RESOURCE VULNERABILITY ASSESSMENT

The Charles A. Weyerhaeuser Memorial Museum

JANUARY 27, 2022

PHOEBE WARD

1. Introduction

There is broad scientific consensus that human-driven greenhouse gas emissions are causing an unprecedented rise in global temperatures. In the words of the Intergovernmental Panel on Climate Change, human-influenced warming of the atmosphere, ocean, cryosphere, and land masses is "unequivocal…widespread and rapid."[1] This trend has only accelerated since 1950, with the ten warmest years on record all occurring since 2005. Of these ten, the top five were 2016, 2020, 2019, 2017, and 2015.[2] The American Midwest largely mirrors these broader global trends: an increase in the frequency and intensity of precipitation events, intermittent but more intense droughts, particularly during the summer months, marked shifts in species ranges, and increased incidence of severe heatwaves that have proven highly detrimental to human, ecological, and agricultural health.[3] In addition, we have seen a potential increase in the intensity of winter snowfall events even as average winter temperatures increase and overall snowfall decreases. The unique dynamics of global climate change have also been a potential driver of the dangerous cold spells that have become more frequent in recent years, as shifts in the atmosphere have led to more Arctic air – the excitingly named "polar vortex" – being funneled down into the Upper Midwest. However, whether recent cold snaps can be definitively linked to climate change or not, the data consistently points towards an increase in average winter temperatures over the long term.[4]

In addition to the threats it poses to the health of our environment, the stability of our economy, and the quality of life for our residents, climate change also threatens Minnesota's rich cultural heritage. Museum structures are as susceptible as any other building to the impacts of elevated temperature, fluctuations in relative humidity, new and more successful pest species, and the damage associated with more frequent and more intense precipitation events. Modern collections are housed in climate-controlled environments, but these environments, in the face of new and/or extreme external stressors, can be compromised. In certain cases, the landscape that the museum is housed on is vulnerable to climate-driven threats like flooding or erosion. Additionally, climate change is already causing shifts in growing seasons and plant and animal communities across the globe, changing ways of life that have persisted for decades and sometimes centuries. Investing over the long term in the four climate response pillars identified by the National Park Service – science, mitigation, adaptation, and communication – and tailoring these to the

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[1] IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

[2] Katherine Brown, "2020 Tied for Warmest Year on Record, NASA Analysis Shows," NASA (NASA, January 14, 2021), https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows. Accessed July 12, 2021.

[3] "U.S. Climate Resilience Toolkit," Midwest | U.S. Climate Resilience Toolkit, accessed July 12, 2021.

[4] Rebecca Lindsey, "Understanding the Arctic polar vortex," Understanding the Arctic polar vortex | NOAA Climate.gov, accessed July 1, 2021, https://www.climate.gov/news-features/understanding-climate/understanding-arctic-polar-vortex.

particular needs of Morrison County, has the potential to head off some of these detrimental effects.

2. Exposures

The objective of this paper is to assess the threats to The Charles A. Weyerhaeuser Memorial Museum. The museum was built in 1975 and is located on four acres of land on the banks of the Mississippi River, within the city limits of Little Falls in Morrison County, Minnesota. Located in the Anoka Sandplain Ecoregion,[5] the site is built on sandy Flak and Menahga soils.[6] In the past decade or so, increasingly intense rainstorms have eroded the soil of this bank, leading to the implementation of various stop-gap measures, including a berm set up by the Morrison County Soil and Water Conservation District.[7] Additionally, the storms have led to water infiltration in the basement of the building and occasionally elevated levels of mold that threaten both the health of museum workers and the integrity of vulnerable collections. Between October and December of 2021, the museum replaced the entire HVAC, including air conditioners, humidifiers, air filters, and a new, high-efficiency gas furnace, all of which they hope will go a long way to saving on utility costs and maintaining optimal air quality within the museum itself.[8] Despite these issues, the building has been diligently maintained and houses an extensive collection of artifacts associated with the history of Morrison County, including stone arrowheads, objects made from birchbark and white pine, flapper dresses, old cards, and antique medicine bottles.

Elevated temperatures

[5] "Anoka Sand Plain Subsection," Minnesota Department of Natural Resources, accessed July 1, 2021, https://www.dnr.state.mn.us/ecs/222Mc/index.html.

[6] "Custom Soil Resource Report for Morrison County," Web Soil Survey, July 12, 2021.

[7] Mike Becker (District Technician) in conversation with the author, July 12, 2021.

[8] Mary Warner via email to the author, January 26, 2022.

