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Natural Resource Stewardship and Science

Climate Change Scenario Planning for Resource Stewardship: Applying a Novel Approach in Devils Tower National Monument

Natural Resource Report NPS/NRSS/CCRP/NRR—2019/2052

ON THIS PAGE
Modern connections between American Indian culture and Devils Tower are maintained through personal and group ceremonies, including sweat lodges and sun dances. Over 20 tribes have cultural affiliation with the tower, which they refer to by a variety of names including Bear Lodge, Bear Lodge Butte, Grizzly Bear's Lodge, Bear's House, Bear's Tipi, Bear Peak, Bear's Lair, Grey Horn Butte, and Tree Rock. American Indian spiritual values are a fundamental Devils Tower NM value. NPS image.

ON THE COVER
Collage of images showing Devils Tower NM resources and workshop participants working together to examine plausible scenarios of climate change and resource impacts to help inform planning and management at the park. NPS image.

Climate Change Scenario Planning for Resource Stewardship: Applying a Novel Approach in Devils Tower National Monument

Natural Resource Report NPS/NRSS/CCRP/NRR—2019/2052

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Abstract

This report explains scenario planning as a climate change adaptation tool in general, then describes how it was applied to Devils Tower National Monument in the context of a first-of-its-kind pilot project to dovetail scenario planning with NPS Resource Stewardship Strategy development.

Park and regional National Park Service staff, other subject-matter experts, natural and cultural resource planners, and the climate change adaptation core team who led the project identified priority resource management topics and associated climate sensitivities in the orientation phase. Next, we used this information to create a set of four divergent climate futures—summaries of relevant climate data from individual climate projections—to encompass the range of ways climate could change in coming decades in the park. Participants in a scenario planning workshop then developed climate futures into robust climate-resource scenarios that included resource impacts and identified potential management responses. Finally, this scenario-based analysis was operationalized in the form of climate change-informed resource stewardship goals and activities selected and adopted by park staff for the park's Resource Stewardship Strategy. This process of engaging resource managers in climate change scenario planning ensures that their management and planning decisions are informed by assessments of critical future climate uncertainties.

Acknowledgments

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Introduction

Ongoing anthropogenic climate change is evident across the National Park System. Mean temperatures in most parks, for example, are already extreme compared to the recent historical record (1901–2012; Monahan and Fisichelli 2014). Climate change is causing widespread physical changes in the environment that reflect the diversity of parks. These changes include loss of sea ice, glaciers, and permafrost; declining snowpack; sea-level rise and warming oceans; earlier snowmelt and changes in streamflow; declining soil moisture; stronger droughts; and flooding (e.g., Stewart et al. 2005, Wang et al. 2014, Mallakpour and Villarini 2015, O'Neel et al. 2015, Lara et al. 2016, Hayhoe et al. 2018, Markon et al. 2018). Such physical changes directly impact organisms, resources, assets, and values, and they also generate powerful indirect effects by driving ecological changes such as widespread tree mortality and recruitment failures, more frequent and severe wildfires, species extirpation and range shifts, vegetation community change and ecosystem transformation, phenological shifts and mismatches, and pest outbreaks and range expansions (e.g., Westerling et al. 2011; 2016, McKinnon et al. 2012, Dolanc et al. 2013, Allen et al. 2015, Anderegg et al. 2015, Pecl et al. 2017, Socolar et al. 2017, Freeman et al. 2018, Maxwell et al. 2018, Nolan et al. 2018, Davis et al. 2019). Despite these observed and potential changes, many consider anticipatory management for climate change daunting because projections of climate change and its impacts are imprecise. Forward-looking resource stewardship in an era of continuous change, therefore, requires effective approaches for understanding and working with consequential and irreducible uncertainty.

This challenge has increased awareness of uncontrollable (i.e., irreducible) uncertainty's influence in decision-making (Peterson et al. 2003, Rowland et al. 2014). However, such uncertainties are inherent to planning around complex environmental issues (Gregory et al. 2012) and are addressed by resource managers in a variety of ways. Scenario planning is a structured approach to work with consequential uncertainties and is increasingly used by resource managers (Rowland et al. 2014, Star et al. 2016). Scenario planning is a flexible tool that is useful for understanding potential climate change implications and uncertainties in a way that is relevant to resource and landscape management (IPBES 2016). Scenario planning facilitates decision making by providing a structured process for building and thinking about a range of possible futures that managers may face, in order to consider not just what is thought to be most likely, but instead the full range of what is plausible, relevant, and highly consequential (Figure 1, NPS 2013a). A scenario-based process encourages long-term science-management partnerships by providing a setting to consider the breadth of uncertainty around climate change vulnerabilities and their interactions with other stressors, and an opportunity to explore a range of innovative responses. Using scenarios as part of planning can offer benefits in the form of (1) increased understanding of key uncertainties facing resource management and operations, (2) incorporation of alternative perspectives into resource management planning, and (3) improved capacity for adaptive management to achieve desired conditions.

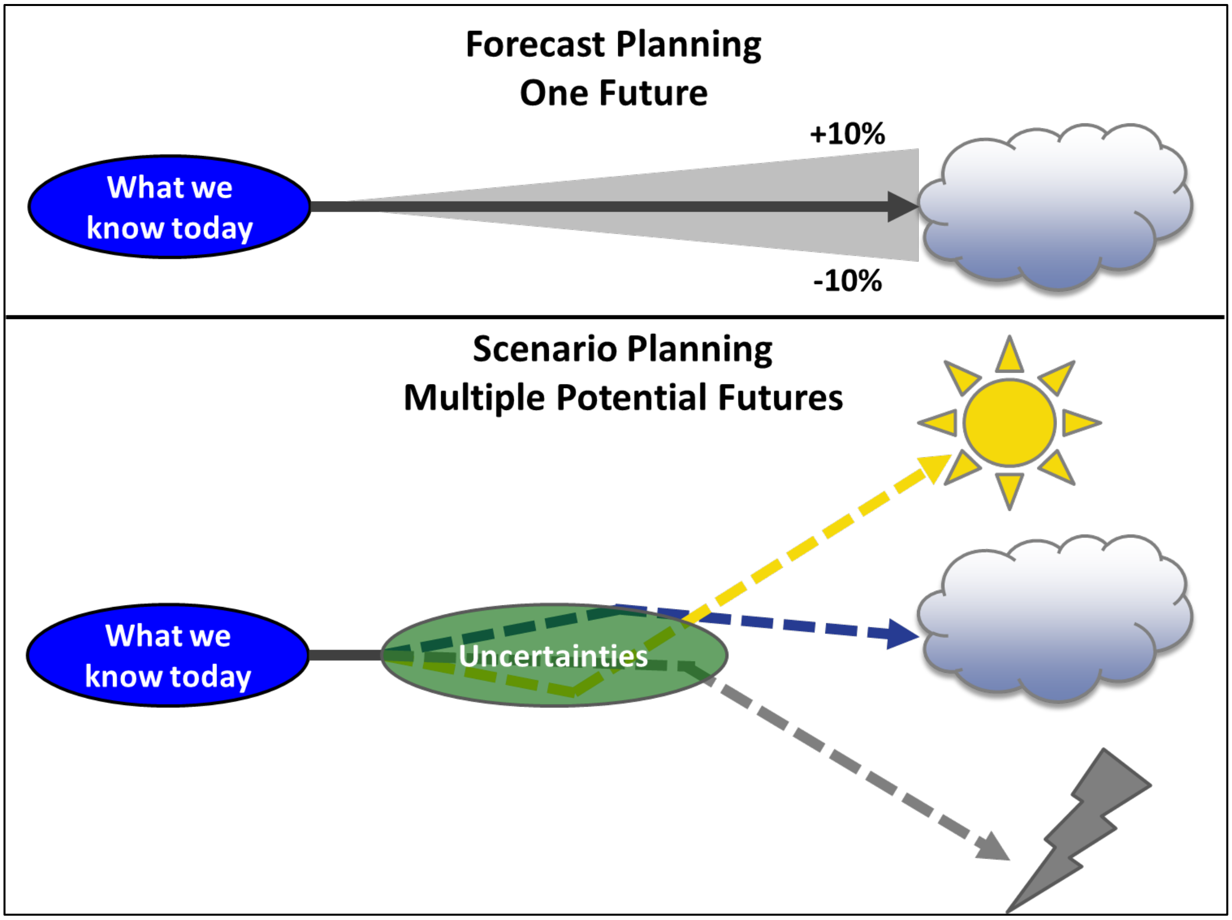

Figure 1. Forecast-based approaches to planning (top panel) use predictions of a single future within a (typically relatively narrow) range of probability (gray shading). Scenarios (bottom panel) characterize a (typically wide) range of distinct future conditions that are all plausible (dashed lines) and provide a framework to support decision making under conditions that are uncertain and uncontrollable. Graphics adapted from Global Business Network (GBN).

A crucial part of climate change scenario planning is assessing and understanding relevant climate uncertainties. Climate scientists use complex models to project trends in climate variables into the future. Because our understanding of Earth's climate is incomplete, each of these models is unique in the way it represents the various physical and biological forces that influence climate patterns. Consequently, each global climate model (GCM) produces a different—and plausible—view of future climate. Moreover, the magnitude of climate changes also depends on societal decisions that affect the emissions of gasses that influence climate—principally carbon dioxide and methane. Projections have thus been developed for multiple greenhouse gas emissions pathways, known as representative concentration pathways (RCPs), for each GCM.

Although this range of projected futures provides resource managers a realistic representation of the uncertainties about future climate, the volume of information can be daunting for managers trying to incorporate climate change into their planning. Science and adaptation partners can help managers winnow down plausible climate futures by (1) determining which aspects of climate strongly shape focal resources and how to quantify those aspects in distinct climate metrics, (2) evaluating uncertainty in these metrics from their ranges represented in climate projections, and (3) synthesizing coherent climate summaries that cover the range of plausible futures for the key climate metrics at the relevant spatial scale.

> ***“Scenarios are stories about the ways that the world might turn out tomorrow...that can help us recognize and adapt to changing aspects of our current environment.”***
>
> \- Peter Schwartz, *The Art of the Long View*

Climate projections are made relevant to management by comparing them to historical climate trends and weather events, then determining the consequences of plausible future climates for resources in the context of other stressors. The National Park Service (NPS) and partners have developed and refined a climate change scenario planning approach focused on expert opinion and synthesis of pre-existing science (NPS 2013a, Fisichelli et al. 2016a, Star et al. 2016), and we used it in this case to develop a set of plausible climate-resource scenarios for Devils Tower National Monument (NM). These scenarios were then used to inform the park’s subsequent Resource Stewardship Strategy[1] (RSS; NPS 2019a) development process, as part of a pilot effort to incorporate a full set of detailed climate-resource scenarios into an RSS. This report focuses on documenting the scenario development part of the overall process, and it will complement RSS supplemental guidance (NPS 2019b) that draws on this pilot to describe how to incorporate scenario planning outcomes into an RSS.

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[1] A Resource Stewardship Strategy is a long-range planning tool for a National Park Service unit to achieve its desired natural and cultural resource conditions.

Overview of project timeline and process

Climate-resource scenario development for Devils Tower NM was a process (fall 2017–spring 2018; Figure 2) of iterative engagement among climate change adaptation core team members and Devils Tower NM Chief of Resource Management Rene Ohms (i.e., authors of this report), park and regional staff, a climatologist, natural and cultural resource planners, and other subject-matter experts. The process began with an orientation phase, the key elements of which were introducing team members to each other and to the park resources and context, and preliminarily identifying climate-sensitive park resources. Next, in a roughly seven-week phase that overlapped with and extended beyond the later stages of orientation, we characterized the park's past and current climate and the climate sensitivity of each identified resource by examining existing research and consulting park staff and other subject-matter experts.

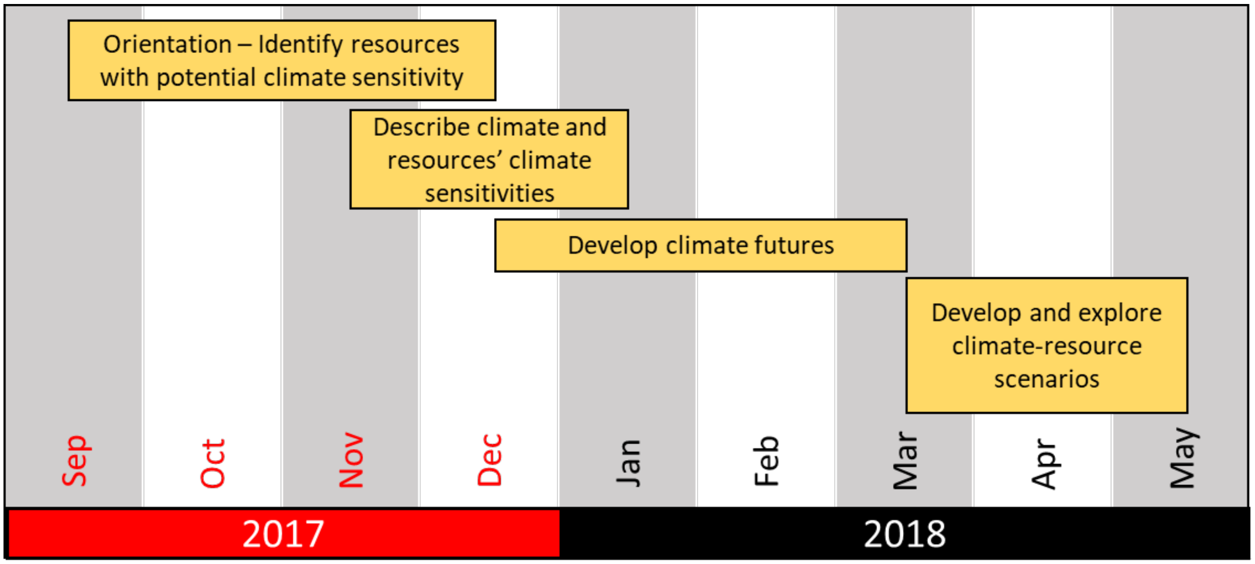

Figure 2. Devils Tower NM scenario development timeline.

Precise characterization of resources' climate sensitivities led into the third phase of the process (mid-Dec 2017–early March 2018)—developing climate futures. A climate future is a summary of output from a single projection (i.e., a single GCM run for a given RCP) and is therefore temporally and physically coherent and plausible. The climate futures focus on climate metrics that are relevant to park resources and to which people can easily relate. Developing the climate futures entailed first determining the appropriate climate metric to match each resource's specific climate sensitivity based on scientific literature and expert (including park staff) input, then using this information to select four climate futures that were sufficiently divergent to encompass the range of ways climate could change in coming decades in the park.

In the final phase, we fleshed out climate futures into robust climate-resource scenarios that described resource implications (often referred to as vulnerabilities[2]) under each climate future. Participants (Appendix 1) in a climate change scenario planning workshop on March 29, 2018 and an RSS workshop on May 1–2, 2018 (both in Hulett, Wyoming) completed this phase together, and follow-up conversations with specific participants clarified some workshop contributions. The scenario planning workshop included presentations on key scientific topics and management issues to provide context and information to characterize conditions at Devils Tower NM and the climate change implications for park resources:

- Brian Miller (U.S. Geological Survey and North Central Climate Adaptation Science Center) described current and historical climate;
- John Valainis (NPS Intermountain Region; remote participant) and Rene Ohms (Devils Tower NM) described cultural resources;
- Amy Symstad (U.S. Geological Survey Northern Prairie Wildlife Research Center) described vegetation and fire;
- Amy Hammesfahr (Devils Tower NM) described wildlife; and
- Sharla Stevenson (NPS Intermountain and Midwest Regions) described hydrological features.

The climate-resource scenarios developed through this process may be used for many forms of climate change adaptation, but a specific goal of this project was to have the scenarios inform resource stewardship goals and activities for the Devils Tower NM RSS. Therefore, this report concludes with a description of how participants operationalized scenario planning insights in the RSS context.

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[2] Potential resource responses to projected climate conditions are generally described as "vulnerabilities" (e.g., Dawson et al. 2011). However, the resource response could in some cases be positive from the perspective of management goals. For this reason and for consistency with RSS terminology, we refer to these potential responses with the neutral "implications."

Orientation

The orientation phase began with an initial small-group visit to the park in late September 2017, followed by a large-group call in mid-November, a review of Devils Tower NM's Foundation Document (NPS 2014) and Natural Resource Condition Assessment (Komp et al. 2011), and further smaller-group discussions regarding specific resources. During this phase, the climate change adaptation core team introduced the project to key park staff and regional partners and described how it serves as a pilot for incorporating more robust climate change scenario planning into the RSS development process. In addition, core team members, RSS experts, and key park staff and regional partners listed and described all park cultural and natural resources with potential climate sensitivities (Table 1). They then identified and explored additional information sources for these sensitivities (see Appendix 2 for methods used to characterize cultural resource climate sensitivities).

Table 1. Devils Tower NM resources, stressors, management activities, and management concerns identified as important and climate-sensitive in the orientation phase.

Category	Details
Ethnographic resources	• Tower (geologic formation) • Ethnographic landscape • Ethnobotanical species
Historic built structures	• Civilian Conservation Corps (CCC)-era structures • Mission 66 structures • 1893 wooden stake ladder on the tower
Archeological resources	• Lithic scatters • Prehistoric rock art (pictographs) • Historical graffiti • Historical sites • Historical trails
Native vegetation	• Mixed-grass prairie • Ponderosa pine forest and woodland • Deciduous trees including bur oak and green ash • Riparian terrace including cottonwood trees • Prairie dog town
Wildlife	• Prairie dogs • Ungulates (white-tailed and mule deer) • Fishes • Bats • Peregrine falcons
Aquatic resources	• Springs and wetlands • Belle Fourche River

Table 1 (continued). Devils Tower NM resources, stressors, management activities, and management concerns identified as important and climate-sensitive in the orientation phase.

Category	Details
Stressors	• Mold and pests affecting building integrity • Non-native plants • Insect pests of trees • Visitation
Management activities	• Ability to implement prescribed fire
Other management concerns	• Staff and visitor well-being

Devils Tower NM natural and cultural resources, climate, and climate sensitivities

Devils Tower NM is in northeast Wyoming (Figure 3). The central feature of the park—and the reason for its existence—is the igneous monolith (tower) rising above the surrounding hills and plains (Figure 4). Native peoples consider the feature sacred and have lived and held ceremonies beside it for thousands of years. Consequently, the whole park is treated as an ethnographic landscape. Specific cultural resources at Devils Tower NM include: the tower itself (a Traditional Cultural Property; Parker and King 1990), ethnographic resources such as ceremonial sites (Inside cover image), archeological resources including lithic scatters, and historic buildings representing different eras of NPS architecture. Challenges to these cultural resources include high visitation, the popularity of the tower as a rock-climbing destination, and erosion.

This ethnographic landscape includes a complex of ponderosa pine (*Pinus ponderosa*) forest and woodland, some with a bur oak (*Quercus macrocarpa*) understory, and meadows flanking the hillsides descending from the base of the tower, as well as a riparian terrace of grasses and deciduous trees and shrubs along the Belle Fourche River (Figure 3). Historical wildfires and modern prescribed fires strongly influence the distribution and structure of the upland vegetation features, and the Keyhole Reservoir upstream from the park has, since 1952, largely eliminated flooding that historically would have maintained a dynamic riparian zone. Plants and animals represent a mix of species associated with both eastern and western North America. The Belle Fourche River bounds the southeastern portion of the park, and a variety of springs and associated wetlands provide park wildlife water and unique habitat. Challenges in managing the vegetation and wildlife in this relatively small (1,347-acre) park include invasive plant species, browse pressure on deciduous species, a fence that inhibits movement of large wildlife, and wildlife disease.

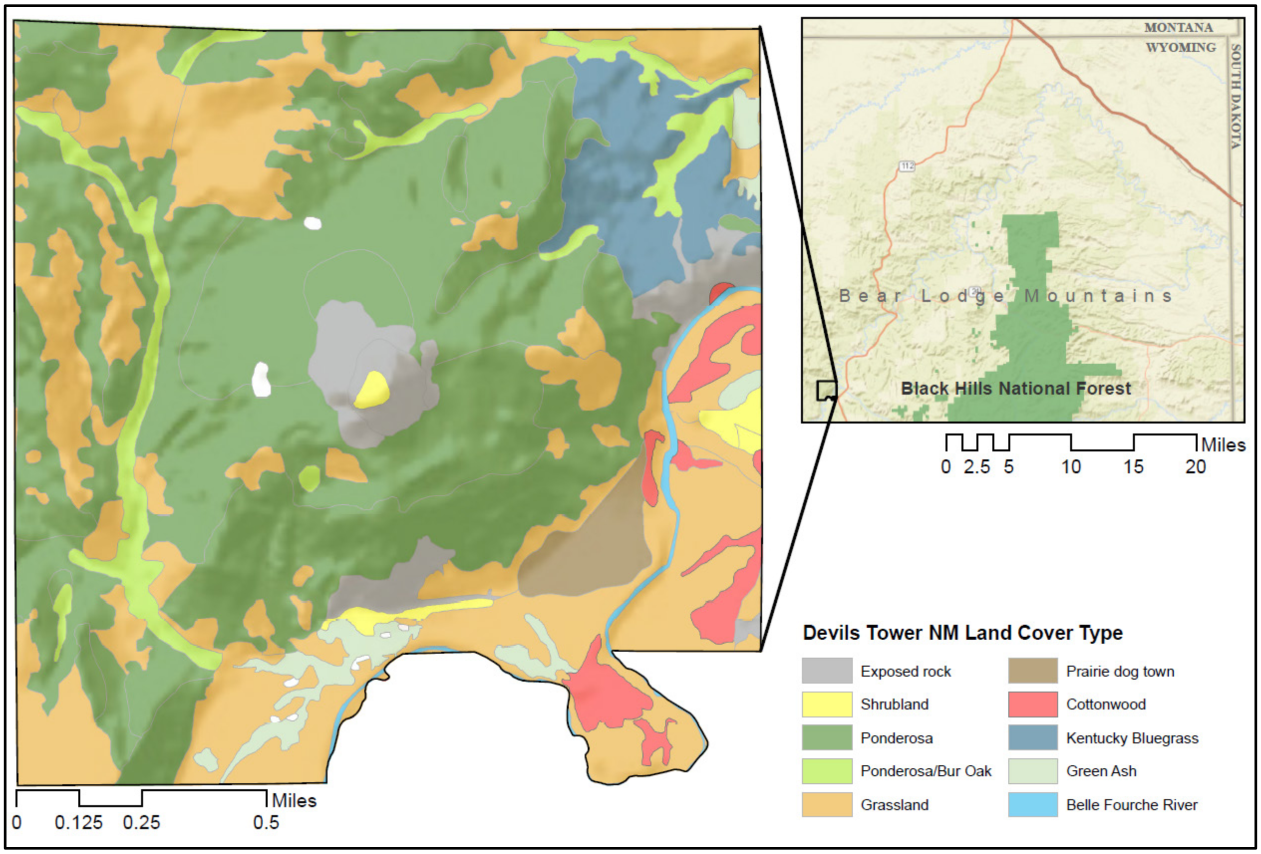

Figure 3. Location of Devils Tower National Monument in northeastern Wyoming and a map of the park (inset) showing natural land cover types (white shapes are developed areas). Map by Hannah Vincelette. Data sources: Salas and Pucherelli 1998; USFS boundaries.

Figure 4. Devils Tower. NPS image.

