). Further detail on how climate change was incorporated in to landscape dynamic simulation models is provided in Appendix B of the EIS. As noted in the EIS, another key plan component that is critical in the context of future climate change is the establishment of a monitoring plan to inform an adaptive management approach. This enables the intentional use of monitoring to evaluate effectiveness of actions and if course corrections are needed. For example, monitoring tree regeneration will provide critical information on possible climate change effects to this vulnerable life stage.

Research and Monitoring

Glacier Monitoring. Glaciers are sensitive indicators of climate change because they respond to both temperature and precipitation. All glaciers in Grand Teton National Park have retreated since the late 1800s, although there have been brief periods of advance, most notably the mid-1970s to mid-1980s. Fritiof Fryxell conducted the first survey of the Teton glaciers in the late 1920s and 1930s, and studies continued sporadically through the 20th century. Historic photographs show the extent of these glaciers as early as 1924, and scientists can trace glacial retreat using ground and aerial photos over the last 90 years. Current monitoring focuses on Teton, Middle Teton, Schoolroom, Petersen, and Falling Ice glaciers. Park scientists are studying how these ice bodies change yearly, how much ice volume is melting, and what climatic factors control these changes.

Climate Monitoring in Yellowstone National Park. In 2017 Yellowstone established seven, long-term climate monitoring sites along a 4,500 ft elevation gradient in the northern section of the park. Each site has two fixed transects for natural resource data collection, and equipment that continuously monitors weather (temperature, precipitation, snow depth), soil conditions (temperature and moisture), the soundscape, plant phenology and wildlife visits (multiple photographs each day). During the winter, park staff visits most sites once a month to describe and measure the snowpack. Between 2018 and 2020, a team of NPS staff and citizen science volunteers visited each site every two weeks and made observations of vegetation phenology (first emergence, leaf out, blooming, senescence) and collected beetle, ant, and grasshopper specimens to establish a baseline inventory for these important insect groups. By documenting when flowers bloom or certain insects become active, volunteers are helping park managers better understand climate driven changes that occur at these sites. In 2020 a student from Montana State University inventoried native bees at all seven sites and will compare species diversity to a similar native bee inventory conducted between 2010 and 2012.

Ice Patch Archeology. Perennial ice patches at high latitudes and high elevations are melting and releasing ancient paleo-biological and archaeological materials. Researchers have conducted systematic investigations of ice patches in the GYE including the Shoshone, Bridger-Teton, Caribou-Targhee, and Custer Gallatin national forests as well as in Grand Teton and Yellowstone national parks. (Lee et al. 2014). Chipped stone projectile points, bows, dart and arrow foreshafts and shafts, and the remains of prey species—certainly bighorn sheep (*Ovis canadensis*) and probably bison

(*Bison bison*) as well— have been recovered in direct association with melting GYE ice patches. Artifacts unearthed by melting ice patches were both studied *in situ* and collected to add to our knowledge base of prehistoric people and to protect these rare artifacts.

National Park Service water balance modeling. The NPS Inventory and Monitoring and Climate Change Response Programs are modeling historic and future water balance (soil moisture, snowpack, runoff, evapotranspiration and water deficit) at 1 km resolution for the Continental U.S. In the GYA results from the model are used to establish natural resource response relationships with monitoring programs that track vegetation, amphibians, whitebark pine and river flow. These relationships can be projected into the future to determine the rate, magnitude and direction of resource response. This gives managers lead time to develop mitigation actions that are grounded in goals for the resource conservation.

The National Science Foundation's National Ecological Observatory Network (NEON) (<https://www.neonscience.org/about>) is a continental-scale observation facility operated by Battelle and designed to collect long-term open access ecological data to better understand how U.S. ecosystems are changing. The comprehensive data, spatial extent and remote sensing technology provided by NEON will enable a large and diverse user community to tackle new questions at scales not accessible to previous generations of ecologists. The Northern Rockies Domain (D12) sprawls across 290,000 km² (112,000 square miles) of western Montana, Idaho, and northwestern Wyoming. The Northern Rockies Domain has one terrestrial field site (<https://www.neonscience.org/data-collection/terrestrial-organisms>) and one aquatic field site (<https://www.neonscience.org/field-sites/about-field-sites>), which are co-located in Yellowstone National Park.

Literature Cited

- Ashton, I.W. 2010. Observed and projected ecological response to climate change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature. Fort Collins, CO: National Park Service. Natural Resource Report NPS/ROMN/NRR—2010/220.
<https://irma.nps.gov/DataStore/Reference/Profile/2124855>
- Bingham, B., M. Britten, L. Garrett, P. Latham, and K. Legg. 2010. Enhanced monitoring to better address rapid climate change in high-elevation parks: a multi-network strategy. Natural Resource Report NPS/IMR/NRR—2011/285. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/DownloadFile/423640>
- BLM. 2012. Middle Rockies Rapid Ecoregional Assessment.
<https://landscape.blm.gov/geoportal/rest/find/document?searchText=isPartOf%3AREA-MIR2011&start=1&max=10&f=searchpage&contentType=document>
- Chang, T. and A. J. Hansen 2014 Greater Yellowstone Climate Primer, Montana State University
http://www.montana.edu/lccvp/documents/LCCVP_GYE_ClimateBrief.pdf
- Erdody, T.L. and G.C. Carnwath. 2018. Future fire assumptions for CGNF SIMPPLLE Modeling: estimating area burned, fire size distribution, fire severity/effects to vegetation and reburning. Custer-Gallatin National Forest. 3 p.

- Gray, S. T. 2008. Framework for linking climate, resource inventories and ecosystem monitoring. Natural Resource Technical Report NPS/GRYN/NRTR-2008/110. National Park Service, Fort Collins, Colorado. http://files.cfc.umt.edu/cesu/NPS/MSU/2006/06Gray_climate_IMRO_frpt.pdf
- Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., eds. 2018. Climate change vulnerability and adaptation in the Northern Rocky Mountains [Part 1]. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 1–273. <https://www.fs.usda.gov/treearch/pubs/55974>
- Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., eds. 2018b. Climate change vulnerability and adaptation in the Northern Rocky Mountains [Part 2]. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 275–475. <https://www.fs.usda.gov/treearch/pubs/55975>
- Hansen, A.J., T. Olliff, G. Carnwath, B.W. Miller, L. Hoang, M. Cross, J. Dibenedetto, K. Emmett, R. Keane, V. Kelly, N. Korb, K. Legg, K. Renwick, D. Roberts, D. Thoma, A. Adhikari, T. Belote, K. Dante-Wood, D. Delong, B. Dixon, T. Erdody, D. Laufenberg, B. Soderquist. 2018. Vegetation climate adaptation planning in support of the Custer Gallatin National Forest Plan revision. Technical Report. Landscape Biodiversity Lab, Montana State University, Bozeman, MT. <http://www.montana.edu/hansenlab/documents/downloadables/CGNF%20Final%20Report.Sept%202018.pdf>
- Hansen, A., T. Olliff, D. Theobald, B. Monahan, editors. 2016. *Climate change in wildlands: pioneering approaches to science and management in the Rocky Mountains and Appalachians*. Island Press. <https://islandpress.org/books/climate-change-wildlands>
- Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C. Luce, S. Hostetler, J. Dunham, B. Roper, S. Wollrab, G. Chandler, D. Horan, S. Parkes-Payne. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. *Water Resources Research*, 53: 9181–9205. <https://doi.org/10.1002/2017WR020969>
- Lee, C.M, R. L. Kelly, R.R., I.L. Matt, P.L. Yu. 2014. "Ice Patch Archaeology in Western North America" *SAA Archaeological Record* Vol. 14 Iss. 2 (2014). http://works.bepress.com/pei-lin_yu/8/
- McWethy, D.B., S.T. Gray, P.E. Higuera, J.S. Littell, G.T. Pederson, A. Ray, and C. Whitlock. 2010. Climate and ecosystem change in the US Rocky Mountains and Upper Columbia Basin: Historic and future perspectives for natural resource management. US Department of the Interior, National Park Service, Natural Resource Program Center. <https://irma.nps.gov/DataStore/DownloadFile/644640>

- Nelson, R., Cross, M., Hansen, L., and G. Tabor. 2016. A three-step decision support framework for climate adaptation: Selecting climate informed conservation goals and strategies for native salmonids in the northern U.S. Rockies. Wildlife Conservation Society, EcoAdapt, Center for Large Landscape Conservation. Bozeman, MT, USA. <http://rmpf.weebly.com/cold-water-ecosystem-management-tool.html>
- NPS 2010. Monitoring ecological response to climate change in high elevation park units of the great northern landscape conservation cooperative. <http://npshistory.com/publications/climate-change/cc-high-elevation.pdf>
- Olliff, T., G. Plumb, J. Kershner, C. Whitlock, A. Hansen, M. Cross, and S. Bischke. 2010. A science agenda for the Greater Yellowstone Area: Responding to landscape impacts from climate change, land use change, and invasive species. Yellowstone Science, Vol. 18, Issue 2, 2010.
- Rice, Janine; Tredennick, Andrew; Joyce, Linda A. 2012. Climate change on the Shoshone National Forest, Wyoming: a synthesis of past climate, climate projections, and ecosystem implications. Gen. Tech. Rep. RMRS-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 60 p. <https://www.fs.usda.gov/treearch/pubs/39736>
- Thoma, D, T. Olliff, A. Rodman, J. Hoffman, A. Sesser, M. Cross, and S. Woolfolk. 2018. Summary of GYCC Climate-Smart Conservation Training, and Recommendations. <https://irma.nps.gov/DataStore/DownloadFile/647753>
- Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. <http://live-mca-site.pantheon.io/sites/default/files/thumbnails/image/2017-Montana-Climate-Assessment-lr.pdf>

Appendix F. Climate Summaries

The climate data summaries for the workshop were created by running a water balance model using historical and projected temperature and precipitation data for each study area. The model (Tercek et al., 2021) included historical as well as future conditions so that the magnitude and rate of change could be determined for different time periods. Data summarized here were obtained from <http://screenedcleanedsummaries.s3-website-us-west-2.amazonaws.com/>.