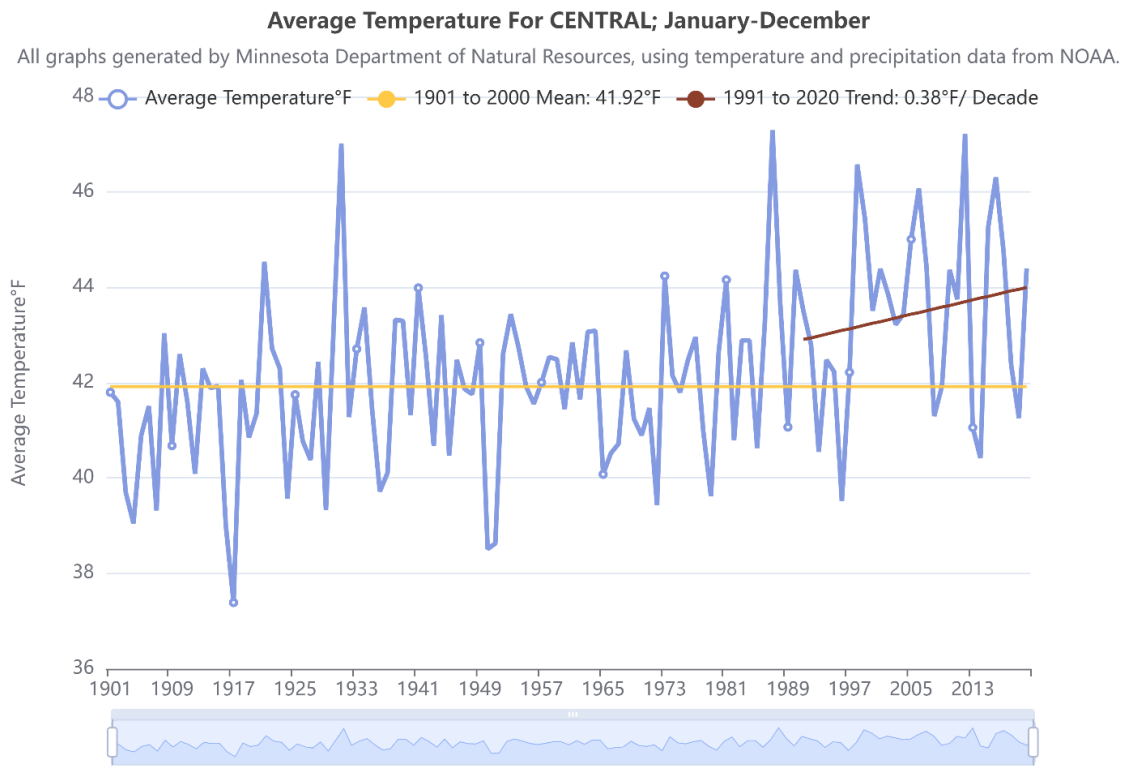

Fig. 1. Average annual temperature for Central Minnesota 1991-2020 compared to 1901-2000. Source: Minnesota Climate Explorer, Minnesota Department of Natural Resources.

The state of Minnesota has warmed between one to three degrees Fahrenheit over the last century.[9] Figure 1 compares the average annual temperatures for Central Minnesota from 1991-2020 compared against the baseline of 1901-2000, in accordance with the recommendations of the National Oceanic and Atmospheric Administration and World Meteorological Organization's recommendations on presenting climate information.[10] According to these measurements, the average temperature in the Central Minnesota region has increased by 0.38 degrees Fahrenheit per decade since 1991. These rising temperatures have resulted in longer and more frequent heatwaves, more prolific tick and mosquito seasons, and potentially toxic algal blooms in our

[9] "What Climate Change Means for Minnesota," United States Environmental Protection Agency, August 2016. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-mn.pdf. Accessed September 25, 2021.

[10] "Updated 30-Year Reference Period Reflects Changing Climate," World Meteorological Organization, May 5, 2021, https://public.wmo.int/en/media/news/updated-30-year-reference-period-reflects-changing-climate.

lakes and rivers.[11] [12] [13] In addition, higher temperatures place unprecedented stress on HVAC systems, leading to higher utility bills for the affected buildings and an elevated risk of failure for climate control systems.[14] [15]

More Intense and Frequent Precipitation Events

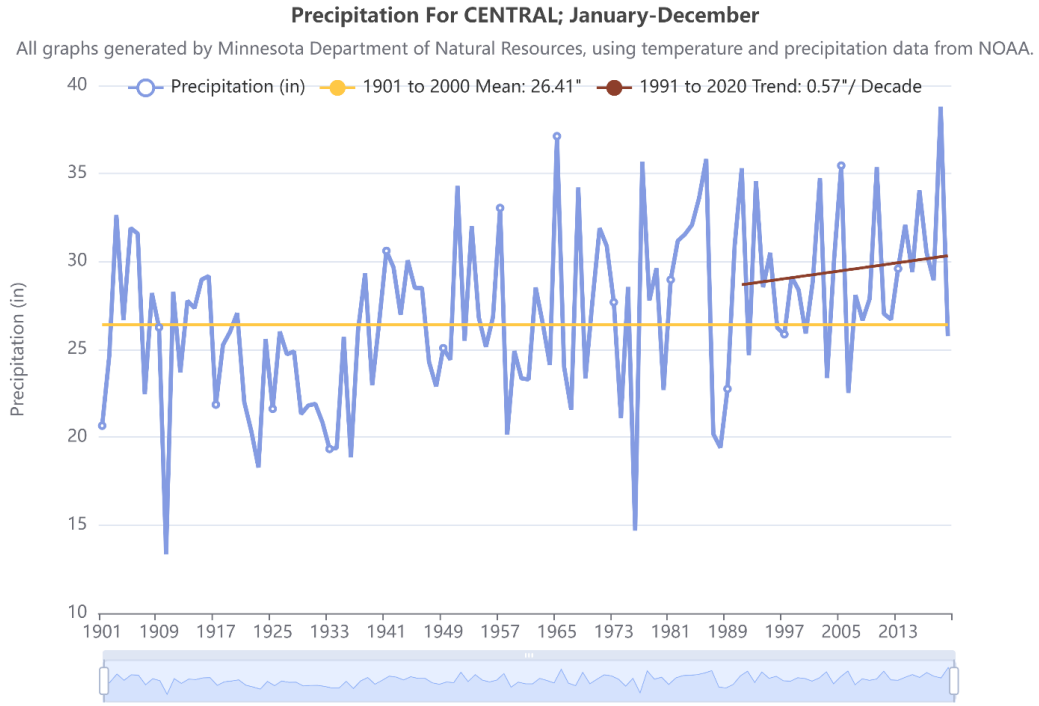

Fig. 2. Total annual precipitation for Central Minnesota; 1991-2020 compared to 1901-2000. Source: Minnesota Climate Explorer, Minnesota Department of Natural Resources.

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[11] "What Climate Change Means for Minnesota," United States Environmental Protection Agency, August 2016. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-mn.pdf. Accessed September 25, 2021.

[12] Cody Nelson, "Minn. Lawmakers Get Caught up on Climate Science," MPR News (MPR News, July 14, 2019), https://www.mprnews.org/story/2019/01/17/minnesota-house-climate-committee-hearing.

[13] "Tick…tick…boom: May-June 2019: Minnesota Conservation Volunteer," Minnesota department of Natural Resources, accessed January 15, 2022, http://www.dnr.state.mn.us/mcvmagazine/issues/2019/may-jun/lyme-disease.html.

[14] Mike Rampey, "How Does Your AC Adapt to Heat Waves?" Air Assurance (Air Assurance, June 18, 2020), https://www.airassurance.com/blog/2020/6/18/how-does-your-ac-adapt-to-heat-waves.