Current and historical climate

Devils Tower NM experiences a mid-latitude, continental climate, with warm summers and cold winters. Climate is generally semi-arid with a spring-early summer precipitation peak and strong diurnal and seasonal temperature variability (Figure 5). Interannual variation in precipitation is high (Figure 5).

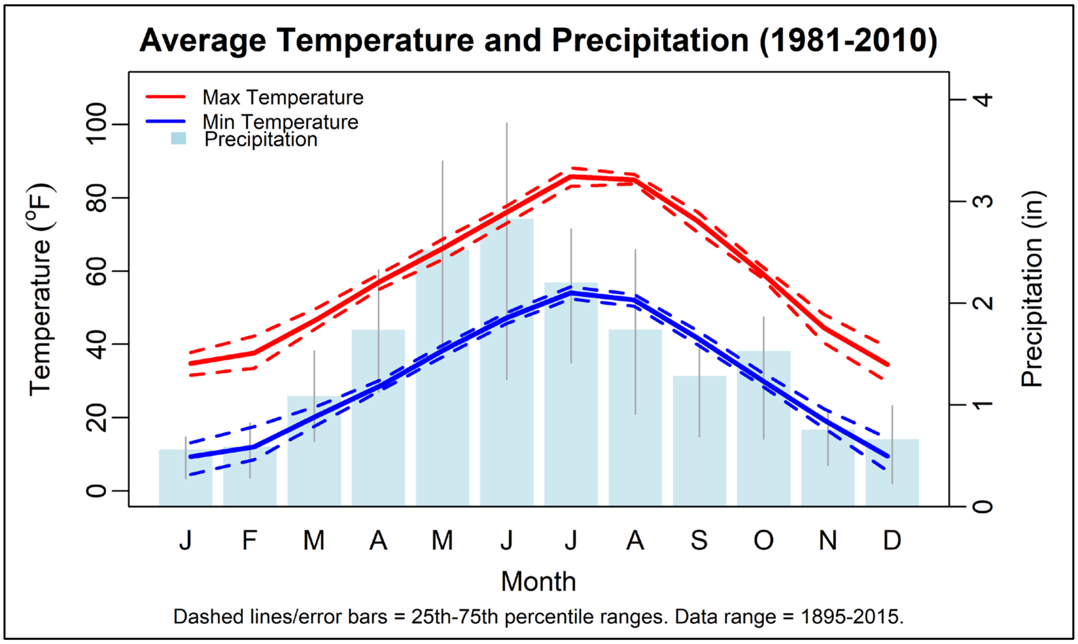

Figure 5. Historical (1895-2015) average monthly minimum (blue line) and maximum (red line) temperature and precipitation (blue bars) for Devils Tower NM. Data from the PRISM historical gridded dataset (http://prism.oregonstate.edu/).

Based on historical (1895–2015) gridded data for the park from the PRISM (Parameter-elevation Relationships on Independent Slopes Model; from PRISM Climate Group) dataset (http://prism.oregonstate.edu/), average annual temperature ranged from 41 to 49 °F, with a mean of 44 °F, and annual precipitation varied from about 10 to 29 inches, with a mean of 17 inches (Figure 6). Annual mean maximum temperature rose significantly (probability value [p]=0.009) from 1895 to 2015; the regression slope shows an increase of +1.3 °F/100 years[3]. Annual mean minimum temperature showed no trend (p=0.674) from1895 to 2015, but it did rise from 1970 to 2015 (+6.7 °F/100 years; p<0.001). Together, these patterns resulted in a weaker trend for increasing annual mean temperature for the full historical period (+0.7 °F/100 years; p=0.079) and no trend from 1970

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[3] We used standard linear regressions (using the R base package) to evaluate trends, and an alpha value of 0.05 as the criterion for statistical significance throughout the report.

to 2015 p=0.137). Annual precipitation showed no trend, either for the full or more recent historical period (p=0.118 and 0.164, respectively).

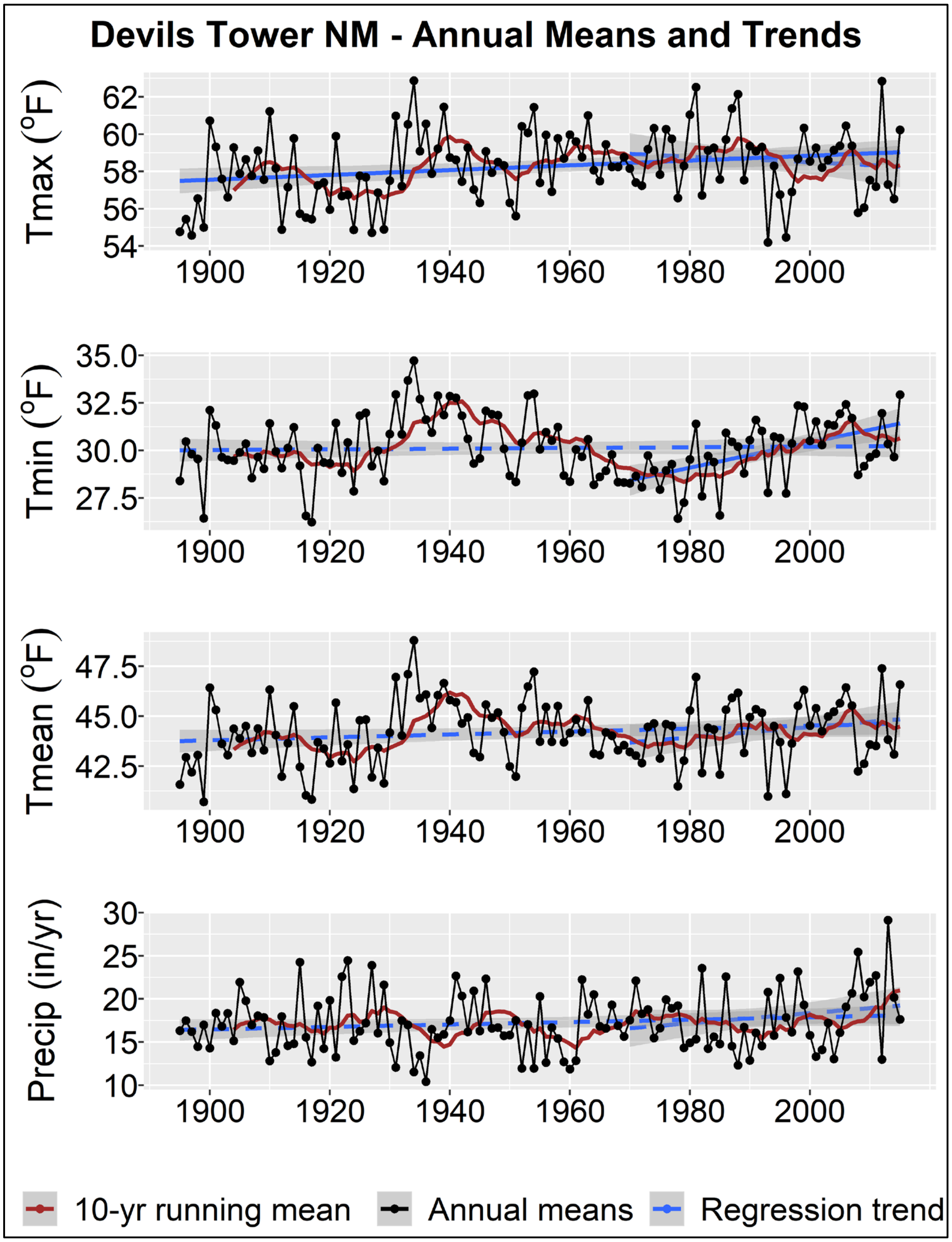

Figure 6. Historical annual temperature (top 3 panels) and precipitation (lower panel) from 1895–2015. Black points and lines show annual values, and red lines are 10-year running averages. Each graph includes two blue linear regression lines—one for the entire period and another for 1971–2015. Solid regression lines indicate changes that are statistically significant (i.e., p<0.05), and non-significant lines are dashed. Gray-shaded areas around the regression lines represent standard error of predicted y values. Data from the PRISM historical gridded dataset (http://prism.oregonstate.edu/).

Temperature trends for Devils Tower NM are consistent with those observed for the state of Wyoming, where mean annual temperature has increased 1.4 °F since the early 20th century (Frankson et al. 2017). Since 1995, winter and summer temperatures in Wyoming averaged 1.9 °F and 1.2 °F, respectively, above the 1895–2009 average (Frankson et al. 2017). Since 2000, the state has seen a below-average number of very cold days (days with maximum temperatures <0 °F), and an above-average number of very hot days (days with max temp >95 °F) compared to 1950–2014 (Frankson et al. 2017). The frost-free season (defined as the period between the last occurrence of 32 °F in the spring and the first occurrence of 32 °F in the fall) has also lengthened; the Great Plains experienced an increase of 10 frost-free days during 1991–2012 relative to 1901–1960 (Walsh et al. 2014).

Resource climate sensitivities

Assessment of climate sensitivities often generates a long list of susceptible resources, and Devils Tower NM was no exception (see Table 1). Therefore, it is often important to dig deeper and identify a subset that "pose the greatest risk for achieving one's agreed-upon conservation goals and objectives" (Stein et al. 2014). For Devils Tower NM, we used an iterative process in which climate change adaptation core team members, park and regional NPS staff, a climatologist, natural and cultural resource planners, and other subject-matter experts worked together to characterize the climate sensitivity of each of the park's natural and cultural resources and identify such a subset (Table 2, left column). The greatest management-related climate concerns fell into four major categories. Extreme precipitation events were a concern because of their erosion-related effects on archeological, paleontological, and cultural resources, including built structures. Drought—specifically summertime drought—was also a concern due to its effects on plant community composition and production, and carry-on effects on wildlife. Freeze-thaw cycling was identified as a substantial influence on archeological sites, built structures, and possibly the tower through its potential for physical movement and fracturing of any of these resources. Finally, high temperatures in the hottest time of the year were a focus because of their potential impacts on the tower itself (Collins and Stock [2016] suggest high temperatures may cause separation of rocks from the tower face, a phenomenon known as exfoliation or spalling), as well as on human well-being. We used this subset of most critical, park-identified climate sensitivities to identify a small set of key climate metrics (see Table 2) around which to construct a set of relevant and divergent climate futures for the park.

Table 2. Key Devils Tower NM resource sensitivities related to climate, and associated climate metrics. These climate metrics were used to select specific climate projections to develop climate futures and ultimately climate-resource scenarios.

Climate-related resource sensitivities	Climate metrics
Erosion impacts on *in situ* archeological resources and historic built structures	Frequency of extreme precipitation events (>1 inch in a day)
Drought impacts on vegetation, hydrology, and wildlife, and wildfire-driven vegetation transformation	Mean monthly summer water deficit (see Appendix 3 for details)
Exposure of archeological sites, fracturing of historic built structures, and rock exfoliation from the tower	Number of freeze-thaw cycles per year (see Appendix 4 for details)
Rock exfoliation from the tower, and impacts on staff and visitor well-being	Frequency of maximum daily temperatures above historical 99th percentile (~96 °F)

Devils Tower NM climate futures

Average future climate projections for the Northern Great Plains indicate continued warming, an increase in the frequency of drought and heat waves, and increases in winter and spring precipitation (Conant et al. 2018). However, projections specific to Devils Tower NM vary among individual models. To explore this variation and to develop climate futures specifically for the park, we used climate output from the World Climate Research Programme's CMIP5 (Coupled Model Intercomparison Project phase 5) multi-model dataset (Taylor et al. 2012), statistically downscaled using the MACA (Multivariate Adaptive Constructed Analogs) method (Abatzoglou and Brown 2012). Data for the Devils Tower NM area were downloaded from the Northwest Knowledge Network (University of Idaho, https://climate.northwestknowledge.net/MACA/). We considered two simulations each of 18 downscaled CMIP5 GCMs; one simulation used a moderate (RCP 4.5) and the other a business-as-usual, high greenhouse gas emissions pathway (RCP 8.5). Our exploration of the projections focused on comparisons of means calculated from future (2025–2055) and historical (1950–1999) periods for each metric (Abatzoglou 2011); see Appendix 5 for methods. We also used the unsummarized data from the projections to derive climate metrics related to water balance, as described in Appendix 3.

These climate projections spanned a range of warming in average annual temperature from +1.8 °F to +5.8 °F, and a range of annual precipitation change from -1.0 inches (-5.5%) to +3.8 inches (+21.2%) for Devils Tower NM (Figure 7). Seasonal shifts in precipitation patterns (type, frequency, and intensity) and growing season conditions (onset, duration, and soil moisture levels) also varied among climate models. Given this range of future projections, planning for a single future is highly unlikely to prepare a manager for what will actually transpire in the coming decades, which is why identifying and developing several climate futures tied to key resource sensitivities is important.

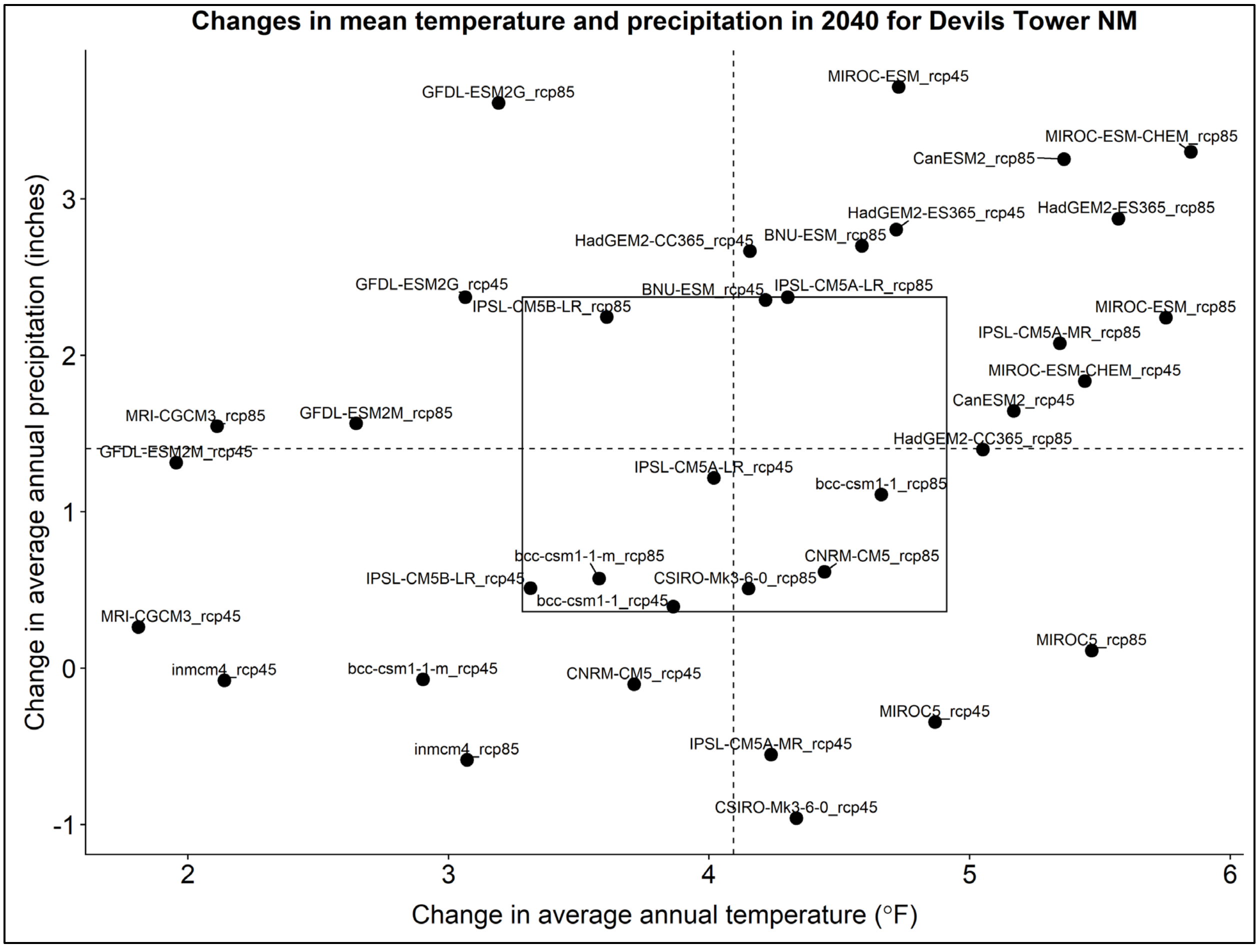

Figure 7. Projected changes in average annual temperature and precipitation for Devils Tower NM. Points represent differences between average values for the 3-decade period 2025–2055 and 1950–1999 for each GCM. Data are from two simulations each of 18 downscaled CMIP5 GCMs for the park. Each model was run with a moderate (RCP 4.5) and business-as-usual, high greenhouse gas emissions pathway (RCP 8.5) (climate data from MACA [Multivariate Adaptive Constructed Analogs; Abatzoglou and Brown 2012]). Dashed lines indicate the median value for each axis and the box around the intersection of the dashed lines defines the central tendency, which includes models inside the 25th and 75th percentiles for both axes.

Climate futures establish the fundamental structure of climate-resource scenarios, which are created by adding associated resource implications. Therefore, we selected four climate projections from those illustrated in Figure 7 to meet four key expectations of scenarios useful for resource management: they must be *plausible*, *relevant*, and *divergent* enough to *challenge* entrenched mindsets (NPS 2013a). The selection process began by eliminating from consideration four models (eight projections) in Figure 7—BNU-ESM RCP 4.5, BNU-ESM RCP 8.5, bcc-csm1-1 RCP 4.5, bcc-csm1-1 RCP 8.5, bcc-csm1-1-m RCP 4.5, bcc-csm1-1-m RCP 8.5, IPSL-CM5B-LR RCP 4.5, IPSL-CM5B-LR RCP 8.5—due to their poor performance in representing observed large-scale atmospheric conditions for the region in which Devils Tower NM lies (Rupp et al. 2017, I. Rangwala, University of Colorado Boulder, written commun. 2018), thereby ensuring plausibility.

Next, to ensure challenging divergence in implications for the key resources, we identified projections whose climate metrics produced the five "best" and five "worst" situations for key resource groups described in Table 2. For example, a combination of the lowest frequency of freeze-thaw cycles and extremely hot days was considered the best situation for historical structures; further details are in Table 3. This approach winnowed the possible number of projections from 28 to 20. Finally, using Table 3 and the scatterplots in Figure 8, we selected four projections that together provided maximal divergence in resource implications. Our previous experience has shown that four futures are generally needed to achieve this divergence and that a larger number is overwhelming for scenario workshop participants.

Table 3. Climate projections that produced the five "best" and five "worst" situations for key resource concerns. Projections chosen as the basis for the four climate futures are noted below and include the number that refers to the specific climate future (also in distinguishing colors).

Concern	Worst situations	Best situations	Based on
Historical structures, tower exfoliation	• CanESM2_rcp45 • CanESM2_rcp85 • GFDL-ESM2G_rcp85 *(1) • HadGEM2-CC365_rcp85 *(3) • IPSL-CM5A-LR_rcp45	• MIROC5_rcp85 • MIROC-ESM_rcp85 • inmcm4_rcp85 • MIROC5_rcp45 • IPSL-CM5A-MR_rcp45 *(4)	Freeze-thaw cycles (primary), Extremely hot days (secondary)
Vegetation	• CSIRO-Mk3-6-0_rcp45 • MIROC5_rcp85 • MIROC5_rcp45 • CSIRO-MK3-6-0_rcp85 • IPSL-CM5A-MR_rcp45 *(4)	• GFDL-ESM2G_rcp85 *(1) • GFDL-ESM2M_rcp45 *(3) • GFDL-ESM2G_rcp45 • HadGEM2-CC365_rcp45 • GFDL-ESM2M_rcp85	Mean (primary) and maximum (secondary) summer water deficit
Erosion	• MIROC-ESM-CHEM_rcp85 • GFDL-ESM2G_rcp85 *(1) • MIROC-ESM_rcp45 • HadGEM2-ES365_rcp45 • MIROC-ESM-rcp85	• IPSL-CM5A-MR_rcp45 *(4) • MIROC5_rcp45 • inmcm4_rcp85 • CSIRO-Mk3-6-0_rcp85 • CanESM2_rcp45	>1-inch precipitation events
Tower exfoliation, visitor and staff safety	• HadGEM2-ES365_rcp85 • HadGEM2-CC365_rcp85 *(3) • CSIRO-Mk3-6-0_rcp45 • inmcm4_rcp85 • CSIRO-Mk3-6-0_rcp85	• GFDL-ESM2M_rcp45 *(3) • GFDL-ESM2G_rcp45 • MRI-CGCM3_rcp85 • GFDL-ESM2G_rcp85 *(1) • MRI-CGCM3_rcp45	Extremely hot days

* Indicates that the projection was selected as a climate future, and the number that follows is the number that refers to this climate future throughout the report.

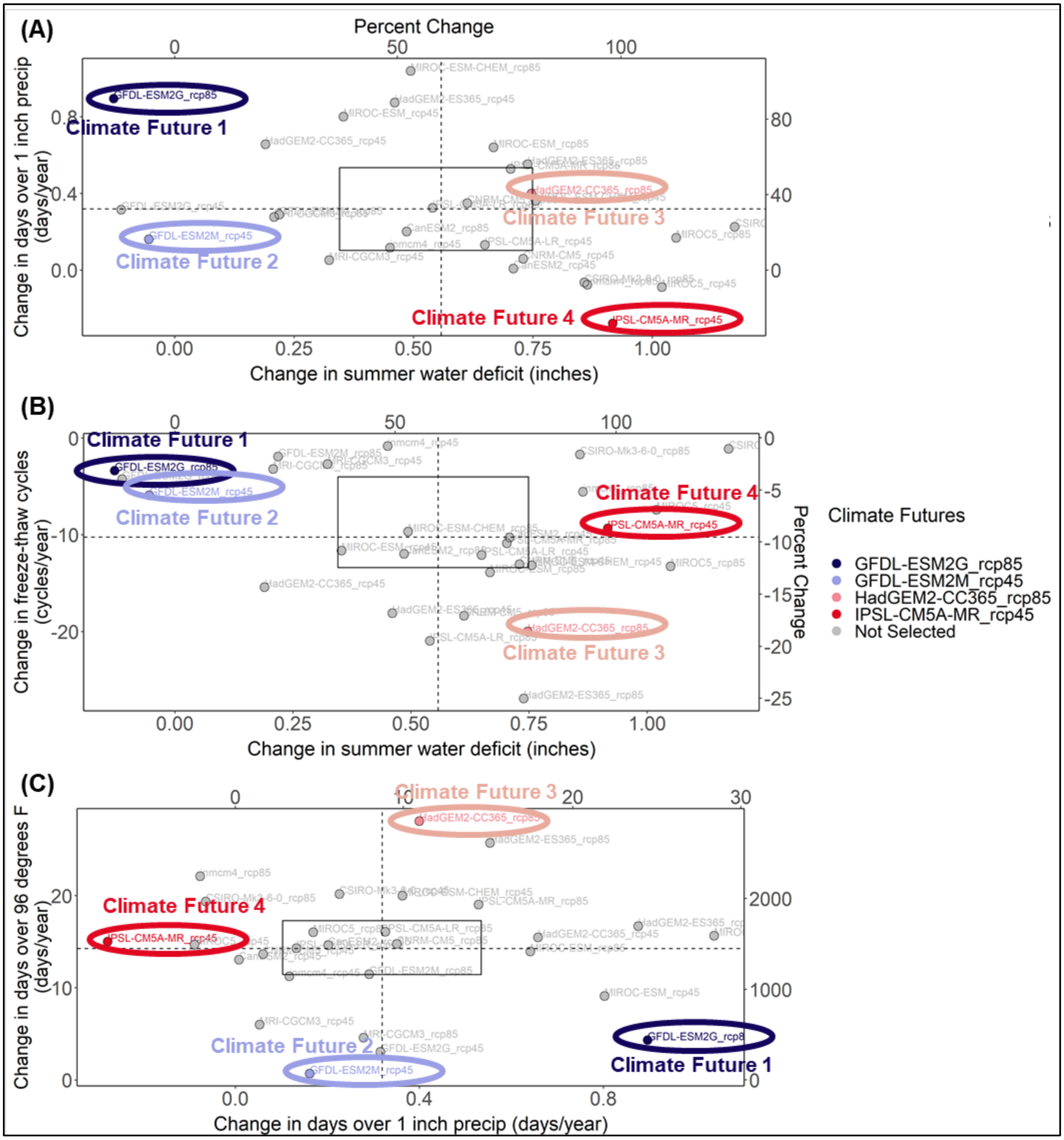

Figure 8. Projected changes in key climate metrics for Devils Tower NM, including change in summer water deficit (averaged over June, July, and August—see Appendix 3) and number of days in a year with precipitation >1 inch (panel A), change in summer water deficit and number of freeze-thaw cycles in a year (panel B), and change in number of days in a year with precipitation >1 inch and number of days in a year >96 °F (panel C). Points represent differences between average values for the 3-decade period 2025–2055 and 1950–1999 for each GCM. Circled GCM/RCP combinations are projections selected for climate futures. Circle color corresponds with the color of the climate futures and scenarios used throughout this document. Dashed lines indicate the median value for each axis, and the box around the intersection of the dashed lines defines the central tendency of the projections (models inside the 25th and 75th percentiles for both axes).