Table F-1. RCP 4.5: Low Emissions Scenario for Blacktail Lakes, 1981–2010.

Variable	Annual	Spring (MAM ^A)	Summer (JJA ^B)	Winter (DJF ^C)	Fall (SON ^D)
Mean Avg. Temperature (F)	37.6	36.2	57.7	18.3	37.6
Mean Max. Temperature (F)	49.7	48.1	73.2	27.7	49.5
Mean Min. Temperature (F)	25.4	24.3	42.2	8.9	25.8
Days Above 90 F	0.3	0.0	0.3	0.0	0.0
Days Above 80 F	20.3	0.0	19.7	0.0	0.5
Days Below Freezing	227	70	6	90	61
Avg. Total Precip (in.)	18.3	5.7	5.2	3.3	4.2
Avg. Days / Yr with Precipitation > 0.25 inch	15	5	5	1	4
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	114	33	31	25	25
Maximum 5 Day Precipitation (in.)	1.5	1.2	1.1	0.6	1.1
Mean Avg. Soil Water (in.)	3.4	4.7	3.0	3.6	2.3
Mean Min. Soil Water (in.)	1.4	3.7	1.6	2.8	1.4
Mean Runoff (in.)	4.2	3.6	0.2	0.4	0.0
Mean Total Moisture Deficit (in.)	4.7	0.2	3.3	0.0	1.3
Mean Cumulative AET (in.)	11.0	2.7	7.0	0.0	1.3
Mean Growing Season (days) (AET > 0)	187	43	91	1	52
Peak Snow Water Equivalent (in.)	2.6	2.3	0.0	2.4	0.7
Days with SWE > 0	176	48	1	89	38

^A March–April–May

^B June–July–August

^C December–January–February

^D September–October–November

Table F-2. RCP 4.5: Low Emissions Scenario for Blacktail Lakes, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	41.7	40.4	62.2	22.1	41.8
Mean Max. Temperature (F)	54.0	52.4	78.1	30.9	53.9
Mean Min. Temperature (F)	29.5	28.4	46.3	13.2	29.6
Days Above 90 F	3.9	0.0	3.9	0.0	0.0
Days Above 80 F	49.8	1.0	44.7	0.0	4.1
Days Below Freezing	198	58	2	90	49
Avg. Total Precip (in.)	20.1	6.5	5.3	3.8	4.5
Avg. Days / Yr with Precipitation > 0.25 inch	18	7	5	2	5
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	125	37	32	29	27
Maximum 5 Day Precipitation (in.)	1.8	1.3	1.3	0.8	1.1
Mean Avg. Soil Water (in.)	4.0	5.9	3.5	4.1	2.4
Mean Min. Soil Water (in.)	1.6	4.7	1.9	3.0	1.7
Mean Runoff (in.)	1.3	1.1	0.1	0.1	0.0
Mean Total Moisture Deficit (in.)	6.5	0.4	4.4	0.0	1.7
Mean Cumulative AET (in.)	13.1	4.0	7.4	0.1	1.6
Mean Growing Season (days) (AET > 0)	220	60	92	5	63
Peak Snow Water Equivalent (in.)	1.4	0.8	0.0	1.4	0.4
Days with SWE > 0	96	12	0	71	12

Table F-3. RCP 4.5: Low Emissions Scenario for Blacktail Lakes, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	43.3	41.9	63.7	23.6	43.4
Mean Max. Temperature (F)	55.5	53.8	79.7	32.1	55.8
Mean Min. Temperature (F)	31.1	30.0	47.6	15.1	31.1
Days Above 90 F	7.8	0.0	7.7	0.0	0.1
Days Above 80 F	60.2	1.8	52.2	0.0	6.3
Days Below Freezing	187	52	1	88	45
Avg. Total Precip (in.)	20.6	6.9	5.3	4.1	4.3
Avg. Days / Yr with Precipitation > 0.25 inch	19	7	5	2	4
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	127	39	31	31	26
Maximum 5 Day Precipitation (in.)	1.8	1.4	1.4	0.9	1.1
Mean Avg. Soil Water (in.)	3.9	5.8	3.4	4.1	2.2
Mean Min. Soil Water (in.)	1.5	4.7	1.8	2.7	1.6
Mean Runoff (in.)	1.2	1.0	0.1	0.2	0.0
Mean Total Moisture Deficit (in.)	7.2	0.5	4.7	0.0	2.0
Mean Cumulative AET (in.)	13.5	4.3	7.5	0.1	1.6
Mean Growing Season (days) (AET > 0)	231	65	92	8	66
Peak Snow Water Equivalent (in.)	1.2	0.6	0.0	1.2	0.4
Days with SWE > 0	81	8	0	63	10

Table F-4. RCP 8.5: Current Emissions Trajectory for Blacktail Lakes, 1981–2010.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	37.6	36.2	57.7	18.3	37.6
Mean Max. Temperature (F)	49.7	48.1	73.2	27.7	49.5
Mean Min. Temperature (F)	25.4	24.3	42.2	8.9	25.8
Days Above 90 F	0.3	0.0	0.3	0.0	0.0
Days Above 80 F	20.3	0.0	19.7	0.0	0.5
Days Below Freezing	227	70	6	90	61
Avg. Total Precip (in.)	18.3	5.7	5.2	3.3	4.2
Avg. Days / Yr with Precipitation > 0.25 inch	15	5	5	1	4
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	114	33	31	25	25
Maximum 5 Day Precipitation (in.)	1.5	1.2	1.1	0.6	1.1
Mean Avg. Soil Water (in.)	3.4	4.7	3.0	3.6	2.3
Mean Min. Soil Water (in.)	1.4	3.7	1.6	2.8	1.4
Mean Runoff (in.)	4.2	3.6	0.2	0.4	0.0
Mean Total Moisture Deficit (in.)	4.7	0.2	3.3	0.0	1.3
Mean Cumulative AET (in.)	11.0	2.7	7.0	0.0	1.3
Mean Growing Season (days) (AET > 0)	187	43	91	1	52
Peak Snow Water Equivalent (in.)	2.6	2.3	0.0	2.4	0.7
Days with SWE > 0	176	48	1	89	38

Table F-5. RCP 8.5: Current Emissions Trajectory for Blacktail Lakes, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	42.7	41.2	63.6	22.6	43.1
Mean Max. Temperature (F)	54.9	53.0	79.5	31.2	55.3
Mean Min. Temperature (F)	30.5	29.4	47.6	13.9	30.9
Days Above 90 F	8.2	0.0	8.1	0.0	0.1
Days Above 80 F	58.5	1.5	50.7	0.0	6.4
Days Below Freezing	191	55	1	89	46
Avg. Total Precip (in.)	20.4	6.6	5.3	4.0	4.6
Avg. Days / Yr with Precipitation > 0.25 inch	18	7	5	2	4
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	126	38	31	30	27
Maximum 5 Day Precipitation (in.)	1.9	1.3	1.4	0.9	1.2
Mean Avg. Soil Water (in.)	3.9	5.7	3.4	4.1	2.3
Mean Min. Soil Water (in.)	1.5	4.6	1.8	2.8	1.6
Mean Runoff (in.)	1.4	1.0	0.1	0.2	0.0
Mean Total Moisture Deficit (in.)	7.2	0.5	4.8	0.0	1.9
Mean Cumulative AET (in.)	13.2	4.1	7.4	0.1	1.6
Mean Growing Season (days) (AET > 0)	225	63	92	6	64
Peak Snow Water Equivalent (in.)	1.3	0.7	0.0	1.3	0.4
Days with SWE > 0	89	11	0	68	11

Table F-6. RCP 8.5: Current Emissions Trajectory for Blacktail Lakes, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	47.7	45.6	68.9	27.8	48.0
Mean Max. Temperature (F)	59.9	57.5	85.2	35.8	60.4
Mean Min. Temperature (F)	35.6	33.6	52.7	19.8	35.6
Days Above 90 F	33.6	0.1	31.3	0.0	2.2
Days Above 80 F	87.9	4.6	68.7	0.0	14.7
Days Below Freezing	160	40	0	84	35
Avg. Total Precip (in.)	21.4	7.5	4.9	4.4	4.5
Avg. Days / Yr with Precipitation > 0.25 inch	21	9	5	3	5
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	127	40	29	32	26
Maximum 5 Day Precipitation (in.)	1.9	1.5	1.3	1.0	1.2
Mean Avg. Soil Water (in.)	3.5	5.5	2.9	3.9	1.8
Mean Min. Soil Water (in.)	1.1	4.4	1.3	2.4	1.1
Mean Runoff (in.)	0.9	0.7	0.1	0.1	0.0
Mean Total Moisture Deficit (in.)	9.8	0.8	6.4	0.1	2.6
Mean Cumulative AET (in.)	14.3	5.0	7.3	0.2	1.8
Mean Growing Season (days) (AET > 0)	258	74	92	19	72
Peak Snow Water Equivalent (in.)	0.8	0.3	0.0	0.8	0.2
Days with SWE > 0	48	3	0	40	5

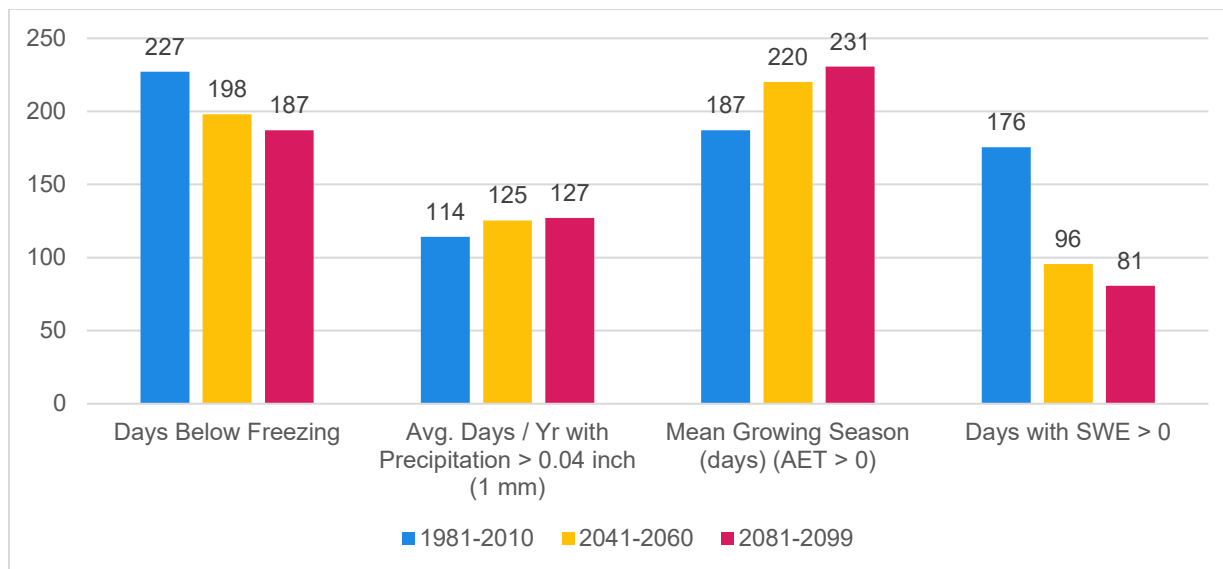


Figure F-1. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-1 through F-3 for Blacktail Lakes.