[15] Mitchell Cooling + Heating, "What's Wrong with My Air Conditioner?," Mitchell Cooling + Heating (Mitchell Cooling + Heating https://mitchellmechanical.com/wp-content/uploads/2020/04/Mitchell-Cooling-Heating.png, June 3, 2021), https://mitchellmechanical.com/why-your-air-conditioner-will-not-cool-well-when-the-temperature-is-100/.

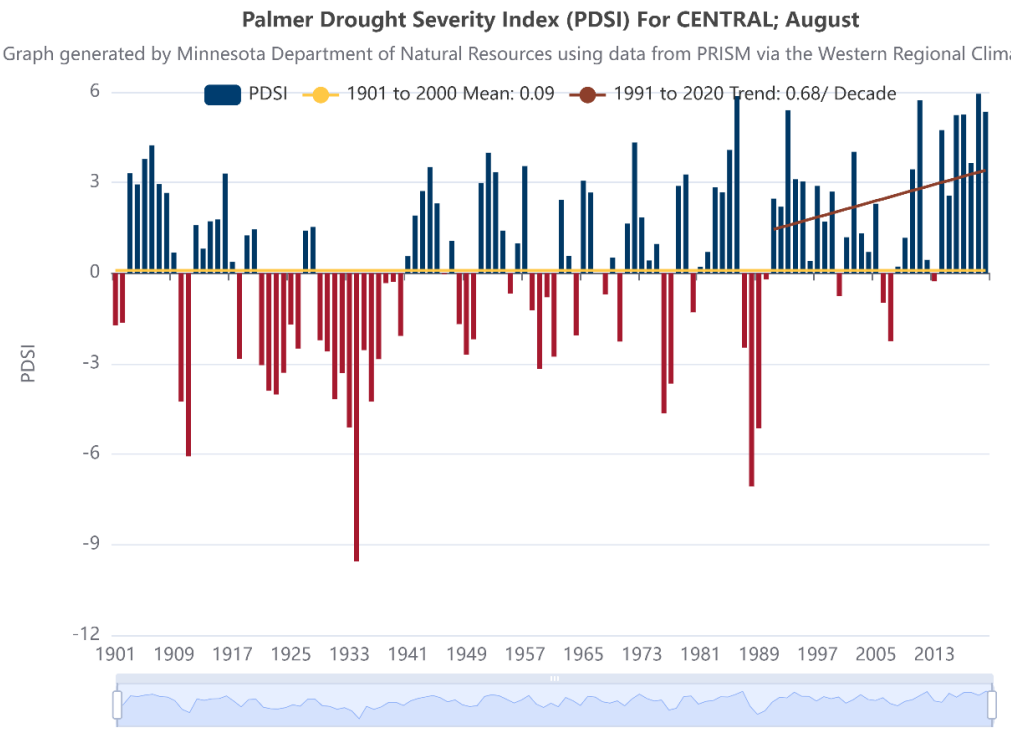

Fig. 3. Palmer Drought Severity Index for Central Minnesota; 1991-2020 compared to 1901-2000. Source: Minnesota Climate Explorer, Minnesota Department of Natural Resources.

Despite periodic drought conditions, including the severe drought of summer 2021, drought overall has been on the decline in Minnesota over the last thirty years (fig 3). The Palmer Drought Severity Index (PDSI) measures drought on scale using values that range from -2 or less to 2 or more, with -2 representing "Extremely Dry" conditions and 2 or more representing "Extremely Wet."[16] The overall trend has been a decrease in drought and a general increase in wetter, warmer temperatures year-round, including increased incidence of severe storms, although these precipitation events are now more likely to be punctuated by dry spells, particularly during the summer months. Since 2000, Minnesota has seen an increase in large precipitation events.[17][18][19] These intensified rain and snow events disrupt local ecosystems and

[16] William M. Alley, "The Palmer Drought Severity Index: Limitations and Assumptions," *Journal of Applied Meteorology and Climatology* 23 no. 7 (1984): 1100-1109, 1102. https://doi.org/10.1175/1520-0450(1984)023<1100:TPDSIL>2.0.CO;2, 1102.

[17] Manoj Jha et al., "Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective," *Journal of Geophysical Research* 109 (2004), doi:10.1029/2003JD003686.

[18] Climate Change Trends and Action Plan," Minnesota Board of Water and Soil Resources, accessed July 12, 2021, https://bwsr.state.mn.us/sites/default/files/2019-09/ClimateChangeTrends%2BActionPlan_Sept2019.pdf.

[19] Minnesota Department of Natural Resources. "Climate change and Minnesota." https://www.dnr.state.mn.us/climate/climate_change_info/index.html. Accessed September 15, 2021.

damage human infrastructure, including raising the likelihood of harmful algal blooms in our state waterways and washing out roads essential to travel.[20]

Unpredictable Levels of Relative Humidity

The relationship between climate change and humidity is somewhat less clear, at least when it comes to humidity over land masses. Absolute humidity, defined as the measure of the absolute amount of water vapor in the air, is projected to increase over the coming century, as warmer air evaporates, and therefore has greater capacity to hold water. However, relative humidity, which is the usual metric used for humidity in cultural heritage collections, has a slightly more complex relationship with rising temperatures. Defined as the absolute humidity of sampled air divided by the absolute humidity of saturated air at the same temperature, relative humidity can be high at cool or hot temperatures alike – as a ratio, the overall value is generally higher the larger the absolute humidity of sampled air (the numerator, in this case) is in relation to the absolute humidity of saturated air at a given temperature (the denominator). Because cold air holds less potential moisture, an abrupt dip in indoor temperatures can cause relative humidity to rise.[21] Relative humidity can also rise indoors when the water table on the surrounding land is exceptionally high or when the building itself is flooded.[22] From conversations with museum staff Mary Warner and Ann Marie Johnson, the soil onsite generally prevents the water table from rising to hazardous levels, but there has been occasional flooding in the museum basement during rainfall events.[23] If, as projected, these rainfall events increase in frequency and intensity in the Midwest over the next fifty years, there may be an accordingly higher risk of flooding. Given this information, it might be wise to keep an eye on how – or even if – this metric changes over time.

