



Climate Change Hazards Summary Report for Facility Investment Planning

Mount Rushmore National Memorial January 2021

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Introduction

Parks are required to complete a PARK Project Narrative Template for each proposed Great American Outdoors Act Facility Investment Plan (GFIP) project for Legacy Restoration Funding in fiscal years 2023-2025. Information provided in this report is intended to help parks consider climate change related hazards when addressing Question 16 of the narrative template.

Specifically: What risks or hazards (current and projected, e.g. effects of climate change) are likely to affect this project? If applicable, what adaptation strategies and/or resiliency measures have been identified for scenarios that pose high risks to project assets?

Step 1: Review summary information for known or potential hazards identified for Mount Rushmore National Memorial

- Review the list of potential hazards below and decide whether or not they apply to your specific GFIP project. NPS Climate Change Response Program (CCRP) staff attempted to identify potential hazards for the park; however, park staff and project planners have more information about hazards that are likely to be applicable to a specific project.
- The hazards below were selected from a longer list included in Appendix 1, which also indicates CCRP's 'best professional judgement' about the relevance of the hazard for this park. Note both lists serve as a "coarse filter" screening tool to help identify potential climate-related hazards for facility and asset planning.

Hotter average days and more very hot days

Greenhouse gas emissions from human activities have increased temperatures globally (Intergovernmental Panel on Climate Change et al. 2013), across the U.S. (U.S. Global Change Research Program et al. 2017), and in U.S. national parks (Gonzalez et al. 2018). This trend is projected to continue, with record setting years becoming more common in the future (U.S. Global Change Research Program et al. 2017). The annual average temperature in the United States is expected to increase by 2.3 to 11°F by the end of the century depending on greenhouse gas emissions, relative to 1986-2015 (U.S. Global Change Research Program et al. 2018). The highest emissions projections indicate that most areas of contiguous United States will experience about 20-30 more days per year with a maximum temperature over 90°F (32°C) (Vose et al. 2017). Widespread warming is also projected to result in 20-30 fewer days per year with a minimum temperature below freezing in the northern parts of the nation, and 40-50 fewer days below freezing in much of the West (Vose et al. 2017).

For Mount Rushmore National Memorial, annual average temperature increased at the statistically significant rate of $0.9 \pm 0.3^{\circ}\text{C}$ ($1.6 \pm 0.5^{\circ}\text{F}$) per century from 1895 to 2009 (Gonzalez et al. 2018). Under the highest greenhouse gas emissions scenario, climate models project additional heating of the area within park boundaries of $5.2 \pm 1.3^{\circ}\text{C}$ ($9.4 \pm 2.3^{\circ}\text{F}$) by 2100 (Gonzalez et al. 2018). The temperature increase could be kept to $1.8 \pm 0.8^{\circ}\text{C}$ ($3.2 \pm 1.4^{\circ}\text{F}$) under a scenario of reduced emissions (Gonzalez et al. 2018). Extreme temperatures can increase weathering of structures, threaten park staff and visitor

safety, and increase stresses for HVAC systems. Demand for complex air conditioning systems can add stress to building envelopes and often requires significant alterations to a structure.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Increased drought frequency, intensity, magnitude, and duration

Rising air temperatures and changing precipitation patterns are exacerbating drought risk in many parts of the United States (Wehner et al. 2017). Changing drought conditions (frequency, severity, duration) can challenge a variety of infrastructure and operations (Department of Homeland Security 2015) in the NPS (e.g., water supply and wastewater systems), impair water quality (Mosley 2015), affect soil heaves and shrinkages (Fernandes et al. 2015), and will enhance other related risks such as wildfire (Halofsky et al. 2020).

The Great Plains region is drought-prone. A high degree inter-annual variability in precipitation is characteristic of the Northern Plains, leading to periodic drought conditions and creating uncertainty that is challenging for water resource management. This variability in precipitation, coupled with increasing temperatures create conditions for rapid onset of intense droughts, with conditions deteriorating quickly (Conant et al. 2018). These "flash droughts" rapidly decreased soil moisture, resulting in both the 2012 and 2020 extreme wildfire seasons. Climate change projections are uncertain about precipitation changes, but warmer temperatures will increase evaporative demand, worsening drought conditions (Wehner et al. 2017, Conant et al. 2018). Short-term "flash droughts" are expected to intensify in this region (Shafer et al. 2014), becoming more frequent and severe due to increasing precipitation variability and rising temperatures and will challenge water resource management throughout the region (Pendergrass et al. 2020). Rapidly changing soil moisture with soil shrinkage and heaves can cause soil cracking and structural issues with pipes, roads, and buildings (Fernandes et al. 2015).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Increased wildfire frequency, intensity, magnitude, and duration

