IT’S HOT, AND GETTING HOTTER:
Implications of Extreme Heat on Water Utility Staff and Infrastructure, and Ideas for Adapting

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Prepared for:

Water Utility Climate Alliance (WUCA)

Association of Metropolitan Water Agencies (AMWA)

WUCA
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1. Executive Summary

Water utilities across the country will experience new and enhanced vulnerabilities due to future increases in extreme heat events stemming from climate warming. The Water Utility Climate Alliance (WUCA) and the Association of Metropolitan Water Agencies (AMWA) recognized these threats and sponsored a study to analyze the impact of such extreme temperature events on critical water utility physical infrastructure assets and personnel. The methodology focuses on examining the effects of extreme temperatures on personnel and facilities in the years 2030, 2050 and 2070, compared to a 1990 to 2009 baseline.

Climate Summary: The climate data used to project future climate conditions in the analysis are the Localized Constructed Analogs (LOCA) climate projections for North America[1]. In total 32 models and two representative concentration pathways (RCPs) were used in this analysis (RCP 4.5 and RCP 8.5 represent intermediate and high future greenhouse gas emissions scenarios, respectively).

The historical data used in this analysis is the Livneh et al. (2015) data set[2]. This data set was chosen to remain consistent with the observed dataset used in the downscaling process. The historical period used is 1990 to 2009. The projection data used is set over the period 2021 to 2080. For brevity, results are presented for three future time periods averaged over a 20-year time span for each RCP. The time frames used are 2030 which averages 2021-2040, 2050 (averages 2041 to 2060), and 2070 (averages 2061 to 2080).

Each of the five water utility locations see an increase in average maximum summer temperature from the historical model to the average of the 32 projected models. This increase ranges from 2.0°F to 4.1°F across the utility locations in 2030 for RCP 4.5. In 2070 the increase ranges from 4.5°F to 7.7°F across the utility locations for RCP 8.5. Figure 1 illustrates this data for each utility location, projection year, and RCP. It is important to note that these values are maximum summer temperatures averaged over the 20-year projection periods and averaged over the 32 projection climate models. Therefore, higher values can be expected in some years and models, and daily high temperatures will also exceed these values. Therefore, study results are a lower boundary of future impacts because average seasonal values are evaluated.

Personnel Summary: According to data compiled from the Bureau of Labor Statistics (BLS), exposure to excessive environmental heat stress killed 783 U.S. workers and seriously injured 69,374 workers from 1992 through 2016 across all industries[3]. Increases in daily heat index, heatwaves, and daily maximum temperatures will put additional stress on outdoor workers.

In this analysis, the impact on personnel from temperatures is based on the Heat Index, which is a heat indicator that factors in both air temperature and relative humidity and represents how hot it really feels to the human body. The impact of rising temperatures on water utility workers was modeled according to two nationally recognized heat stress standards that define heat index thresholds above which specific safety precautions need to be taken to limit heat stress. Projected increases in temperature have ramifications for the health, safety and productivity of field workers including increased need for worker breaks, a decrease in worker productivity, the potential for increased worker accidents and worker safety in enclosed spaces. Costs associated with reduced productivity could potentially reach six figures for many of the five water utilities by 2030 while workplace accidents could increase 8% by 2030 and 17% in some case study locations by 2070.

While increasing temperatures could lead to loss of productivity and additional workplace accidents, resulting in increased costs for water utilities, adaptation measures can be implemented that would both reduce costs and reduce heat-related injuries. The projected heat index in several locations would place workers at high levels of risk if no adaptation measures are taken. Refer to Section 4.2 and Appendix B for personnel adaptation strategies.

Infrastructure Assets Summary: In addition to water utility workers, the facilities and assets owned and operated by water utilities will also experience additional stress due to temperature increases. Cooling operating costs are projected to increase and the increase in outdoor temperature is projected to reduce the lifespan of critical assets, evaluated as part of this study to include motors, motor control centers, roofing and parking lot pavement.