Potential Shifts in the Range of Museum Pest Species

There is growing evidence that the species range and life histories of agricultural and museum pests will shift under warmer temperatures, although the nature of these shifts is still in many ways an open question. According to a 2020 study by Philipp Lehmann *et al.*, the overall impacts of pest species on agricultural and forestry operations are expected to become more serious as the global climate warms; however, of the 31 major global pest species they surveyed, approximately half exhibited an increase in projected damage to human operations, while the rest exhibited mixed responses.[24]

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[20] "What Climate Change Means for Minnesota," United States Environmental Protection Agency, August 2016. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-mn.pdf. Accessed September 25, 2021.

[21] "Discussion on Humidity," National Weather Service (NOAA's National Weather, June 13, 2015), https://www.weather.gov/lmk/humidity.

[22] Marcy Rockman, Marissa Morgan, Sonya Ziaja, George Hambrecht, and Alison Meadow, *Cultural Resources Climate Change Strategy,* 2016, Washington, DC: Cultural Resources, Partnerships, and Science and Climate Change Response Program, National Park Service.

[23] Ann Marie Johnson and Mary Warner in conversation with the author, July 1, 2021.

[24] Lehmann et al., "Complex responses of global insect pests to climate warming," *Frontiers in Ecology and the Environment* 18 no. 3 (2020): 141-150, https://doi.org/10.1002/fee.2160.

A study of the brown carpet beetle, *Attagenus smirnovi,* which has become a pest of organic collections in Europe and North America, showed that consumption of organic materials increased at higher temperatures in Scandinavian museums without climate regulation.[25] These species, which generally thrive in warm, humid conditions, may increase in number in poorly insulated or otherwise structurally compromised buildings, including those that house collections vulnerable to these particular pests. A study conducted in central England in 2012 concluded that increasing temperatures and improperly controlled interior climates in historic houses were likely to lead to an increased presence of pest insects in the collections, as the elevated temperatures may benefit insect lifecycles and create environmental conditions inside the structures that are favorable to their survival. For instance, the biscuit beetle, *Stegobium paniceum,* which attacks books, upholstery, and other organic materials in museum collections, grows faster under warmer conditions.[26]

In its *Cultural Resources Climate Change Strategy* document, the National Park Service identifies a need to account for potential new pest risks as the climate warms, particularly in places where a warmer climate allows for the introduction of species that were previously dealt with at more southerly latitudes. It goes on to warn that thermal stress on facilities may damage their structures and create new routes for these pests to enter buildings and wreak havoc on organic collections.[27] Like the question of humidity, it might be worth continuing to monitor how the pest situation at the Weyerhaeuser Museum changes over time using what resources the museum has available, as this variable is still relatively new and there are multiple unknowns.

Declines in Air Quality

Air quality is projected to decrease due to climate change. Higher temperatures are closely linked to greater incidence of ground-level ozone, a component of smog that contributes to diminished lung function, increased hospital admissions, more emergency department visits for asthma, and increases in premature deaths, particularly among vulnerable individuals. Higher temperatures are also associated with wildfires that contribute to a decrease in air quality, sometimes many miles from the site of the fire, as Minnesota residents learned in the summer of 2021, when wildfires in Canada caused AQIs of up to 305 in the Central Minnesota region, changing the color of the sky and causing ash to fall from the sky as far south as Brainerd.[28] [29] Particulate matter, ozone, and other pollutants such as sulfur dioxide, all associated with climate change and

[25] Lise Stengaard Hansen et al., "Future pest status of an insect pest in museums, *Attagenus smirnovi:* Distribution and food consumption in relation to climate change," *Journal of Cultural Heritage* 13 no. 1 (2012): 22-27. https://doi.org/10.1016/j.culher.2011.05.005.

[26] Peter Brimblecombe and Paul Lankester, "Long-term changes in climate and insect damage in historic houses," *Studies in Conservation* 58, no. 1 (2012): 13-22.

[27] NPS 2016.

[28] María Luisa Paúl. "As wildfires burn in Canada, an 'unprecedented' blanket of smoke hangs over Minnesota." *The Washington Post.* July 31, 2021. https://www.washingtonpost.com/nation/2021/07/31/wildfires-burn-canada-an-unprecedented-blanket-smoke-hangs-over-minnesota/. Accessed October 25, 2021.

[29] Chris Burns, "Smoke from Canadian Wildfires Leads to Poor Air Quality in Minnesota," Lakeland PBS. July 21, 2021, https://lptv.org/smoke-from-canadian-wildfires-leads-to-poor-air-quality-in-minnesota/.

its root causes, are known detriments to museum collections, and the risk of exposure increases as the climate warms.[30]

Declines in Crop Yields

A final area of potential exposure is more indirect. Morrison County has a rich history of agricultural production, including of wild rice, corn, soy, beans, alfalfa, and vegetable crops. Shifts in temperature, rainfall, and pest species stand to imperil the way of life that has persisted here since European settlement in the 19th century, and indeed the ways of life established by Dakota, Ojibwe, and earlier Native peoples on this land. Wild rice, an intrinsic part of Ojibwe culture and tradition, is a crop of increasing concern due to its sensitivity to fluctuations in water level.[31] As a cool-climate crop, the rising temperatures also pose a potential threat to its continued success in Minnesota waterways. Yields of corn, soy, and wheat, among others, have been shown in numerous peer-reviewed studies to be negatively impacted by rising temperatures by as soon as 2050, with significant declines in productivity predicted across the board.[32] [33] This suggests that there is a serious risk to crops closely associated with the cultures of both Native and settler communities in the area, and that farmers might be required to make major adjustments or potentially go out of business if conditions turn out to be sufficiently hostile to our current crop varieties.