Wildfire is a natural part of many forest, woodland, and grassland ecosystems. Excessive fire, however, can damage ecosystems, kill people, and damage infrastructure. Climate change is intensifying the heat that drives wildfire (Jolly et al. 2015) and altering the distribution and density of vegetation that comprises the fuel for wildfires (Gonzalez et al. 2010). These effects combine with the unnatural buildup of fuels due to decades of suppression of all fires, even natural ones (Agee and Skinner 2005). The effects of climate change on wildfire vary across landscapes. In the Great Plains states, under the highest greenhouse gas emissions scenario, projected climate change could increase the frequency of large fires

(>50 km², 20 sq. mi.) up to six times in the grasslands of Montana, North and South Dakota, and Nebraska by 2050 (Barbero et al. 2015). For areas where projected climate change increases fire risk, buildings, cultural landscapes, or other infrastructure located under or near tree canopies or dense grasslands are vulnerable to burning and destruction.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Altered precipitation patterns and changing humidity

Changing precipitation patterns have been observed in many regions of the United States as result of climate change and changes are expected to continue. Depending on the region in the United States, increases or decreases in precipitation have been experienced (U.S. Global Change Research Program et al. 2018). Changing precipitation and humidity conditions can result in local flooding, encourage mold growth, wood decay, increase fire risk, and intensify drought conditions, depending on the pattern of change. For Mount Rushmore National Memorial, total annual precipitation changed at the non-statistically significant rate of $+9 \pm 7\%$ per century from 1895 to 2010 (Gonzalez et al. 2018). Under the highest emissions scenario, the average of climate model projections is a total annual precipitation increase of $11 \pm 9\%$ by 2100 for Mount Rushmore National Memoria (Gonzalez et al. 2018).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Increased extreme precipitation

Increased frequency and intensity of extreme precipitation events have been attributed to climate change within some regions of the United States and such increases are projected to continue over the next century (U.S. Global Change Research Program et al. 2018). Furthermore, the intensity of extreme precipitation events increase with increasing temperatures (Easterling et al. 2017). The frequency of intense precipitation throughout the MWR increased up to 53% from 1958-2016, especially in the upper central and Great Lakes states (Easterling et al. 2017) and projections for all emissions scenarios are for additional increases in the future. Intense precipitation, especially on snow, can result in record-setting flooding, higher water tables, extreme erosion and changes in stream and riverbanks, presenting a variety of threats to infrastructure and operations including flooding of sites, sewage backup, accelerated decay of masonry, overcoming drainage systems, road wash out, cracks in building infrastructure, erosion of adobe, destabilization of buildings and pipes, erosion of supporting ground around structures, among many other effects. Saturated soils may fail to support roads, pilings, foundations and other structural supports. Increased humidity, flooding, and driving rain can damage building cladding, increase risk of mold and rot, and promote insect damage.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
☐ No

Riverine flood/Flash Flood

Extreme precipitation events and the risk of flooding are expected to regionally intensify with a changing climate (Dethier et al. 2020, Tabari 2020). Floods threaten infrastructure and operations through a variety of mechanisms, including inundation of structures, enhanced erosional forces, road wash out, structural collapse from force of floodwaters, sewage backup, and damage to utilities, generators, and electrical systems. Post-flooding effects include increased rot, fungal/insect attack, mold and mildew, and physical deterioration of wood, brick and stone building materials. Increased annual precipitation (Melillo et al. 2014), and increased frequency and intensity of heavy rain events (Easterling et al. 2017), have increased the overall flood risk in the Midwest region. Dethier et al. (2020) found annual high-flow frequency has increased in the midwestern U.S. comparing the past two decades (2007-2016) to the reference period 1950-1969. While flood frequency appears to be increasing in the Midwest, the largest flood peaks have not been strongly increasing across the region (Mallakpour and Villarini 2015). Winter and spring precipitation, which play an important role in flood risk for the region are projected to increase by 30% by the end of this century (Angel et al. 2018). Within region flood trends show high spatial variability depending on catchment conditions and the flood generating mechanism. In many cases climate is just one factor leading to flooding (Peterson et al. 2013), with urbanization and other land cover changes exerting a strong influence (Criss and Luo 2017, Angel et al. 2018). In some cases it is inadequate to assume that design flood values will remain stationary in the future as climate changes (Van Dusen et al. 2020). As a result, local studies to characterize changes in extreme flows (Van Dusen et al. 2020) or increases in current safety factors may be necessary to account for climate change in infrastructure design.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
☐ No