We then developed the four climate futures by characterizing changes in the four key climate metrics (Table 2) and a large suite of additional climate metrics related to all other climate-sensitive park resources, stressors, management activities, and management concerns (Table 4). Climate future descriptions–including text, figures (Figures 9-21 at the end of this section), and a table (Table 5)– provided to scenario planning workshop participants are reproduced in the next section. Note that data presented are all mean conditions, around which substantial variation occurs.

Table 4. Additional climate-sensitive Devils Tower NM resources, stressors, management activities, and management concerns and their associated climate metrics that were summarized for each Devils Tower NM climate future. Note that humidity projections were identified as important only late in the scenario development process, after climate future information was provided to scenario planning workshop participants, and thus are shared here for the first time (see Appendix 6).

Climate-sensitive resources, stressors, management activity, or management concern	Climate metric
Prescribed fire (ability to implement)	Spring green-up date (day of year)
Vegetation (including ethnographic plants), wildlife, and pests	Days per year with minimum temperature <32 °F & 0 °F
Vegetation (including ethnographic plants)	Growing season length
Vegetation (including ethnographic plants)	Monthly mean soil moisture
Staff & visitor well-being	Days per year of “Dangerous” and “Extreme caution” heat index
Visitation (numbers of visitors)	Monthly and daily temperature
Built structures	Relative humidity change (%)
Archeological resources and geological features	Annual and seasonal precipitation
Springs and wetlands (infiltration) and Belle Fourche River (runoff)	Excess soil moisture*

*Excess soil moisture is precipitation that cannot be held in the top 1 meter of soil, and therefore either becomes runoff or infiltrates into the groundwater.

Climate futures information provided for scenario planning workshop

Synopses

"Climate Future 1”

- Moderate warming (+3 °F), with relatively constant change across all months
- 8 days/year >96 °F (4-day increase from historical)
- 167 days/year <32 °F (15-day decrease from historical)
- Precipitation increase in all seasons, highest in spring and summer
- Substantial increase in the frequency of large precipitation events (>1 inch/day)
- Summer water deficit decreases slightly
- Moderate increases in spring soil moisture

"Climate Future 2"

- Low warming (+2 °F), most pronounced in early spring
- 5 days/year >96 °F (1-day increase from historical)
- 168 days/year <32 °F (14-day decrease from historical)
- Precipitation increases in all seasons except fall (slight decrease)
- No change in the frequency of large precipitation events (>1 inch/day)
- Summer water deficit decreases slightly
- Slight increase in early spring soil moisture

"Climate Future 3"

- Severe warming (+5 °F), most pronounced in early spring
- 32 days/year >96 °F (28-day increase from historical)
- 151 days/year <32 °F (30-day decrease from historical)
- Substantial precipitation increases in spring, moderate increases in winter, and decreases in summer
- Moderate increase in the frequency of large precipitation events (>1 inch/day)
- Summer water deficit increases substantially
- Slight decrease in spring soil moisture

"Climate Future 4"

- Severe warming (+4 °F), most pronounced in late spring and early summer
- 18 days/year >96 °F (15-day increase from historical)
- 161 days/year <32 °F (20-day decrease from historical)
- Substantial precipitation decreases in summer and increases in spring
- Decrease in the frequency of large precipitation events (>1 inch/day)
- Summer water deficit increases substantially
- Substantial decrease in late spring soil moisture

Narrative descriptions

"Climate Future 1"

The warming trend at Devils Tower NM since the 1970s continues, but the magnitude of change is at the lower end of projections for midcentury; average annual daily minimum temperature increases by 3.1 °F relative to late-20th-century values, most strongly in the winter months, and average annual daily maximum temperature increase is similar (+3 °F) and is strongest in the fall. Temperatures at Devils Tower NM exceed 96 °F 8 days/year, up 4 days from the historical 4/year. Winter now includes, on average, 167 days with below-freezing temperatures, down 14 days from the historical average of 181 days. Precipitation change is substantial, with a maximum seasonal increase of 1.5 inches in the summer and a substantial increase in the frequency of annual precipitation events over 1 inch in a day. Summer water deficit decreases slightly and there is a moderate increase in spring soil moisture.

"Climate Future 2"

The warming trend at Devils Tower NM since the 1970s continues, but the magnitude of change is at the lower end of projections for midcentury; average annual daily minimum temperature increases by 1.9 °F relative to late-20th-century values, with gains even across the year except for somewhat higher gains in winter, and average annual daily maximum temperature increase is similar (+2 °F) and is strongest in the late fall and spring. Temperatures at Devils Tower NM exceed 96 °F 5 days/year, up 1 day from the historical 4/year. Winter now includes, on average, 168 days with below-freezing temperatures, down 13 days from the historical average of 181 days. Precipitation change is minor, with a maximum seasonal increase of 0.9 inch in summer and no change in the frequency of large precipitation events. There is no change in summer water deficit and an increase in early spring soil moisture.

"Climate Future 3"

The warming trend at Devils Tower NM since the 1970s continues, and the magnitude of change is at the upper end of projections for midcentury; average annual daily minimum temperature increases by 5 °F relative to late-20th-century values, most strongly in the late summer and fall months, and average annual daily maximum temperature increase is slightly higher (+5.5 °F) and is strongest in the late summer and fall. Temperatures at Devils Tower NM exceed 96 °F 32 days/year, up 28 days from the historical 4/year. Winter now includes, on average, 151 days with below-freezing temperatures, down 30 days from the historical average of 181 days. Precipitation change is substantial, with a maximum seasonal increase of 1.3 inches in spring but a 1-inch decrease in summer and a moderate increase in the frequency of annual precipitation events over 1 inch in a day. Summer water deficit increases substantially. There is little change in spring soil moisture, but a slight decrease in late spring months.

"Climate Future 4"

The warming trend at Devils Tower NM since the 1970s continues, and the magnitude of change is near the upper end of projections for mid-century; average annual daily minimum temperature increases by 4 °F relative to late-20th-century values, most strongly in late summer and fall months, and average annual daily maximum temperature increase is slightly higher (+4.2 °F) and is strongest in the summer and fall. Temperatures at Devils Tower NM exceed 96 °F 18 days/year, up 14 days from the historical 4/year. Winter now includes, on average, 161 days with below-freezing temperatures, down 20 days from the historical average of 181 days. Precipitation increases substantially in spring (0.7 inch) declines substantially in the summer season (0.9 inch), and frequency of large precipitation events declines. Summer water deficit increases substantially and there are substantial declines in spring soil moisture, particularly in late spring months.

Quantitative summary

Climate conditions for the years 2025–2055 for Devils Tower NM climate futures can be seen in Table 5. Values are differences between averages for the 3-decade period 2025–2055 and 1950–1999, with negative values indicating declines. W: winter (Dec–Feb); Sp: spring (Mar–May), Su: summer (Jun–Aug), Fa: fall (Sep–Nov).

Table 5. Devils Tower NM climate futures (average for 3-decade period 2025–2055), expressed in terms of change relative to the historical period (1950–1999). The "Historical" column represents the 1950–1999 average value for each metric. Note that humidity projections were identified as important only late in the scenario development process, after climate future information was provided to scenario planning workshop participants, and thus are shared here for the first time (also see Appendix 6).

Climate metric	**Season**	**Climate Future 1**	**Climate Future 2**	**Climate Future 3**	**Climate Future 4**	**Historical Averages**
Average annual temperature (°F)	—	3.1	2.0	5.2	4.1	45.3
Seasonal daily max. temp. (°F)	W	3.6	1.8	3.9	3.7	35.6
	Sp	2.1	2.5	3.5	3.5	57.5
	Su	2.1	0.9	7.3	5.5	82.4
	F	4.2	2.8	7.3	4.2	59.3
Seasonal daily min. temp. increase (°F)	W	4.3	1.9	5.3	3.9	11.9
	Sp	2.3	2.1	3.8	2.8	30.8
	Su	2.4	1.8	5.2	5.6	52.7
	F	3.5	1.9	5.8	4.2	31.9
Annual precipitation (in)	—	3.9	1.3	1.0	-0.4	17.6
Seasonal precipitation (in)	W	0.5 (23%)	0.1 (7%)	0.6 (32%)	0	2.0
	Sp	1.5 (26%)	0.5 (9%)	1.3 (23%)	0.7 (12%)	5.7
	Su	1.1 (17%)	0.9 (14%)	-1.0 (15%)	-0.9 (-14%)	6.4
	F	0.9 (24%)	-0.3 (-7%)	0	-0.2 (-6%)	3.8

Table 5 (continued). Devils Tower NM climate futures (average for 3-decade period 2025–2055), expressed in terms of change relative to the historical period (1950–1999). The "Historical" column represents the 1950–1999 average value for each metric. Note that humidity projections were identified as important only late in the scenario development process, after climate future information was provided to scenario planning workshop participants, and thus are shared here for the first time (also see Appendix 6).

Climate metric	Season	Climate Future 1	Climate Future 2	Climate Future 3	Climate Future 4	Historical Averages
Monthly water deficit (in), averaged by season	W	0	0	0	0.1	0
	Sp	0	0	0	0	0.1
	Su	-0.2	-0.1	0.8	0.9	1.0
	F	0	0.1	0.4	0.3	0.4
Monthly soil moisture (in), averaged by season	W	0.5 (12%)	-0.3 (-7%)	-1.0 (-28%)	-1.6 (-41%)	3.8
	Sp	0.7 (13%)	0	-0.1 (-2%)	-1.2 (-21%)	5.7
	Su	0.5 (9%)	0.2 (5%)	-0.6 (-13%)	-1.4 (-29%)	4.9
	F	0.5 (12%)	-0.3 (-8%)	-1.1 (-29%)	-1.6 (-42%)	3.8
Monthly excess moisture (in), averaged by season	W	0	0	0	0	0
	Sp	0.3	-0.1	-0.2	-0.3	0.3
	Su	0	0	0	-0.1	0.1
	F	0	0	0	0	0
Relative humidity (%)	W	-1.9	-0.1	0.5	-3.5	65.9
	Sp	2.1	1.1	0.3	-1.6	60.7
	Su	3.8	3.9	-4.7	-5.1	57.2
	F	1.1	0.1	-2.9	-1.8	58.8

Table 5 (continued). Devils Tower NM climate futures (average for 3-decade period 2025–2055), expressed in terms of change relative to the historical period (1950–1999). The "Historical" column represents the 1950–1999 average value for each metric. Note that humidity projections were identified as important only late in the scenario development process, after climate future information was provided to scenario planning workshop participants, and thus are shared here for the first time (also see Appendix 6).

Climate metric	Season	Climate Future 1	Climate Future 2	Climate Future 3	Climate Future 4	Historical Averages
Freeze-thaw cycles (days/year)	–	-2.3 (-2%)	-6.7 (-6%)	-19.6 (-18%)	-10.0 (-9%)	107.7
Days/year >96 °F	–	3.8	1.2	28.4	14.7	3.7
Days/year with >1 inch precip.	–	0.9 (90%)	0.1 (14%)	0.4 (39%)	-0.3 (-27%)	1.0
Days/year with min. temp. <32 °F	–	-14.7 (-8%)	-13.6 (-7%)	-30.4 (-17%)	-20.4 (-11%)	181.3
Days/year with min. temp. <0 °F	–	-5.8 (-33%)	-3.5 (-20%)	-8.3 (-47%)	-3.7 (-21%)	17.7
Growing season length (days/year)	–	16.3 (7%)	12.6 (6%)	20.5 (9%)	30.9 (14%)	227.7
Green-up date (days/year)	–	4 days earlier (Apr-7)	5 days earlier (Apr-6)	15 days earlier (Mar-27)	18 days earlier (Mar-24)	Apr-11
Days/year with "dangerous" heat index	–	0.1	0	0.8	0	0
Days/year with "extreme caution" heat index	–	7.7	7.0	30.7	19.9	6.1

Climate future figures

For all plots below (Figures 9-21), the future and historical periods are 2025–2055 and 1950–1999, respectively. Each future is an individual projection and historical is the average of modeled past conditions for each of the four GCMs that were used to create the climate futures.

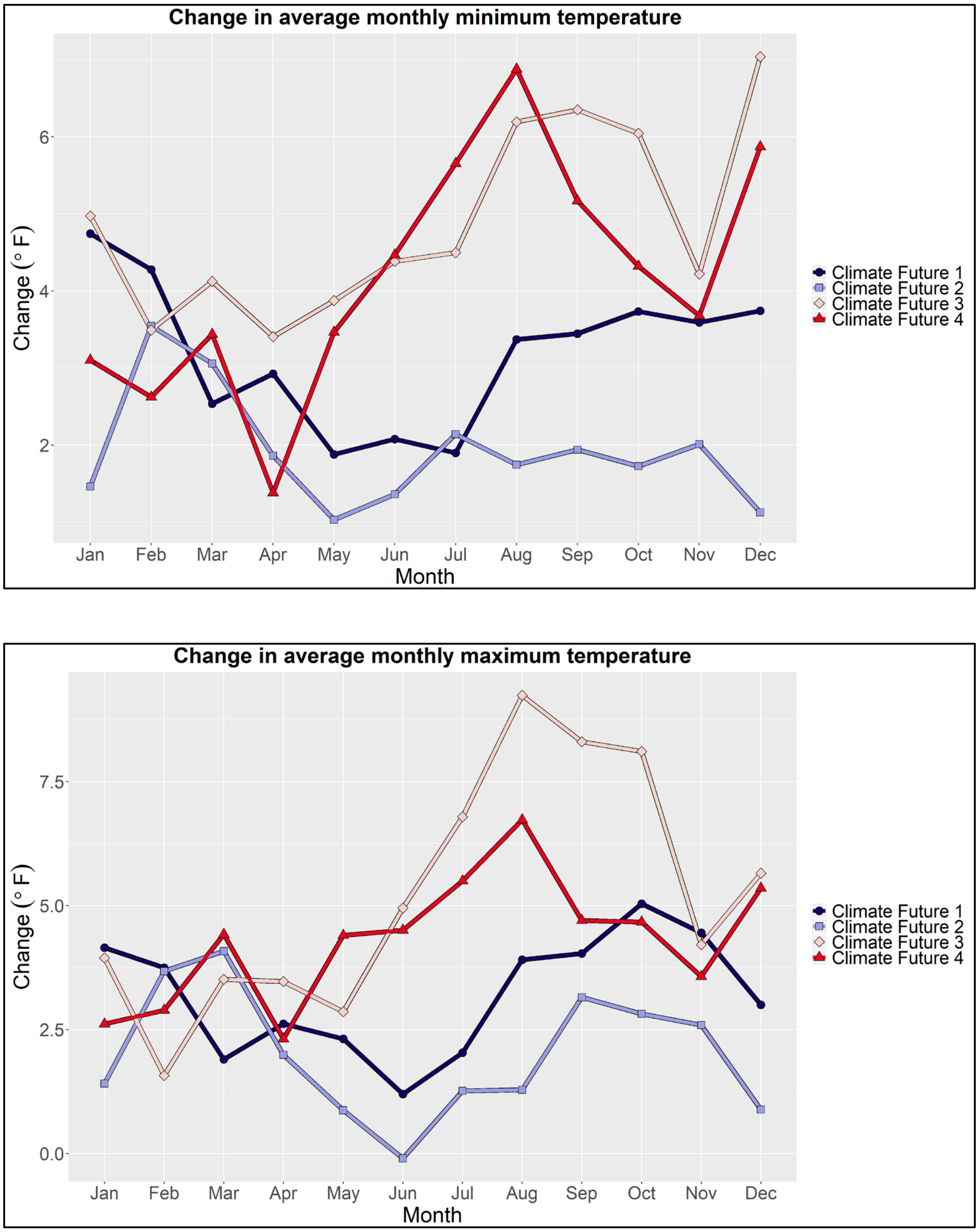

Figure 9. Change in average (over 2025–2055, compared to 1950–1990) monthly minimum (upper panel) and maximum temperature (lower panel) for each month.

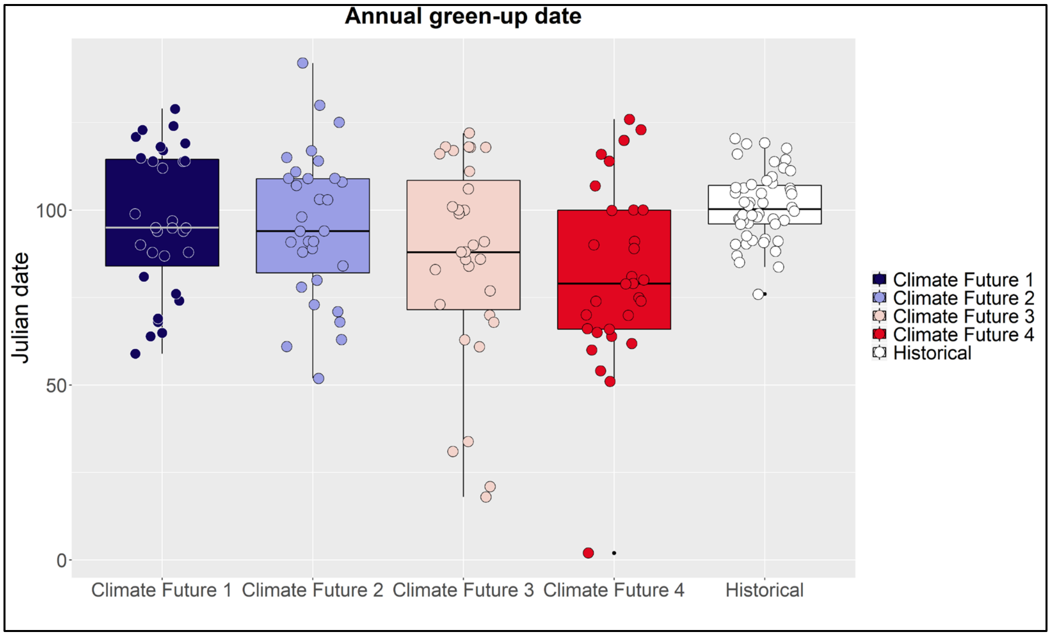

Figure 10. Annual green-up date, measured as the start of the first spell of warm days in the first half of the year. A spell of warm days is defined as six or more days with mean temperature >5 °C (41 °F). Individual points in the Climate Future columns are green-up dates for individual years in the projection. Individual points in the Historical column are the average, for each year, of modeled past conditions for each of the four GCMs that were used to create the climate futures. In each column, the upper and lower ends of the boxes correspond to the first and third quartiles (25th and 75th percentiles) of the points, the horizontal line in each box indicates the median value of the points, and the vertical lines extend to the maximum and minimum values, excluding outliers (i.e., points >1.5 times the quartile), which are plotted individually as small black circles. Note that points are scattered horizontally within columns to avoid overlap.

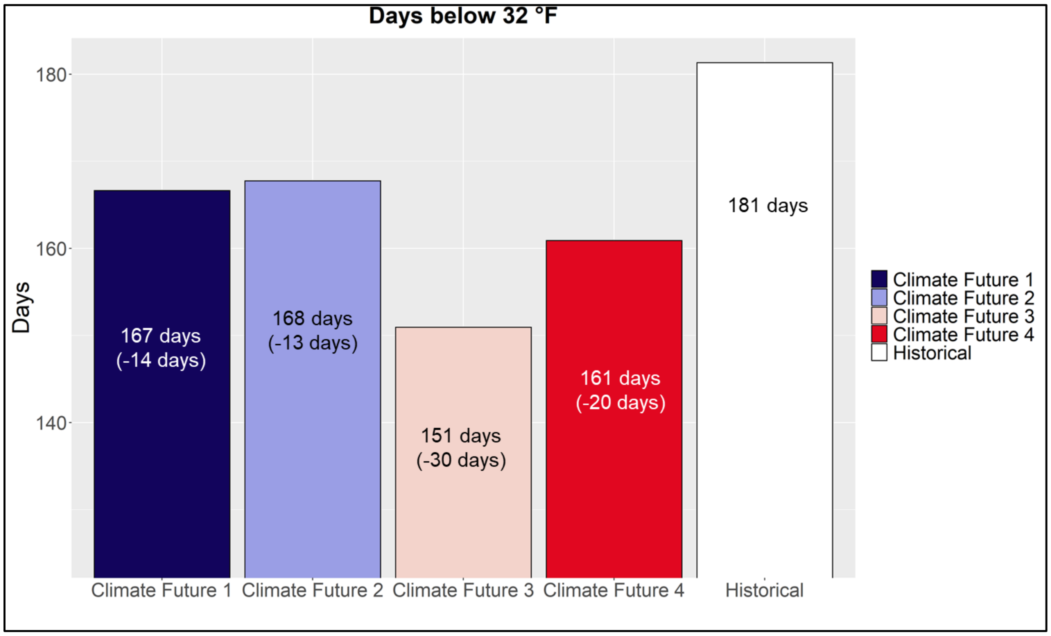

Figure 11. Average number of days per year when the minimum temperature <32 °F.