To evaluate the increase in cooling costs associated with rising climatic temperatures this study used a Cooling Degree Day (CDD) based analysis. CDD is a metric used to quantify the amount of cooling required at a specific location based on daily temperatures above a specific baseline temperature. Analyzing the historical data against the projected models, the study determined that each utility location is projected to experience an increase in CDDs ranging from 20% in Southern Nevada in 2030 for RCP 4.5 to 192% in Denver in 2070 for RCP 8.5. Refer to Figure 5 for more detail. These values represent the average summer projection across 32 models, so more extreme temperatures, especially daily temperatures, are expected.

The lifespan of critical equipment decreases as the ambient temperature within which it operates increases. As lifespan decreases, replacement costs increase. Decreased lifespan due to increasing climatic temperature was quantified using the industry standard “10-degree rule,” which says that for every 10°C (18°F) rise in operating temperature, the motor insulation lifespan is reduced by a factor of one-half[4].

Ambient operating temperature was calculated within water utility facilities based on historical and projected outdoor air temperatures depending on the type of cooling system present in the facility. In general, ambient temperatures in facilities with cooling systems increased the least in response to rising outdoor temperatures, which led to less degradation of motor lifespan and therefore less increase in replacement costs. In contrast, unconditioned and outdoor facilities saw the largest increase in indoor temperatures due to rising outdoor temperatures, leading to more degradation of equipment lifespan and an increase in replacement costs.

The study also evaluated roof and parking lot degradation due to increasing climatic temperatures. In the case of asphalt-based roofing, for every 18°F rise in temperature, the rate of thermal oxidation approximately doubles, leading to a shorter roofing lifespan[5]. For thermoplastic polyolefin (TPO) roofing systems, higher temperatures assist photodegradation which leads to a shorter roofing lifespan[6]. These relationships were modeled to estimate the degradation rates of each roofing system.

Parking lot asphalt binders are rated to a certain temperature and when that threshold is crossed, the surface is weakened resulting in cracking and rutting. The temperature when this softening occurs is related to the historical temperature in a specific area, therefore increases in temperature can cause weakening of the surface in any geographic location. For this reason, all study sites are susceptible to this degradation based on projected temperature increases.

Various adaptation strategies, some of which are region-specific and some which are universal, can be employed by water utilities to help prepare for the extreme heat and mitigate heat impacts. Refer to Section 4.3 and Appendix B for facility and infrastructure adaptation strategies.

2. Introduction

The Water Utility Climate Alliance and the Association of Metropolitan Water Agencies recognize that warming from climate change could pose risks to member agencies beyond future water supply availability impacts. Warming, which is considered more certain than changes in precipitation, could negatively impact the health of utilities' most important asset – its personnel – and it could also shorten the lifespan of critical infrastructure.

Extreme heat is one of the leading causes of weather-related deaths in the U.S. The National Oceanic and Atmospheric Administration lists heat waves as causing four of the top 10 deadliest U.S. disasters since 1980[7]. With rising temperatures, the safety and health hazards from extreme heat will be amplified. Outdoor workers are vulnerable populations as they spend a considerable amount of time in these extreme conditions. From a health and safety standpoint it is critical that water utilities monitor and adapt with these changing working conditions.

Additionally, the "Fourth National Climate Assessment Report" warned that infrastructure currently designed for historical climate conditions is more vulnerable to future weather extremes and climate change, and that forward-looking infrastructure design, planning, and operational measures and standards can reduce exposure and vulnerability to the impacts of climate change[8]. Water utilities depend on the operation of critical infrastructure, such as pumps, cooling systems, building envelopes and parking surfaces, to provide reliable services. Extreme weather and climate change pose threats to the dependable operation of these critical assets and thereby pose risks to reliable water utility service. Therefore, a second key motivator for this study is to evaluate the impacts of a changing climate on water utility infrastructure and devise suitable adaptation strategies to mitigate its effect.

In response, WUCA and AMWA sponsored this study to evaluate climate change impacts at a suite of water utilities, representing a range of climates and geographies, and to identify potential adaptions. Five case study utilities were evaluated: Denver Water (DW), Miami-Dade Water and Sewer Authority (MDWASD), Oklahoma City Utilities, Portland Water Bureau and Southern Nevada Water Authority (SNWA). The heat impacts study was conducted to evaluate the effect of future air temperature and extreme heat conditions on (1) the health and safety of outdoor personnel for each case study utility and (2) a range of infrastructure impacts which varied by case study, including:

- Changes in building cooling requirements,
- Reduced motor and motor control center lifespans,
- Degraded roof systems, and
- Degraded parking lots.