Hurricanes and tornados

With continued climate change, the potential for severe thunderstorms that provide conditions for tornadoes may increase substantially (Abell et al. 2007, Diffenbaugh et al. 2013, Gensini and Mote 2015). In the midwestern U.S., under the highest emissions scenario, models project more than a 40% increase from 2000 to 2100 of the number of days in spring with severe thunderstorms that could produce tornadoes (Diffenbaugh et al. 2013). Tornadoes can result in catastrophic damage to infrastructure from high winds, and associated debris, hail, and flash flooding.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
☐ No

Pest infestation

Increased temperatures and CO₂, changes in precipitation, and disturbance due to extreme climate events can increase the survival, spread, growth, and establishment of pests (Intergovernmental Panel on Climate Change et al. 2014). Rooting and burrowing mammals and termites have the potential to cause direct damage to power, water, transportation, and building facilities (Vissichelli 2018). Facilities may be impacted indirectly through other mechanisms exacerbated by climate change such as forest insect pest invasions or fluctuating ground water levels leading to increased tree mortality, hazard trees, and treefall. Fewer days below freezing may increase pest outbreaks and infestations in facilities, and forest pests unhindered by freezing temperatures may cause increased tree mortality, hazard trees, and tree fall that may indirectly impact facilities. When and where invasions and infestations may occur is difficult to predict precisely given that other factors such as landscape change, habitat disturbance, and human-facilitated vectors synergistically interact with climate change to limit or accelerate the range-expansion of invasives and pests. Consult with your regional NPS pest and invasive species management coordinators to identify current and potential invasive and pest infestation threats.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Invasive species

Increased temperatures and CO₂, changes in precipitation, and disturbance due to extreme climate events can increase the survival, spread, growth, and establishment of invasive species (Intergovernmental Panel on Climate Change et al. 2014). Weeds and aquatic mussels have the potential to cause direct damage to power, water, transportation, and building facilities (Vissichelli 2018). Non-native species that may not currently impact facilities may become harmful due to changes in local climates (National Research Council 2002, Intergovernmental Panel on Climate Change et al. 2014). When and where invasions and infestations may occur is difficult to predict precisely given that other factors such as landscape change, habitat disturbance, and human-facilitated vectors synergistically interact with climate change to limit or accelerate the range-expansion of invasives and pests. Consult with your regional NPS pest and invasive species management coordinators to identify current and potential invasive and pest infestation threats.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

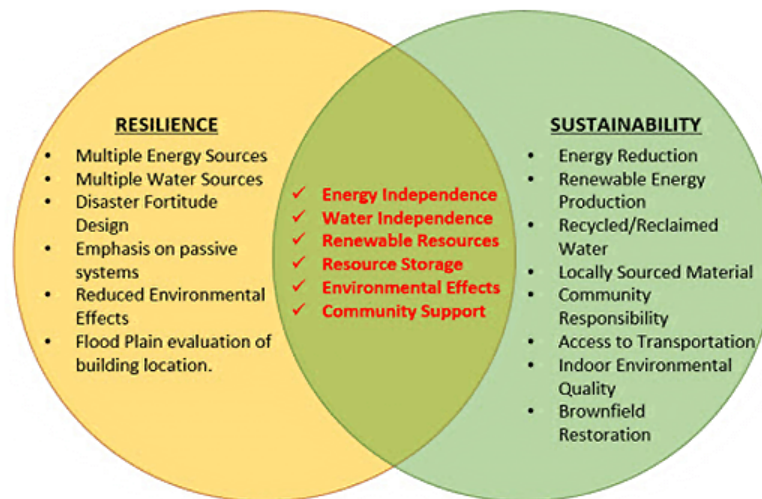
Step 2: Consider adaptation and resiliency strategies

- Review definitions of resiliency and adaptation strategies.
- Identify adaptation strategies that will help park resources respond to the hazards identified in Step 1.

Question 16 requires a screening for climate hazards followed by a review of adaptation and resiliency strategies that would be put in place to respond to these hazards. For the purposes of this report and investment planning, resilience is a property of a system or asset and generally refers to the ability of the system or asset to maintain its intended purpose following a temporary disturbance.

Adaptation strategies, in the context of built infrastructure, refers to the intentional management decision to identify, prepare for, and respond to observed or expected sustained changes in hazards, including climate change, to adjust to a sustained change in conditions.

It is important to note that resilient park operations can be supported through the use of green infrastructure such as sustainable landscaping, as well as sustainable energy, water, and building envelope solutions. The figure below illustrates this relationship.