Sensitivities

a. Sandy soils

The Charles A. Weyerhaeuser Memorial Museum site is located on approximately four acres of Menahga loamy sand and Flak sandy loam, with the Flak soil series occupying the majority of the slope area. Flak is a coarse-loamy, mixed, superactive, frigid Inceptic Hapludalf, which means that it formed under mixed deciduous or mixed deciduous-coniferous forest on top of deep or moderately deep to dense glacial till.[34] Similarly, the Menahga soil series typically forms on sandy glacial outwash plains, valley strains, and some morainal and drumlin formations.[35] These soils have rapid permeability and, like most silty and sandy soils, are highly prone to water erosion in areas with high rainfall and a steep slope. There are steep slopes on the property, and Mary Warner and Ann Marie Johnson have both indicated that increasingly intense precipitation

[30] Jillian Mackenzie and Jeff Turrentine, "Air Pollution: Everything You Need to Know," Natural Resources Defense Council, June 22, 2021, https://www.nrdc.org/stories/air-pollution-everything-you-need-know, accessed January 20, 2022.
[31] Kathy Lynn et al., "The impacts of climate change on tribal traditional foods," *Climatic Change* 1200 no. 3 (2013): 545-556, https://doi.org/10.1007/s10584-013-0736-1, accessed July 15, 2021.
[32] Aaron Shew, Jesse Tack, Lawton Nalley, and Petronella Chaminuka, "Yield reduction under climate warming varies among wheat cultivars in South Africa," *Nature Communications* 11 (2020).
[33] Jonas Jägermeyr et al. 2021, "Climate impacts on global agriculture emerge earlier in new generation of climate and crop models, *Nature Food* 2 (2021): 873-885, https://doi.org/10.1038/s43016-021-00400-y. Accessed September 17, 2021.
[34] United States Department of Agriculture. "Flak Series." March 1999. https://soilseries.sc.egov.usda.gov/OSD_Docs/F/FLAK.html. Accessed July 12, 2021.
[35] United States Department of Agriculture. "Menahga Series." March 1998. https://soilseries.sc.egov.usda.gov/OSD_Docs/M/MENAHGA.html. Accessed July 12, 2021.

events over the past five years have accelerated the rate of erosion into the river.[36] Museum staff also point to the undercutting of the bank as a result of the river's increased rate of flow after intense or heavy rainfalls.[37] Climate projections suggest a continuing overall trend towards warmer and wetter conditions over the next decades, so there is a distinct probability that the stressors on the sandy soils and steep banks of the site will continue.[38]

Mike Becker, Lead Technician for the Morrison County Soil and Water Conservation District (SWCD) agrees. The SWCD has constructed a berm on the banks of the museum property to slow the rate of erosion, but he indicated that this was only a stopgap measure to address a longer-term issue at the site, which might ultimately need to be addressed by a complete re-grading of the slope.[39]

"What we did to their site – or what we helped cost-share out there – is just a very temporary measure to divert some of the rainwater hitting the parking lot and going over the bank," Becker says. "So, we built a little diversion berm to divert that runoff to a more vegetated, flatter-sloped area. Something that needs to be done above and beyond that? Yeah, probably. Otherwise, potentially it could just keep going and the building could fall off." He estimates that the cost of a more comprehensive fix could range from anywhere between $60,000 and $250,000.[40]

b. HVAC & Building Envelope

Climate-controlled buildings face a uniquely 21st century Catch-22 when it comes to their HVAC systems: these systems, essential to our modern way of life, are also prolific producers of the very greenhouse gases that threaten it. According to a 2013 estimate, the world annually consumes approximately one trillion kilowatt hours (kWh) in electricity for air conditioning alone, most of which comes from non-renewable sources like coal and natural gas.[41] As the world warms and prolonged, dangerous heatwaves become more frequent and push further into northern latitudes, this dependency on electricity-based cooling mechanisms only stands to grow.

In addition to producing greenhouse gases, our current electrical grid is also vulnerable to the impacts of increasingly severe storms. Who in Minnesota, after all, has not experienced a power outage during an especially intense summer thunderstorm? This kind of incident could potentially become more frequent in the coming decades.[42] Researchers at the UK's Newcastle University found that warming temperatures in some regions of the country were the main drivers of an increase in short-duration, severe rainfall events. Similarly, a study published in the *Proceedings of the National Academy of the Sciences* found that while total number of severe

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[36] Mary Warner and Ann Marie Johnson in conversation with the author, July 1, 2021.
[37] Ann Marie Johnson in conversation with the author, January 31, 2022.
[38] Minnesota Department of Natural Resources. "Climate trends." https://www.dnr.state.mn.us/climate/climate_change_info/climate-trends.html. Accessed July 12, 2021.
[39] Mike Becker (District Technician) in conversation with the author, July 12, 2021.
[40] Ibid.
[41] Richard Dahl, "Cooling Concepts: Alternatives to Air Conditioning for a Warm World." *Environmental Health Perspectives* 121 (1): 2013. https://doi.org/10.1289/ehp.121-a18. Accessed July 28, 2021.
[42] Adam Voiland. "In a Warming World, Storms May Be Fewer but Stronger." NASA Earth Observatory. March 5, 2013. https://earthobservatory.nasa.gov/features/ClimateStorms. Accessed October 4, 2021.

storms in the United States might not change very much, the strongest storms could be more intense and more destructive than they have been in the past, with an increase of approximately 100-300 Joules/kilogram in convective potential energy in Central Minnesota and much of the rest of the Midwest.[43] This increase in intense storms could make it more likely that power might be knocked out, even temporarily, which poses a potential risk to the integrity of sensitive museum collections.

There is an additional risk of power overload on hot days when the demand of multiple air conditioners operating simultaneously can tax an unprepared power gird and lead to brownouts or blackouts.[44] [45] This happened during the heatwave of summer 2021, when temperatures in the 90s and 100s overwhelmed the infrastructure of the Pacific Northwest and forced the City of New York to plead with its citizens to cut back on energy consumption during late June temperatures that got as high as 98 degrees in Central Park.[46] [47] [48] The grid in Minnesota, where temperatures can swing wildly from sweltering heat in August to bitter Arctic cold in January, is generally better prepared than the ones in states with historically milder climates, but due to the interconnected nature of our infrastructure, there is still potential for energy issues to arise if we continue to see an increase in total days above 90 degrees Fahrenheit, or for severe weather events to disrupt the functioning of the grid more directly.[49] [50]

Collections

Museum collections nearly universally house items that are sensitive to fluctuations in temperature, humidity, and air quality. High temperatures can cause disintegration, discoloration,

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[43] Robert Trapp, Noah Diffenbaugh, Harold Brooks, Michael Baldwin, Eric Robinson, and Jeremy Pal. "Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing." *Proceedings of the National Academy of Sciences of the United States of America* 104 (50) (2007): 19719-19723. https://doi.org/10.1073/pnas.0705494104.