This report summarizes key findings but does not detail explicit cost savings at each case study. Detailed information on study methods, data and cost information can be found in each individual case study report. Refer to Appendix A for contact information for representatives at each utility.

2.1 Objective

The overall goal of the study was to understand the impacts of extreme heat on public water utilities located in diverse urban climates around the U.S., and then develop suitable adaptations to address those impacts. It is recognized that increasing temperatures will impact both personnel and equipment, and these impacts will become more extreme as the temperatures continue to climb over the next several decades. This recognition is the primary motivation for the study and the development of the results presented in this report.

3. Approach

The results presented here are based on analysis conducted with the Infrastructure Planning Support System (IPSS), a proprietary system developed and administered by Resilient Analytics, Inc. (RA) that models infrastructure vulnerability to future climate and weather conditions and considers specific adaptation scenarios. IPSS sources its data from a range of climate science projections, engineering, and materials studies.

The results are based on a stressor-response approach of the IPSS system that provides cost and risk estimates for health threats to water utility personnel, as well as the selected water infrastructure assets. Using the IPSS approach, the climate stressor (temperature) is analyzed in terms of each component (equipment and personnel) to determine the potential impact in relation to a historical baseline (the response). The response identified for each component is then interpreted to the potential costs related to that impact. For personnel, the impact is the cost of lost hours or potential reductions in productivity due to extreme heat impact on worker hours. For equipment, this response is the increased cooling demand and the degradation of equipment lifespan.

In developing the results presented here, the team engaged in a data gathering process that included working with the utilities to obtain historical personnel trends as well as inventories of physical assets. Additionally, the team held meetings with utility personnel to obtain feedback on potential adaptation strategies and areas of specific concern.

The study results for personnel risk are based on established studies highlighting the impacts of extreme heat on occupational health and safety by public health entities like the Occupational Safety and Health Administration (OSHA), the Bureau of Labor and Statistics (BLS), and the National Center for Environmental Health (NCEH). Similarly, the study results for impacts on utility physical assets and equipment reflect accepted standards for specific impact thresholds for costs for maintenance, operation, and construction. The adaptation options developed in the study are intended to reduce the vulnerability of both the health risks to the utility workers and the physical water utility infrastructure.

4. Analysis

4.1 Climate Projection Results

The analysis utilized historical and future climate data. The climate data used to project future climate conditions are the Localized Constructed Analogs (LOCA) climate projections for North America. LOCA is a technique for downscaling climate model projections for future climate scenarios. The LOCA data used for this study includes daily maximum and minimum temperature, and relative humidity, which are spatially allocated at 1/16th degree. In total 32 models and two representative concentration pathways (RCPs) were used in this analysis (RCP 4.5 and RCP 8.5), although for the calculation of heat index only 24 models out of the 32 were used due to data constraints for relative humidity. The RCP 4.5 is a stabilization scenario and assumes that climate policies are invoked to achieve the goal of limiting emissions, concentrations, and radiative forcing. This would lead to global carbon emissions peaking and declining by 2040. The RCP 4.5 scenario would limit the increase in global mean temperatures to 1.98°F to 4.68°F relative to 1986 to 2005 levels, respectively. The RCP 8.5 is a business as usual scenario with a continuous rise in global carbon emissions. The RCP 8.5 scenario would limit the increase in global mean temperatures to 4.68°F to 8.64°F relative to 1986 to 2005 levels, respectively. The projection data used is set over the period 2021 to 2080. For brevity, results are presented for three future time periods averaged over 20-year time span for each RCP. The time frames used are 2030, which averages 2021-2040, 2050 (averages 2041 to 2060), and 2070 (averages 2061 to 2080).

The historical data used in the analysis was the Livneh et al. (2015) data set[2]. This was chosen to remain consistent with the observed dataset used in the downscaling process. The historical period used is 1990 to 2009.