Lists of adaptation strategies for different types of infrastructure projects in response to different hazards can be found here: [Incorporating Climate Change Adaptation in Infrastructure Planning and Design](#) (see Chapter 4, Tables 25-34). If used, these adaptation strategies will need to be modified for proposed park projects.

Buildings and assets within national parks may include cultural resources (e.g., historic and pre-historic buildings and structures). The adaptation and resiliency options for cultural resources often overlap with those defined for facilities; however, NPS has detailed specific strategies when dealing with cultural resources and climate change in national parks ([Cultural Resources Climate Change Strategy](#)). “Climate

change poses an especially acute problem for managing cultural resources because they are unique and irreplaceable — once lost, they are lost forever.” ([NPS Policy Memorandum 14-02](#)).

Step 3: Develop an answer to Question 16 for your specific project and location, as well as strategies to address each hazard

- Two example responses to Question 16 are provided below. THESE ARE GENERIC EXAMPLES FROM OTHER PARKS.
- You will need to modify the answers below based on the hazards identified in Step 1 and the adaptation strategies identified in Step 2 for your park and project. The park response should be as project-specific as possible.

Question 16: What risks or hazards (current and projected, e.g. effects of climate change) are likely to affect this project? If applicable, what adaptation strategies and/or resiliency measures have been identified for scenarios that pose high risks to project assets?

Example from Minute Man National Historic Park: Restoring historic structures

Several climate change hazards have been identified that may affect building-related projects at MIMA, including hotter average days, more extreme heat days, increased hurricane impacts from wind and flooding, altered precipitation patterns, and increased extreme precipitation. Adaptation and resiliency strategies for the expected hazards are described below:

- Hotter average days and more extreme heat days will increase demand and requirements for appropriately sized air conditioning systems.
- Extreme heat and humidity can stress the building envelope and will require significant humidity control alterations for structures.
- Hurricane force wind and wind-blown rain as well as damage from wind-blown debris or treefall will require wind resistant fortification of the structure. Addressing hazardous trees and retrofitting roof structures to be more wind resistant may also be required.
- Flooding from increased hurricane events, increased extreme precipitation, or in conjunction with altered precipitation patterns may require modifications to building infrastructure location and landscape drainage systems.
- Post-flooding effects may include increased rot, mold and mildew, and physical deterioration of wood, brick and stone building materials. Adaptation actions will include identifying appropriate dehumidification and air handling systems and coordinating with the NPS Historic Architecture, Conservation and Engineering Center or Historic Preservation Training Center regarding alternatives and maintenance for historic structures.

Example from Grand Teton National Park: Building assets, water development, or road construction

Several climate change hazards have been identified that may affect projects in GRTE, including hotter average days, more extreme heat days, increased drought frequency and intensity, altered precipitation and flooding patterns, increased wildfire, and increased invasive species abundance or distribution. Some example adaptation and resiliency strategies for the expected hazards are described below:

- Hotter average days and more extreme heat days will increase demand and requirements for appropriately sized air conditioning systems.
- Energy demand increases should be offset by conservation measures and renewable energy implementation where possible.
- Extreme heat can stress the building envelope and may require significant humidity control alterations for structures.
- Increased and more intense wildfires will require more planning in the wildland-urban interface, either by relocating park assets, using fire-resistant building materials, reducing fuels near structures, or all of these measures.
- Increased drought and faster runoff can reduce the amount of water available for park use. New water sources might need to be identified and water conservation measures should be prioritized.
- Heavy rains during the spring thaw can cause rapid melting of the snowpack resulting in severe flooding. Road construction may require relocation, as well as larger culverts and other flood control measures to accommodate heavy runoff.
- Buildings, infrastructure, and roads in existing flood zones may need additional mitigation.
- The potential for increased invasive species should be mitigated. Measures include mitigation during construction (e.g., using weed-free gravel and cleaning construction equipment) and increased weed treatment post construction.
- Termites are likely to arrive in GRTE by mid-century. Early detection monitoring and eradication, if possible, will help protect historic structures and other buildings.

Step 4: Seek additional assistance if desired

- Additional resources for answering question 16 and related questions can be found in:
 - Appendix 1 below, which includes a full hazards checklist, providing additional links for supporting information related to each hazard.
 - Appendix 2 below, which provides a map to visualize how climate is changing for the park.
 - The [GFIP Guidance and Logistics](#) folder under the [Resources to Assess Risks and Hazards tab](#) includes:
 - An Excel workbook labeled [T75 Parks GFIP NRSS Supporting Materials](#) that provides links to information for natural resources to be considered during project design and construction.
 - A [FAQs – Assessing Risks and Hazards](#) document that provides detailed guidance for answering Question 16.