[44] Rebecca Heilweil, "The US power grid isn't ready for climate change," *Vox,* July 3, 2021, https://www.vox.com/recode/2021/7/3/22560691/power-grid-climate-change-heat-wave, accessed January 13, 2022.

[45] Umair Irfan, "Why every state is vulnerable to a Texas-style power crisis," *Vox,* March 11, 2021, https://www.vox.com/22308149/texas-blackout-power-outage-winter-uri-grid-ercot, accessed January 13, 2022.

[46] Mark Chediak and Brian K. Sullivan, "New York City Averts Blackouts With Texts Calling for Energy Conservation," Bloomberg.com (Bloomberg), accessed November 5, 2021, https://www.bloomberg.com/news/articles/2021-07-01/new-york-city-averts-blackouts-as-heat-wave-subsides. Accessed November 5, 2021.

[47] Nicholas K. Geranios, "Rolling blackouts hit Pacific Northwest as cities swelter in record-breaking heat wave," *Los Angeles Times,* June 29, 2021, https://www.latimes.com/world-nation/story/2021-06-29/rolling-blackouts-us-northwest-heat-wave, accessed November 5, 2021.

[48] Justin Yau. "Portland residents suffer in sweltering Pacific Northwest heat wave." *Reuters.* August 12, 2021. https://www.reuters.com/world/us/portland-residents-suffer-sweltering-pacific-northwest-heat-wave-2021-08-12/. Accessed November 5, 2021.

[49] Andrew Hazzard, "Could Minnesota suffer a Texas-size energy grid failure?" *Sahan Journal,* February 18, 2021, https://sahanjournal.com/climate/minnesota-energy-grid-texas-polar-vortex-power-outage/, accessed December 28, 2021.

[50] Dylan Miettinen, "The U of M's Gabriel Chan on why Texas' energy grid failed – and what it means for Minnesota." *MinnPost.* February 25, 2021, https://www.minnpost.com/environment/2021/02/the-u-of-ms-gabriel-chan-on-why-texas-energy-grid-failed-and-what-it-means-for-minnesota/, accessed December 28, 2021.

and expansion of certain materials, particularly those with an organic origin; fluctuating temperatures, such as those associated with oscillating night and day temperatures, for example, can cause delamination and fractures in artifacts composed of multiple materials.[51] A relative humidity above 65% can lead to mold growth and swelling of hygroscopic materials, as well as corrosion of metals and increased pest activity.[52] [53] Excessively low relative humidity can be equally detrimental, leading to desiccation and shrinkage of organic materials, as well as dehydration of certain minerals. A fluctuating humidity level also causes damage, as a cycle of swelling and shrinkage can deform artifacts made of organic materials or lead to fractures, delamination, and the loosening of joints in wooden or other organic-derived artifacts such as wooden furniture. Airborne pollutants such as particulate matter from wildfires, sulfur dioxide, ozone, and hydrogen sulfide likewise risk causing corrosion of metals, degradation of organic artifacts, and provide a more hospitable environment for pests.[54]

The timeline for this damage ranges from a few hours to several weeks, which means that certain artifacts can tolerate temporary spikes in temperature, humidity, and air pollution. However, in situations where external conditions involve prolonged extreme temperatures and/or excessively high or low levels of relative humidity, and internal conditions are sufficiently compromised by gaps in building insulation or a lapse in the electrical grid, damage to collections may be significant. The NPS document lists both high and low relative humidity within museums as a potential climate change-driven risk to collections.[55] The Weyerhaeuser Museum has already experienced cases of water seepage in the basement as the result of minor gaps in the join of the meeting and clogging in the drain causing overflow during a rainfall event and if, as is projected by most climate models, extreme precipitation events will increase in frequency over the course of the 21st century, then the risk of these events may increase accordingly. These factors, combined with higher temperatures, suggest that the HVAC system for the museum may come under increased stress as the climate warms and rainfall becomes more intense.[56] [57] This, in turn, may result in increased costs for the building and an elevated risk of damage to sensitive collections.

Human Impacts

There is also a low but present risk to museum visitors from the impacts of climate change. On a very basic level, extreme heat, more frequent freeze-thaw events, and more severe precipitation events are known threats to the quality of our nation's network of roads, and it becomes more

[51] Jessica S. Johnson, "Chapter 4: Museum Collections Environment," in *NPS Museum Handbook,* Philadelphia: National Park Service, 1999.
[52] Johnson 1999.
[53] Dava Aiken Tobey, "Preserving History: Here's how to keep that historic newspaper for years to come," *Minnesota Historical Society,* https://www.mnhs.org/preserve/conservation/reports/nytimes_preserving.pdf, accessed October 11, 2021.
[54] Op. cit.
[55] NPS 2016.
[56] NPS 2016.
[57] Kool Breeze of Northwest Florida, Inc, "How High Humidity Affects Your Air Conditioning System," https://www.koolbreeze.com/blog/air-conditioning-service/how-high-humidity-affects-your-air-conditioning-system/, accessed January 14, 2022.

difficult to visit a museum located on the edge of a scenic state park when you are functionally unable to drive there. Heatwaves, flooding, drought, and intensified storms also present a threat to human health, from the risk of severe dehydration, acute cerebrovascular accidents, and heart attacks among susceptible populations during heatwaves[58] to the more direct risks of injury and drowning associated with severe storms and flash floods. The COVID-19 pandemic has shown that impacts to one sector of human life can have unanticipated consequences for other sectors, and so monitoring the relationship between human health, the quality of local infrastructure, and success metrics like levels of museum attendance and engagement might be worth investigating further.