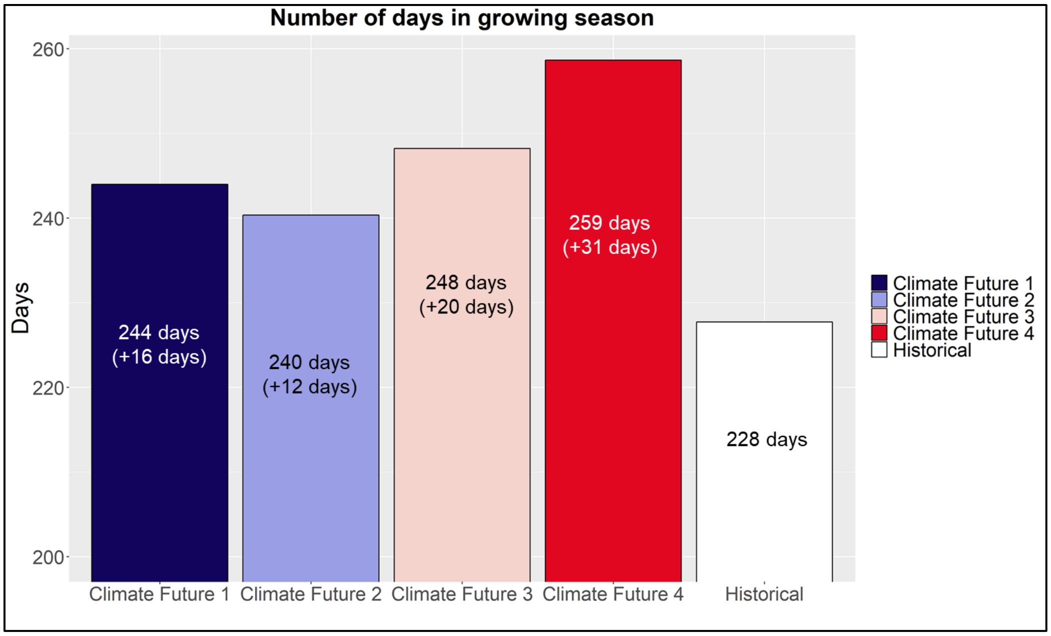

Figure 12. Average growing season length, measured in days, as defined by the CLIMDEX (https://www.climdex.org/) definition of growing season: the number of days between the start of the first spell of warm days in the first half of the year, and the start of the first spell of cold days in the second half of the year. A spell of warm days is defined as six or more days with mean temperature >5 °C (41 °F); a spell of cold days is defined as six or more days with a mean temperature <5 °C.

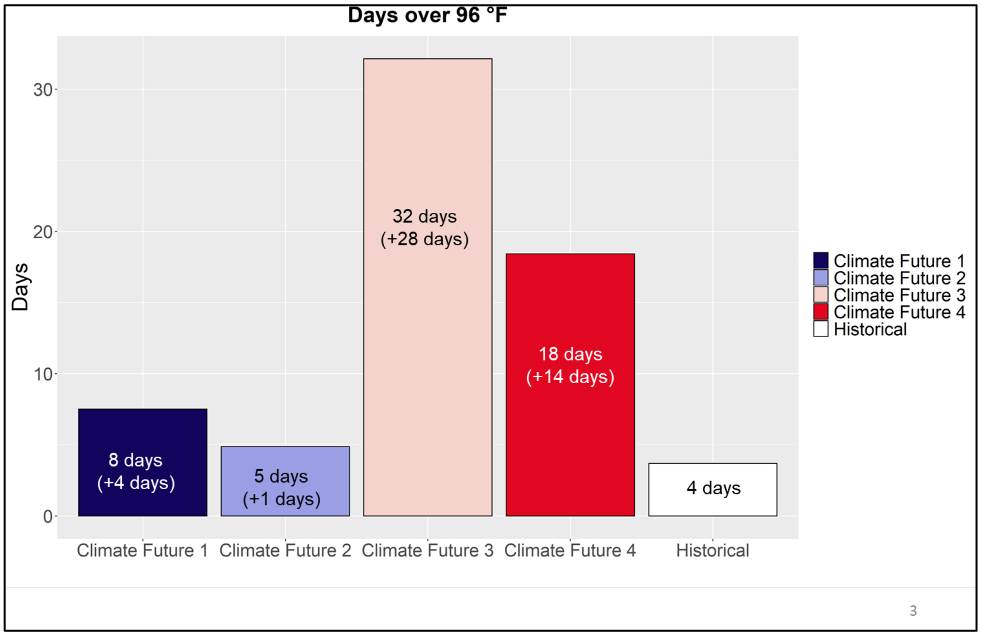

Figure 13. Average number of days per year when the maximum temperature >96 °F. Historically, a day that exceeds 96 °F is a 99th-percentile event at Devils Tower NM.

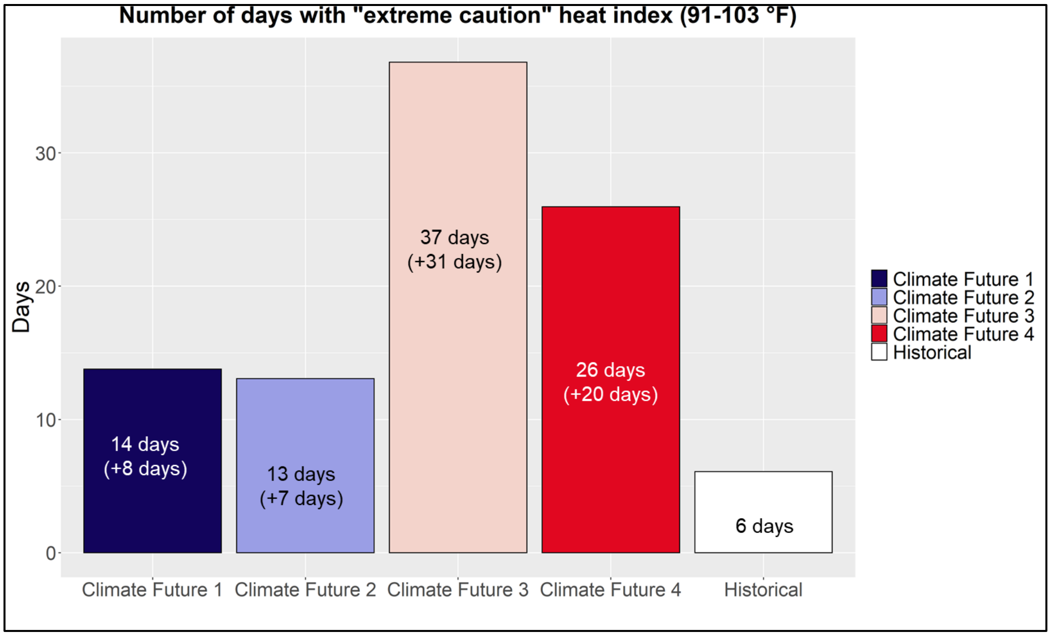

Figure 14. Average number of days per year when heat index reaches “extreme caution” levels (91–103 °F) (see Appendix 7 for details regarding heat index, how it is calculated, and precautions that should be taken for risk levels). The heat index is an equation used by the National Weather Service to measure the discomfort felt as a result of the combined effects of air temperature and humidity.

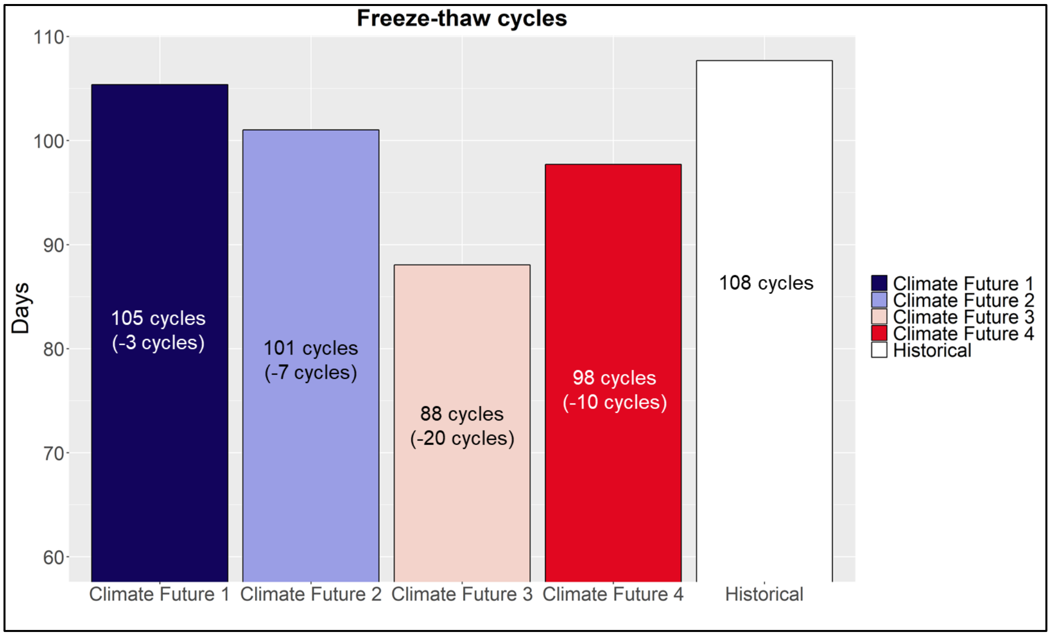

Figure 15. Number of freeze-thaw cycles per year, measured as days where the maximum temperature >34 °F and the minimum temperature <28 °F.

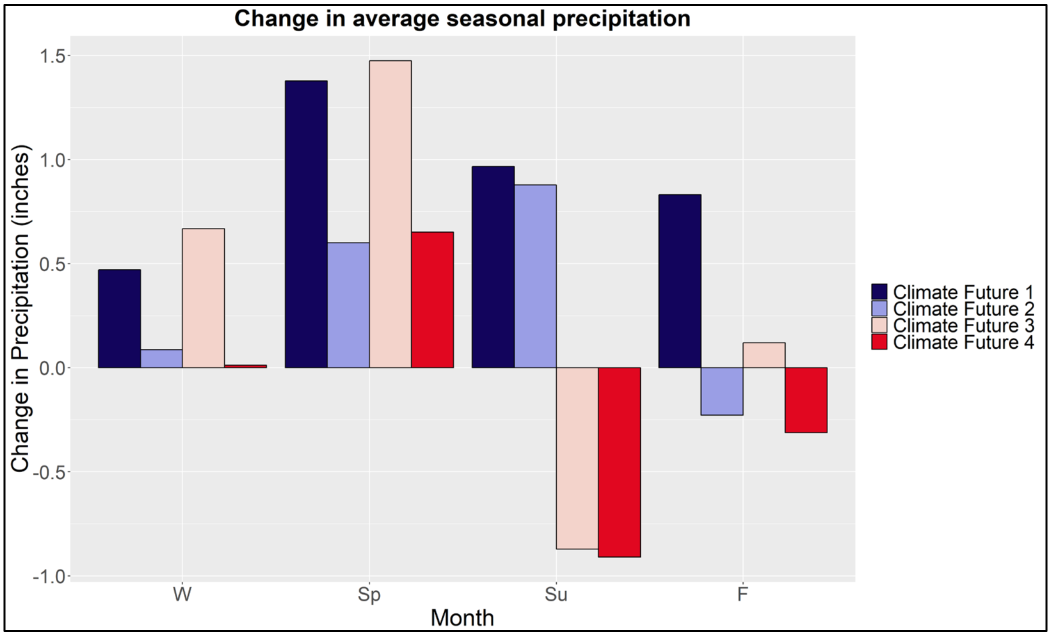

Figure 16. Change in average (over 2025–2055, compared to 1950–1990) seasonal precipitation. Winter = Dec–Feb; Spring = Mar–May; Summer = Jun–Aug; Fall = Sep–Nov.

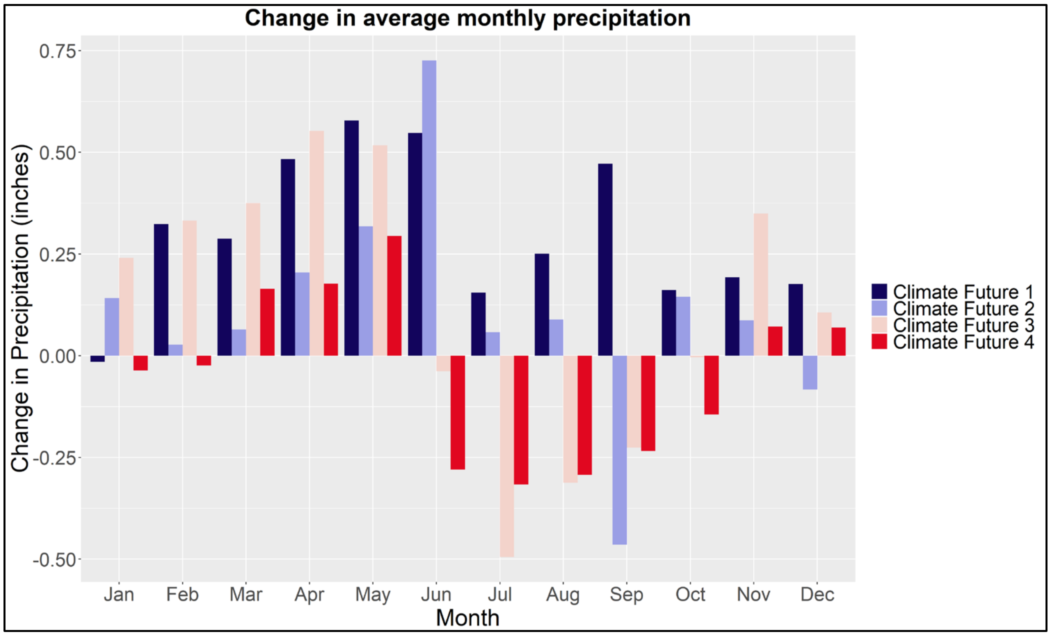

Figure 17. Change in average (over 2025–2055, compared to 1950–1990) monthly precipitation.

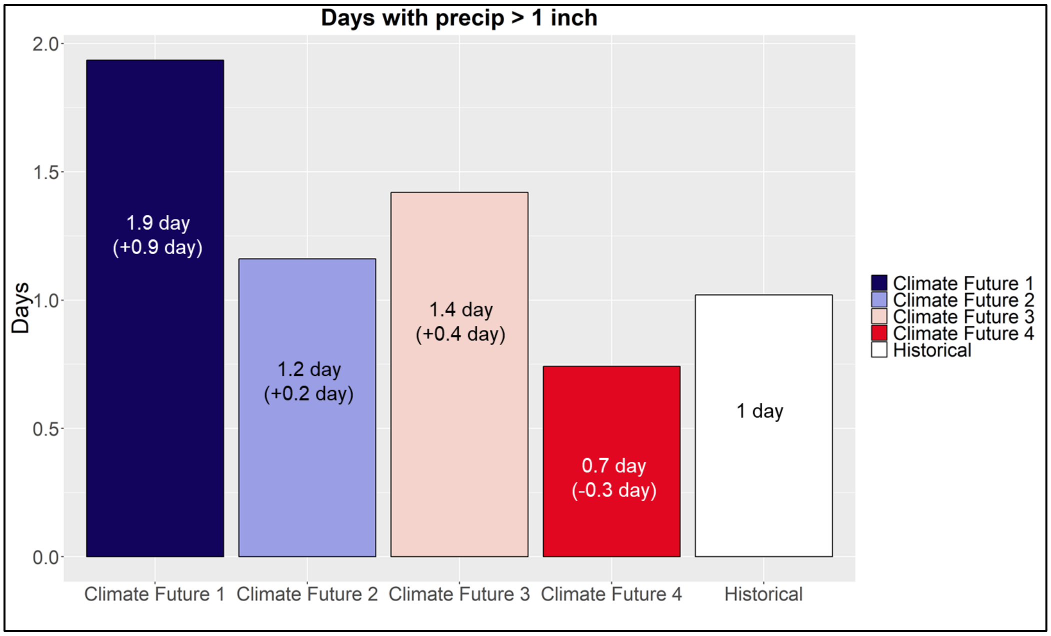

Figure 18. Number of days per year receiving large precipitation events (>1 inch). Historically, 1 inch is a 99th-percentile event at Devils Tower NM.

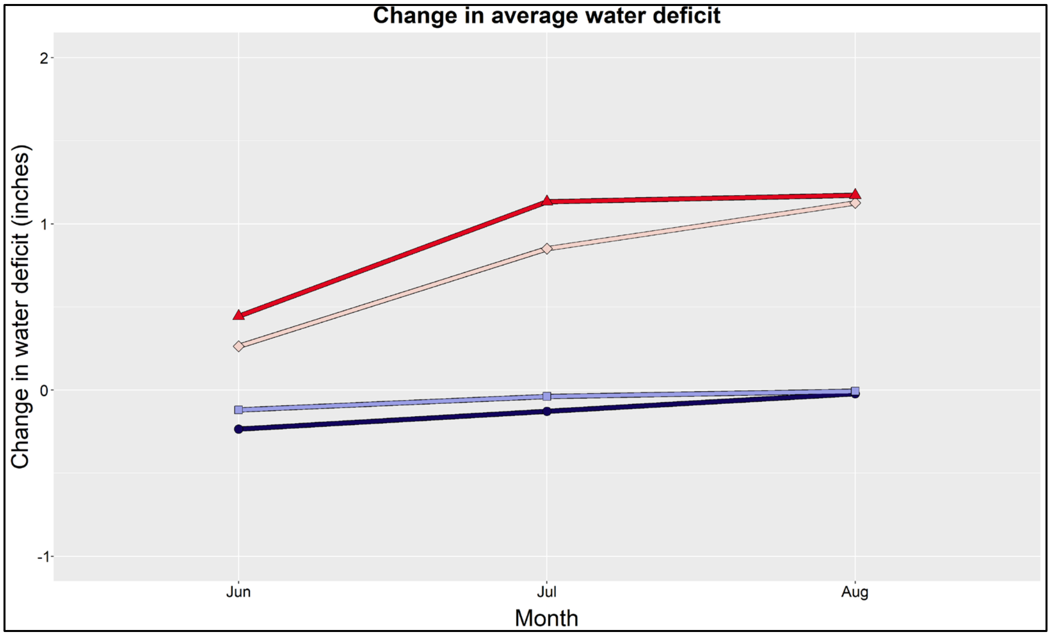

Figure 19. Change in average (over 2025–2055, compared to 1950–1999) monthly water deficit (the difference between precipitation and actual evapotranspiration) for summer months. This indicator is a good measure of vegetation stress and has been shown to be a strong indicator of area burned by wildfire (Williams et al. 2015).

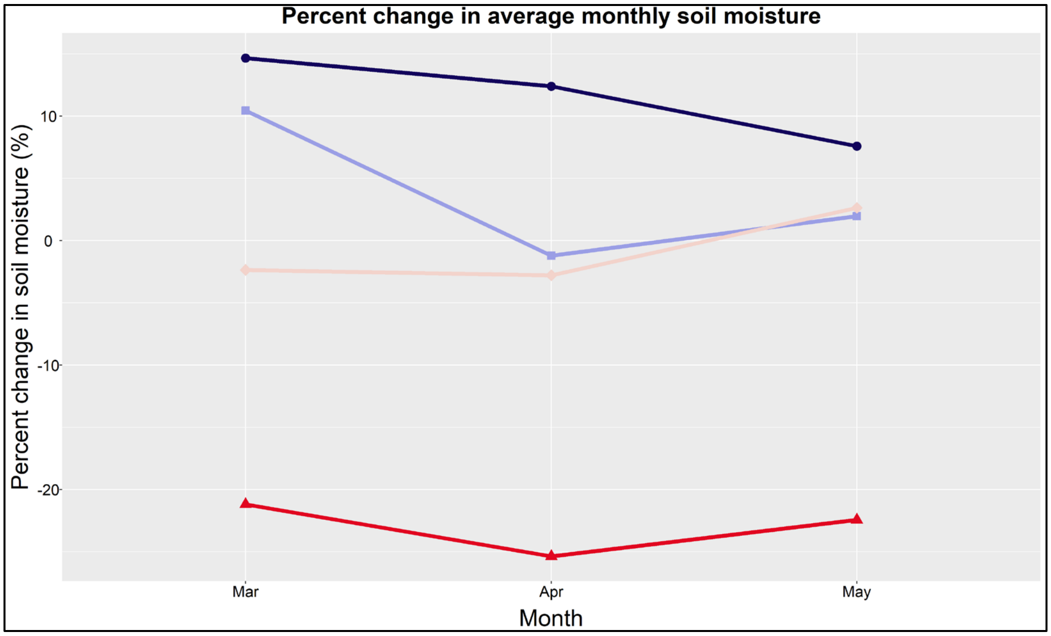

Figure 20. Change in average (over 2025–2055, compared to 1950–1999) monthly soil moisture (moisture stored in the top 1 meter of soil that is available for vegetation use) in spring months.

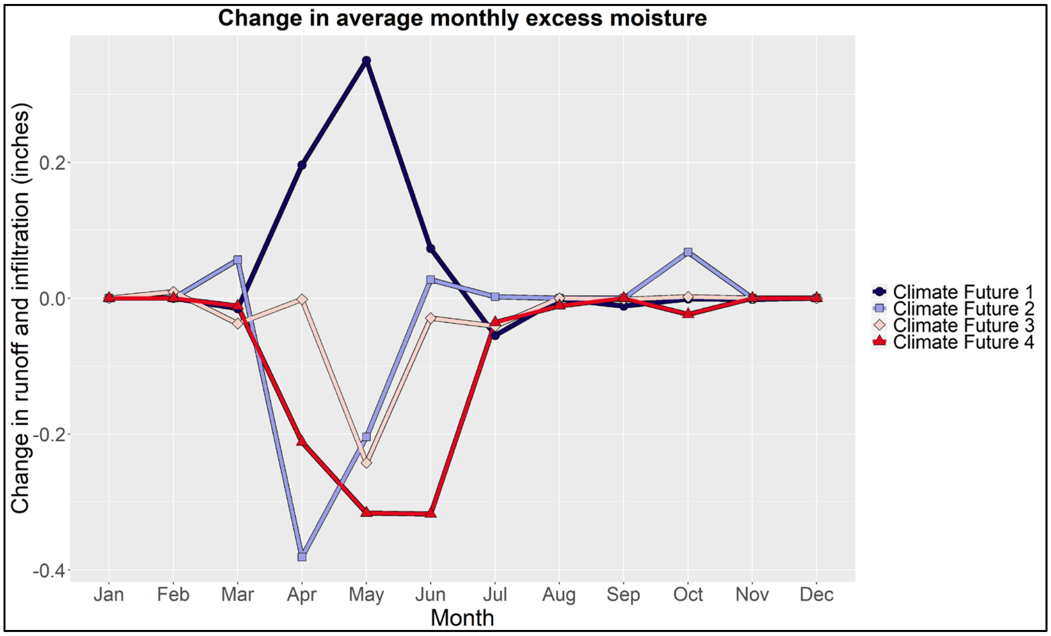

Figure 21. Change in average (over 2025–2055, compared to 1950–1999) monthly excess soil moisture (i.e., precipitation not stored in the top 1 meter of soil) that either becomes runoff or infiltrates into groundwater.

Climate-resource scenario development and implications

Scenario planning workshop participants worked as a single group during the late-March 2018 scenario planning workshop to describe potential effects of each climate future on priority resources. The end-point of this process was four climate-resource scenarios. After this, participants examined current management goals and actions in terms of feasibility and effectiveness, respectively, under each scenario.

Scenario development

We took a whole-group approach because the number of workshop participants was relatively small. If we had created breakout groups to discuss the effects of each climate future on all resources (as has been done for previous NPS climate change scenario planning workshops), some groups would have lacked areas of expertise. Instead, we created resource-specialty subgroups (see Appendix 1; hereafter referred to as resource subgroups). For each climate future, each subgroup conferred for 10 or 15 minutes about its resource, and any specific components of that resource, before the whole group engaged in a facilitated process to populate a worksheet (poster-sized template) with resource responses to the climate future. This approach allowed for both focused consideration of resource-specific impacts and identification of important interactions across resources. At the end of this process, participants named the scenarios—Spearfish, Still DETO (i.e., Still Devils Tower NM), Blazin' Hot (but not too dry) (hereafter abbreviated as Blazin' Hot), and Are we in western Kansas? (hereafter referred to as Western Kansas)—to reflect resource responses to each climate future (Climate Futures 1 through 4, respectively). Five weeks later (Figure 2), most of the scenario planning workshop participants joined several additional subject-matter experts and park staff in an RSS workshop that used and added to or revised these implications. The scenario descriptions below are from discussions in these two workshop settings. These descriptions are not vetted research statements of responses to the climate futures, but are instead insights and examinations of possible futures based on a combination of available science, local expert knowledge, and management experience.