- A [Natural Hazard Assessment Webinar](#) recording that provides key information, definitions, and guidance for understanding natural hazards and related resources.
- The NPS Climate Change Response Program (CCRP) and Sustainable Operations and Maintenance Branch (SOMB) are also available for assistance in evaluation of climate change hazards and resiliency strategies as they relate to specific projects. Questions can be sent to the NPS [GFIP Hazards and Risk Assistance email account](#) and a member of that team will reply with support.

Appendix 1: The Climate-Related Hazard Checklist

This appendix provides an initial evaluation of climate hazards for **Mount Rushmore National Monument** according to the hazard ratings identified below. The information used to identify hazards in the checklist is mostly from regional assessments. Park and project specific information was generally not available when assessing these hazards. NPS Climate Change Response Program (CCRP) staff made an initial attempt to identify potential hazards for the park broadly (see 'Best Professional Judgement' column); however, park staff and project planners have more information about hazards that are likely to be applicable to a specific project.

Explanation of Hazard Ratings

Known hazard: Conditions that cause the hazard are well documented in the area where the park occurs. If applicable to the project site, these hazards should always be addressed in the project plan.

Potential hazard: Conditions that cause or underlie the hazard are known to occur nearby or are likely to occur based on studies with conditions similar to the park. If applicable to the project site, these hazards should be considered for inclusion in the project plan.

Not applicable: No evidence *was identified* showing this hazard is relevant to the park. Note this is a coarse filter evaluation; local knowledge of a hazard(s) should be used, when available.

Table 1. Climate-related Hazards Checklist

Potential Climate Hazard	Best Professional Judgment	Examples of risk or secondary hazard	Sources of General Non-site specific Data	Sources for Site Specific Data
Hotter average days and more very hot days	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Inadequate HVAC • Road surface degradation • Lack of water due to increased water for irrigation • Increased humidity • Danger to staff	• National Climate Assessment	• National Climatic Data Center • DAYMet gridded climate data • National park historical and projected climate change

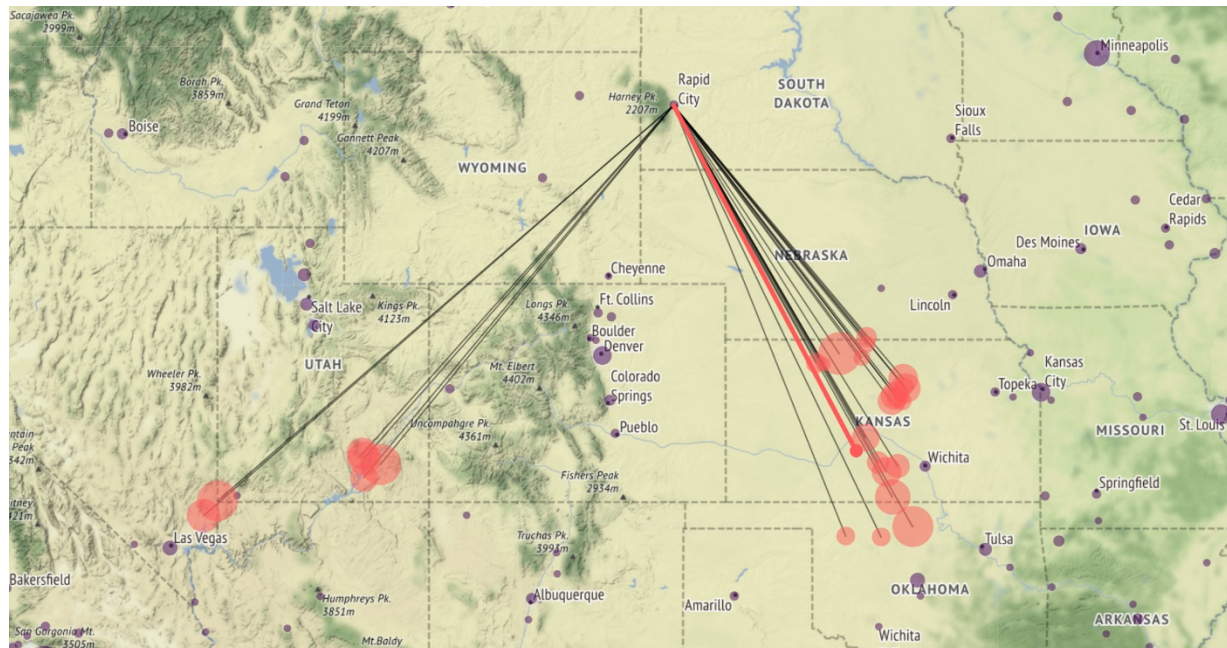
Potential Climate Hazard	Best Professional Judgment	Examples of risk or secondary hazard	Sources of General Non-site specific Data	Sources for Site Specific Data
Increased drought frequency, intensity, magnitude, and duration	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Limited water supply for cooling, landscaping, structural fire suppression, other equipment • Increased competition for available water and water rights conflicts • Crack/heave damage in drier soils • Increased vulnerability to wildfire (below)	• Drought Monitor • National Integrated Drought Information Center • National Climate Assessment	• Drought Monitor • National Integrated Drought Information Center
Increased wildfire frequency, intensity, magnitude, and duration	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Damage to facilities and contents • Smoke damage • Air quality dangerous to staff and visitors • Increased runoff • Increased erosion • Damage to water treatment plants	• Barbero et al. 2015 International Journal of Wildland Fire	• NIFC • International Wildland-Urban Interface Code
Altered precipitation patterns and changing humidity	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Local flooding • Mold growth • Wood decay • Drought • Fire • Groundwater change	• National Climate Assessment	• National Climatic Data Center • DAYMet gridded climate data • National Park historical and projected climate change

