



Climate Change Hazards Summary Report for Facility Investment Planning

Mammoth Cave National Park January 2021

Prepared By
NPS Climate Change Response Program
NPS Sustainable Operations and Maintenance Branch

Executive Summary

By the end of the century, projections indicate that annual mean temperature is expected to increase by as much as 4.9° C along with annual average precipitation increases of as much as 11% (Gonzalez et al. 2018), and the most recent three decades have been significantly warmer than the remainder of the past century (Monahan and Fisichelli 2014). Climate change is also increasing the intensity of storms, driving up the risk of flooding and subsequent erosion at Mammoth Cave National Park. Climate change may also alter natural systems, pests and invasive species, and will likely affect seasonal use patterns at the park. These increasing risks can be anticipated and addressed in the planning phase of new facilities projects.

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.

Overall precipitation, the frequency and intensity of severe thunderstorms, and extreme precipitation events are all projected to increase at MACA. Changing precipitation, extreme precipitation events, and humidity conditions present a variety of threats to infrastructure and operations including flooding of sites, sewage backup, accelerated decay of masonry, mold growth, overcoming drainage systems, road wash out, cracks in building infrastructure, destabilization of buildings and pipes, and erosion of supporting ground around structures, among other effects. However, it is also possible that changes in precipitation alongside warming temperatures could result in the park experiencing dry conditions coincident with mass tree mortality events and increasing wildfire risk.

Introduction & Purpose

Mammoth Cave National Park is developing a facility investment plan and associated projects for funding through the Great American Outdoors Act and Legacy Restoration Fund. Information provided in this report is intended to help the park consider climate change related hazards when addressing Question 16 of the narrative template.

The park has significant deferred maintenance and future investment in Mammoth Cave National Park assets can be made with an eye toward reducing risk due to climate related impacts. Awareness is the first step toward endurance for Great American Outdoors Act and Legacy Restoration Funded projects. Further dialogue beyond this report can help to move from awareness to adaptive construction. The following section describes potential climate related hazards for MACA based on an assessment by the NPS Climate Change Response Program and NPS Sustainable Operations and Maintenance Branch.

Summary Information for Hazards

Hotter average days and more very hot days

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.

Temperature can be used to predict visitation patterns with a 95% accuracy, with peak visitation occurring in the summer (Fischelli et al. 2015). It's possible that increasing temperatures and humidity may make the park inhospitable to individuals seeking outdoor experiences, and more climate controlled indoor environments may be needed to provide an escape from the elements for park staff and visitors.

Low greenhouse gas scenarios for this century (RCP 2.6) lead to projections of annual mean temperature increase of 1.6° C. Higher greenhouse gas scenarios (RCP 8.5) project an increase of annual mean temperature of 4.9° C (Gonzalez et al. 2018). When looking over the past century, the three most recent decades have been extremely warm, notably during the time of year with the most precipitation (Monahan and Fischelli 2014). The threats of future heat waves and extended periods of above average temperatures are associated with spikes in unhealthy ozone levels. Extreme temperatures and elevated ozone levels can increase weathering of structures, threaten park staff and visitor safety, and increase stresses for HVAC systems.

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Increased drought frequency, intensity, magnitude, and duration

Changing drought conditions (frequency, severity, duration) can challenge a variety of infrastructure and operations 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).

Although annual precipitation totals in the Southeastern U.S. haven't changed statistically over the past century, increasing intensity of extreme events and hotter, drier summers have led to droughts becoming more intense and longer (Kunkel et al. 2013, USDA 2017, Carter et al. 2018). Climate change is expected to continue intensifying the hydrological cycle, increasing the frequency and severity of extreme events like drought (Mitchell et al. 2014, Carter et al. 2018).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Increased wildfire frequency, intensity, magnitude, and duration

There is fire risk to buildings, cultural landscapes, or other infrastructure located under or near tree canopies or dense grasslands. Even though precipitation is projected to increase at MACA, it's possible that the park could experience dry conditions coincident with mass tree mortality events. Climate change is intensifying the heat that drives wildfire (Jolly et al. 2015) and is expected to adversely impact sugar maple, black walnut, pawpaw, yellow poplar, scarlet oak, and other MACA trees (Fisichelli et al. 2014), which could result in additional fuel on the ground. MACA has a fire management plan which can be found at [NPS PEPC - Mammoth Cave National Park Fire Management Plan 2018](#).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Altered precipitation patterns, increased extreme precipitation, and changing humidity

Changing precipitation, extreme precipitation events, and humidity conditions present a variety of threats to infrastructure and operations including flooding of sites, sewage backup, accelerated decay of masonry, mold growth, overcoming drainage systems, road wash out, cracks in building infrastructure, destabilization of buildings and pipes, and erosion of supporting ground around structures, among other effects.