Topics discussed included changes in fire risks, flooding and erosion impacts, changes in vegetation composition and productivity, wildlife implications, invasive species, and freeze-thaw impacts to built structures (Table 6; see Table 1 for more details). More precipitation and more intense storms, especially under Spearfish, Still DETO, and springtime in Blazin' Hot (Figures 17 and 18), were expected to lead to greater erosion and impacts to archeological resources, paleontological resources, and built structures. Changes in vegetation were expected to occur in all scenarios and range from strong decreases in productivity and a decline in ponderosa pines plus increased fire risk (Western Kansas, and Blazin' Hot to some degree), to increased productivity (Still DETO and Spearfish) and decreased fire risk (Spearfish). In all scenarios, green ash (Fraxinus pennsylvanica) was expected to disappear due to the arrival of the emerald ash borer (Agrilus planipennis), a phenomenon unrelated to climate change. Changes in vegetation and hydrology, along with other climate change implications, were expected to affect a broad spectrum of animals at Devils Tower NM, including amphibians, birds, and mammals. Visitors are a major focus of park facilities and operations, and a potential source of impacts to resources. Visitation and the visitor experience were also assessed alongside these other resource impacts.

These discussions largely focused on climate implications, but we recognize that there are other relevant socio-political developments that could have important implications for resources. Population growth, land use change, and fossil fuel extraction near Devils Tower NM are likely to have substantial management implications but are not included here because they were not clearly linked to the climate futures and could be considered in follow-on work, including in the RSS process.

Table 6. Scenario planning workgroup-envisioned developments and resource implications for Devils Tower NM climate-resource scenarios for each priority resource and resource component.

Priority resource	**Resource component**	**Spearfish**	**Still DETO**	**Blazin' Hot**	**Western Kansas**
Cultural resources	Structures	• Roads and culverts could be impacted by increased rain/precipitation • Paved surfaces and ADA (Americans with Disabilities Act) accessibility need to factor in slope and runoff • Historical structures—potential for water infiltration (ensure gutters are clear) • Increased air conditioning use • Increased potential for tree-fall impacts • Stake ladder potential loss due to increased moisture/ humidity and rot?	• Fewer freeze-thaw cycles; could be beneficial • Least likely to impact the stake ladder (continuation of existing impacts) • Continuation of current maintenance cycles	• "High-fire" scenario—structures vulnerable • Benefits due to decreased freeze-thaw cycling • Increased air conditioning use • Issue of visitor center capacity (if used as a refuge from heat) • Stake ladder would probably do OK	• Potential fire issue/danger • Roads and culverts—no/little runoff issues • Drier conditions would help preserve historical structures • Increased air conditioning use • Reduced impacts on the stake ladder
	Ethnographic	• Formation (tower) less impacted due to less freeze-thaw • Would continue (persist) regardless of changes	• Less likely to increase spalling on formation (tower) due to fewer freeze-thaw cycles	• Formation (tower) would see benefits due to less freeze/thaw • If climbing season shifts, it may support June closure	• Formation (tower)—less impacts, less moisture, less rock fall • Potential for increased emergency response if cultural use coincides with high temperatures
	Archeological	• Potential for increased erosion and exposure of sites/lithics • Pictographs and historical graffiti more vulnerable to erosion? • Increased potential for tree-fall impacts	• Continuation of erosion and loss of pictographs and historical graffiti • Continuation of current (management) activities	• "High-fire" scenario—likely exposure of new archeological sites • Increasing visitation/longer visitation season could lead to site impacts • Pictographs and historical graffiti—no significant impacts	• Increased fire scenario could result in exposed sites • Benefits to pictographs and historical graffiti

Table 6 (continued). Scenario planning workgroup-envisioned developments and resource implications for Devils Tower NM climate-resource scenarios for each priority resource and resource component.

Priority resource	**Resource component**	**Spearfish**	**Still DETO**	**Blazin' Hot**	**Western Kansas**
Vegetation	–	• Increased productivity • Decreased fire risk & prescribed fire difficult • More pine, maybe more species of conifers (increased spruce) • Thick stands increase mountain pine beetle (MPB) risk but trees are less susceptible • Oaks increase but disease and pests increase? • Cottonwoods happy • Ash trees extirpated by emerald ash-borer (EAB) • Ethnographic plants increase growth but may be outcompeted by exotics • Cool-season invasives do well	• Increased productivity b/c of spring rain • Increased fire risk in fall b/c of spring growth and dry fall • Pine mortality risk is lower • MPB risk is lower • Oaks do OK • Cottonwood recruitment decreases less, less flooding • Ash trees extirpated (by EAB) • Less change to ethnographic plants in this scenario • Cool-season invasives love this • Overall, relatively good for native plants; possible increased fire but increased cool-season invasives	• No change in productivity? • Increased fire • Decreased ponderosa establishment and survival in fires • MPB decreases with decreased tree density but trees are stressed • Oaks decrease due to summer drought • Cottonwood same or worse • Ash trees extirpated (by EAB) • Ethnographic plants OK (many are drought-tolerant) • Cool-season invasives do well • Phenology mismatch increases variation in green-up (warm temps in winter) • Highly favorable for cheatgrass	• Decreased productivity • Increased fire, more drought so less fuel. Long fire season • Ponderosa decreases due to drought • MPB increases, trees are stressed but fewer trees • Oaks potentially disappear with drought • Cottonwoods sad • Ash trees extirpated (by EAB) • Ethnographic plants decrease • Cool-season invasives do poorly

Table 6 (continued). Scenario planning workgroup-envisioned developments and resource implications for Devils Tower NM climate-resource scenarios for each priority resource and resource component.

Priority resource	**Resource component**	**Spearfish**	**Still DETO**	**Blazin' Hot**	**Western Kansas**
Wildlife	–	• Increased bats, aquatic life, land-snails, and amphibians • Increased Chytrid, decreased frogs • Increased herbivores, both rodents and ungulates • Birds—decreased nest success, but good insect prey • Zoonotic and wildlife disease: West Nile, tularemia, insect-vectors • Phenotypic mismatch • Increased sediment leads to biocontaminants in prey (ag. nutrients and decreased runoff) • Slug invasion? • Possible change in pollination	• Overall, good for amphibians and birds, not good for mammals • Potential increase in amphibians due to increased water, but note that Chytrid would likely increase as well • Increased nest success due to fewer heavy (>1 inch) precip. events • Increased risk of hemorrhagic disease outbreaks due to midges increase with increased wet, increased temps, decreased days <32 °F • Increased flea and tick population due to increased precip. in spring = increased plague, tularemia • Phenological mismatch for migratory birds and insect hatches • Possible change in pollination	• Insects would do well—including pest species • Increase in reptiles • Forage/browse quality reduced • Less prey for raptors, mesocarnivores, and snakes • Increase or decrease in fires depending on intensity and frequency • Phenological timing/mismatch migration • If shoulder-season climbing increases, disturbance to overwintering bats would increase if research results prove the bats to be there • Possible change in pollination	• Amphibian habitat declines, potential population declines • Peregrines do well • Increased prairie dog diseases (but favorable winter condition) • Reduced forage quality • Porcupines may suffer from fires—no food • Insect and disease increases • Landscape-level habitat changes—higher variability in herbivore habitat occupancy • Phenological mismatch • Possible change in pollination

Table 6 (continued). Scenario planning workgroup-envisioned developments and resource implications for Devils Tower NM climate-resource scenarios for each priority resource and resource component.

Priority resource	Resource component	Spearfish	Still DETO	Blazin' Hot	Western Kansas
Aquatic Resources	General	• Increased flooding throughout the park • Increased rain-on-snow events in early spring • Decreased water quality from contaminants and turbidity • Increased erosion along storm water drainage (culverts washing out, etc.) • Flooding exacerbated by inadequate culvert size	• Potential impacts from increased fossil fuel energy development (decreased spring flow and/or decreased park water supply)—however, this is speculative • Decreased water quality from urban and agricultural runoff • Earlier snow melt	• Possible HAB (harmful algal bloom) occurrence in springs or river • Dry conditions = negative on amphibians and aquatic inverts • Increased runoff events and erosion during the extreme precipitation events (from drier soil, <veg)	• Decrease in flooding relative to Spearfish and Blazin' Hot scenarios • Possible HAB
	Springs & wetlands	• Increased spring flow • Increased spring flow seasonality (those that dry occasionally may no longer do so) • Wetlands expand • More ice-free days at springs/wetlands (benefit for wildlife) • Tarpot Spring—where the water now sinks (meadow west of housing area), it would flow above ground toward river and affect infrastructure	• Graham Spring could dry up in late-summer/fall • More ice-free days at springs (compared to historical, but least relative to the other scenarios) = benefit to wildlife • Reduced flow in springs in late summer/fall	• Wetland retreat at Tarpot Spring • Ice free in winter at Tarpot Spring • Graham Spring could be dry in fall and summer • Decreased water quality	• Ice-free conditions at springs • Dry conditions at Graham Spring • Wetland retreat at Tarpot Spring in summer • Low DO (dissolved oxygen) in springs

Table 6 (continued). Scenario planning workgroup-envisioned developments and resource implications for Devils Tower NM climate-resource scenarios for each priority resource and resource component.

Priority resource	**Resource component**	**Spearfish**	**Still DETO**	**Blazin' Hot**	**Western Kansas**
Aquatic Resources (continued)	Belle Fourche River	• Increased river flood frequency/intensity • Increased river bank erosion (river bank is park boundary in places) • Increased releases from dam	• Increased flood frequency • Potential increased river bank erosion (note: park boundary is river bank—loss of acreage as bank erodes)	• Potential for ice-free conditions year-round • Earlier releases from dam, increased water temp and decreased flow = decreased DO (fish kill?) • Decreased water quality	• Less water • Low DO • Increased releases from dam • Possible shift to fish spp. that prefer warmer water
Visitors	–	• Wetter = more ticks and mosquitos, leading to worse visitor experience at times • Wetter = increased disease risk with potential impacts on visitors (tularemia) • Decreased climbing if wet? • Increased fall visitation (longer season)	• Increased visitation due to longer warm season that doesn't get too hot compared to other scenarios • More visitation hard to manage due to interannual variation in springtime arrival	• Shoulder seasons expand dramatically • Peak-season visitation increases b/c peak-season temps still amenable • More climbing in spring & fall; less in summer • More heat-related illness • Concern about visitor center capacity (i.e., more people might seek relief from the heat inside the visitor center)	• Shoulder seasons expand dramatically • Peak-season visitation increases b/c peak season temps still amenable • More climbing in spring & fall; less in summer • More heat-related illness • Concern about visitor center capacity (i.e., more people might seek relief from the heat inside the visitor center)

Using scenarios to test goals and actions

Climate change and other global change stressors not only challenge land managers' abilities to protect natural areas but also demand that we re-think conservation concepts, goals, and actions in a continuously changing world (Hobbs et al. 2010, NPS AB 2012, Fisichelli et al. 2016b). Climate change adaptation is, in simple terms, adjustment to changing conditions. It is, more formally, "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007).

Adaptation frameworks can be useful to structure thinking, incorporate climate change into decisions, and ensure that the full spectrum of adaptation options is considered. One such adaptation framework involves aligning goals and actions with climate change (Figure 22; adapted from Stein et al. 2014). This framework includes three categories: business as usual, climate retrofit, and climate rebuild. In "business as usual," current goals and actions are deemed appropriate and effective based on climate change implication assessments including the climate conditions and timeframe of the project. With "climate retrofit," current goals are retained, but achieving them under changing conditions will require revised actions. Finally, under "climate rebuild," neither current goals nor actions are tenable, and thus revisions to both are necessary for success.

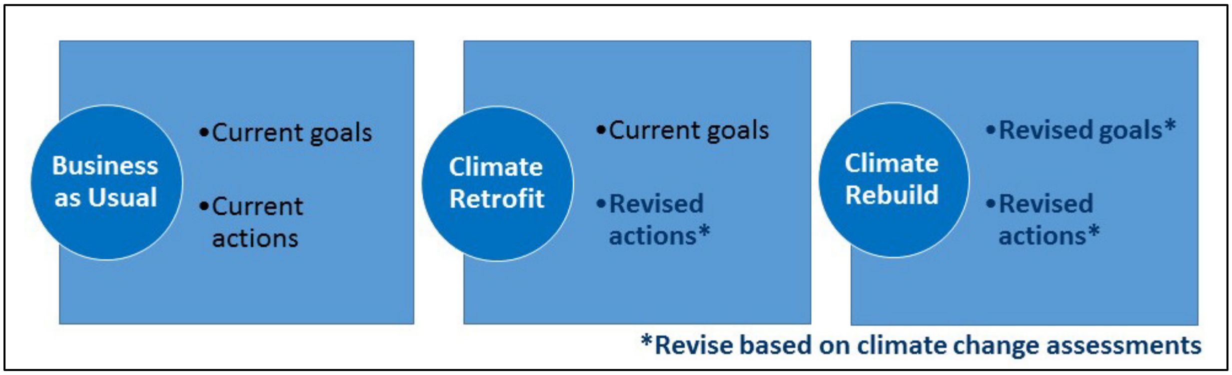

Figure 22. Aligning goals and actions in climate change adaptation. Depending on climate change impacts and implications, adaptation will vary from keeping current goals and actions to revising both. Figure adapted from Stein et al. (2014).

As goals and actions are evaluated and revised, it is worth considering whether they seek to resist, accept, or direct change (adapted from Fisichelli et al. 2016b; see also Millar et al. 2007, Stein et al. 2014). This step encourages clarity and transparency regarding the ultimate intended outcomes of a particular management action or program. "Resist change" strategies aim for persistence by maintaining current or past conditions. A "direct change" strategy actively shapes a trajectory of change in a resource towards new, specific desired conditions. In an "accept change" strategy, the resource responds to climate change, and management intervention supports its capacity to do so without seeking to alter the trajectory of change. There is no single adaptation option that is appropriate in all situations; rather, the appropriate strategy will vary across resources, space, and time. For example, many persistence-oriented strategies are suitable in the near term but are likely to become increasingly risky and costly as time goes on (Millar et al. 2007). Management response to climate change therefore needs to be continuous and continually reassessed.

Inland fisheries management provides a useful example of the application of these frameworks. If maintaining a cold-water fishery (goal) through annual stocking (action) is feasible given the range of projected changes in conditions, then the current approach—i.e., "business as usual"—remains viable. Under warming conditions, this goal may still be achievable but require revised actions (i.e., "climate retrofit") of more frequent stocking and stream shading. Assuming an extremely climate-vulnerable fishery, the existing goal of a cold-water fishery may not be achievable using any available adaptation actions. Under a "climate rebuild," a revised goal may be to instead to direct change towards new conditions and establish a cool-water fishery, with the action of managed relocation of cool-water species.

Scenarios provide a platform for strategic conversations about aligning goals and actions in the context of change and uncertainty. Most commonly, scenarios help teams generate ideas about what they might do or change under a new set of conditions, as well as identify indicators to monitor to detect changing conditions and adjust actions. In the context of climate change adaptation, scenarios provide the setting for examining the efficacy of a range of management responses across a range of plausible climate futures. In conditions under which existing plans and options fall short, scenarios can be used to help revise current options and develop new ones. The result is sets of options for each scenario and resource, some of which will be common to all futures, whereas others will be unique to the particular conditions of a given scenario or subset. This type of exercise can generate a portfolio of options, where the investment in specific options is anticipated to shift over time as the future plays out.

After we presented the above information to participants in the scenario planning workshop, the group broke again into resource specialty subgroups (Appendix 1) to examine current management goals and actions for each aspect of that resource in light of the resource implications under each climate-resource scenario (resource implications detailed in Appendix 8). Devils Tower NM Chief of Resource Management Rene Ohms also examined the topic of visitor enjoyment and well-being. The results of these assessments are summarized in Table 7 and described in detail in the following text; both the table and the text are derived from workshop results transcribed in Appendix 9.

Table 7. Resource subgroups' assessments of the achievability of current goals with current actions, versus needed revisions by mid-century for nine resources and management concerns (see Appendix 9 for details). The adaptation responses shown in the table below include "Business as Usual" (current goals and actions), "Climate Retrofit" (current goals and revised actions), and "Climate Rebuild" (revised goals and actions) (Figure 22). Rows with more than one entry (e.g., "Retrofit, Rebuild") for a given scenario indicate short-term (ST) and long-term (LT) responses. See text that follows this table and Appendix 9 for details of each resource's current and revised goals and actions.

Resource or management concern	**Goals***	**Spearfish**	**Still DETO**	**Blazin' Hot**	**Western Kansas**
Cultural resources	Historic structures—maintain integrity and utility	Retrofit	Business as Usual	Retrofit	Retrofit
	Ethnographic resources—embrace cultural history & resource uses	Business as Usual	Business as Usual	ST - Business as Usual LT - Retrofit	ST - Business as Usual LT - Retrofit
	Archeological resources—protect and document	Retrofit	Business as Usual	Retrofit	Retrofit
Vegetation	Upland vegetation—maintain pine forest/ prairie landscape	Retrofit	Business as Usual	ST - Retrofit LT - Rebuild	Rebuild
	Riparian forest—improve condition	Business as Usual	Rebuild	Rebuild	Rebuild
	Nonnative plants—keep at low abundance	Rebuild	Rebuild	Retrofit	Rebuild
Aquatic Resources	Springs and wetlands—restore to natural/well-functioning condition	Retrofit	Rebuild	Rebuild	Rebuild
Wildlife	Wildlife—maintain historical communities	Rebuild	ST - Business as Usual LT - Rebuild	ST - Business as Usual LT - Rebuild	ST - Business as Usual LT - Rebuild
Visitors	Visitor experience—provide safe and enjoyable experience	ST - Business as Usual LT - Retrofit	ST - Business as Usual LT - Retrofit	ST - Business as Usual LT - Retrofit	ST - Business as Usual LT - Retrofit

*Goal descriptions are abbreviated; see Appendix 9 for full goal statements.

Cultural resources

Historic structures

Devils Tower NM historic structures include Civilian Conservation Corps (CCC) buildings, Mission 66 buildings, trails, roads, culverts, and the 1893 stake ladder. The overall goal for all but the stake ladder is to maintain integrity and utility through cyclical maintenance, and this broad goal was seen as achievable in the near term and long term under all scenarios; however, major additional actions may be needed. Heavier precipitation events in Spearfish pose flooding threats to buildings and other infrastructure, and they call for more frequent gutter maintenance and a hydrological study of the park's culverts. The two warmest and driest scenarios—Western Kansas and Blazin' Hot (Figure 19)—pose increased fire risks, and therefore both call for increased defensible space around structures and increased emergency response capabilities (e.g., building wraps). With regard to the stake ladder, the park has already recognized ongoing degradation of this exposed wooden resource and the need to make a decision regarding how to respond (Appendix 9), and scenario work did not alter this need.

Ethnographic resources

The management goal for ethnographic resources—including the tower formation itself—is to embrace the cultural history and resource uses of this culturally important site. Major supporting actions include working closely with tribes, training employees, and continuing the June voluntary climbing closure. The only changes the resource subgroup suggested were additional actions of enhanced emergency response under the two warmer scenarios (Western Kansas and Blazin' Hot) to address substantial increases in the frequency of high-heat-index days (Figure 14).

Archeological resources

Archeological resources at Devils Tower NM consist mostly of abundant lithic scatters, and the overall management goal is to protect known sites and document new ones. Key supporting actions are to implement the NPS ASMIS (Archeological Sites Management Information System) protocol and communicate with tribes regarding archeological work. A major potential challenge to this goal is an increase in the rate of exposure of new sites, which could be brought about by (1) wildfires driven by drier conditions (Western Kansas and Blazin' Hot) (Figure 19), and (2) increases in the frequency of heavy precipitation events, as seen for Spearfish (including a near doubling of the historical frequency of 1-inch events) and Blazin' Hot (Figure 18). Three of the four scenarios therefore include the prospect of increased rates of exposure—with Blazin' Hot including both substantial increases in dry late-season conditions and frequency of heavy precipitation events—and the resource subgroup suggested the additional action of enhancing the park's capacity to document and protect new sites.

Vegetation

The overall current goal for vegetation management is to keep nonnative species at low abundance and maintain historical conditions or get as close as is feasible, using a variety of approaches including prescribed fire, chemical and mechanical treatments, grazing, and restoration. Across all scenarios, however, historical vegetation conditions become much more challenging to maintain or achieve in the long term, and the resource subgroup identified the need to revise resource component goals under most scenarios. Targeted monitoring will be necessary to understand the rates and nature of these community changes and the forces that drive them.

Upland vegetation

Upland vegetation at Devils Tower NM is a mosaic of ponderosa pine forest, pine woodland, and open prairie meadows. Bur oak occurs in the forest understory in some locations, particularly along drainages. The current management goal is to maintain this historical landscape condition, with prescribed fire being an important supporting action, and precipitation and soil moisture being important environmental influences on this ecotone. The resource subgroup determined that the enhanced rainfall (relative to historical conditions) in the Spearfish scenario in spring and to some degree in summer would challenge this goal and contract prairie patches (as ponderosa pine forest encroaches), but that this change could be resisted via the additional action of increased prescribed fire frequency and thinning. Still DETO was deemed similar enough to current conditions that current goals and actions are appropriate, but for the warmer and drier scenarios (Blazin' Hot and Western Kansas) in the long term, pines are likely to be lost from much of the park in favor of grassland, suggesting the need for a revised goal that accepts this change. The subgroup did suggest the possibility that this change could be resisted in places via irrigation of trees. Finally, an option not explored at the workshop but suggested later arose from research by Diana Six (University of Montana) of identifying and protecting trees that are genetically resistant to drought.

Riparian forests

Riparian forests at Devils Tower NM consist of plains cottonwood (Populus deltoides) and green ash stands along the Belle Fourche River floodplain on the southeast side of the park (Figure 3). Riparian forests are strongly influenced by hydrology and flooding regimes, and the park's cottonwood stands lack regeneration primarily because an upstream dam has drastically reduced flooding. In addition, the park's green ash face almost certain extirpation due to the emerald ash borer, which occurs in Colorado and was recently found in Nebraska and South Dakota (USDA 2019). With these non-climate threats and stressors in mind, the resource subgroup assessed the current riparian forest management goal—improving the forest's condition. The subgroup recognized that these systems will inevitably transform due to the emerald ash borer and that only one scenario—Spearfish—involved improving conditions for Devils Tower NM cottonwoods (Appendix 8). The subgroup suggested that (1) under the other three scenarios, goals would have to be revised to accept the decline or disappearance of cottonwoods, (2) Blazin' Hot conditions might still allow for the encouragement of oaks, and (3) under Western Kansas conditions this system might lack tree species unless species new to the park arrived from elsewhere.

Nonnative plants

The nonnative plant management goal is to keep exotic plant abundances low. Projected changes in seasonal precipitation and soil moisture led the resource subgroup to conclude that the current goal is untenable in three scenarios—Spearfish, Still DETO, and Western Kansas—and warrants revision to prioritize/focus weed control and restoration on specific high-value areas, and otherwise accept the occurrence of some nonnative species. For Blazin' Hot, the subgroup felt that the current goal could perhaps still be achieved with additional actions of increasing capacity for prevention, early detection, and rapid response to eradicate new invaders.