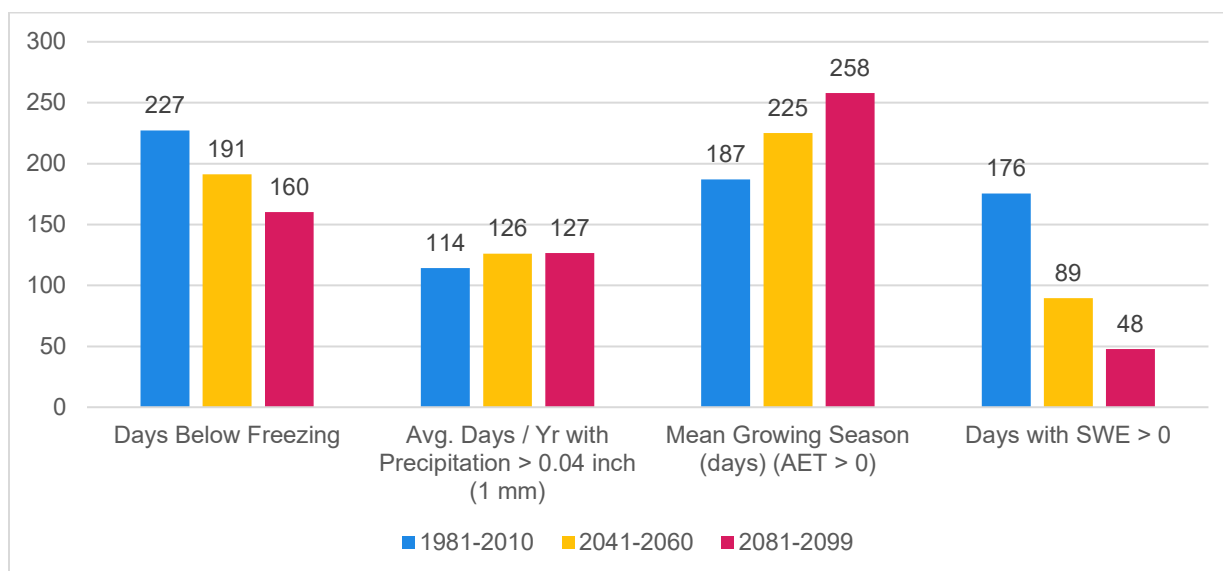


Figure F-2. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-4 through F-6 for Blacktail Lakes.

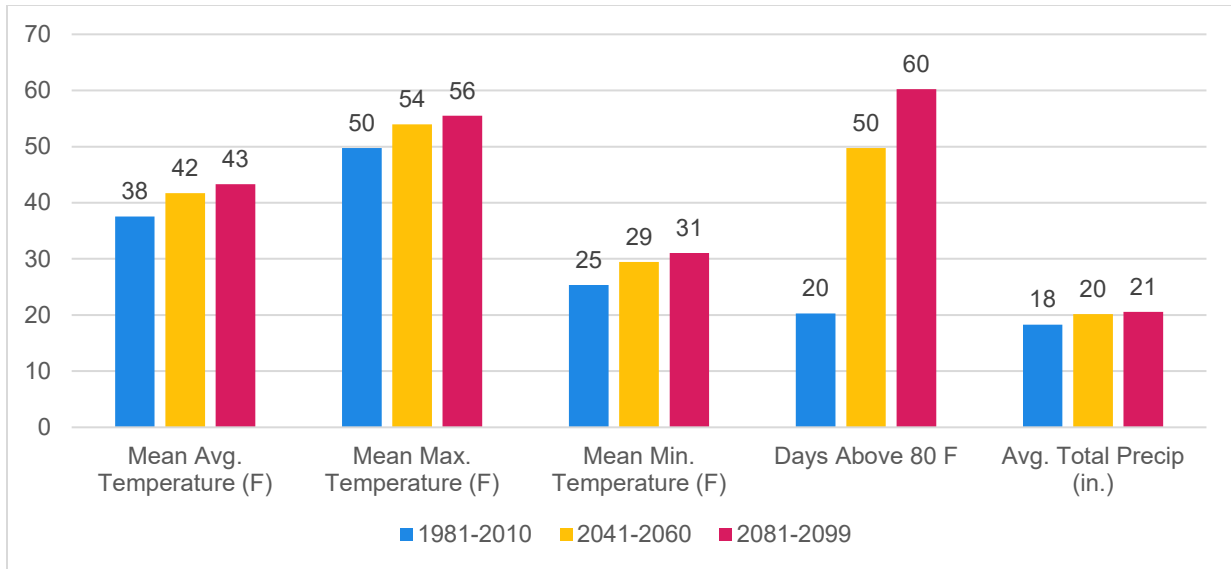


Figure F-3. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-1 through F-3 for Blacktail Lakes.

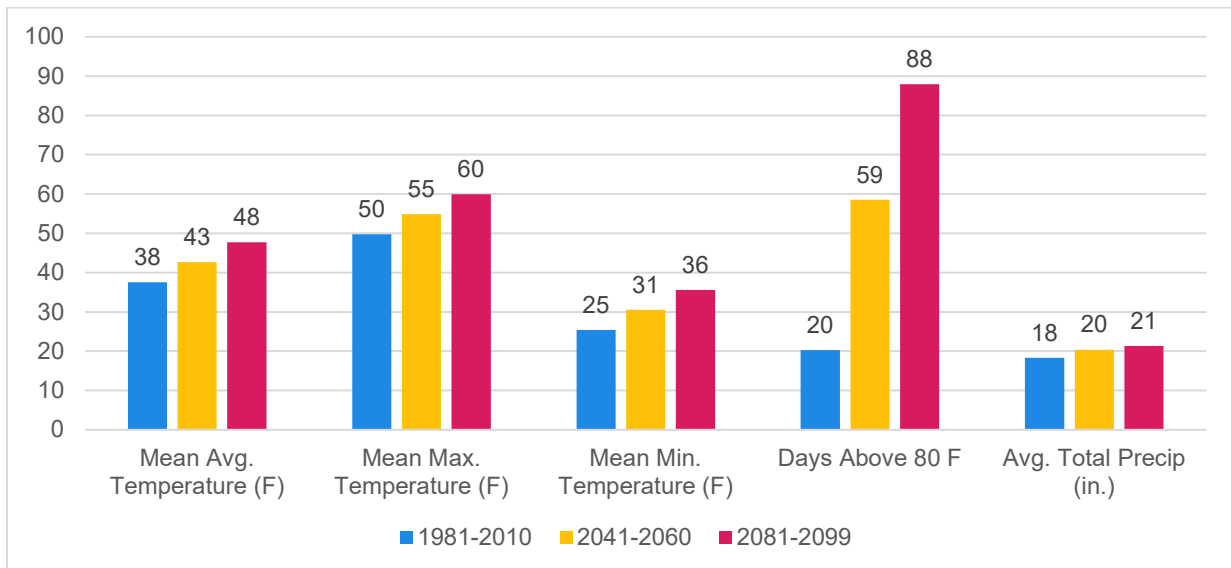


Figure F-4. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-4 through F-6 for Blacktail Lakes.

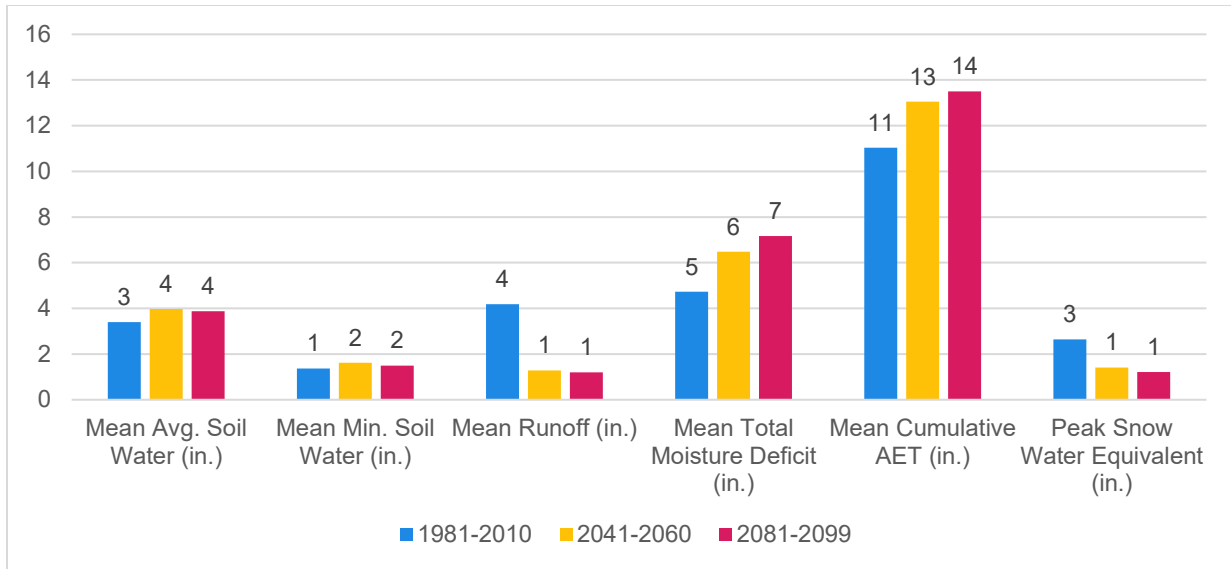


Figure F-5. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-1 through F-3 for Blacktail Lakes.