Potential Climate Hazard	Best Professional Judgment	Examples of risk or secondary hazard	Sources of General Non-site specific Data	Sources for Site Specific Data
Increased extreme precipitation	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Surface erosion • Floods (see below) • Water damage to structures from driven rain • Unstable saturated soils	• National Climate Assessment	• Evaluations are mostly at regional scales
Riverine flood/flash flood	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Damage or destruction of infrastructure • Stream channel migration • Stream bank erosion/extreme erosion • Safety • Water quality diminished • Damage to water source and delivery infrastructure • Changing requirements for culvert flow capacity	• FEMA Flood map service	• FEMA Map Service Center • Floodplain maps for HUD projects • Van Dusen et al. 2020 (for select parks) • May require a special flood study
Sea/lake level change and coastal storm surge	Known Hazard ☐ Potential Hazard ☐ Not Applicable ☒	• Rising sea and lake levels • Rising water – wind driven (e.g. hurricane, nor’easter) • Saltwater intrusion • Vegetation damage	• NOAA SLR viewer • NOAA - Great Lakes Environmental Research Laboratory	• IRMA – Coastal reports • NPS SLR viewer • Specific Hazard Assessment: Coastal Storm Surge with Climate Change Effects (requires VPN connection) • SLR reports • Great Lakes Dashboard Project

Potential Climate Hazard	Best Professional Judgment	Examples of risk or secondary hazard	Sources of General Non-site specific Data	Sources for Site Specific Data
Hurricanes and tornados	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Building destruction • Flying debris • Storm surge • Tree fall (see other categories for associated intense rainfall and floods)		• Wind speed data – from local codes • International Building Code • FEMA Map Service Center
Pest infestation	Known Hazard ☐ Potential Hazard ☒ Not Applicable ☐	• Historic/facility fabric loss • Vegetation loss • Disease vectors may increase • Termites and other woodboring pests expanding range with warming and increased humidity	• USFS Forest Health Program	• Integrated Pest Management • Fisichelli et al. forest pests • USFS maps
Invasive species	Known Hazard ☒ Potential Hazard ☐ Not Applicable ☐	• Aquatic mussels – water intakes clogged • Vegetation (kudzu, vines) – damage buildings, kill trees, obstruct waterways	• National Invasive Species Council	• Early Detection and Distribution Mapping System (current distribution) • Early Detection and Distribution Mapping System (projected distribution)

Appendix 2. What Will the Park Climate Feel Like in 60 Years?

The map below is intended to help visualize how the present-day climate in the region of **Mount Rushmore National Monument** is projected to change as a result of climate change (Fitzpatrick and Dunn 2019). Under a high greenhouse gas emission scenario, Rapid City, South Dakota's climate in 2080 may feel like today's climate near Great Bend, Kansas. The typical summer in Great Bend, Kansas is 9.0°F (5.0°C) warmer and 27.2% wetter than summer in Rapid City, South Dakota. The red line shows the average of the 27 climate models; the black lines show the 27 individual projections assuming continued high emissions, providing a sense of the plausible range of future climates. Circle size gives a sense of how good of a match that location is, with larger circles indicating poorer matches; all circles (red or purple) denote cities used in the analysis. The analysis is based on twelve climate metrics, including minimum and maximum temperature and precipitation by season (spring, summer, fall, winter). More details are available in the reference cited above and the website <https://fitzlab.shinyapps.io/cityapp/>.



