Grappling with Climate Change: Impacts to Heritage Resources
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17th century adobe walls collapsing at Tumacácori; historic inscriptions rapidly eroding at El Morro; ancestral pueblo field houses at Bandelier impacted by significant soil erosion. Is this deterioration and loss the result of a lack of proper maintenance, a misunderstanding of the needs of fragile site materials, the cumulative effects of ‘normal’ deterioration, or the result of random and unpredictable natural events and material failures? Could any (or all) of it be related to climate change? As a cultural resource manager, climate change is a difficult matter to grapple with. Can one comfortably say that a wall collapse is the direct result of climate change, rather than a lack of timely maintenance? Are aging resources eroding at a faster rate because of gradually changing climatic conditions? With natural systems, the impacts of climate change are direct and measurable – increased air temperatures result in: ice cap and glacial shrinkage that then lead to increases in sea level; decreases in snowpack that lead to decreased river flows and lake levels; faster evaporation of terrestrial water that leads to decreases in surface water supplies; and floral and faunal habitat migration and species loss that occur due to changing conditions. The effects of these predicted climatic changes on human systems are also direct, and include impacts related to personal comfort, health, energy consumption, water usage, and general resource availability. As for cultural resources, while we have a general idea of how a changing climate could affect these non-renewable resources, there have been few studies aimed at clearly identifying risks and determining potential and actual impacts from changing conditions. As climate scientists and natural resource specialists continue to develop and present projections for changes ahead, cultural resource professionals can begin to develop strategies for response and mitigation.

What is Climate Change?
Climate refers to prevailing weather conditions over long periods of time, while weather is the state of the atmosphere, including temperature, moisture, wind velocity, and barometric pressure, at a given time in a given place. Climate change, as defined by the Intergovernmental Council on Climate Change (IPCC), is “any change in climate over time, whether due to natural variability or as a result of human activity.” While it is understood that the earth’s climate is variable, and has gone through both minor and significant shifts throughout the planet’s history, the changes documented over the last 50 years have more to do with human effects than natural cycles. The primary cause of this change is the increase in greenhouse, or heat-trapping, gases (i.e. carbon dioxide – CO₂, methane – CH₄, nitrous oxide – N₂O, and synthetic fluorinated gases such as hydrofluorocarbons) in the atmosphere. Observed global changes in climate that have resulted from the increase in greenhouse gas concentrations include increased surface and atmospheric temperatures, changes in precipitation patterns, sea level rise, ocean acidification, and an increase in extreme weather events (droughts, precipitation, wind events, etc.). In fact, the earth’s average temperature has increased by 1.5 degrees Fahrenheit (F) in the last century, with much of the warming occurring in the last 50 years. According to climate scientists, “Global average surface and lower-troposphere temperatures during the last three decades have been progressively warmer than all earlier decades, and the first decade of the 21st century (2000–09) was the warmest in the instrumental record.” In fact, 2009 and 2010 are included in the ten warmest years globally, and 2010 tied 2005 as the warmest year of the global surface temperature record.

And the future? Obviously there is some level of uncertainty, but current climate models make use of the best, and most current data available, including plausible emissions scenarios (based on assumptions about human activity, energy use, etc.) to account for this. There is a high degree of confidence that by the end of this century: global temperatures will increase an additional 3 to 7 degrees F, with the most warming occurring over land and in the northernmost latitudes; sea levels will rise between .2 meters (m) and .5m; there will be substantial shifts in precipitation patterns; snow cover, sea ice and permafrost regions will be greatly impacted; extreme events (heat extremes, heat waves and heavy precipitation events) will increase; and tropical storm systems will intensify and move poleward. These changes will, no doubt, have serious consequences for ecosystems and human sectors throughout the world.

Photo: Craig Lee
A wooden artifact that has been embedded and preserved in ice for centuries slowly emerges from the ice as regional temperatures rise.

What are We Seeing in the Arid Southwest?
The arid Southwest is home to some of the most varied and iconic landscapes, biota, and cultural artifacts in the nation. The area encompasses the Sonoran, Chihuahuan, Mojave and Great Basin deserts, the river basins of the Colorado and the Rio Grande, and numerous mountain ranges. Elevations range from some of the highest peaks in the U.S. (including several 14,000+ foot peaks in Southern Colorado), to the lowest point in the lower 48 states (Death Valley National Park, CA). Within this landscape of extremes, unique flora and fauna, iconic geologic and hydrologic features, and ancient cultures and traditions coexist alongside massive industrial sites, and modern urban centers. These regional features exist in a harsh and challenging environment that is exceedingly dry and drought-prone, with extreme temperature fluctuations (both from day to night, and seasonally) and intense winds. Wildfire is a constant threat, as is flooding due to heavy monsoonal rains.