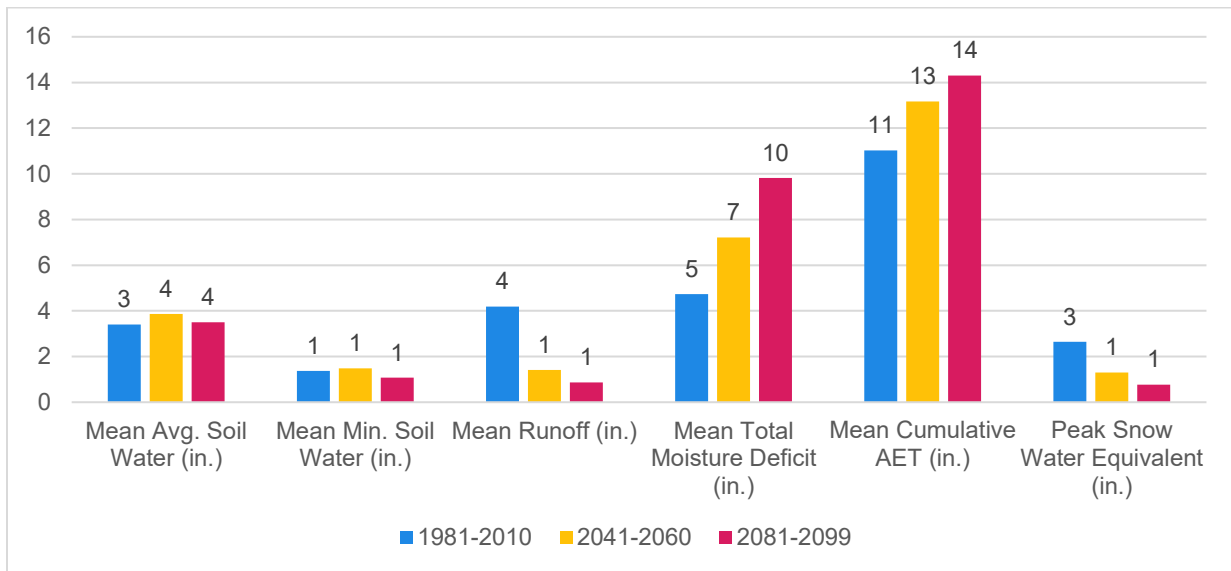


Figure F-6. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-4 through F-6 for Blacktail Lakes.

Table F-7. RCP 4.5: Low Emissions Scenario for Buffalo Creek at northern boundary, 1981–2010.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	35.9	34.3	54.7	18.4	35.8
Mean Max. Temperature (F)	47.5	46.3	69.0	27.8	46.5
Mean Min. Temperature (F)	24.2	22.2	40.4	9.0	25.0
Days Above 90 F	0.0	0.0	0.0	0.0	0.0
Days Above 80 F	4.7	0.0	4.6	0.0	0.0
Days Below Freezing	240	76	10	90	64
Avg. Total Precip (in.)	26.6	8.0	6.6	6.2	6.0
Avg. Days / Yr with Precipitation > 0.25 inch	27	9	6	5	6
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	154	44	38	39	33
Maximum 5 Day Precipitation (in.)	1.8	1.5	1.4	1.1	1.3
Mean Avg. Soil Water (in.)	4.9	5.4	4.5	5.2	4.5
Mean Min. Soil Water (in.)	3.2	5.0	3.3	4.9	3.4
Mean Runoff (in.)	24.4	20.1	2.3	0.4	1.6
Mean Total Moisture Deficit (in.)	1.5	0.0	1.1	0.0	0.4
Mean Cumulative AET (in.)	9.4	0.9	7.1	0.0	1.4
Mean Growing Season (days) (AET > 0)	136	13	86	0	37
Peak Snow Water Equivalent (in.)	14.0	14.0	0.5	11.8	3.2
Days with SWE > 0	228	79	6	90	53

Table F-8. RCP 4.5: Low Emissions Scenario for Buffalo Creek at northern boundary, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	40.0	38.3	59.2	22.1	39.9
Mean Max. Temperature (F)	51.7	50.5	73.9	31.0	51.0
Mean Min. Temperature (F)	28.3	26.2	44.5	13.3	28.9
Days Above 90 F	0.4	0.0	0.4	0.0	0.0
Days Above 80 F	24.0	0.2	22.9	0.0	0.9
Days Below Freezing	209	65	4	89	51
Avg. Total Precip (in.)	29.8	9.4	6.7	7.2	6.6
Avg. Days / Yr with Precipitation > 0.25 inch	32	11	6	7	7
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	164	49	38	42	35
Maximum 5 Day Precipitation (in.)	2.2	1.7	1.5	1.5	1.5
Mean Avg. Soil Water (in.)	4.8	5.4	4.1	5.3	4.2
Mean Min. Soil Water (in.)	2.5	5.0	2.7	5.0	2.8
Mean Runoff (in.)	23.5	19.0	1.5	1.5	1.6
Mean Total Moisture Deficit (in.)	2.4	0.0	1.8	0.0	0.6
Mean Cumulative AET (in.)	11.7	2.0	7.9	0.0	1.8
Mean Growing Season (days) (AET > 0)	163	27	90	0	46
Peak Snow Water Equivalent (in.)	11.9	11.6	0.1	10.5	2.5
Days with SWE > 0	181	58	0	90	33

Table F-9. RCP 4.5: Low Emissions Scenario for Buffalo Creek at northern boundary, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	41.6	39.8	60.7	23.6	41.6
Mean Max. Temperature (F)	53.2	51.8	75.5	32.2	52.8
Mean Min. Temperature (F)	29.9	27.8	45.8	15.1	30.4
Days Above 90 F	1.0	0.0	1.0	0.0	0.0
Days Above 80 F	33.5	0.4	30.8	0.0	2.3
Days Below Freezing	198	60	3	88	47
Avg. Total Precip (in.)	30.7	10.0	6.7	7.7	6.2
Avg. Days / Yr with Precipitation > 0.25 inch	34	13	7	8	7
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	165	50	38	44	34
Maximum 5 Day Precipitation (in.)	2.3	1.9	1.6	1.5	1.5
Mean Avg. Soil Water (in.)	4.7	5.4	4.0	5.3	3.9
Mean Min. Soil Water (in.)	2.4	4.9	2.6	5.0	2.6
Mean Runoff (in.)	24.1	18.6	1.4	2.7	1.5
Mean Total Moisture Deficit (in.)	2.9	0.1	2.1	0.0	0.8
Mean Cumulative AET (in.)	12.3	2.4	8.1	0.0	1.8
Mean Growing Season (days) (AET > 0)	172	32	90	0	50
Peak Snow Water Equivalent (in.)	10.8	10.3	0.1	9.8	2.2
Days with SWE > 0	171	51	0	89	30

Table F-10. RCP 8.5: Current Emissions Trajectory for Buffalo Creek at northern boundary, 1981–2010.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	35.9	34.3	54.7	18.4	35.8
Mean Max. Temperature (F)	47.5	46.3	69.0	27.8	46.5
Mean Min. Temperature (F)	24.2	22.2	40.4	9.0	25.0
Days Above 90 F	0.0	0.0	0.0	0.0	0.0
Days Above 80 F	4.7	0.0	4.6	0.0	0.0
Days Below Freezing	240	76	10	90	64
Avg. Total Precip (in.)	26.6	8.0	6.6	6.2	6.0
Avg. Days / Yr with Precipitation > 0.25 inch	27	9	6	5	6
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	154	44	38	39	33
Maximum 5 Day Precipitation (in.)	1.8	1.5	1.4	1.1	1.3
Mean Avg. Soil Water (in.)	4.9	5.4	4.5	5.2	4.5
Mean Min. Soil Water (in.)	3.2	5.0	3.3	4.9	3.4
Mean Runoff (in.)	24.4	20.1	2.3	0.4	1.6
Mean Total Moisture Deficit (in.)	1.5	0.0	1.1	0.0	0.4
Mean Cumulative AET (in.)	9.4	0.9	7.1	0.0	1.4
Mean Growing Season (days) (AET > 0)	136	13	86	0	37
Peak Snow Water Equivalent (in.)	14.0	14.0	0.5	11.8	3.2
Days with SWE > 0	228	79	6	90	53

Table F-11. RCP 8.5: Current Emissions Trajectory for Buffalo Creek at northern boundary, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	41.0	39.1	60.5	22.6	41.2
Mean Max. Temperature (F)	52.6	51.1	75.3	31.2	52.4
Mean Min. Temperature (F)	29.3	27.1	45.8	14.0	30.1
Days Above 90 F	1.5	0.0	1.5	0.0	0.0
Days Above 80 F	33.2	0.3	30.5	0.0	2.4
Days Below Freezing	202	63	3	89	48
Avg. Total Precip (in.)	30.4	9.6	6.8	7.5	6.6
Avg. Days / Yr with Precipitation > 0.25 inch	33	12	7	8	7
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	165	49	38	44	34
Maximum 5 Day Precipitation (in.)	2.3	1.7	1.6	1.5	1.6
Mean Avg. Soil Water (in.)	4.7	5.4	4.0	5.3	4.0
Mean Min. Soil Water (in.)	2.4	4.9	2.6	4.9	2.6
Mean Runoff (in.)	24.0	18.8	1.6	1.9	1.7
Mean Total Moisture Deficit (in.)	2.8	0.0	2.1	0.0	0.7
Mean Cumulative AET (in.)	12.1	2.2	8.1	0.0	1.8
Mean Growing Season (days) (AET > 0)	168	29	90	0	48
Peak Snow Water Equivalent (in.)	11.6	11.2	0.1	10.2	2.3
Days with SWE > 0	176	55	0	90	31