Aquatic resources

For this goals-and-actions review process, the resource subgroup focused exclusively on aquatic resources under Devils Tower NM management control—i.e., springs and wetlands—and did not consider the Belle Fourche River. The park's springs and wetlands are important microhabitats and resources for a wide diversity of species and are the subject of research to better understand their hydrology. The current goal for these resources is to restore them to natural and well-functioning condition; this is a long-term goal, so the "achievable in the short term?" question does not apply. The subgroup deemed the goal feasible in the long term under the wettest scenario—Spearfish. In contrast, the subgroup concluded that the substantially drier conditions under Western Kansas, Blazin' Hot, and Still DETO would require revising the goal and actions. Specifically, the subgroup suggested accepting the decline (Still DETO) or outright loss (drying up) of all springs except Tarpot Springs (Western Kansas?, Blazin' Hot). For the two hottest and driest scenarios (Western Kansas and Blazin' Hot), the subgroup suggested additional/new actions of retaining (rather than the currently proposed action of removing) some of Tarpot spring's water-collection infrastructure (e.g., tiles and pipes), and—if resources, permitting, and compliance issues allow—providing guzzlers at the spring exit and planting trees adapted to emerging climate conditions to provide additional shading to reduce evaporation.

Wildlife

Wildlife at Devils Tower NM is diverse and includes the federally listed (threatened) northern long-eared bat (*Myotis septentrionalis*), mountain lions (*Felis concolor*), black-tailed prairie dogs (*Cynomys ludovicianus*), ungulates, amphibians, and peregrine falcons (*Falco peregrinus*). The park's wildlife goal is to maintain historical assemblages, and this goal is supported by a wide variety of actions including inventory and monitoring (both standard protocols and disease-focused), fire (monitoring, prescriptions, and structural protection planning), wildlife-human interaction mitigation, research, and a diversity of management plans.

As this resource subgroup pointed out, the goal of maintaining historical wildlife assemblages is challenged by ongoing climate change-driven changes in wildlife abundance and distribution (e.g., Staudinger et al. 2013, Pecl et al. 2017). The blue-gray gnatcatcher (*Polioptila caerulea*) is an example: birds are highly mobile and early indicators of climate change impacts on climate suitability for species (Wu et al. 2018), and this small bird has been expanding northward for some time and has been documented in the park in recent years. Should this species be accepted at the park or should its arrival be resisted? Ultimately, this reality of ongoing species range shift led the wildlife resource subgroup to conclude that substantial climate change-driven changes in Devils Tower NM species assemblages—including changes in abundance and losses of historical species, and arrivals of species that haven't been seen in the park before—makes the overall goal for this resource increasingly infeasible for all scenarios. The subgroup therefore called for revision of this goal across all scenarios to account for ongoing and projected climate change-driven shifts in distributions of North American species.

Wildlife disease, which is difficult to predict due to its ecological complexity, is a major management concern because climate change may be a strong influence. Increased zoonotic and wildlife diseases were the dominant concerns under the wet scenario (Spearfish), in which the subgroup suggested additional actions of refining and expanding the park's disease outbreak response protocols to address new diseases and mentioned the Devils Tower Black-Tailed Prairie Dog Management Plan/Environmental Assessment (NPS 2013b) in particular. For the two warmer scenarios—Blazin' Hot and Western Kansas—the subgroup suggested that the drier conditions could lead to expansion of the prairie dog town. Consequently, the subgroup suggested that such an expansion may call for more intensive prairie dog management. For Blazin' Hot, they also suggested reevaluating forest health and IPM (integrated pest management) responses/mitigation and reassessing the climbing management plan to address potential impacts to bat hibernacula. Finally, it should be noted that the dependence of fish and wildlife on ecological context (e.g., vegetation and hydrology) required that this subgroup build on findings from the vegetation and hydrology subgroups, a complicating factor that was not accounted for in initial workshop design.

Visitors

The annual total number of visitors to the park has hovered around a half-million over the past few years, representing a substantial increase from the recent past. The increase is due largely to increasing population in the area related to the recent fossil-fuel boom, but visitation is also influenced by temperature (Fisichelli and Ziesler 2015), and the park has seen an expansion of their "shoulder seasons" in recent decades. Visitors are not only a focus of park management and operations, but—when concentrated in sensitive areas—can also negatively impact park resources. The park goal for visitors—a safe and enjoyable experience—is supported by a range of actions and programs including emergency medical services (EMS), search and rescue, outreach and education, public announcements, exotic plant treatments in areas frequented by visitors, and interpretive programs. The review found that this broad goal would remain feasible under all scenarios, but that it would require additional supporting actions. For Spearfish, the wettest and most torrential scenario, the subgroup suggested increased need for response to fleas, ticks, and mosquitos and associated diseases; advance notice for storm events; and enhanced ranger response capabilities (evacuations, etc.). For Still DETO, the review identified a need for additional staffing to manage earlier spring visitation. For the two warmest scenarios, additional suggested actions included increasing EMS response capacity for heat-related illnesses and increasing staffing and search and rescue response capability to address substantially expanded shoulder-season visitation, climbing, and associated potential impacts to resources.

Operationalizing climate change scenario planning outcomes

The next step in the climate change adaptation process is operationalizing insights derived from scenario planning into climate-informed management planning and implementation. In the case of Devils Tower NM, the climate adaptation core project team engaged with natural and cultural resource planners and resource managers in developing an RSS for the park (NPS 2019a). Materials and insights from this scenario planning process, including a draft of this report, directly informed multiple steps of the RSS process, including identifying key threats and stressors and developing stewardship goals and activities. Incorporation of scenario implications into two RSS planning workshops also provided the opportunity for participants to verify and update the results presented here. NPS planners and project team members are drawing on this first-of-its-kind pilot project to develop guidance (NPS 2019b) for integrating climate change scenario planning into the RSS development process, and the following thoughts provide insight into the process of operationalizing scenario planning outcomes.

A portfolio of management options based on divergent scenarios typically includes both familiar management actions and new or challenging ideas. Evaluating and categorizing options as “no-brainers,” “no-gainers,” “no regrets,” and “hard choices” can help facilitate adaptation (NPS 2013a). “No-brainers” are currently implemented actions that are likely to continue to be effective. “No-gainers” are current actions that are unlikely to be beneficial for achieving desired outcomes under any future scenario. “No regrets” actions are likely to be successful in achieving desired outcomes under all future scenarios (e.g., control invasive species). “Hard choice” options may be controversial, complicated, difficult to implement, or take time to execute, and they would need to be considered carefully. For example, the balance between forest and meadow, and ensuring that some meadows remain unforested, is a priority for the park. Recognizing changes in this balance and the extent of specific meadows—changes that the scenario planning workshop suggested would occur in any of the scenarios (although in different directions)—requires a new, no-regrets action of developing and implementing monitoring methods to detect these changes.

Organizing these potential actions into a management strategy requires consideration of risks, risk tolerance, available resources (e.g., funding and staff), and priorities (e.g., NPS 2013a, Maier et al. 2016, Rowland et al. 2014). In some situations, the potential actions may be relevant across all scenarios and can collectively form a strategy that is robust to all scenarios. Or, it may be appropriate to “hedge bets” against multiple scenarios by investing in diverse actions that are each beneficial under a particular climate future. For example, Devils Tower NM may increase defensible space around buildings to address elevated wildfire risks under the hotter and drier scenarios while also addressing possible flooding under the wetter Spearfish scenario. Or, a park may hedge its bets while emphasizing response to one particular scenario (a “core/satellite” strategy). Or, it may “bet the farm” on one particular scenario by investing in actions that are relevant to one expected future. Effective, scenario-based management responses also often require organizing actions temporally. Some actions, for example, are “contingent,” such that they would only be useful in addressing a subset of scenarios; these actions—although important to identify and prepare for now—would only be applied in response to emergence of specific conditions expressed in that subset. On the other hand, some actions may be robust to all scenarios but cannot be applied today because “bridging” or “transition” actions must be carried out first. An approach that explicitly considers temporal sequencing and complementarity is important for revealing activities that need to be completed in advance (e.g., permitting), or identify decision points where indicators of high-impact changes in climate or other conditions might warrant shifting actions.

Scenarios also provide accessible storylines that lend themselves to outreach and communication about the risks and challenges linked with management decisions in the face of very different potential future climate and socio-economic conditions. Sharing such descriptions with expanded stakeholder groups can be an important precursor, particularly for public agencies, to implementing the changes that some future trajectories might require.

Conclusion

This project's overall goal was to engage resource managers and scientists in climate change scenario planning so that their management and planning decisions will be informed by assessments of critical future climate-related uncertainties. Specifically, we pioneered an approach for including robust climate-resource scenarios in a comprehensive NPS planning process—development of a park's Resource Stewardship Strategy (RSS). As documented in this report: we (1) synthesized climate projection information for the park into four plausible, relevant, and divergent potential futures; (2) built on these climate futures to develop climate-resource scenarios through a participatory scenario planning process; and finally (3) brought these climate-resource scenarios into the RSS process.

This pilot effort, including the scenario component documented here and the RSS supplemental guidance (NPS 2019b) we are developing to describe how to incorporate climate change scenario planning outcomes into an RSS, has accomplished several things. First, for the park, robust climate-resource scenarios and park staff's enhanced understanding of climate change can continue to inform natural and cultural resource management at Devils Tower NM, whether through ongoing updates of the park's RSS or in more specific plans and actions. Second, these scenarios can inform Devils Tower NM management and planning beyond natural and cultural resources, including facilities, operations, and the visitor experience. More broadly, this successful and well-documented effort to link climate change scenario planning with natural and cultural resource management planning and action in a major Federal land management agency can serve as a model for others to build upon.

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Appendix 1. Scenario planning participants

Table A1-1. Titles and affiliations of all in-person scenario planning participants, as well as indications of which workshop(s) each attended and, for those who attended the scenario planning workshop, their resource-specialty subgroup. Both workshops took place in the Best Western Devils Tower Inn in Hulett, Wyoming. Check marks (✓) indicate that the workshop was attended by that person.

Name	Title	Affiliation*	Scenario planning workshop (29 Mar 2018)	Resource Stewardship Strategy workshop 1 (1–2 May 2018)	Scenario planning workshop resource-specialty subgroup
Isabel Ashton	Vegetation Ecologist	NPS-NGPN	✓	–	Vegetation
Jim Cheatham	Environmental Protection Specialist	NPS-ARD	–	✓	–
Amber Runyon	Research Associate	NPS-CCRP	✓	–	Aquatics
Amy Hammesfahr	Wildlife Biological Science Technician	NPS-DETO	✓	✓	Wildlife
Amanda Hardy	Wildlife Biologist	NPS-CCRP/BRD	✓	–	Wildlife
Justin Henderson	Project Manager - Planning Division/Cultural Resources Specialist	NPS-DSC	✓	✓	Cultural resources
Richard Lambert	Chief of Maintenance	NPS-DETO	–	✓	–
Brian Miller	Research Ecologist	USGS-NC CASC	✓	–	N/A (Facilitator)
Rene Ohms	Chief of Resource Management	NPS-DETO	✓	✓	Aquatics & Visitation

*ARD = Air Resources Division, CCRP = Climate Change Response Program, DETO = Devils Tower National Monument, DSC = Denver Service Center, IMRO = Intermountain Regional Office, NC CASC = North Central Climate Adaptation Science Center, NGPN = Northern Great Plains Inventory and Monitoring Program Network, NPWRC = Northern Prairie Wildlife Research Center. Miller and Schuurman facilitated group activities and did not join subgroups.

Table A1-1 (continued). Titles and affiliations of all in-person scenario planning participants, as well as indications of which workshop(s) each attended and, for those who attended the scenario planning workshop, their resource-specialty subgroup. Both workshops took place in the Best Western Devils Tower Inn in Hulett, Wyoming. Check marks (✓) indicate that the workshop was attended by that person.

Name	Title	Affiliation*	Scenario planning workshop (29 Mar 2018)	Resource Stewardship Strategy workshop 1 (1–2 May 2018)	Scenario planning workshop resource-specialty subgroup
S. Tom Olliff	Great Northern LCC Co-Coordinator/NPS IMR Chief, Landscape Conservation and Climate Change	NPS-IMRO	✓	–	Cultural resources
Robin O'Malley	Director	USGS-NC CASC	✓	–	Vegetation
Kara Painter-Green	Coordinator	NPS-NGPN	✓	✓	Vegetation
Gregor Schuurman	Climate Change Ecologist	NPS-CCRP	✓	✓	N/A (Facilitator)
Sue Skrove	Acting Superintendent/ Administrative officer	NPS-DETO	✓	–	Cultural resources
Sharla Stevenson	Hydrologist	NPS-IMRO	✓	✓	Aquatics
Nancy Stimson	Chief of Interpretation	NPS-DETO	–	✓	–
Amy Symstad	Research Ecologist	USGS-NPWRC	✓	✓	Vegetation
Don Wojcik	Natural Resource Specialist - Planning Division	NPS-DSC	–	✓	–

*ARD = Air Resources Division, CCRP = Climate Change Response Program, DETO = Devils Tower National Monument, DSC = Denver Service Center, IMRO = Intermountain Regional Office, NC CASC = North Central Climate Adaptation Science Center, NGPN = Northern Great Plains Inventory and Monitoring Program Network, NPWRC = Northern Prairie Wildlife Research Center. Miller and Schuurman facilitated group activities and did not join subgroups.

Appendix 2. How we used the NPS Cultural Resources Climate Change Strategy for Devils Tower NM scenario development

The NPS Cultural Resources Climate Change Strategy (Rockman et al. 2016; hereafter referred to as "the Strategy") is an important resource for addressing potential climate change impacts to cultural resources. We used the Strategy's compendium of NPS cultural resource sensitivities (described as "impacts" in the Strategy)—i.e., the Climate Change Impacts to Cultural Resources table (referred to as Graphic 2)—to flesh out Devils Tower NM cultural resource sensitivities. The Strategy describes this compendium as a tool derived from "literature review and consultation with cultural resource management specialists from across the NPS" that can be used to identify "the broad range of climate impacts to cultural resources, subtle to dramatic and coastal to interior, so that they can be included in stewardship." We screened each park cultural resource identified in the fall 2018 orientation against this compendium, then re-named and characterized each in a manner consistent with the Strategy. We also added sensitivities identified in the compendium that we had missed. The Strategy's compendium is broken into four distinct tables reflecting four broad classes of cultural resource climate sensitivity—temperature change, precipitation change, sea-level rise, and combined stressors. For landlocked Devils Tower NM, we created separate spreadsheets for temperature, precipitation, and combined stressors. Each spreadsheet included: (1) a row for each unique aspect of change that could apply to the park's cultural resources, and (2) columns for Devils Tower NM cultural resources. We subdivided the park's cultural landscape resources to align with the Strategy's categories of archeological resources, cultural landscapes, ethnographic resources, and buildings and structures. We then copied and pasted specific plausible resource sensitivities from the Strategy's tables into the corresponding cells of each spreadsheet.

Devils Tower NM Chief of Resource Management Rene Ohms reviewed the spreadsheets to identify which sensitivities are real concerns to the park and the most important (critical) of these. Although all of the sensitivities would ultimately be addressed in climate-resource scenarios, the critical sensitivities were used to develop the divergent climate futures that served as the basis for the scenarios.

Literature cited in Appendix 2

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Appendix 3. Water balance modeling details

We used a spreadsheet-based water balance model developed by David Thoma (NPS) to translate climate projection data into water availability metrics. Specifically, climate input for the model consists of monthly mean maximum and minimum temperatures and monthly total precipitation, which we obtained directly from the MACA-downscaled data for a single cell (Figure A5-1, Appendix 5). The model also requires site characteristics (modeled slope and aspect, and mapped soil types' water holding capacity for the top 1 meter of soil), which we obtained for six randomly selected sites in Devils Tower NM (see Figure A3-1). The model runs separately for each site and output is then averaged across all sites.

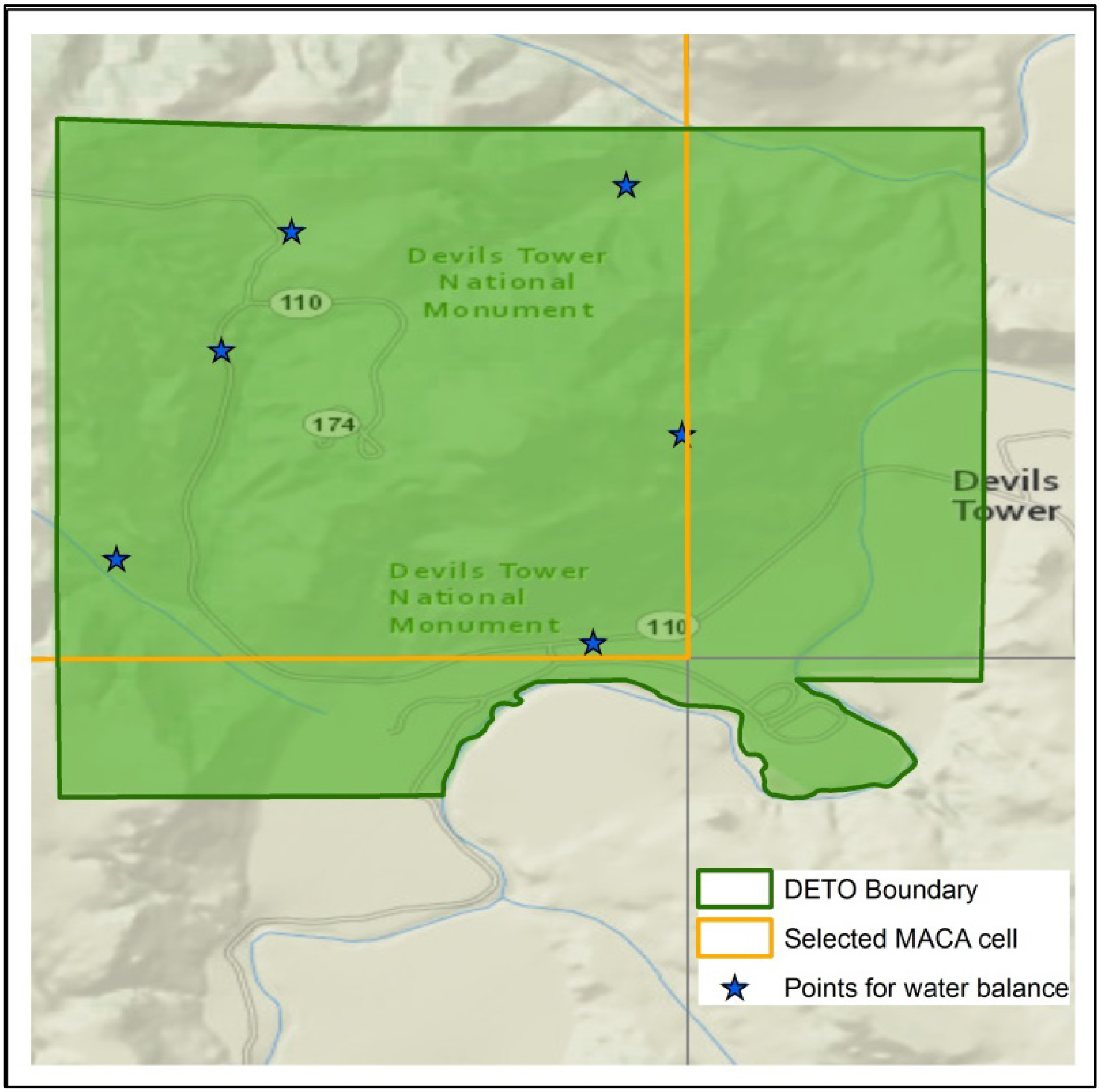

Figure A3-1. Randomly selected Devils Tower NM sites used for water balance modeling.

The water balance model is a simple “bucket model” that represents inputs and outputs of the hydrologic cycle, with soil moisture acting as the reservoir. Precipitation enters the system either as rain or snow, and site characteristics (described above) and temperature determine the proportion that leaves the system through potential evapotranspiration (PET). PET is calculated using the Thornthwaite (1948) method, which uses temperature to estimate water loss from evapotranspiration while assuming that water is not limiting. If water in the soil exceeds the water-holding capacity at the site, that excess minus actual evapotranspiration (AET) is calculated as runoff/groundwater infiltration (also referred to as excess moisture). Because the model estimates the water balance in the system, it does not differentiate between these two hydrological processes for water leaving the system. Soil moisture is calculated as the portion of the precipitation event that remains in the top meter of soil (i.e., is not lost to evaporation, runoff, or infiltration to deeper soil layers) plus the antecedent soil moisture.

The climatic water deficit (Stephenson 1998) is calculated by estimating AET, or the actual amount of water that could be extracted from the soil, given precipitation, and subtracting it from precipitation. Climatic water deficit (also referred to as water deficit) is an estimate of drought stress on soils and plants, and can be interpreted as the amount of additional water that would have evaporated or transpired had it been present in the soils. Thus, higher values demonstrate less water in the system for evaporation or transpiration.

Literature cited in Appendix 3

Stephenson, N. 1998. Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales. Journal of Biogeography 25:855–870.

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Appendix 4. Freeze-thaw cycling and calculation methods

Resource managers at Devils Tower NM were interested in how plausible climate futures may influence rock exfoliation (otherwise known as spalling) and impact other cultural resources in the park. Two aspects of climate are known to affect rock exfoliation—changes in freeze-thaw cycles (Fraser 1959, Hall and André 2001, Hall 2004) and diurnal fluctuations between summer daily high and low temperatures (Collins and Stock 2016). Mechanisms that drive effects of summer temperature fluctuations on rock exfoliation are not well known and no empirical analysis has been performed outside of Yosemite National Park (Collins and Stock 2016). However, the effects of freeze-thaw cycles on lithic and cultural resources have been well studied, making freeze-thaw cycling an appropriate indicator for changes in the park under varying climate futures.

Because freeze-thaw can be measured in several different ways (e.g., days where temperature goes above and below freezing, days where temperature fluctuates around some predetermined buffer around freezing [e.g., ±2 degrees], days with rain followed by a hard freeze), we conducted a literature review of how freeze-thaw has been measured to determine appropriate metrics for park-specific resources. Specifically, we performed a Google Scholar search for "freeze-thaw daily temperature weathering" and we kept for further evaluation documents that use daily weather data to analyze some element of freeze-thaw cycling. We also relied on expertise from NOAA/North Central Climate Adaptation Science Center climate scientist Imtiaz Rangwala to inform an additional metric that we considered for analysis.

Climate data available to calculate metrics were daily maximum and minimum temperature, daily maximum and minimum relative humidity, and daily precipitation. Therefore, we evaluated only metrics that can be calculated using these data. Baker and Ruschy (1995) provide a review of nine published methods to calculate freeze-thaw cycle frequency. Similarly, Grossi et al. (2007) reviewed six freeze-thaw measures and discussed their application to evaluating how changes in freeze-thaw processes due to climate change can damage historic structures. These two comprehensive reviews of freeze-thaw metrics provided a foundation for determining appropriate metrics for Devils Tower NM. Table A4-1 provides a summary of methods used to obtain estimates of freeze-thaw cycles. Unless otherwise noted, the methods are discussed by Baker and Ruschy (1995) and the observation period for all methods presented in the table is a calendar day.