Projections are that as temperatures increase, annual average precipitation will also increase by 6% to 11% by the end of the century (Gonzalez et al. 2018). The intensity of extreme precipitation events also increases with increasing temperatures. Extreme rainfall events have increased in frequency and intensity in the Southeast, and there is high confidence they will continue to increase in the future (Easterling et al. 2017). The region, as a whole, has experienced increases in the number of days with more than 3 inches of precipitation, and a 16% increase in observed 5-year maximum daily precipitation (the amount falling in an event expected to occur only once every 5 years) (Easterling et al. 2017). Both the frequency and severity of extreme precipitation events are projected to continue increasing in the region under both medium and higher scenarios (RCP4.5 and RCP8.5). By the end of the century under a higher scenario (RCP8.5), projections indicate approximately double the number of heavy rainfall events (2-day precipitation events with a 5-year return period) and a 21% increase in the amount of rain falling on the heaviest precipitation days (days with a 20-year return period) (Easterling et al. 2017).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Riverine flood/Flash flood

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. With higher temperatures driving up the intensity of storms, flash flood risk could increase.

As discussed above, extreme rainfall events have increased in frequency and intensity in the southeastern U.S., and there is high confidence this trend will continue into the future (Easterling et al. 2017). By the end of the 21st century high greenhouse gas emission projections indicate a doubling of the number of heavy rainfall events (2-day precipitation events with a 5-year return period) and a 21% increase in rain falling on the heaviest precipitation days (days with a 20-year return period) (Allan and Soden 2008, Easterling et al. 2017).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Tornados

Tornadoes can result in catastrophic damage to infrastructure from high winds, and associated debris, hail, and flash flooding. 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). The number of days in spring in the eastern U.S. with severe thunderstorms that could produce tornadoes could increase 40% from 2000 to 2100 under the highest greenhouse gas emissions scenario (Diffenbaugh et al. 2013).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Pest infestation

Termites have the potential to cause direct damage to wooden components of structures. 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. Increased temperatures and CO₂, changes in precipitation, and disturbance due to extreme climate events can increase the survival, spread, growth, and establishment of pests (IPCC 2014).

Park staff assessment – relevant to GFIP Project:

- ☐ Yes
- ☐ No

Invasive species

Non-native species that may not currently impact facilities may become harmful due to changes in local climates (NRC 2002, IPCC 2014). Even native species invading new territory can present a risk (i.e.

armadillo). 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 (IPCC 2014).

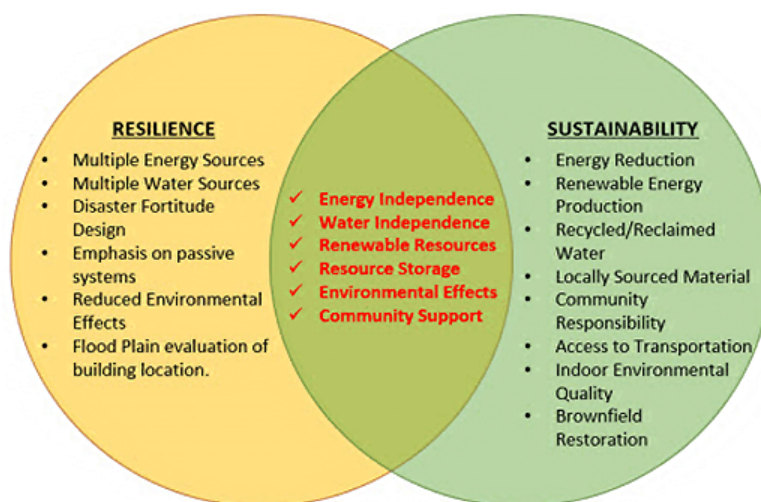
Park staff assessment – relevant to GFIP Project:

- ☐ Yes
☐ No

Adaptation and Resiliency Strategies

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 using 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](#)).

What Climate Change Risks or Hazards are Likely to Affect a Project at MACA?

- 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.
- Flooding from increased intensity storm 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 and more warm humid days 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 National Center for Preservation Technology and Training regarding alternatives and maintenance for historic structures.
- Early detection monitoring and eradication, if possible, will help protect historic structures and other buildings from termite damage.
- There is some chance that wildfire risk will increase. If possible, consider landscaping options that will reduce fuels around structures.