The Southwest is seeing a greater number of significant effects from climate change than are other parts of the United States and these effects are expected to continue. In fact, the Southwest is being included with the Arctic as one of the indicator regions for climate change. Climate projections for the Southwest are discouraging – increases in temperature (particularly summer temperatures) that will exceed the global mean; precipitation likely to fall below the annual mean; an increase in intense weather events (heat waves, flooding, etc.); northward movement of winter storm tracks and shortening of the snow season; changes in river flow; and an increase in drought frequency and duration.
In the region, average annual temperatures have already increased approximately 1.5 degrees F when compared to a baseline period between 1960 and 1979. In fact, since 1976, the average annual temperature in Arizona has increased by 2.5 degrees F, and by 1.8 degrees F in New Mexico. Predictions show these average temperatures increasing an additional 4 to 10 degrees F from this baseline by the end of the century. Additionally, precipitation is expected to decrease by approximately 5% across the region by the end of the century (as compared to the average precipitation in the region over the last three decades).

In the last decade, the region has been subject to devastating wildfires in both urban and wildland areas as a result of changing precipitation patterns, earlier spring snowmelt, increasing temperatures, and rapid drying of vegetation; changing landscapes caused by tree mortality, invasive plants, floral and faunal species shifting their ranges, and increased erosion due to soil moisture changes and vegetation mortality; and significant flooding due to increases in extreme precipitation events and changes in soil character. In the national parks of the arid west snow-pack decreased up to 35% from 1950 to 1999 at weather stations and snow courses in 53 National Parks and other areas in the western U.S.; spring stream flow advanced by up to 8 days between 1950 and 1999; and conifer tree mortality has increased across the western U.S. by approximately 4% per century since the 1950s. In fact at Bandelier National Monument and Mesa Verde National Park, drought has brought about a massive die-off of Piñon pine (*Pinus edulis*), with 90% mortality rates recorded at some sites.

**How does all of this relate to cultural resources?**

We know from experience that the environment is the greatest threat to fragile site materials such as adobe, wood, and stone masonry. Water, wind, salts, soil chemistry, fire, floods, extreme temperatures, fluctuations in humidity, and freeze/thaw and wet/dry cycling are the primary threats to the heritage resources protected and preserved by the National Park Service (NPS). Predicted climatic changes include changes in the frequency, duration, and intensity of all of the above, and these changes, where they occur, will impact preservation planning and the active conservation of heritage sites.

Natural resource managers have been studying climate models, risk factors and impacts of climate change to natural systems for decades. The effects of climate change on cultural resources have not received the same focus and attention and NPS cultural resources managers are currently working to develop policy, and provide leadership and support. In addition to the NPS, individuals and large heritage conservation organizations including the International Council on Monuments and Sites (ICOMOS), United Nations Educational, Scientific and Cultural Organization (UNESCO), the Getty Conservation Institute, English Heritage, and a number of European governments and non-governmental organizations are investing time and expertise into research on the potential impacts of climate change on heritage resources, and the development of strategies for adapting and responding to changing environmental conditions. Using climate models and risks identified for natural systems, actual and potential impacts to cultural resources are being identified (see Table 1). As a result of this work, it is now recognized that all types of cultural and heritage resources and values are at risk from climate-change related impacts: from archives and archeological sites to traditional cultural properties and architecture, both historic and prehistoric.

**What does this mean for the physical remnants of heritage architecture in the parks of the arid west?**

In the western regions of the United States, as throughout the nation and the world, architecture is a direct expression of culture, tradition, and history. Throughout much of the past, building materials, construction techniques, and architectural styles were determined by geographic location, access to locally available and abundant resources, space concepts held by the group, traditional knowledge that was passed from generation to generation, and, perhaps most significantly, climate. This local focus brought about truly indigenous, well-adapted building traditions that are still evident throughout the world. These locally-derived building traditions had inherent characteristics that were adapted to very specific climatic conditions. For example, adobe structures with flat, mud roofs perform well in a dry climate like the Southwest, whereas structures in wetter climates require sloped roofs and more durable roofing materials to withstand more frequent rains. The preservation of the remains of locally developed building styles will likely become more difficult as the climatic conditions that these structures were designed to withstand change around them.

While it is true that many sites in the Southwest have survived hundreds of years of climatic fluctuations, much of what remains is quite fragile, and the majority of these sites remain viable only because of the priority placed on maintaining them. It is feasible that a dryer climate in the Southwest may, to some degree, have positive impacts on the preservation of the remaining archeological architecture in the region, since rainfall is a major agent in the deterioration of these structures. But changes in precipitation and wind patterns, soil characteristics, and temperature extremes will make it more difficult to predict failures, and may result in more accelerated and catastrophic losses than we have seen in the past. Additionally, preservation treatments that have worked well in the past may no longer be up to the task, or may prove counterproductive under changing weather conditions.