Methods based on a once-per-day reading (or estimate) of maximum and minimum temperatures and daily precipitation are suitable for use with daily climate data, but they are limited in their ability to measure multiple freeze-thaw cycles in a single day. The one method that uses hourly data (Method 9, Table A5-1) provides more insight into fine-scale freeze-thaw patterns, but we did not consider it further because it is incompatible with the available downscaled climate data.

We discussed potentially useful methodologies with climate and cultural resource experts to determine their utility in addressing the research question. We discussed with Imtiaz Rangwala the appropriateness of using downscaled daily climate data for this analysis, and he confirmed that comparisons can be made between averages over long time periods and used as estimates of change. He also suggested exploring an additional, unpublished method to capture the large amount of energy required to cause rock fracture. This method (Method 11, Table A4-1) focuses on freeze-thaw cycles that occur over a slightly longer period of time, so that there is enough time for the impact of accumulated heat to be expressed. A cultural resource expert—Marcy Rockman of the NPS Climate Change Response Program—directed us to The Atlas of Climate Change Impact on European Cultural Heritage (Sabbioni et al. 2010), which specifically addresses methodologies for evaluating climate impacts. This reference drew attention to the wet-frost metric (Method 11, Table A4-1) as one that appropriately captures damaging climate effects on cultural resources.

Table A4-1. Calculation methods used to characterize freeze-thaw cycle frequency.

Method	Description
1	Maximum temperature ≥0 °C (32 °F) and minimum temperature ≤-2.2 °C (28 °F) in observation day (Schmidlin et al. 1987)
2	Maximum temperature ≥0 °C (32 °F) occurring after a minimum temperature ≤-2.2 °C (28 °F) (Russel 1943, Schmidlin et al. 1987)
3	A day with maximum temperature ≥0 °C (32 °F) and minimum temperature ≤0 °C (32 °F) (Vishner 1945)
4	Maximum temperature >0 °C (32 °F) and minimum temperature <0 °C (32 °F) in the observation day (Hershfield 1974, Connor 1979)
5	Maximum temperature >0 °C (32 °F) and minimum temperature ≤0 °C (32 °F) (Dale et al. 1981, Wexler 1982, Hayhoe et al. 1992)
6	Maximum temperature >1.2 °C (34.2 °F) followed by a minimum temperature <-2.2 °C (28 °F) (Fraser 1959)
7	Maximum temperature >0 °C (32 °F) after minimum temperature <0 °C (32 °F) (Fahey 1973)
8	Air temperature crosses 0 °C (32 °F) and returns to the original side (Hershfield 1974)
9[a]	Hourly temperatures cross 0 °C (32 °F) and return to the original size (Baker and Ruschy 1995)
10[b]	Frost intensity, which includes the length of time or temperature (Walder and Hallet 1985, Nelson and Outcalt 1987)
11 [b]	Wet-frost index: # rainy days (precip. >2 mm and temp >0 °C [32 °F]) followed immediately by days with mean temp <-1 °C (30.2 °F) (Sabbioni et al. 2010)
12 [c]	One cycle is a day with maximum temperature <0 °C (32 °F), followed by a day with minimum temperature >0 °C (32 °F), or vice versa

[a] Uses hourly data

[b] Added by Grossi et al. (2007)

[c] Added by expert elicitation

Ultimately, we determined that Methods 4, 6, and 11 in Table A4-1 were the most commonly used and robust indicators of freeze-thaw impacts on lithic resources and therefore considered them further.

We eliminated Method 4 (days crossing 32 °F) because so many days cross the freezing point annually at the park that we felt it unlikely that this was a major driver of rock exfoliation. Although Method 11 (wet-frost index) seemed to be a robust measure for potential impact on exfoliation, we did not choose it for two reasons. First, it diverged little among climate projections for the park; this is likely because many freeze-thaw cycles occur during fall months, a relatively dry time of year at Devils Tower NM. Second, the method showed little change from current conditions: average annual frequency for the historical period (1950–1999) was 18 cycles/year, and the range among climate projections for 2050 was 10 to 26 cycles/year. Ultimately, we chose Method 6—number of days/year in which Tmin <28 °F and Tmax >34 °F—which we refer to as the "buffer method" because a freeze-thaw event requires temperature to cross not only the freezing point in a single day, but also a six-degree (F) buffer around the freezing point. (We considered a similar metric that tallies the frequency of more dramatic day-to-day temperature swings [Method 12, Table A4-1] but rejected it because most years in Devils Tower NM climate projections had few [if any] fluctuations of this magnitude.) A buffer of 4 degrees (F) below freezing and 2 degrees above was expected to ensure that the day had enough time above and below freezing to allow energy transfer.

We discussed our freeze-thaw metric deliberations and ultimate choice with a geomorphologist actively engaged in studying rockfall at the park (Eric Bilderback, NPS Geologic Resources Division). He provided insights on interpretation of freeze-thaw effects on exfoliation, and explained that rockfall involves *triggers* (e.g., earthquakes, disturbance, lightening, etc.) and long-term *drivers* of rock deterioration that make those triggers more likely to lead to a rockfall event. We were interested in the drivers, which work on various timescales from daily to annual occurrences. Freeze-thaw is only one of those drivers, but there is not a clear understanding of how the drivers interact to increase the probability that a trigger will lead to rockfall. Thus, freeze-thaw is potentially useful in thinking about rock exfoliation, but it should not be over-interpreted in thinking about rockfall causality. Ultimately, changing environmental conditions *can* change rates of rockfall, but more data are needed to correlate rockfall with those processes in places like Devils Tower NM, and additional data to track rockfalls are needed.

The selected freeze-thaw metric showed a decline in average yearly cycles for all climate futures because the scenarios all estimated substantially fewer days with freezing temperatures (i.e., most freezing days include a freeze-thaw cycle, so fewer days below 32 °F results in fewer cycles). However, this makes freeze-thaw cycles an interesting phenomenon to study regarding climate change because many mid-latitude parks have a similar pattern where the number of freeze-thaw cycles are primarily driven by the number of days below 32 °F. As these parks see fewer days below freezing, they will also experience fewer freeze-thaw cycles, seemingly a positive outcome concerning damage to lithic and built structures and cultural resources. However, parks that do see an increase in freeze-thaw cycles in seasons that experience high rainfall could experience increased impacts to resources and may find the wet-frost metric useful.

Literature cited in Appendix 4

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Appendix 5. Climate future creation methods

The process of developing plausible and divergent climate futures used climate output from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset, which was used for the IPCC Fifth Assessment (IPCC 2013). Translating coarse global climate model (GCM) signals down to scales useable for applied climate work and resource decision making requires downscaling. The most frequently used downscaling method is Bias-Corrected Statistical Downscaling (BCSD), which assesses the GCM bias relative to an observed dataset and corrects the whole GCM (historical and future) accordingly. In contrast, the MACA (Multivariate Adaptive Constructed Analogs) method (Abatzoglou and Brown 2012) used to develop Devils Tower NM climate futures is a statistical downscaling method that enables modelers to process the core determinants of climate change, rather than imposing a statistical correction on monthly data (as is done with BCSD). This method has been shown to be preferable to direct daily interpolated bias correction in regions of complex terrain due to its use of a historical library of observations and its multivariate approach (Abatzoglou and Brown 2012).

Three MACA datasets are available; we downloaded MACAv2-METDATA, in which climate forcings were drawn from a statistical downscaling of GCM data from the CMIP5 dataset (Taylor et al. 2012) using a modification of the MACA method (Abatzoglou and Brown 2012) with the METDATA (Abatzoglou 2011) observational dataset as training data[4]. The product is available at a daily time step and downscaled to 1/24 degree (~4 km). Variables that are downscaled include 2-m maximum/minimum temperature, 2-m maximum/minimum relative humidity, 10-m zonal and meridional wind, downward shortwave radiation at the surface, 2-m specific humidity, and precipitation accumulation. We downloaded MACA maximum and minimum temperature, precipitation, and maximum and minimum relative humidity data for a grid cell that encompasses the Devils Tower NM centroid (44.591° latitude and -104.716° longitude) (see Figure A5-1, below), for two greenhouse gas emissions pathways (the moderate Representative Concentration Pathway [RCP] 4.5 and the high RCP 8.5).

The MACA archive contains output from 18 GCMs for the contiguous United States, available for RCP 4.5 and RCP 8.5, totaling 36 model-RCP combinations or projections. Based on expert climatologist input (Imtiaz Rangwala, North Central Climate Adaptation Science Center, Co-operative Institute for Research in Environmental Sciences, University of Colorado, Boulder), four GCMs (eight projections) were removed from consideration due to poor performance in this geographical region (BNU-ESM, bcc-csm1-1, bcc-csm1-1-m, and IPSL-CM5B-LR). Thus, we calculated a variety of climate and soil moisture metrics for 28 downscaled projections (14 GCMs, 2 emissions pathways each) for use in selecting climate futures (specific projections) for the scenario planning workshop. We then calculated the difference in these metrics between the 1950–1999 historical period and a 2025–2055 planning period.

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[4] https://climate.northwestknowledge.net/MACA/MACAreferences.php

We visually inspected graphical representation of these key climate metrics to choose four divergent climate futures (see Figure 8 in the main text): Climate Future 1 (GFDL-ESM2M_rcp45 [NOAA Geophysical Fluid Dynamics Laboratory-Earth Systems Model 2M]); Climate Future 2 (GFDL-ESM2G_rcp85 [NOAA Geophysical Fluid Dynamics Laboratory-Earth Systems Model 2G]), Climate Future 3 (IPSL-CM5A-MR_rcp45 [Institut Pierre Simon Laplace, France]), and Climate Future 4 (HadGEM2-CC365_rcp85 [Met Office Hadley Center, UK]). Using a specific climate projection for a climate future ensures that climate futures are internally consistent (physically coherent) and provides specific climate input for quantitative modeling.

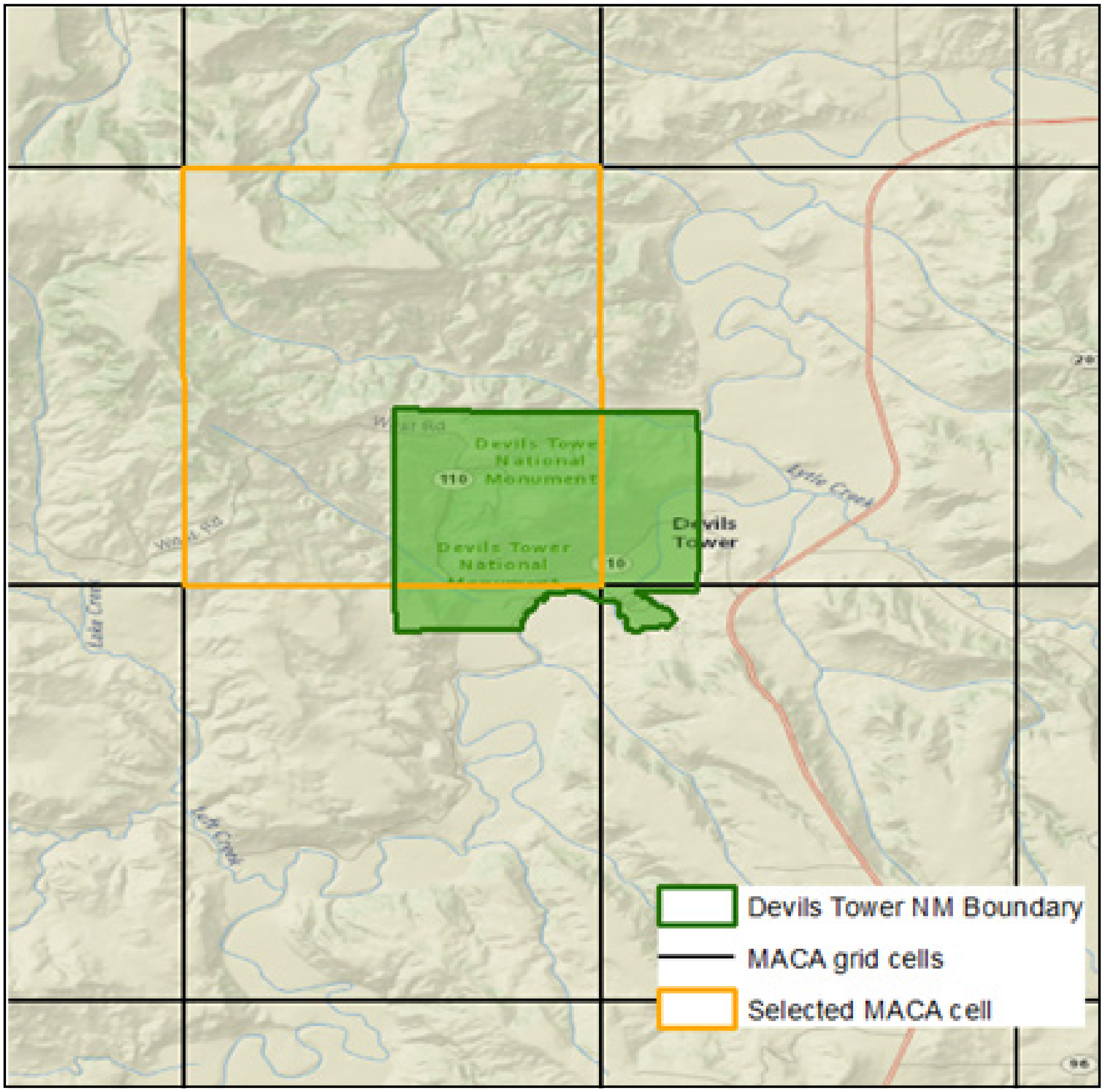

Figure A5-1. Devils Tower NM relative to MACA grid cells. The orange “selected MACA cell” is the grid cell selected for climate futures development.

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Appendix 6. Projected changes in humidity at Devils Tower NM

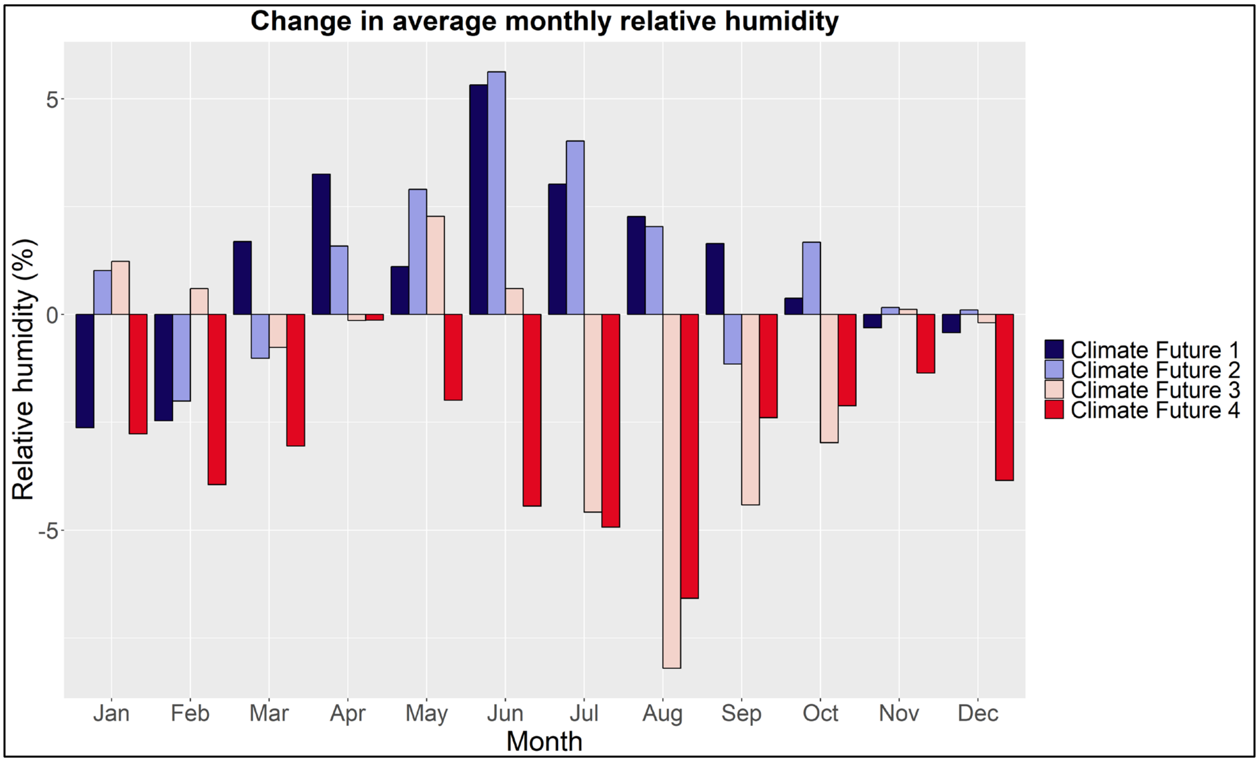

Figure A6-1. Projected change in average monthly relative humidity (over 2025–2055, compared to 1950–1999). Humidity projections were identified as important only late in the scenario development process and so are provided for the first time in this report.

Appendix 7. Heat indices and calculation methods

Calculating heat index for national parks using global climate models

A number of factors influence the effects of heat on human bodies, and understanding how changes in environmental conditions affect human welfare is more complicated than simply looking at a change in temperature. The primary mechanism that the body uses to cool itself is evaporation of sweat. However, when the atmospheric moisture content (i.e., relative humidity) is high, the rate of evaporation is reduced, resulting in a lower rate of heat removal from the body that can lead to overheating (NWS 2016; 2019a). To measure this sensed heat, George Winterling developed a "heat index" in 1978, which was adopted by the National Weather Service the following year (Samenow 2011). The heat index is similar to wind chill in that it is what the temperature feels like based on the influence of additional weather factors beyond temperature. An alternative calculation of sensible heat is the WetBulb Globe Temperature (WBGT), which is a more sophisticated measure of heat stress in direct sunlight. In addition to temperature and humidity estimates (also required for the heat index), the WBGT requires data for wind speed, sun angle, and cloud cover (solar radiation). Military agencies often use WBGT instead of heat index because of its more accurate measure of heat stress in direct sunlight (NWS 2019b).

Heat index values in arid locations with direct sun exposure may underestimate sensible heat because the heat index assumes temperatures are in shaded conditions. Thus, heat index has been found to systematically underestimate sensible heat in full sunlight, where heat indices can increase as much at 15 °F. For example, daily heat index values calculated in Grand Canyon National Park averaged 7 °F below maximum temperature values (unpublished data).

Despite the heat index's limitations, we chose it as an indicator of heat stress for this project because it is easy to calculate from available climate data (daily temperature and relative humidity). The National Weather Service refined computation of the heat index in 1990 to perform more accurately under varying temperature and relative humidity conditions (see adjustments 1 and 2, below) (NWS 2014). The base equation is:

$$\begin{aligned} Heat\ Index = & -42.379 + (2.04901523 * T) + (10.1433127 * Rh) - (0.22475541 * \mathrm{T} * \mathrm{Rh}) \\ & - (0.00683783 * T^2) - (0.05481717 * Rh^2) + (0.00122874 * T^2 * \mathrm{Rh}) \\ & + (0.00085282 * \mathrm{T} * Rh^2) - (0.00000199 * T^2 * Rh^2) \end{aligned}$$

Where T is temperature in degrees F and Rh is relative humidity in percent

If Rh <13% and 80 °F <T <112 °F, adjustment 1 should be subtracted from heat index

$$Adjustment\ 1 = \frac{13 - Rh}{4} * \sqrt{17 - |\frac{T - 95}{17}|}$$

If Rh >85% and 80 °F <T <87 °F, adjustment 2 should be added to heat index

$$Adjustment\ 2 = \frac{Rh - 85}{10} * \frac{87 - T}{5}$$

The heat index is assumed to be a measure of instantaneous heat stress from current conditions, but available downscaled climate data are only available at daily temporal resolution. Specifically, the Multivariate Adaptive Constructed Analogs (MACA) datasets (Abatzoglou and Brown 2012) include daily maximum and minimum temperature and maximum and minimum relative humidity. To resolve this data limitation, we examined hourly station data (from Sheridan, WY, station number GHCND:USW00024029) to determine which of the available metrics were appropriate for the heat index equation. Because hourly data show an inverse relationship between humidity and temperature (see Table A7-1 below), we assumed that the warmest part of the day would have the lowest relative humidity. Therefore, we calculated the heat index using maximum temperature and minimum relative humidity from the MACA data.

The National Weather Service (NWS 2019a) provides a table that classifies heat index values and describes effects those conditions would have on the body. Additionally, the Occupational Safety and Health Administration (OSHA) has established guidelines (OSHA 2019) associated with these classifications and protective measures that should be taken for ranges of heat index values (see Table A7-1 below). In 2004, the National Park Service Risk Management Office issued guidance for heat stress suggesting that general heat stress controls should be practiced (NPS 2004) when heat index >105 °F, but the guidance hasn't been updated according to the OSHA guidelines. Thus, we used the OSHA "Extreme Caution" classification as the basis for estimating the number of days where precautions would need to be taken. These heat stress controls include: encouraging hydration, promoting exposure self-limitation, encouraging co-worker observation, proper worker acclimatization, counseling and monitoring medicated workers, encouraging healthy lifestyles, and adjusting expectations of workers. No guidance exists for limiting visitor exposure to the risks, but similar controls can be applied.

Table A7-1. Occupational Safety and Health Administration heat index classifications and protective measures.

Classification	Heat Index	Effect on the body	Protective measures
Caution	80 °F– 90 °F	Fatigue possible with prolonged exposure and/or physical activity	Basic heat safety and planning
Extreme Caution	90 °F–103 °F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity	Implement precautions and heighten awareness
Danger	103 °F–124 °F	Heat cramps or heat exhaustion likely, and heat stroke possible, with prolonged exposure and/or physical activity	Additional precautions to protect workers
Extreme Danger	≥125 °F	Heat stroke highly likely	Triggers even more aggressive protective measures

Literature cited in Appendix 7

Abatzoglou, J. T., and T. J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology 32:772–780,

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Appendix 8. Building on climate futures to create robust climate-resource scenarios

Scenario planning workshop participants summarized conditions within each climate future, discussed additional features (e.g., impacts of a climate future on development around the park), and then spelled out implications for Devils Tower NM resources. As part of this exercise, groups named their climate futures as follows: **Spearfish** (Climate Future 1, GFDL-ESM2M_rcp45 [NOAA Geophysical Fluid Dynamics Laboratory-Earth Systems Model 2M]); **Still DETO** (Climate Future 2, GFDL-ESM2G_rcp85 [NOAA Geophysical Fluid Dynamics Laboratory-Earth Systems Model 2G]), **Blazin' Hot (but not too dry)** (Climate Future 3, IPSL-CM5A-MR_rcp45 [Institut Pierre Simon Laplace, France]), and **Are we in western Kansas?** (Climate Future 4, HadGEM2-CC365_rcp85 [Met Office Hadley Center, UK]). This appendix is provided so that workshop participants can review results of their work in detail and to provide ideas for others wishing to use scenario planning. A distilled version of this appendix is presented in Table 6.

Climate Future 1: 2025–2055 Spearfish

In your scenario:

Climate Features:

- Moderate warming
- WET
- Increased (frequency of) large precipitation events
- More humid

What other developments might occur?

- Increased (human) population and development
- Emerald ash borer - ash trees disappear (added here b/c note in Climate Future 2 entry points out that this development is certain and will occur regardless of climate future)

What happens to:

See Table A8-1 for specific implications for each resource.

Table A8-1. Implications for each resource under Climate Future 1.