Table F-12. RCP 8.5: Current Emissions Trajectory for Buffalo Creek at northern boundary, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	46.0	43.5	66.0	27.8	46.2
Mean Max. Temperature (F)	57.7	55.6	81.0	35.9	57.5
Mean Min. Temperature (F)	34.4	31.4	50.9	19.8	34.9
Days Above 90 F	14.1	0.0	13.8	0.0	0.3
Days Above 80 F	65.8	2.0	55.2	0.0	8.5
Days Below Freezing	172	50	1	84	37
Avg. Total Precip (in.)	32.2	11.0	6.2	8.4	6.5
Avg. Days / Yr with Precipitation > 0.25 inch	37	14	6	9	7
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	165	51	35	45	34
Maximum 5 Day Precipitation (in.)	2.5	2.0	1.6	1.7	1.5
Mean Avg. Soil Water (in.)	4.5	5.4	3.6	5.4	3.6
Mean Min. Soil Water (in.)	1.8	4.9	2.0	5.0	2.1
Mean Runoff (in.)	24.2	14.6	1.0	7.0	1.6
Mean Total Moisture Deficit (in.)	4.4	0.1	3.2	0.0	1.1
Mean Cumulative AET (in.)	14.3	3.4	8.6	0.1	2.2
Mean Growing Season (days) (AET > 0)	199	46	92	3	58
Peak Snow Water Equivalent (in.)	7.4	5.5	0.0	7.1	1.6
Days with SWE > 0	138	33	0	83	22

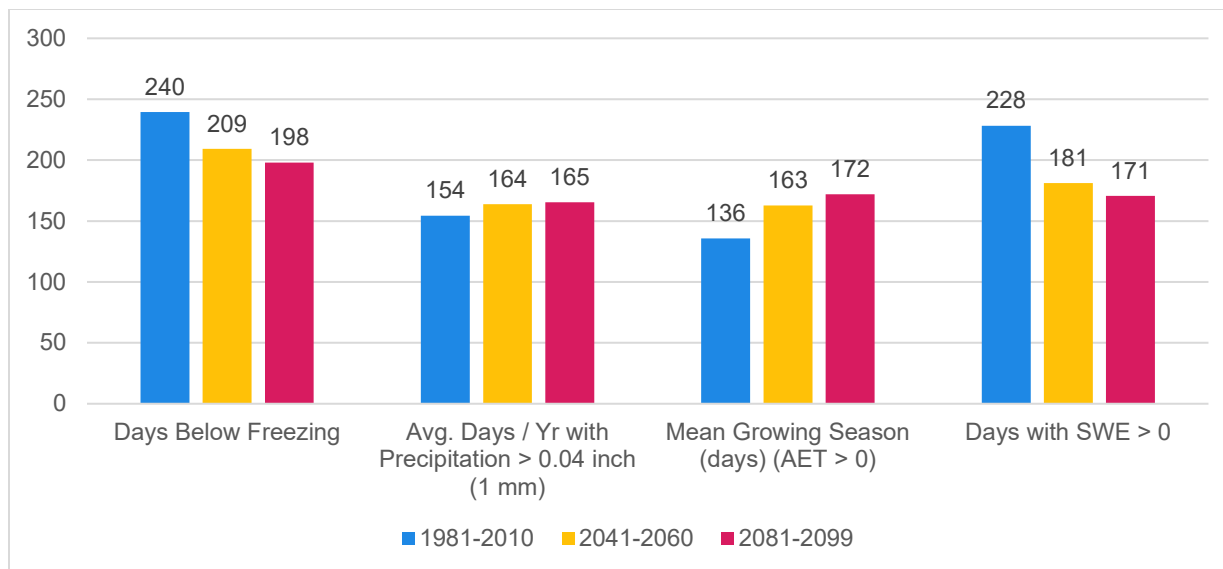


Figure F-7. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-7 through F-9 for Buffalo Creek at northern boundary.

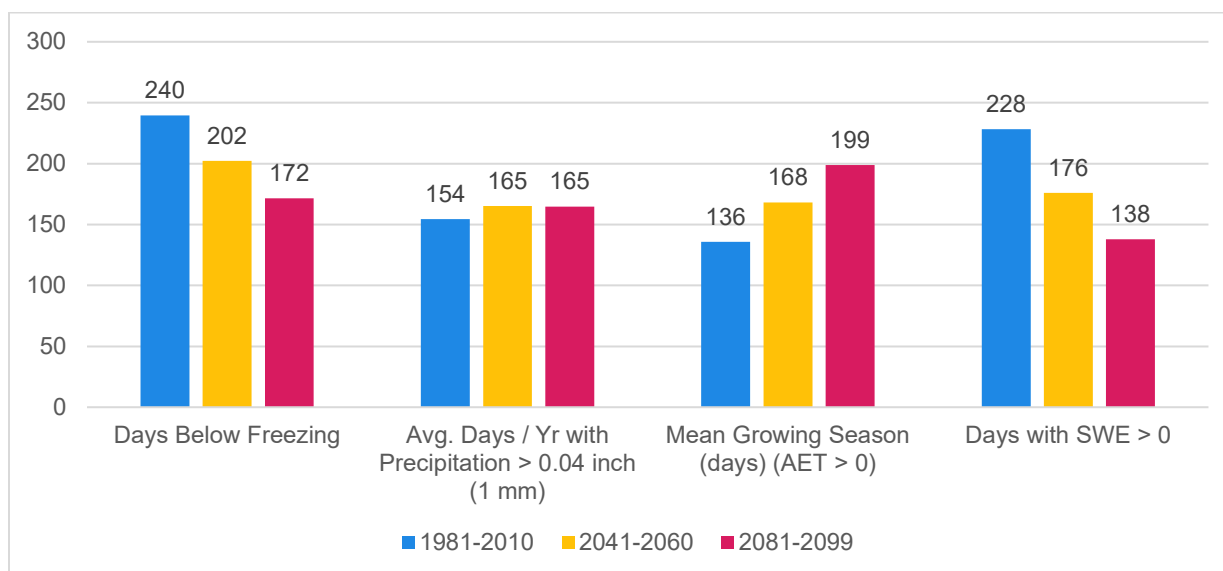


Figure F-8. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-10 through F-12 for Buffalo Creek at northern boundary.

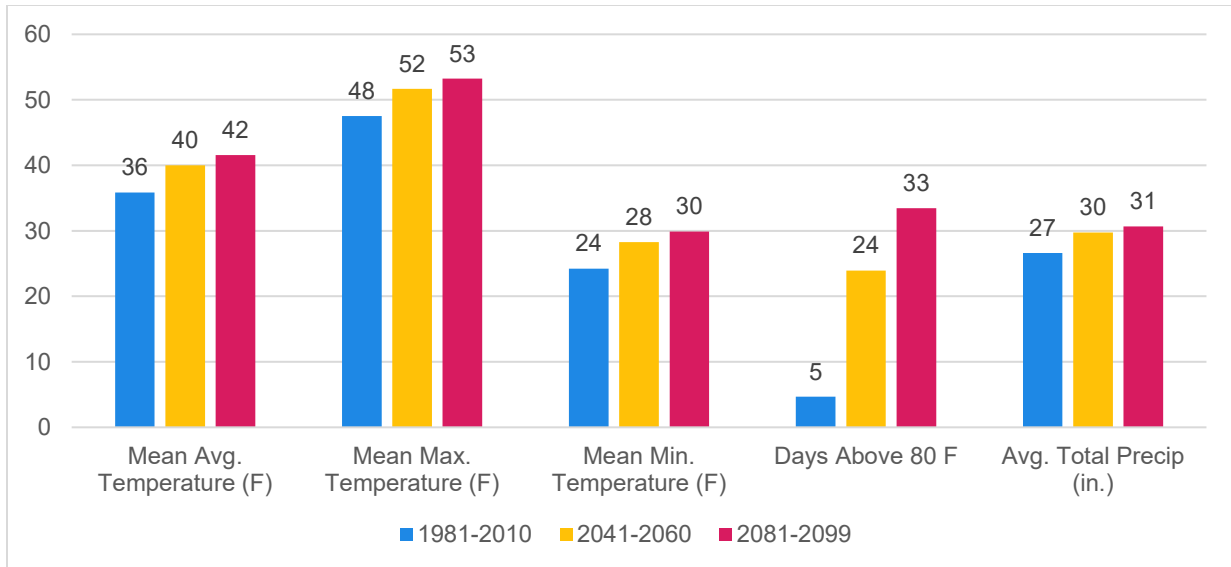


Figure F-9. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-7 through F-9 for Buffalo Creek at northern boundary.