The Morrison County Historical Society's 2017 Strategic Plan articulates as one of its strategic objectives the development of "new programming on an ongoing basis."[59] The projected changes in climate, and their cascading impacts on erosion, agriculture, and quality of life in Morrison County, might therefore be an area worth exploring when developing this new programming. These are not the first climatic changes seen in the area, but they are possibly the first to take place over such an accelerated timeframe, and with such as-yet-unknown consequences for residents; there is a developing story here. The way that climate change shapes the collections and exhibits at the Weyerhaeuser Museum is possibly the *only* area of change over which the museum has any real control and informing the public of the context behind their lived environment is essential in mobilizing support for climate mitigation efforts as we move forward.

Another area of potential interest is climate migration. These migrants may come from a variety of places impacted by climate change. Already, severe droughts and increasingly unpredictable rains in Central America have been linked to an unprecedented number of migrants moving north, seeking a livelihood in Mexico and the United States. A recent report by the World Bank estimates that as many as 216 million people could be internally displaced by climate change impacts by 2050, with lower numbers projected under lower-emissions scenarios.[60] If we look at past patterns of intra- and international migration, it is not unreasonable to assume that groups of climate refugees will end up in the United States, and that, like countless immigrants before them, some of these refugees might find their way to Minnesota. Despite the adverse effects projected to occur in the future – and indeed, those adverse effects that are already demonstrably happening in the present – Minnesota is comparatively well positioned to weather global climate change. There are already anecdotal reports of families from wildfire-stricken part so the United

[58] World Health Organization, "Heatwaves," https://www.who.int/health-topics/heatwaves#tab=tab_1, accessed October 1, 2021.
[59] Morrison County Historical Society, "Strategic Plan: Morrison County Historical Society," May 2017, http://morrisoncountyhistory.org/mchsstrategicplan2017.pdf, accessed August 15, 2021.
[60] Viviane Clement et al, *Groundswell Part 2: Acting on Internal Climate Migration,* World Bank, Washington DC, 2021, https://openknowledge.worldbank.org/handle/10986/36248, accessed November 28, 2021.

States moving to the Duluth, for instance.[61] [62] While it is hard to tell how this migration might take place before it actually takes place, it may become an area of interest for tomorrow's historians of Morrison County.

3. Recommendations

In its 2016 report, *Cultural Resources Climate Change Strategy,* the National Park Service lays out four pillars of its climate change response: Science, Mitigation, Adaptation, and Communication. The Science pillar involves gathering the relevant climate data, analysis, and response techniques. The Mitigation pillar involves activities that reduce the greenhouse gas emissions and other environmental impacts generated by the given organization. The Adaptation pillar follows the IPCC's definition as being "an adjustment in natural or human systems that moderates harm or exploits beneficial opportunities in response to change." The Communication pillar involves sharing climate change information within the organization and with organizational partners and members of the public.[63] In writing this assessment, it felt appropriate to draw on this existing framework in formulating my recommendations, as the National Park Service serves the largest organization overseeing natural and historical assets in the United States and has comprehensively explored the issue of climate change as it relates to cultural heritage.

Based on this framework, my recommendations are as follows:

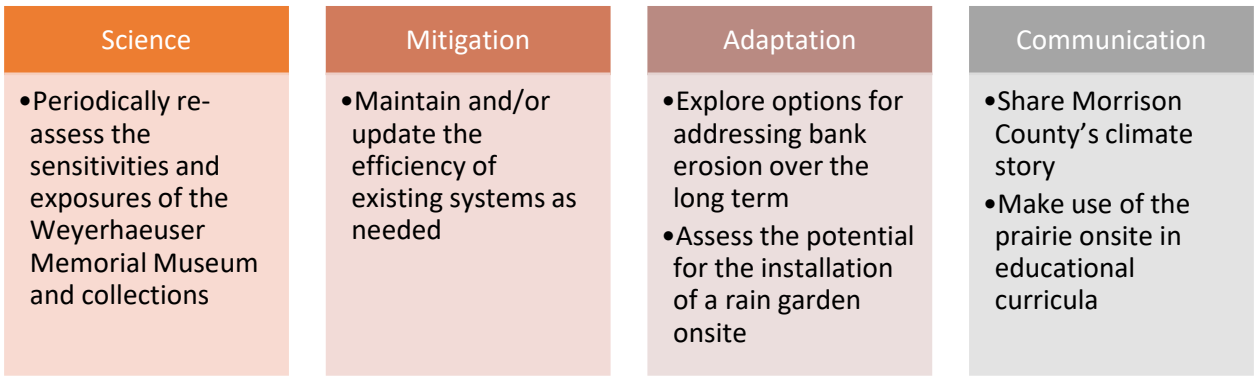

Fig. 4. Final recommendations for the Morrison County Historical Society.

My first suggestion is that museum staff periodically reassess potential sensitivities and exposures of the Weyerhaeuser Museum structure based on information as it becomes available. As we learn more about the risks and opportunities associated with climate change in the Central

[61] Daniel Cusick, "Climate pioneers flee fire, heat for famously frigid Duluth," *E&E News,* November 21, 2021, https://www.eenews.net/articles/climate-pioneers-flee-fire-heat-for-famously-frigid-duluth/, accessed December 15, 2021.
[62] Dan Kraker, "Climate-proof Duluth? Why the city is attracting 'climate migrants,'" *MPR News,* October 4, 2021, https://www.mprnews.org/story/2021/10/04/climateproof-duluth-why-the-city-is-attracting-climate-migrants, accessed December 15, 2021.
[63] NPS 2016.