References

- Abell, R., J. D. Allan, and B. Lehner. 2007. Unlocking the potential of protected areas for freshwaters. *Biological Conservation* 134:48–63.
- Agee, J. K., and C. N. Skinner. 2005. Basic principles of forest fuel reduction treatments. *Forest Ecology and Management* 211:83–96.
- Angel, J. R., C. Swanson, B. M. Boustead, K. Conlon, K. R. Hall, J. L. Jorns, K. E. Kunkel, M. C. Lemos, B. M. Lofgren, T. Ontl, J. Posey, K. Stone, E. Takle, and D. Today. 2018. Chapter 21 : Midwest. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program.

- Barbero, R., J. T. Abatzoglou, N. K. Larkin, C. A. Kolden, and B. Stocks. 2015. Climate change presents increased potential for very large fires in the contiguous United States. *International Journal of Wildland Fire* 24:892.
- Conant, R. T., D. Kluck, M. Anderson, A. Badger, B. M. Boustead, J. D. Derner, L. Farris, M. J. Hayes, B. Livneh, S. McNeeley, D. Peck, M. D. Shulski, and V. A. Small. 2018. Chapter 22 : Northern Great Plains. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program.
- Criss, R. E., and M. Luo. 2017. Increasing risk and uncertainty of flooding in the Mississippi River basin. *Hydrological Processes* 31:1283–1292.
- Department of Homeland Security. 2015. Drought Impacts to Critical Infrastructure. Office of Cyber and Infrastructure Analysis.
- Dethier, E. N., S. L. Sartain, C. E. Renshaw, and F. J. Magilligan. 2020. Spatially coherent regional changes in seasonal extreme streamflow events in the United States and Canada since 1950. *Science Advances* 6:eaba5939.
- Diffenbaugh, N. S., M. Scherer, and R. J. Trapp. 2013. Robust increases in severe thunderstorm environments in response to greenhouse forcing. *Proceedings of the National Academy of Sciences* 110:16361–16366.
- Easterling, D. R., K. E. Kunkel, J. R. Arnold, T. Knutson, A. N. LeGrande, L. R. Leung, R. S. Vose, D. E. Waliser, and M. F. Wehner. 2017. Precipitation change in the United States. Pages 207–230 in D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock, editors. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. U.S. Global Change Research Program, Washington, D.C.
- Fernandes, M., A. Denis, R. Fabre, J.-F. Lataste, and M. Chrétien. 2015. In situ study of the shrinkage-swelling of a clay soil over several cycles of drought-rewetting. *Engineering Geology* 192:63–75.
- Fitzpatrick, M. C., and R. R. Dunn. 2019. Contemporary climatic analogs for 540 North American urban areas in the late 21st century. *Nature Communications* 10:614.
- Gensini, V. A., and T. L. Mote. 2015. Downscaled estimates of late 21st century severe weather from CCSM3. *Climatic Change* 129:307–321.
- Gonzalez, P., R. P. Neilson, J. M. Lenihan, and R. J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change: Global vulnerability to climate change. *Global Ecology and Biogeography* 19:755–768.
- Gonzalez, P., F. Wang, M. Notaro, D. J. Vimont, and J. W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. *Environmental Research Letters* 13:104001.
- Halofsky, J. E., D. L. Peterson, and B. J. Harvey. 2020. Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology* 16:4.
- Intergovernmental Panel on Climate Change, C. B. Field, and V. R. Barros, editors. 2014. *Climate change 2014: Impacts, adaptation, and vulnerability: Working Group II contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, New York, NY.
- Intergovernmental Panel on Climate Change, D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. Midgley. 2013. *Climate change 2013: The physical science basis*.

- Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds TF Stocker et al.):5–14.
- Jolly, W. M., M. A. Cochrane, P. H. Freeborn, Z. A. Holden, T. J. Brown, G. J. Williamson, and D. M. J. S. Bowman. 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications* 6:7537.
- Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. *Nature Climate Change* 5:250–254.
- Melillo, J. M., T. (T. C.) Richmond, and G. W. Yohe. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program.
- Mosley, L. M. 2015. Drought impacts on the water quality of freshwater systems; review and integration. *Earth-Science Reviews* 140:203–214.
- National Research Council, editor. 2002. *Predicting invasions of nonindigenous plants and plant pests*. National Academy Press, Washington, D.C.
- Pendergrass, A. G., G. A. Meehl, R. Pulwarty, M. Hobbins, A. Hoell, A. AghaKouchak, C. J. W. Bonfils, A. J. E. Gallant, M. Hoerling, D. Hoffmann, L. Kaatz, F. Lehner, D. Llewellyn, P. Mote, R. B. Neale, J. T. Overpeck, A. Sheffield, K. Stahl, M. Svoboda, M. C. Wheeler, A. W. Wood, and C. A. Woodhouse. 2020. Flash droughts present a new challenge for subseasonal-to-seasonal prediction. *Nature Climate Change* 10:191–199.
- Peterson, T. C., R. R. Heim, R. Hirsch, D. P. Kaiser, H. Brooks, N. S. Diffenbaugh, R. M. Dole, J. P. Giovannettone, K. Guirguis, T. R. Karl, R. W. Katz, K. Kunkel, D. Lettenmaier, G. J. McCabe, C. J. Paciorek, K. R. Ryberg, S. Schubert, V. B. S. Silva, B. C. Stewart, A. V. Vecchia, G. Villarini, R. S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C. A. Woodhouse, and D. Wuebbles. 2013. Monitoring and Understanding Changes in Heat Waves, Cold Waves, Floods, and Droughts in the United States: State of Knowledge. *Bulletin of the American Meteorological Society* 94:821–834.
- Shafer, M., D. Ojima, J. M. Antle, D. Kluck, R. A. McPherson, S. Petersen, B. Scanlon, and K. Sherman. 2014. Ch. 19: Great Plains. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program.
- Tabari, H. 2020. Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports* 10:13768.
- U.S. Global Change Research Program, D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart. 2018. *Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program.
- U.S. Global Change Research Program, D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock. 2017. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. U.S. Global Change Research Program.
- Van Dusen, P., B. Rajagopalan, D. J. Lawrence, L. E. Condon, G. Smillie, S. Gangopadhyay, and T. Pruitt. 2020. 21st Century flood risk projections at select sites for the U.S. National Park Service. *Climate Risk Management* 28:100211.
- Vissichelli, M. 2018. *Invasive species impacts on federal infrastructure*. National Invasive Species Council Secretariat Deliverable, Washington, DC.

- Vose, R., D. R. Easterling, K. Kunkel, and M. Wehner. 2017. Temperature changes in the United States. Fourth National Climate Assessment, Volume I, U.S. Global Change Research Program.
- Wehner, M. F., J. R. Arnold, T. Knutson, K. E. Kunkel, and A. N. LeGrande. 2017. Ch. 8: Droughts, Floods, and Wildfires. Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program.

Disclaimer

Report Purpose and Scope:

Parks identified for Legacy Restoration Funding in fiscal years 2023-2025 are required to develop a Great American Outdoors Act Facility Investment Plan (GFIP). The intended use of this series of park-specific reports is to help parks address Question 16 of the narrative template: *What risks or hazards (current and projected, e.g. effects of climate change) are likely to affect this project? If applicable, what adaptation strategies and/or resiliency measures have been identified for scenarios that pose high risks to project assets?*

Each report compiled and summarized published information on a suite of climate change hazards. Each report included an analysis of each hazard, for which the report author assigned a 'hazard rating' as follows:

Known hazard: Conditions that cause the hazard are well documented in the area where the park occurs. If applicable to the project site, these hazards should always be addressed in the project plan.

Potential hazard: Conditions that cause or underlie the hazard are known to occur nearby or are likely to occur based on studies with conditions similar to the park. If applicable to the project site, these hazards should be considered for inclusion in the project plan.

Not applicable: No evidence was identified showing this hazard is relevant to the park. Note this is a coarse filter evaluation; local knowledge of a hazard(s) should be used, when available.

As articulated within the report (in an appendix of the hazard ratings) those ratings constitute the author's 'best professional judgement' about the relevance of the hazard for that park based on the reviewed literature (cited in the narrative text for the hazard & provided in the report bibliography).

The intended use of each report is to inform decisions for facility investment planning related to (i) potential hazards that a suggested facility investment concept would need to appropriately consider and avoid or mitigate and (ii) identifying facilities possibly at greater relative vulnerability due to the identified hazards. The level of information quality in the report was calibrated to those purposes, i.e. to inform development of questions for a facility investment scoping process to further explore.

Peer Review Process:

Each report was based on a template, which heavily relied on boilerplate text for the non-park specific elements. The boilerplate text underwent multiple rounds of informal peer review by assorted CCRP staff, including members of the Climate Science and Adaptation Team, the Communications Team, the Regional Climate Change Liaisons, and the Climate Change Liaison to Facilities and Planning. Each report was peer-reviewed by a member of CCRP to check interpretation, consistency in hazard ratings, improve narrative coherence, and flag priority additions/modifications. In situations where revisions were required, the peer reviewer then re-reviewed the final revised report to assure adequate resolution of the identified issues.