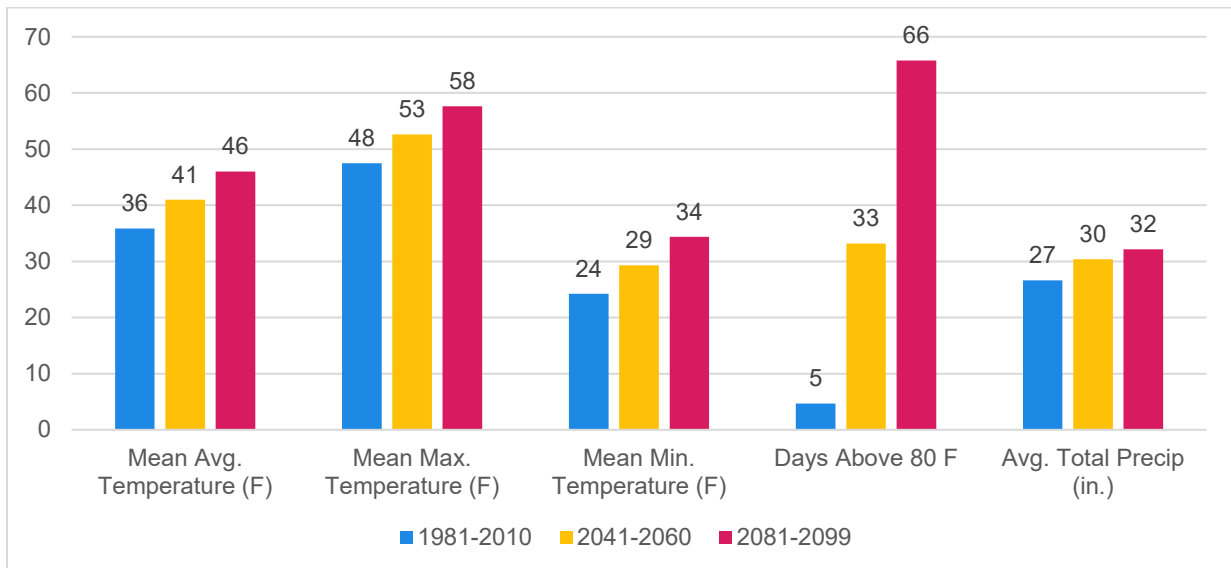


Figure F-10. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-10 through F-12 for Buffalo Creek at northern boundary.

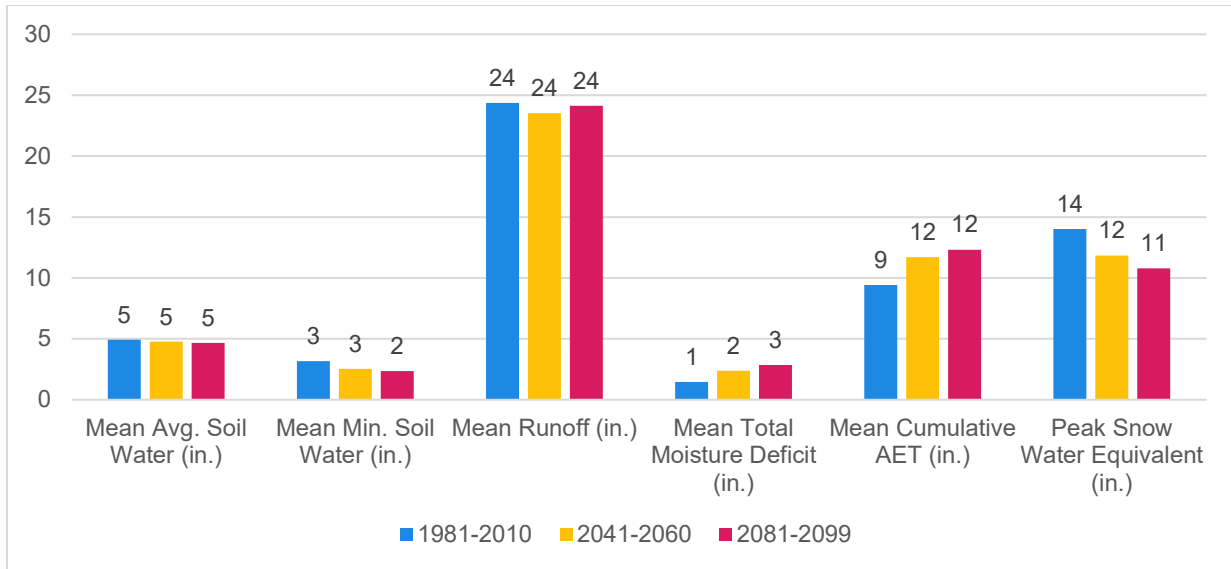


Figure F-11. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-7 through F-9 for Buffalo Creek at northern boundary.

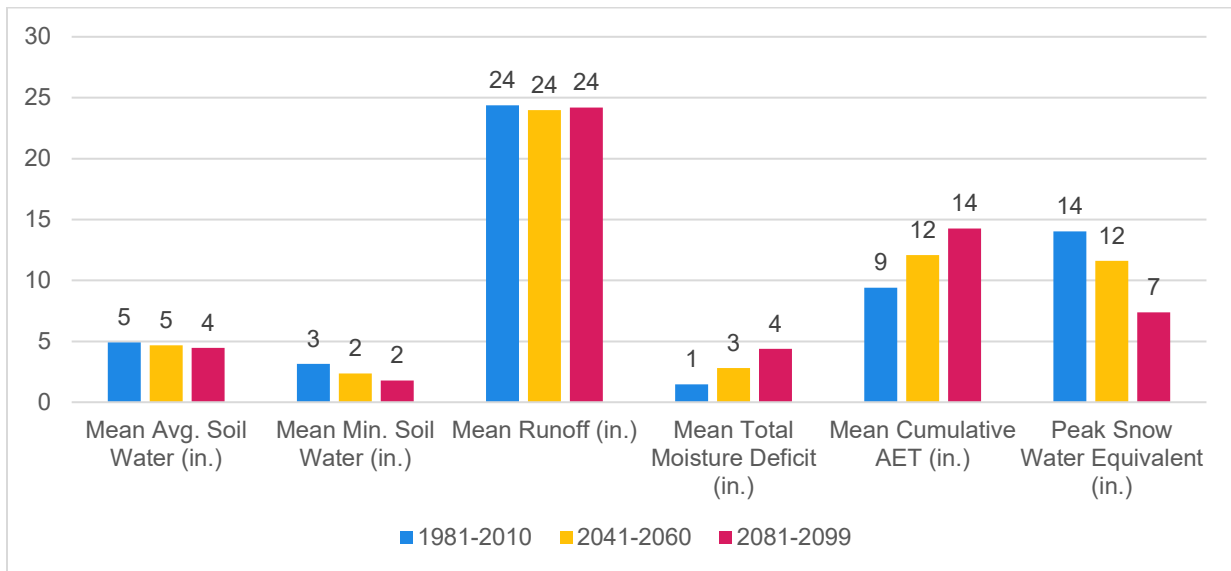


Figure F-12. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-10 through F-12 for Buffalo Creek at northern boundary.

Table F-13. RCP 4.5: Low Emissions Scenario for Swan Creek High Elevation, 1981–2010.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	35.3	33.5	53.4	18.8	35.1
Mean Max. Temperature (F)	46.9	45.6	67.8	28.1	45.7
Mean Min. Temperature (F)	23.7	21.5	39.1	9.5	24.5
Days Above 90 F	0.0	0.0	0.0	0.0	0.0
Days Above 80 F	3.9	0.0	3.9	0.0	0.0
Days Below Freezing	249	80	13	90	66
Avg. Total Precip (in.)	37.1	13.2	7.7	8.7	7.5
Avg. Days / Yr with Precipitation > 0.25 inch	46	18	8	11	9
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	164	49	39	42	34
Maximum 5 Day Precipitation (in.)	2.6	2.4	1.8	1.7	1.6
Mean Avg. Soil Water (in.)	4.7	5.0	4.4	4.9	4.6
Mean Min. Soil Water (in.)	3.3	4.8	3.4	4.9	3.6
Mean Runoff (in.)	35.6	24.7	7.4	0.3	3.3
Mean Total Moisture Deficit (in.)	0.9	0.0	0.7	0.0	0.2
Mean Cumulative AET (in.)	7.8	0.5	6.1	0.0	1.2
Mean Growing Season (days) (AET > 0)	120	7	80	0	33
Peak Snow Water Equivalent (in.)	18.0	18.0	3.0	12.8	3.8
Days with SWE > 0	244	85	12	90	57

Table F-14. RCP 4.5: Low Emissions Scenario for Swan Creek High Elevation, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	39.5	37.8	58.1	22.6	39.3
Mean Max. Temperature (F)	51.2	49.9	72.9	31.4	50.2
Mean Min. Temperature (F)	27.8	25.6	43.3	13.8	28.3
Days Above 90 F	0.2	0.0	0.2	0.0	0.0
Days Above 80 F	20.7	0.1	20.0	0.0	0.6
Days Below Freezing	218	69	6	90	54
Avg. Total Precip (in.)	41.7	15.6	8.0	9.8	8.4
Avg. Days / Yr with Precipitation > 0.25 inch	52	21	8	12	11
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	174	53	40	45	36
Maximum 5 Day Precipitation (in.)	3.3	2.9	2.1	2.0	1.9
Mean Avg. Soil Water (in.)	4.4	4.8	3.8	4.8	4.1
Mean Min. Soil Water (in.)	2.4	4.5	2.5	4.7	2.8
Mean Runoff (in.)	35.8	27.3	3.6	1.6	3.3
Mean Total Moisture Deficit (in.)	1.8	0.0	1.4	0.0	0.4
Mean Cumulative AET (in.)	10.6	1.4	7.5	0.0	1.7
Mean Growing Season (days) (AET > 0)	151	19	88	0	43
Peak Snow Water Equivalent (in.)	15.5	15.4	0.4	12.2	3.2
Days with SWE > 0	196	68	1	90	37