Minnesota region, the best course of action may change, and existing plans may require adjustments. The Environmental Protection Agency provides a list of tools for climate change adaptation on its website, including resources related to siting green infrastructure and a stormwater calculator that incorporates future climate vulnerability scenarios.[6465]

My second suggestion would be to continue to monitor, and upgrade, the energy efficiency of the existing building envelope, HVAC, and electrical systems as appropriate. The recent HVAC update in the fall of 2021 was intended to increase energy efficiency and prevent rapid fluctuations in temperature and moisture within the building. So far, according to museum staff, the system appears to be living up to its promise, although it will take approximately a year before sufficient data can be gathered for a more accurate assessment. A recent audit from Minnesota Power also identified several gaps in insulation. At the moment, however, closing those gaps would constitute a major project that doesn't make sense to pursue in the near term, particularly if early evidence of the new HVAC system's enhanced efficiency turns out to be accurate. Energy retrofitting is a crucial step to reducing thermal load and energy consumption of existing buildings, as heat transfer through the building envelope represents up to 60% of heat loss and gain,[66] [67] and so taking advantage of affordable opportunities to do so as such opportunities arise. Engaging with local partners at Minnesota Power or Clean Energy Resource Teams on the appropriate materials for weatherization would help ensure that the upgrades are both affordable and appropriate.

There is also the question of pursuing a renewable option for climate controls at the museum. Ultimately, our economy will transition to using renewable energy exclusively, but in the near term, achieving this goal on an institutional level can be somewhat more complicated. There is currently no capacity to explore a renewable option for the HVAC system at the moment, although staff were open to the possibility should it become more financially and logistically feasible to do so. Museum staff have suggested that successfully making the National Register of Historic Places would both serve as a recognition of the building's historic value and open up new avenues of funding for any future alterations to the structure's HVAC, insulation, or energy sourcing.

My suggestions for viable adaptation measures are twofold: first, to explore workable options for addressing the erosion of the riverbank over the long term, and second, to assess the potential benefits of a rain garden installation onsite. Based on conversations with District Technician Mike Becker, as well as with museum staff Mary Warner and Ann Marie Johnson, the sandy soil

[64] United States Environmental Protection Agency, "Tools for Climate Change Adaptation," https://www.epa.gov/arc-x/tools-climate-change-adaptation#adaptation, accessed January 24, 2022.
[65] United States Environmental Protection Agency, "National Stormwater Calculator," https://www.epa.gov/water-research/national-stormwater-calculator, accessed January 24, 2022.
[66] Fabrizio Ascione et al., "Building Envelope Design: Multi-Objective Optimiation to Minimize Energy Consumption, Global Cost and Thermal Discomfort. Application to Different Italian Climatic Zones," *Energy* 174 (2019): 359-374.
[67] Dileep Kumar, Morshed Alam, and Jay G. Sanjayan, "Retrofitting Building Envelope Using Phase Change Materials and Aerogel Render for Adaptation to Extreme Heatwave: A Multi-Objective Analysis Considering Heat Stress, Energy, Environment, and Cost," *Sustainability* 13 (2021): 10716-10744, https://doi.org/10.3390/su131910716, accessed November 4, 2021.

of the bank, combined with the increasingly intense rainfall events in the region, have caused significant loss of soil to the Mississippi River, a situation that everyone interviewed acknowledged will ultimately pose an existential threat to the site. Mike Becker estimated that the most long-lasting fix – a complete re-grading of that slope – could run to the hundreds of thousands of dollars in cost, which might not be financially feasible. The alternative, however, would be to relocate entirely, which might also pose logistical issues. Getting a better sense of the timeline of the erosion would allow staff to come to a decision on the best course of action, including investigating viable funding resources should the re-grading be determined as the best course of action. Conversations with Mary Warner and Ann Marie Johnson indicate that these conversations are already happening, as the nature of the erosion and its proximity to the building make addressing it "mission critical" for the museum.

Rain gardens are a popular tool for mitigating the impact of heavy rains in both commercial and residential areas. These plantings reduce runoff, filter out pollutants carried by stormwater, and provide food and shelter for native wildlife.[68] Museum staff are already considering applying for grant funding to install one onsite and have noted that it would also serve as a valuable educational tool to teach visitors about the benefits of green infrastructure. If staff ultimately do decide to pursue this line of action, I am more than willing to write those funding requests.

Finally, there is the matter of communications. Communicating the impacts of climate change, and ways that all of us can take action to mitigate and adapt to them, is essential. Increased public awareness of climate change has a strong positive correlation with increased engagement with an action towards a climate solution. For instance, a study of environmental policymaking in the Irish Citizens' Assembly found that effectively-communicated climate messaging had a direct relationship with participant support for ambitious climate measures.[69] There is also recent evidence that, even in a politically divided America, an increasing number of Americans list "climate change" as a top policy priority and vote accordingly.[70] Putting climate change into the appropriate historical context, and connecting a global phenomenon to its local manifestations, can bring clarity to a phenomenon that many people find confusing. Both the prairie planting and the proposed rain garden can prove useful here; both are touched by climate change in different ways, and, as physical installations, they are not abstract in the same way as a map of temperature changes over time or a graph of carbon dioxide emissions.

It should be stressed that these recommendations are provisional; the museum may decide to adopt them or not adopt them, based on their best understanding of their circumstances. But one thing that is undeniable is that museums as an institution have a critical part to play in the fight to prevent catastrophic climate change. As archives of our collective past, they hold valuable

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[68] United States Environmental Protection Agency, "Soak Up the Rain: Rain Gardens," https://www.epa.gov/soakuptherain/soak-rain-rain-gardens, accessed January 24, 2022.

[69] Lala Muradova, Hayley Walker, and Francesca Colli, "Climate change communication and public engagement in interpersonal deliberative settings: evidence from the Irish citizens' assembly," *Climate Policy* 20 no. 10 (2020): 1322-1335, DOI: 10.1080/14693062.2020.1777928.

[70] Alec Tyson and Brian Kennedy, "Two-Thirds of Americans Think Government Should Do More on Climate," Pew Research Center, June 23, 2020, https://www.pewresearch.org/science/2020/06/23/two-thirds-of-americans-think-government-should-do-more-on-climate/, accessed November 15, 2021.

insights into humanity's capacity for adapting to and even thriving in the midst of seismic global changes. They are full of evidence of society's responses to new weather patterns, new crops, new people, and new paradigms. If the past is prologue, as Shakespeare said, then the Weyerhaeuser Memorial Museum contains valuable information about how to address the challenges that lie in our future.

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