Priority resource	Resource component	Implications
Cultural resources (cultural landscapes, archaeological sites & building structures)	Structures	• Road/culverts could be impacted by increased rain/precipitation • Paved surfaces/ADA (Americans with Disabilities Act) accessibility need to factor slope/runoff • Historical structures—potential for water infiltration (ensure gutters are clear) • Increased air conditioning use • Increased potential for tree fall impacts

Table A8-1 (continued). Implications for each resource under Climate Future 1.

Priority resource	Resource component	Implications
Cultural resources (cultural landscapes, archaeological sites & building structures) (continued)	Structures (continued)	• Stake ladder potential loss due to increased moisture/rot?/humidity
	Ethnographic	• Formation (tower) less impacted due to less freeze/thaw • Would continue (persist) regardless of changes
	Archeological	• Potential for increased erosion, exposure of sites/lithics • Park pictographs and historical graffiti more vulnerable to erosion? • Increased potential for tree fall impacts
Vegetation (e.g., ponderosa forest, prairie, traditional use plant species [e.g., chokecherry])	—	• Decreased fire risk & prescribed fire difficult • More pine, maybe more species of conifers (increased spruce) • Thick stands increase MPB (mountain pine beetle) risk but trees are less susceptible • Cottonwoods happy • Native plants increase growth but may be outcompeted by exotics • Increased productivity • Cool season invasives happy • Oaks increase but disease/pests increase??
Wildlife (e.g., bats, ungulates, peregrine falcons)	—	• Zoonotic and wildlife disease: West Nile, tularemia, insect-vectors • Increased bats, aquatic life (wash?), land-snails, and amphibians • Birds - decreased nest success, but good insect prey • Increased herbivores: rodents and ungulates • Phenotypic mismatch • Increased sediment -> biocontaminants in prey (ag nutrients and decreased runoff) • Slug invasion? • Increased Chytrid, decreased frogs • Possible change in pollination (added here b/c comment in scenario 2 worksheet says this impact is common across all scenarios)
Aquatic Resources (Belle Fourche River & Devils Tower NM springs)	—	• Increased spring flow • Increased spring flow seasonality (those that dry and occasionally may not) • Increased size of wetlands • Increased ice-free days at springs/wetlands (benefit for wildlife) • Increased flooding both in river and elsewhere in park

Table A8-1 (continued). Implications for each resource under this Climate Future 1.

Priority resource	Resource component	Implications
Aquatic Resources (Belle Fourche River & Devils Tower NM springs) (continued)	—	• Increased releases from dam • Increased rain-on-snow events in early spring • Decreased water quality from contaminants and turbidity • Increased river bank erosion (river bank is park boundary in places) • Increased erosion along storm water drainage (culverts washing out, etc.) • Increased flooding due to inadequate culvert size • Tarpot Spring – where the water now sinks (meadow west of housing area), it would flow above ground toward river and affect infrastructure

Additional considerations

Visitation

- Wetter = more ticks/mosquitos, leading to worse visitor experience at times
- Wetter = increased disease risk with potential impacts on visitors (tularemia)
- Decreased climbing if wet?
- Increased Fall visitation (longer season)

Climate Future 2: 2025–2055 Still DETO

In your scenario:

Climate Features:

- Least change in almost every category
- Green-up highly variable
- Precipitation increases in all but autumn
- No change in heavy precipitation events
- Moderate decrease in freeze-thaw cycles

What other developments might occur?

- Increased development and population
- Increased fossil fuel energy development
- Increased visitation (longer incl. season)
- Increased water use
- Increased weed vectors
- Emerald ash borer–ash trees disappear in all scenarios

What happens to:

See Table A8-2 for specific implications for each resource.

Table A8-2. Implications for each resource under Climate Future 2.

Priority resource	Resource component	Implications
Cultural resources (cultural landscapes, archaeological sites & building structures)	Structures	• Fewer freeze/thaw cycles; could be beneficial • Least likely to impact the stake ladder (continuation of existing impacts) • Continuation of current maintenance cycles
	Ethnographic	• Less likely to increase spalling on tower due to fewer "freeze/thaw" cycles • Would continue (persist) regardless of changes
	Archeological	• Continuation of erosion loss of pictographs and historical graffiti • Continuation of current (management) activities
	Overall	• A benign climate future for cultural resources
Vegetation (e.g., ponderosa forest, prairie, traditional use plant species [e.g., chokecherry])	—	• Increased fire risk in fall b/c of spring growth and dry fall • Pine mortality risk is lower • MPB (mountain pine beetle) risk is lower • Cottonwood recruitment decreases less, less flooding • Less change to native plants in this scenario (traditional) • Increased productivity b/c of spring rain • Cool season invasives love this • Oaks do OK • Overall, relatively good for natives; possible increased fire but increased cool season invasives
Wildlife (e.g., bats, ungulates, peregrine falcons)	—	• Potential increase in amphibians due to increased H_2O • Increased nest success due to fewer heavy (>1") precip events • Increased risk of hemorrhagic disease outbreaks due to midges increase with increased wet, increased temps, decreased days (<32F) • Increased Chytrid, decreased frogs • Increased flea and tick population due to increased precip in spring = increased plague, tularemia • Phenotypic mismatch for migratory birds and insect hatches • Possible change in pollination (all scenarios) • Overall, good for amphibians and birds, not good for mammals

Table A8-2 (continued). Implications for each resource under Climate Future 2.

Priority resource	Resource component	Implications
Aquatic Resources (Belle Fourche River & Devils Tower NM springs)	—	• Graham Spring could dry up in late Summer/Fall • Potential impacts from increased fossil fuel energy development (decreased spring flow and/or decreased park water supply)— However, this is speculative • Decreased water quality from urban and ag runoff • Increased ice-free days at springs (compared to historical, but least relative to the other scenarios) = benefit to wildlife • Earlier snow melt • Increased flood frequency— Belle Fourche River • Potentially decreased flow in springs in late summer/fall • Potential increased river bank erosion (note: park boundary is river bank— loss of acreage as bank erodes) • Overall, decreased spring flow in fall • Tarpot Spring – where the water now sinks (meadow west of housing area), it would flow above ground toward river and affect infrastructure

Additional considerations

Visitation

- Increased visitation due to longer warm season that doesn't get too hot compared to other scenarios
- More visitation hard to manage due to interannual variation in springtime arrival

Climate Future 3: 2025–2055 Blazin' Hot (but not too dry)

In your scenario:

Climate Features:

- Hottest of all climate futures
- Highest variability in green-up
- Moderate increase in extreme events
- Increased extremely hot days
- Fewest freeze-thaw cycles

What other developments might occur?

- Wider visitation season (flatter)
- Ranchers suffering

- Climber season spreading out
- Emerald ash borer–ash trees disappear (added here b/c note in Climate Future 2 entry points out that this development is certain and will occur regardless of climate future)

What happens to:

See Table A8-3 for specific implications for each resource.

Table A8-3. Implications for each resource under Climate Future 3.

Priority resource	Resource component	Implications
Cultural resources (cultural landscapes, archaeological sites & building structures)	Structures	• "High-fire" scenario – structures vulnerable • Benefits due to decreased freeze-thaw cycling • Increased use of air conditioning in structures (issue of visitor center capacity) • Stake ladder would probably do OK
	Ethnographic	• Formation (tower) would see benefits due to less freeze/thaw • If climbing season shifts, (the change) may support June closure or other summer events
	Archeological	• "High-fire" scenario – likely exposure of new archeological sites • Increasing visitation/longer visitation season could lead to site impacts • Pictographs and historical graffiti – no significant impacts
Vegetation (e.g., ponderosa forest, prairie, traditional use plant species [e.g., chokecherry])	—	• Increased fire • Decreased ponderosa establishment and survival in fires • MPB (mountain pine beetle) decreases with decreased tree density but trees are stressed • Cottonwood same or worse • Native plants and traditional plants OK (many are drought-tolerant) • No change in productivity?? • Phenology mismatch • Cool season invasives happy again • Oaks decrease due to summer drought • Mismatch phenology increases variation in green-up. Warm temps in winter • Cheatgrass highest

Table A8-3 (continued). Implications for each resource under Climate Future 3.

Priority resource	**Resource component**	**Implications**
Wildlife (e.g., bats, ungulates, peregrine falcons)	—	• If shoulder season climbing increases, disturbance to overwintering bats would increase if results prove the bats to be there • Phenological timing/mismatch migration • Forage/browse quality reduced • Insects would do well – including pest species • Increase in reptiles • Increase or decrease in fires depending on intensity and frequency • Less prey -> raptor, mesocarnivores, and snakes • Possible change in pollination (added here b/c comment in scenario 2 worksheet says this impact is common across all scenarios)
Aquatic Resources (Belle Fourche River & Devils Tower NM springs)	—	• Wetland retreat at Tarpot Spring • Ice-free in winter at Tarpot Spring • Graham Spring could be dry in Fall and Summer • Possible HAB (harmful algal bloom) occurrence in springs or river • Dry conditions = effects to amphibian habitat • Aquatic inverts affected by drying of springs – decreased H_2O quality in springs and river • Potential for ice-free conditions year round on Belle Fourche River • Increased runoff events and erosion during the extreme precipitation events (from drier soil, < veg) • Earlier releases from dam, increased water temp and decreased flow = decreased DO (fish kill?)

Additional considerations

Visitation

- Shoulder seasons expand dramatically
- Peak season visitation may decrease b/c temperatures may exceed the comfortable range, particularly on the extremely hot days
- More climbing in Spring/Fall less in Summer
- More heat-related illness
- As noted above for historical structures, under this hottest scenario there’s a concern about visitor center capacity (i.e., more people might seek relief from the heat inside the visitor center)

Climate Future 4: 2025–2055 Are we in western Kansas?

In your scenario:

Climate Features:

- Driest: decreased precipitation throughout and decreased soil moisture
- Decreased large precipitation
- Warm winters
- Longest growing season
- Moderate decrease in freeze-thaw cycles

What other developments might occur?

- Emerald ash borer - ash trees disappear (added here b/c note in Climate Future 2 entry points out that this development is certain and will occur regardless of climate future)

What happens to:

See Table A8-4 for specific implications for each resource.

Table A8-4. Implications for each resource under Climate Future 4.

Priority resource	Resource component	Implications
Cultural resources (cultural landscapes, archaeological sites & building structures)	Structures	• Potential fire issue/danger • Dry would help preserve historical structures • Increased use of air conditioning • Roads/culverts - no/little runoff issues • Reduced impacts on the stake ladder
	Ethnographic	• Formation (tower) - less impacts, less moisture, less rock fall • Cultural use/temp potential for emergency response
	Archeological	• Increased fire scenario could result in exposed sites, need for decontamination • Benefits to pictographs and historical graffiti
Vegetation (e.g., ponderosa forest, prairie, traditional use plant species [e.g., chokecherry])	—	• Increased fire, more drought so less fuel. Long season • Ponderosa decreases due to drought • MPB (mountain pine beetle) increased, trees are stressed but fewer trees • Cottonwoods sad • Native plants/traditional plants decrease • Decreased productivity • Cool season invasives sad • Oaks potentially disappear with drought

Table A8-4 (continued). Implications for each resource under Climate Future 4.

Priority resource	Resource component	Implications
Wildlife (e.g., bats, ungulates, peregrine falcons)	—	• Phenological mismatch • Reduced forage quality • Amphibian habitat declines, potential population declines • Insect and disease increases • Peregrines do well • Increased prairie dog diseases (but favorable winter conditions) • Landscape-level habitat changes – higher variability in herbivore habitat occupancy • Porcupines may suffer from fires – no food • Possible change in pollination (added here b/c comment in scenario 2 worksheet says this impact is common across all scenarios)
Aquatic Resources (Belle Fourche River & Devils Tower NM springs)	—	• Decreased water in river • Possible HAB (harmful algal bloom; speculative and variable dependent) • Possible shift to fish spp. that prefer warmer water. Impact to cold-water fisheries • Low DO (dissolved oxygen) in springs and Belle Fourche River • Ice-free conditions at springs • Decrease in flooding relative to Spearfish and Blazin' Hot (but not too dry) climate futures • Dry conditions at Graham Spring • Wetland retreat at Tarpot Spring in summer • Increased releases from dam

Additional considerations

Visitation

- Shoulder seasons expand dramatically
- Peak season visitation increases b/c peak season temps still amenable
- More climbing in Spring/Fall less in Summer
- More heat-related illness
- Concern about visitor center capacity (i.e., more people might seek relief from the heat inside the visitor center)

Appendix 9. Testing goals and actions worksheets

Scenario planning workshop participants examined current goals and actions and assessed whether revisions would be needed under the conditions of each scenario (Tables A9-1 through A9-9). Not all revisions or actions identified below are actually being adopted; instead participants continued to work with these ideas in the park's RSS process, including thinking across scenarios to identify goals and actions that are robust across scenarios or address highly consequential potential resource implications under a subset.

Table A9-1. Resource/Management Concern: Historical structures—integrity and utility.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Spearfish	Goal: Maintain the integrity and use of historical structures in the park Actions: • CCC (Civilian Conservation Corps) buildings: cyclic maintenance and LCS (List of Classified Structures) "good condition" • Mission 66 buildings: cyclic maintenance and LCS "good condition" • Roads/culverts: cyclic maintenance and LCS "good condition" • Stake ladder: determine future	Short-term: Yes Long-term: Yes?	- Gutter maintenance - Hydrological study of culverts	–	–
Still DETO	–	Short-term: Yes Long-term: Yes	–	–	–
Blazin' Hot (but not too dry)	–	Short-term: Yes Long-term: Yes?	- Increase defensible space around historical structures - Emergency response to fire (building wraps, etc.)	–	–
Are we in western Kansas?	–	Short-term: Yes Long-term: Yes?	- Increase defensible space around historic structures - Emergency response to fire (building wraps, etc.)	–	–

Table A9-2. Resource/Management Concern: Ethnographic resources—embrace cultural history & resource uses.

Scenario	**Current goals: Current actions**	**Achievable in short-term? Long-term?**	**Current goals: Revised actions**	**Revised goals: Revised actions**	**Insights, Tradeoffs?**
Spearfish	Goal: Embrace/respect the cultural history and uses at Devils Tower NM Actions: • Maintain good relationships/consultation with tribes • Continuation of employee training • Voluntary closure to climbing: education and outreach	Short-term: Yes Long-term:	–	–	–
Still DETO	–	Short-term: Yes Long-term: Yes	–	–	–
Blazin' Hot (but not too dry)	–	Short-term: Yes Long-term:	- Increase/provide EMT - Responses needed due to heat/temp increases	–	–
Are we in western Kansas?	–	Short-term: Yes Long-term:	- Increase/provide EMT - Responses needed due to heat/temp increases	–	–

Table A9-3. Resource/Management Concern: Archeological resources—protect and document.

Scenario	**Current goals: Current actions**	**Achievable in short-term? Long-term?**	**Current goals: Revised actions**	**Revised goals: Revised actions**	**Insights, Tradeoffs?**
Spearfish	Goal: Protect known archeological sites and discover/document new (unknown) sites Actions: • Develop ("implement") ASMIS (Archeological Sites Management Information System) monitoring protocol (staffing constraint) • Maintain communications with tribes on archeology projects	Short-term: Yes Long-term: Yes	- Record sites exposed by severe storm events - Protection/LE (Law Enforcement) if exposed	–	–
Still DETO	–	Short-term: Yes Long-term: Yes		–	–
Blazin' Hot (but not too dry)	–	Short-term: Yes Long-term: Yes	- Record sites exposed by severe storm events or wildfire - Protection/LE if exposed	–	–
Are we in western Kansas?	–	Short-term: Yes Long-term: Yes	- Record sites exposed by wildfire - Protection/LE if exposed	–	–

Table A9-4. Resource/Management Concern: Upland vegetation—maintain pine forest/prairie landscape.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Spearfish	Goal: maintain pine forest/prairie landscape Actions: • Prescribed fire • Spray weeds • Mechanical treatment for weeds • Grassland restoration • Cottonwood planting • Forest thinning biocontrol • grazing	Short-term: Yes Long-term: No	- Need to increase prescribed fire frequency and thinning to keep grassland	–	–
Still DETO	–	Short-term: Yes Long-term: Yes	–	–	Continue current actions
Blazin' Hot (but not too dry)	–	Short-term: Yes Long-term: Maybe	- Plant/water pines	- If you can't get trees to stay, accept grassland	–
Are we in western Kansas?	–	Short-term: Yes Long-term: No	–	- Accept conversion of woodland to grassland	Huge impact on traditional use (local and native American)

Table A9-5. Resource/Management Concern: Riparian forest—improve condition.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Spearfish	Goal: Improve riparian forest habitat Actions: • Prescribed fire • Spray weeds • Mechanical treatment for weeds • Grassland restoration • Cottonwood planting • Forest thinning biocontrol • grazing	Short-term: Yes Long-term: Yes	–	–	No change in management needed
Still DETO	–	Short-term: No Long-term: No	–	- Accept no (i.e., lack of) cottonwoods	–
Blazin' Hot (but not too dry)	–	Short-term: No Long-term: No	–	- Encourage oaks, boxelder "ash", elm	–
Are we in western Kansas?	–	Short-term: No Long-term: No	–	- Accept no (i.e., lack of) cottonwoods - Introduce new tree cultivars/spp.	–

Table A9-6. Resource/Management Concern: Non-native plants—keep at low abundance.

Scenario	**Current goals: Current actions**	**Achievable in short-term? Long-term?**	**Current goals: Revised actions**	**Revised goals: Revised actions**	**Insights, Tradeoffs?**
Spearfish	Goal: (keep) low abundance of non-native plants Actions: • Prescribed fire • Spray weeds • Mechanical treatment for weeds • Grassland restoration • Cottonwood planting • Forest thinning biocontrol • Grazing	Short-term: No Long-term: No	–	- Target areas to “keep” native - Choose to live with some weeds - Active restoration in small areas	–
Still DETO	–	Short-term: No Long-term: No	–	- Target areas to “keep” native - Choose to live with some weeds - Active restoration in small areas	–
Blazin’ Hot (but not too dry)	–	Short-term: No Long-term: Maybe yes	- Increase early detection and eradication of new invaders		–
Are we in western Kansas?	–	Short-term: No Long-term: No	–	- Target areas to “keep” native - Choose to live with some weeds - Target new invaders	–

Table A9-7. Resource/Management Concern: Springs and wetlands—restore to natural/well-functioning condition.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Spearfish	Goal: Restore all wetlands and springs to natural well-functioning condition Actions: • Developing spring monitoring protocol • Developing water quality and flow monitoring • Trail cameras at Tarpot	Short-term: N/A (this is a long-term goal) Long-term: Yes	–	–	An additional action under this scenario that is consistent with the goal (restoration) of well-functioning wetlands and springs is to monitor wetland expansion
Still DETO	–	Short-term: N/A (this is a long-term goal) Long-term: No		- Revised goal: maintain Tarpot Spring/Wetland only and accept decline of other springs and associated wetlands - Monitor wetland retreat	–
Blazin' Hot (but not too dry)	–	Short-term: N/A (this is a long-term goal) Long-term: No		- Revised goal: maintain Tarpot Spring/Wetland only and accept decline of other springs and associated wetlands - Monitor wetland retreat - Monitor aquatic inverts, amphibians, wildlife use - If $$, permitting,& compliance don't preclude: - Keeping some of the current infrastructure in place to collect water (e.g., tiles & pipes) - Guzzlers at spring exit - Plant tree spp. that would survive these conditions, to increase overstory/shading	–

Table A9-7 (continued). Resource/Management Concern: Springs and wetlands—restore to natural/well-functioning condition.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Are we in western Kansas?	–	Short-term: N/A (this is a long-term goal) Long-term: No	–	- Revised goal: maintain Tarpot Spring/Wetland only and accept decline of other springs and associated wetlands - Monitor wetland retreat - Monitor aquatic inverts, amphibians, wildlife use - If $$, permitting,& compliance don't preclude: - Keeping some of the current infrastructure in place to collect water (e.g., tiles & pipes) - Guzzlers at spring exit - Plant tree spp. that would survive these conditions, to increase overstory/shading	–

Table A9-8. Resource/Management Concern: Wildlife—maintain historical communities.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Spearfish	Goal: Maintain historical native wildlife communities Actions: Inventory and monitoring (in park and I&M) – Protocols, surveillance (disease) Fire: monitoring, Rx fires, structural protection Wildlife – human interaction mitigation University research/soft fund projects Management plans: Prairies day Climbing management plan TBD IPM plan Fire management plan General management plan Foundation DOC (?) Bat management plan, zoonotic disease plan	Short-term: ? (unsure) Long-term: No	- Refine/expand disease outbreak response protocols - Include new diseases (tularemia)	- The goal to maintain “native” wildlife will need to be readdressed and redefined - Consider wildlife when modifying need management	Primary wildlife concern related to increased zoonotic diseases and increased wildlife diseases We anticipate species assemblages to change (extirpation/colonization) - Depletion across all scenarios

Table A9-8 (continued). Resource/Management Concern: Wildlife—maintain historical communities.

Scenario	Current goals: Current actions	Achievable in short-term? Long-term?	Current goals: Revised actions	Revised goals: Revised actions	Insights, Tradeoffs?
Still DETO	–	Short-term: Yes Long-term: No	- Expand disease response plan (in prairie dog plan) to include new diseases (tularemia)	- The goal to maintain "native" wildlife will need to be readdressed and redefined - Consider wildlife when modifying need management	We anticipate species assemblages to change (extirpation/colonization) - Depletion across all scenarios
Blazin' Hot (but not too dry)	–	Short-term: Yes Long-term: No	- Consider changing climbing activity to limit impacts to bat hibernacula - Reevaluate forest health and IPM responses/mitigation - Aggressive prairie dog management	- The goal to maintain "native" wildlife will need to be readdressed and redefined - Consider wildlife when modifying need management	We anticipate species assemblages to change (extirpation/colonization) - Depletion across all scenarios
Are we in western Kansas?	–	Short-term: Yes Long-term: No	- Aggressive prairie dog management	- The goal to maintain "native" wildlife will need to be readdressed and redefined - Consider wildlife when modifying need management - Manage for grassland species	We anticipate species assemblages to change (extirpation/colonization) - Depletion across all scenarios

Table A9-9. Resource/Management Concern: Visitor experience—provide safe and enjoyable experience.

Scenario	**Current goals: Current actions**	**Achievable in short-term? Long-term?**	**Current goals: Revised actions**	**Revised goals: Revised actions**	**Insights, Tradeoffs ?**
Spearfish	Goal: Provide a safe and enjoyable experience for visitors Actions: • EMS (Emergency Medical Services) and SAR (Search and Rescue) • Refillable bottles sold in park and refill stations • Educating visitors about zoonotic diseases • Announcements for park house, storm events • Exotic plant treatments prioritized in high use areas • Interpretive programs • Night sky programs	Short-term: Yes Long-term: No	- Increase ranger response (evacuations, etc.) - Possible need to treat for fleas, ticks, mosquitos - Increase advance notice for storm events (NWS)	–	–
Still DETO	–	Short-term: Yes Long-term: No	- Increase staffing to accommodate earlier spring visitation	–	–
Blazin’ Hot (but not too dry)	–	Short-term: Yes Long-term: No	- Increase shoulder season visitation – need to increase staff - Emergency Medical Services (EMS) response – heat related illnesses - Climbers increase over more seasons – need for climbing rangers and SAR (Search and Rescue) response	–	–
Are we in western Kansas?	–	Short-term: Yes Long-term: No	- Increase shoulder season visitation – need to increase staff - EMS (Emergency Medical Services) response – heat related illnesses - Climbers increase over more seasons – need for climbing rangers and SAR (Search and Rescue) response	–	–

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