Table F-15. RCP 4.5: Low Emissions Scenario for Swan Creek High Elevation, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	41.1	39.2	59.5	24.1	41.0
Mean Max. Temperature (F)	52.7	51.2	74.4	32.5	52.1
Mean Min. Temperature (F)	29.5	27.3	44.6	15.6	29.9
Days Above 90 F	0.8	0.0	0.8	0.0	0.0
Days Above 80 F	29.3	0.3	27.3	0.0	1.8
Days Below Freezing	206	64	4	88	50
Avg. Total Precip (in.)	43.3	16.6	8.1	10.6	8.0
Avg. Days / Yr with Precipitation > 0.25 inch	54	22	9	14	10
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	174	54	39	46	35
Maximum 5 Day Precipitation (in.)	3.5	3.2	2.2	2.1	1.9
Mean Avg. Soil Water (in.)	4.3	4.8	3.7	4.8	4.0
Mean Min. Soil Water (in.)	2.3	4.4	2.4	4.7	2.6
Mean Runoff (in.)	36.9	27.5	3.4	2.7	3.2
Mean Total Moisture Deficit (in.)	2.2	0.0	1.6	0.0	0.5
Mean Cumulative AET (in.)	11.3	1.8	7.7	0.0	1.8
Mean Growing Season (days) (AET > 0)	160	24	89	0	46
Peak Snow Water Equivalent (in.)	14.1	13.7	0.2	11.6	2.8
Days with SWE > 0	186	62	1	89	34

Table F-16. RCP 8.5: Current Emissions Trajectory for Swan Creek High Elevation, 1981–2010.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	35.3	33.5	53.4	18.8	35.1
Mean Max. Temperature (F)	46.9	45.6	67.8	28.1	45.7
Mean Min. Temperature (F)	23.7	21.5	39.1	9.5	24.5
Days Above 90 F	0.0	0.0	0.0	0.0	0.0
Days Above 80 F	3.9	0.0	3.9	0.0	0.0
Days Below Freezing	249	80	13	90	66
Avg. Total Precip (in.)	37.1	13.2	7.7	8.7	7.5
Avg. Days / Yr with Precipitation > 0.25 inch	46	18	8	11	9
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	164	49	39	42	34
Maximum 5 Day Precipitation (in.)	2.6	2.4	1.8	1.7	1.6
Mean Avg. Soil Water (in.)	4.7	5.0	4.4	4.9	4.6
Mean Min. Soil Water (in.)	3.3	4.8	3.4	4.9	3.6
Mean Runoff (in.)	35.6	24.7	7.4	0.3	3.3
Mean Total Moisture Deficit (in.)	0.9	0.0	0.7	0.0	0.2
Mean Cumulative AET (in.)	7.8	0.5	6.1	0.0	1.2
Mean Growing Season (days) (AET > 0)	120	7	80	0	33
Peak Snow Water Equivalent (in.)	18.0	18.0	3.0	12.8	3.8
Days with SWE > 0	244	85	12	90	57

Table F-17. RCP 8.5: Current Emissions Trajectory for Swan Creek High Elevation, 2041–2060.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	40.5	38.5	59.4	23.0	40.6
Mean Max. Temperature (F)	52.1	50.4	74.3	31.5	51.7
Mean Min. Temperature (F)	28.9	26.6	44.6	14.5	29.6
Days Above 90 F	1.3	0.0	1.3	0.0	0.0
Days Above 80 F	29.6	0.2	27.4	0.0	2.0
Days Below Freezing	210	66	4	89	50
Avg. Total Precip (in.)	42.6	16.1	8.1	10.2	8.3
Avg. Days / Yr with Precipitation > 0.25 inch	53	22	8	13	10
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	173	53	39	46	35
Maximum 5 Day Precipitation (in.)	3.5	3.0	2.1	2.1	2.0
Mean Avg. Soil Water (in.)	4.3	4.8	3.7	4.7	3.9
Mean Min. Soil Water (in.)	2.3	4.4	2.4	4.6	2.6
Mean Runoff (in.)	36.3	27.6	3.6	1.9	3.3
Mean Total Moisture Deficit (in.)	2.1	0.0	1.6	0.0	0.5
Mean Cumulative AET (in.)	11.0	1.6	7.7	0.0	1.8
Mean Growing Season (days) (AET > 0)	157	22	89	0	46
Peak Snow Water Equivalent (in.)	15.3	15.0	0.2	12.1	2.9
Days with SWE > 0	190	65	1	90	34

Table F-18. RCP 8.5: Current Emissions Trajectory for Swan Creek High Elevation, 2081–2099.

Variable	Annual	Spring (MAM)	Summer (JJA)	Winter (DJF)	Fall (SON)
Mean Avg. Temperature (F)	45.6	42.9	64.9	28.3	45.6
Mean Max. Temperature (F)	57.2	54.9	80.0	36.3	56.8
Mean Min. Temperature (F)	34.0	30.9	49.8	20.4	34.5
Days Above 90 F	12.8	0.0	12.6	0.0	0.2
Days Above 80 F	59.9	1.7	50.9	0.0	7.2
Days Below Freezing	176	52	1	84	39
Avg. Total Precip (in.)	45.7	18.2	7.5	11.7	8.3
Avg. Days / Yr with Precipitation > 0.25 inch	57	24	8	15	10
Avg. Days / Yr with Precipitation > 0.04 inch (1 mm)	173	54	36	47	35
Maximum 5 Day Precipitation (in.)	3.8	3.5	2.1	2.4	2.0
Mean Avg. Soil Water (in.)	4.1	4.7	3.3	4.8	3.7
Mean Min. Soil Water (in.)	1.7	4.3	1.8	4.6	2.1
Mean Runoff (in.)	37.4	23.6	2.6	7.7	3.5
Mean Total Moisture Deficit (in.)	3.5	0.1	2.6	0.0	0.9
Mean Cumulative AET (in.)	13.4	2.9	8.3	0.1	2.2
Mean Growing Season (days) (AET > 0)	190	40	91	3	56
Peak Snow Water Equivalent (in.)	9.5	7.9	0.0	8.7	2.0
Days with SWE > 0	152	43	0	84	25

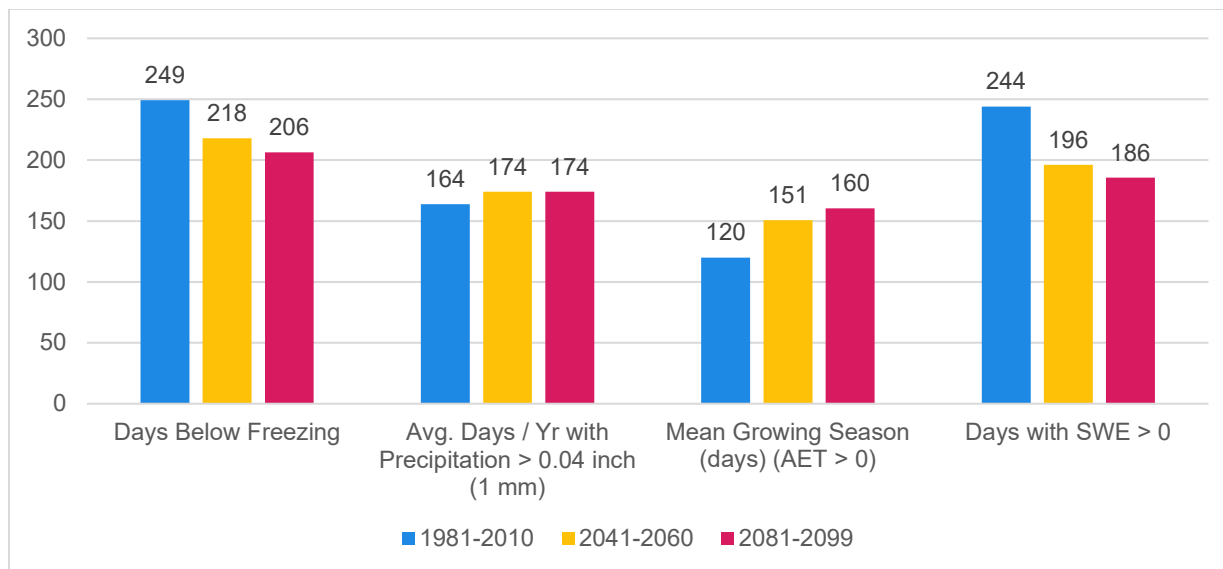


Figure F-13. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-13 through F-15 for Swan Creek High Elevation.

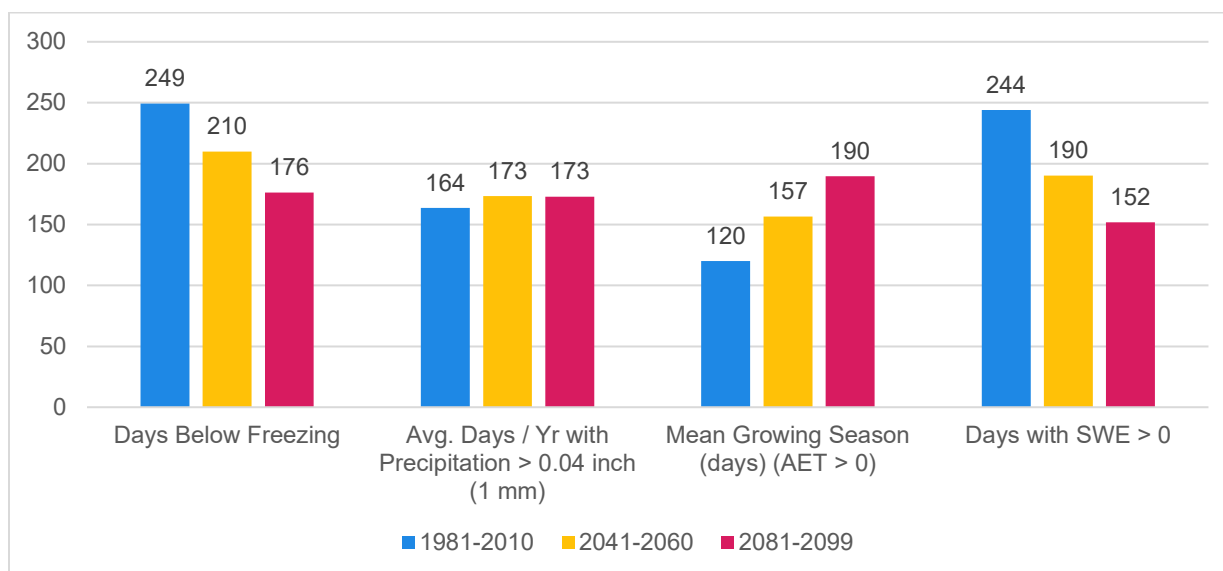


Figure F-14. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-16 through F-18 for Blacktail Lakes Swan Creek High Elevation.