Preservation of vulnerable materials is difficult even in a predictable and stable environment. When conditions become unpredictable or change from the established norm, planning for long-term preservation becomes increasingly complex. In order to manage this unpredictability, cultural resource managers in the parks of the arid west must begin to think strategically about preserving these fragile materials in a future that includes climate change. Climate models can tell us what to expect in the way of temperature increases, precipitation patterns, etc. at a regional level, but down-scaling these predictions to specific locations and anticipating the implications for individual sites will require collaboration with natural resources experts who are working on the ecological aspects of this problem. Developing a better understanding of the materials that comprise...
our heritage resources, their thresholds for deterioration and failure, and the effects of our (well intentioned) preservation treatments will allow managers to look at climate models and anticipate the risks to individual sites and site components. Once these risks are identified, planning can occur that takes into account the potential for damage and loss as a result of changes in climatic variables, whether they are temperature-, water- (precipitation amounts, extreme events, humidity, etc.), wind-, or pollution-derived. Because much of our preservation knowledge, especially about the fragile structures of the arid Southwest, is empirically derived, gained after decades of trial-and-error, our preparations should include the development and testing of alternate preservation treatments that may be required by anticipated changes in climatic conditions.

**Conclusion**

At present, it is difficult to attribute deterioration and loss of architectural materials, such as the wall failures at Tumacácori, the eroding inscriptions at El Morro, and

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<tr>
<th>Climate Indicator</th>
<th>Climate Change Risk</th>
<th>Physical, Social, and Cultural Impacts on Cultural Heritage</th>
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| **Atmospheric Moisture Change** | - Flooding (sea, river)  
- Intense Rainfall  
- Changes in Water table Levels  
- Changes in Soil Chemistry  
- Ground Water Changes  
- Changes in Humidity Cycles  
- Increase in Time of Wetness  
- Sea Salt Chlorides | - Ph Changes to Buried Archeological Evidence  
- Loss of Stratigraphic Integrity caused by Cracking and Heaving from Changes in Sediment Moisture  
- Loss of Data Preserved in Waterlogged / Anaerobic / Anoxic Conditions  
- Eutrophication Accelerating Microbial Decomposition of Organics  
- Physical Changes to Porous Building Materials and Finishes from Rising Damp  
- Damage from Faulty Or Inadequate Water Disposal Systems; Historic Rainwater Goods Not Capable of Handling Heavy Rain, and Often Difficult to Access, Maintain, and Adjust  
- Crystallisation and Dissolution of Salts Caused by Wetting and Drying Affecting Standing Structures, Archeology, Wall Paintings, Frescos and Other Decorated Surfaces  
- Erosion of Inorganic and Organic Materials from Flood Waters  
- Biological Attack on Organic Materials by Insects, Moulds, Fungi, or Invasive Species Such As Termites  
- Subsoil Instability, Ground Heave, and Subsidence  
- Relative Humidity Cycles/Shock Causing Splitting, Cracking, Flaking ,and Dusting of Materials and Surfaces  
- Corrosion of Metals  
- Other Combined Effects e.g.: Increase in Moisture Combined with Fertilizers and Pesticides |

**Table 1: Principal climate change risks and impacts on cultural heritage resources.**

![Table](https://via.placeholder.com/250)
arceological site erosion at Bandelier, to climate change. Changing conditions over the last several decades may not be the sole cause of structural failures, but they certainly have, and will continue to influence the stability and condition of the significant, yet fragile heritage sites extant in the region. Climate change is likely to exacerbate or accelerate rates of deterioration and loss, and regular maintenance and monitoring will be the key to the survival of the non-renewable heritage resources that remain in the Southwestern parks. Utilizing climate models, site plans, and analyses of architectural materials that identify their limits will allow those who participate in the preservation of these resources to develop strategies for adaptation and response. Becoming aware of projected changes, and understanding the response of historic building materials to a variety of likely environmental parameters, will enable preservation specialists to be proactive in their efforts to prepare for the future. Participation in the multi-disciplinary global discussion regarding climate change and its impacts to cultural resources will help the NPS to understand the interactions between nature and cultural resources, and the application of the best possible science and scholarship available will allow us to more effectively work in consultation with the many stakeholders who rely on our good stewardship to preserve these heritage resources for future generations.

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For further information on cultural resources and climate change, see the following publications and websites:


Noah’s Ark, Global Climate Change Impact on Built Heritage and Cultural Landscapes, http://noahsark.isac.cnrs.fr/


University College of London, Centre for Sustainability, Case Study: Climate Change and the Historic Environment, http://www.ucl.ac.uk/sustainableheritage/climate_change.htm


5 Arndt, S19

6 http://www.noaanews.noaa.gov/stories2011/20110112_globalstats.html


10 USGCRP, 129.


12 Email communication with Dr. Patrick Gonzalez, NPS Climate Scientist (email dated 5/13/2011).

13 Southern Colorado Plateau Network, Climate Change Resource Brief (http://www.nps.gov/climatechange/docs/SCPN_CC.pdf)

14 Brimblecombe, P., C.M. Grossi and I. Harris, ‘Climate change critical to cultural heritage,’ in Heritage, Weathering and Conservation, Fort, Alvarez de Burgio, Gomez-Heras & Vazquez-Calvo, Eds.,


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