Additional Assistance

Additional resources for answering question 16 and other questions related to the GFIP process can be found in:

- Appendix 1 below, which includes a full hazards checklist, providing additional links for supporting information related to each hazard.
- 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: Climate-Related Natural Hazards Checklist

The following checklist is an expert-opinion based screening tool that illustrates the hazards that were considered in the development of this report. Knowledge of how climate change will unfold is developing rapidly and new hazards may become evident in the future.

Potential Hazard	Best Professional Judgment	Potential Risk or Secondary Hazard
Air Temperature: 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 and visitors
Melting Permafrost/ Declining Sea and Lake Ice	Known Hazard ☐ Potential Hazard ☐ Not applicable ☒	• Road and building foundations unstable • Landslides and unstable hillsides • Shoreline erosion
Drought: Increased Frequency, Intensity, Magnitude, and Duration	Known Hazard ☐ Potential Hazard ☒ Not applicable	• Limited water supply for cooling, landscaping, other equipment • Increased competition for available water and water rights conflicts • Crack/heave damage in drier soils • Increased vulnerability to wildfire (below)

	☐	
Wildfire: Increased 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
Precipitation: Altered Patterns and Changing Humidity	Known Hazard ☒ Potential Hazard ☐ Not applicable ☐	• Local flooding • Mold growth • Wood decay • Drought • Fire • Groundwater change
Precipitation: Increased Extreme Events	Known Hazard ☐ Potential Hazard ☒ Not applicable ☐	• Surface erosion • Floods (see below) • Water damage to structures from driven rain • Unstable saturated soils
Riverine Flood/ Flash Flood	Known Hazard ☒ Potential Hazard ☐	• Damage or destruction of infrastructure • Stream channel migration • Stream bank erosion/extreme erosion • Safety • Water quality diminished • Damage to water source and delivery infrastructure

	Not applicable ☐	Changing requirements for culvert flow capacity
Sea 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 - Need to elevate or relocate coastal facilities
Hurricanes, Tornados, and Other High Wind Events	Known Hazard ☐ Potential Hazard ☒ Not applicable ☐	- Building destruction - Flying debris - Storm Surge - Tree fall (see other categories for associated intense rainfall, floods)
Pest Infestation	Known Hazard ☒ Potential Hazard ☐ Not applicable ☐	- Historic fabric and facility damage - Vegetation loss - Disease vectors may increase. - Termites and other woodboring pests are expanding range with warming and increased humidity.
Invasive Species	Known Hazard ☐ Potential Hazard ☒	- Vegetation (e.g., kudzu, vines, Brazilian pepper) can damage buildings, kill trees, obstruct waterways. - Marine and aquatic invasive species

	Not applicable ☐	
Subsurface Hazards Cave/Karst (Sinkholes)	Known Hazard ☒ Potential Hazard ☐ Not applicable ☐	• Surface collapse • Contamination • May affect freshwater availability, drainage, and drought potential • Abandoned Mineral Lands (AML) features
Shrink/ Swell Soils	Known Hazard ☐ Potential Hazard ☒ Not applicable ☐	• Damage to structure • “Heaving” of ground beneath structure • Increased landslide susceptibility
Landslide/ Rockfall/ Avalanche	Known Hazard ☐ Potential Hazard ☒ Not applicable ☐	• Rockfall • Mud or debris slides or flows onto structures • Mud or debris slides or flows from under structures • Snow avalanche
Tsunami	Known Hazard ☐ Potential Hazard ☐	• Coastal area inundation associated with earthquakes or undersea landslides • May be triggered by mass wasting events

	Not applicable ☒	
Volcanic Eruption	Known Hazard ☐ Potential Hazard ☐ Not applicable ☒	• Lava Flows • Fire • Toxic gas releases • Ash
Hydrothermal Activity (e.g., Geysers)	Known Hazard ☐ Potential Hazard ☐ Not applicable ☒	• Toxic gas release • Explosion • Boiling water • Steam • Surface collapse into void
Earthquake	Known Hazard ☐ Potential Hazard ☐ Not applicable ☒	• Falling objects • Collapsing structures • Inoperability of major building systems e.g. power, sewer, water • Liquefaction; loss of strength to foundations, silt deposition, standing water • Trigger to other hazards e.g. landslides, debris flows

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