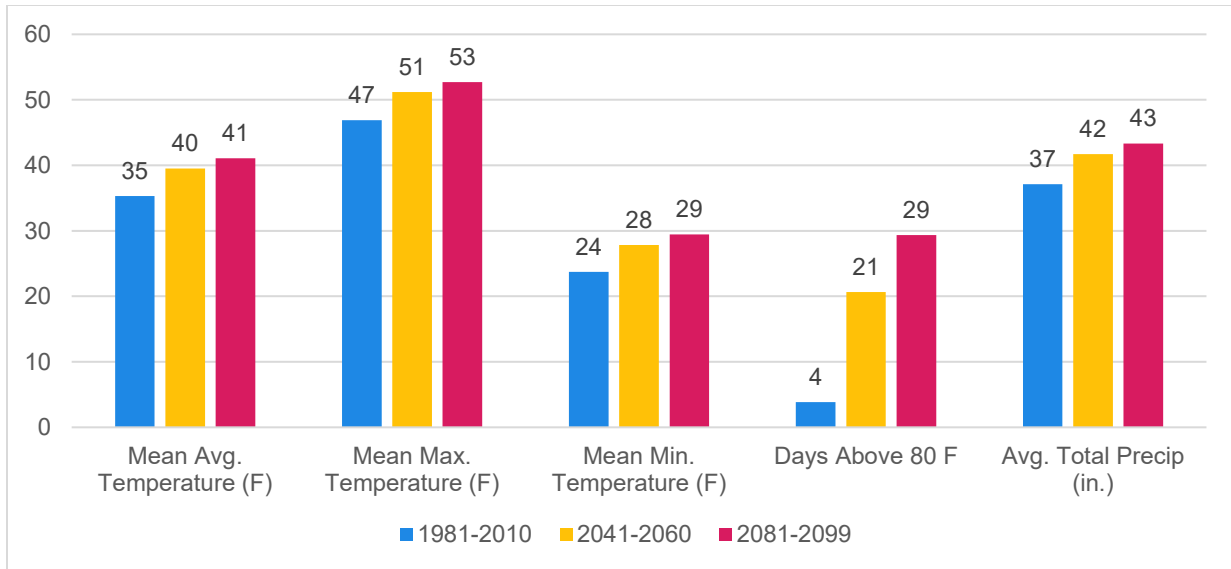


Figure F-15. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-13 through F-15 for Blacktail Lakes Swan Creek High Elevation.

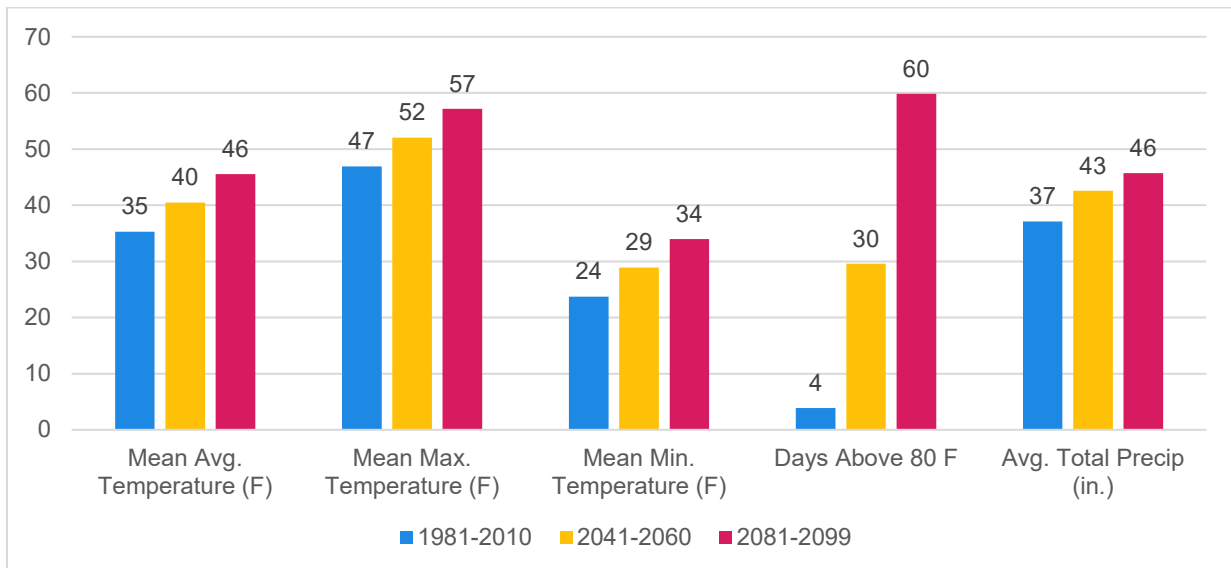


Figure F-16. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-16 through F-18 for Blacktail Lakes Swan Creek High Elevation.

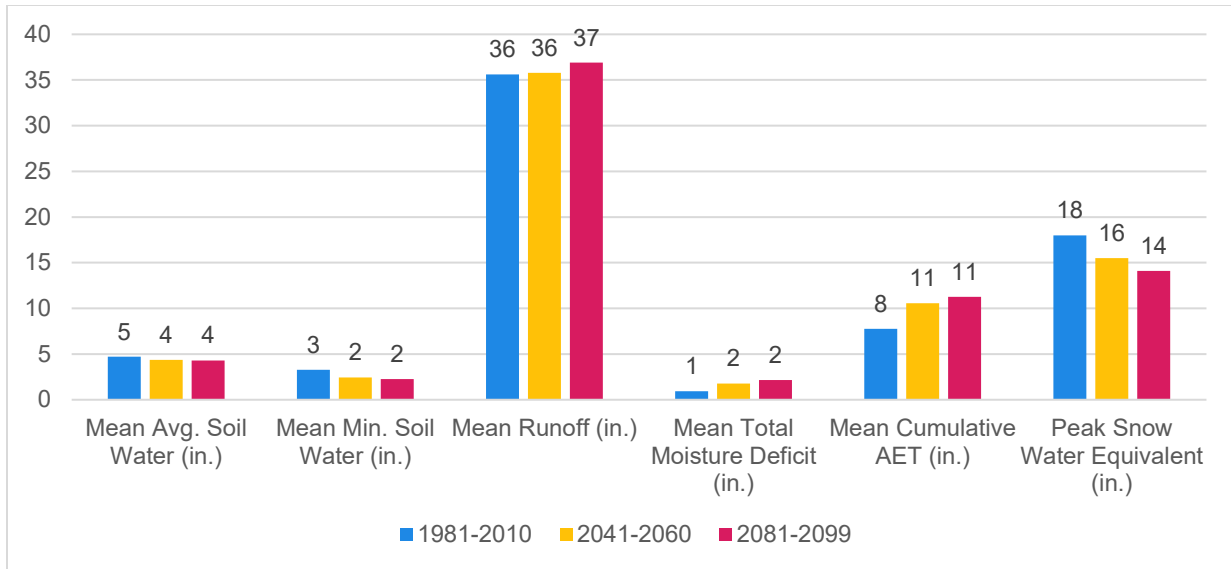


Figure F-17. A visual comparison of selected annual values for RCP 4.5 for each time period in tables F-13 through F-15 for Blacktail Lakes Swan Creek High Elevation.

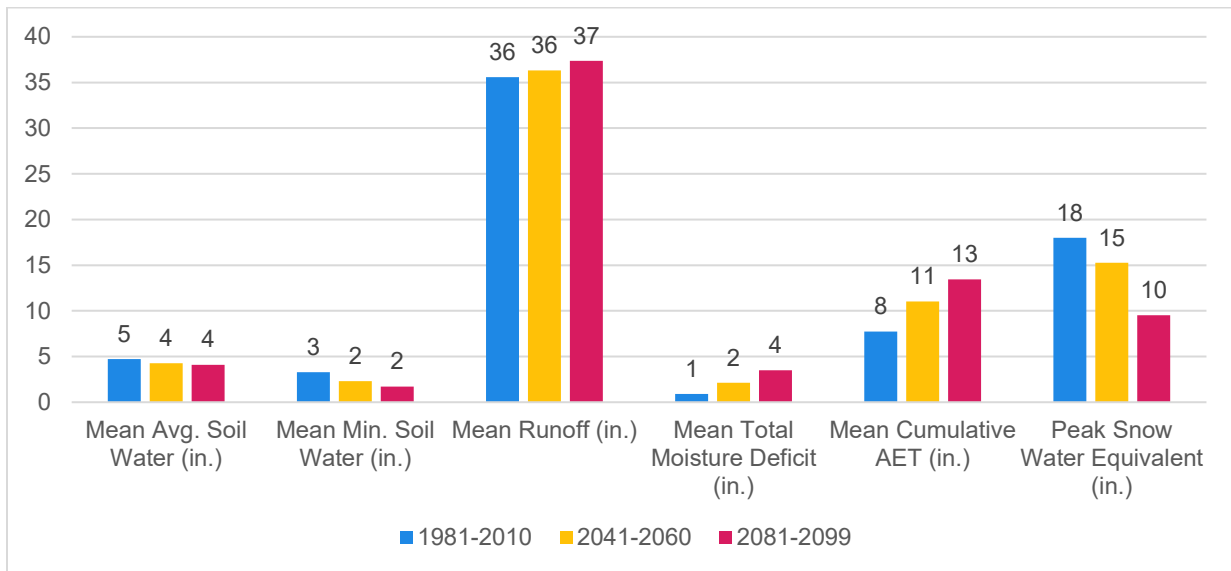


Figure F-18. A visual comparison of selected annual values for RCP 8.5 for each time period in tables F-16 through F-18 for Blacktail Lakes Swan Creek High Elevation.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 101/186557, November 2022

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

EXPERIENCE YOUR AMERICA™