Figure 1 shows the location of each water utility and the projected average summer temperature change for each 20-year period over the next 60 years, averaged over the RCP 4.5 and RCP 8.5 scenarios. Results in Figure 1 are a lower boundary of future impacts because average seasonal values are evaluated.

Change in Average Maximum Summer Temperature (°F)

	Historic Average	2030		2050		2070	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Denver Water	85.4	3.2	3.6	4.1	4.8	5.4	7.5
Miami-Dade Water and Sewer Authority	90.1	2.0	2.2	2.5	2.9	3.2	4.5
Southern Nevada Water Authority	100.8	3.5	3.7	4.2	4.7	5.3	7.2
Oklahoma City Utilities	91.0	4.1	4.3	4.8	5.3	6.0	7.7
Portland Water Bureau	79.0	2.4	2.8	3.2	3.9	4.6	6.8

Figure 1. Case study utilities and expected change in summer temperature between the historical model and the projected models. Projected data is averaged across 32 climate models and across the RCP 4.5 and RCP 8.5 scenarios. Values represent the average change in temperature. Extreme temperature changes both above and below those shown are projected by various model and RCP combinations, and daily extreme temperature values will likely exceed seasonal projections

4.2 Personnel

All five water utilities were interested in evaluating the effect of extreme heat on outdoor workers and personnel.

Extreme heat is one of the leading causes of weather-related deaths in the U.S. The National Oceanic and Atmospheric Administration lists heat waves as causing four of the top 10 deadliest U.S. disasters since 1980[7]. With rising temperatures, the safety and health hazards from extreme heat will be amplified. Outdoor workers are among the most vulnerable populations, as they spend a considerable amount of time in these extreme conditions. Outdoor workers who are performing physically demanding work and/or need to wear protective clothing are especially vulnerable[9].

According to data compiled from BLS, exposure to excessive environmental heat stress killed 783 U.S. workers and seriously injured 69,374 workers from 1992 through 2016 across all industries[3]. Additionally, numerous studies provide evidence that extreme heat increases the number of workplace accidents. Xiang et al. (2014b) find that heat waves, which they define as three or more consecutive days with daily maximum temperature over 95°F, increase workers' compensation claims in outdoor industries by 6.2%[10]. Adam-Poupart et al. (2015) conducted similar analysis in 16 health administration regions of Quebec, finding that an increase of 1°C (1.8°F) in daily maximum temperature is associated with a 42% increase in the count of daily heat-related occupational injury compensations[11].

In another study, the NCEH found a correlation between the average number of hospitalizations and the average monthly maximum temperature/heat index in all 20 states in the study. The study looked at a 10-year period from 2001 to 2010 and notes that the rate of hospitalizations increased by 2%-5% in all 20 states over that period[12]. Building on the hospitalization and safety focus, a study conducted by MIT and William and Mary found that days with maximum temperature between 90° and 95°F result in 10.3% more accidents, days between 95° and 100°F have 12.7% more accidents, days between 100° and 105°F have 29.4% more accidents, and days with maximum temperature over 105°F have 37.8% more accidents, all relative to days with maximum temperature between 65° and 70°F[13]. OSHA accident data used to develop these estimates of daily temperature on daily accident includes only temperature-sensitive industries such as construction, utilities, and sanitary services.

Impacts

The impact on personnel from temperatures is based on the Heat Index, a heat indicator that factors in both air temperature and relative humidity. The Heat Index represents how hot it really feels to the human body. In 2018, the Centers for Disease Control and Prevention and the National Institute for Occupation Safety and Health (NIOSH) released a report recommending that companies comply with OSHA's unofficial Heat Index exposure limits. The exposure limits are the heat index thresholds in which specific actions need to take place (basic heat safety and planning, additional breaks, encourage workers to wear sunscreen, etc.) to limit heat stress. The paper echoed NIOSH's long-standing recommendations that OSHA adopt an occupational heat stress rule[14].

Heat Index	Risk Level	Protective Measure
Less than 91°F	Lower (Caution)	Basic heat safety and planning
91° to 103°F	Moderate	Implement precautions and heighten awareness
103° to 115°F	High	Additional precautions to protect workers
Greater than 115°F	Very High to Extreme	Triggers even more aggressive protective measures

Table 1: OSHA Heat Index Risk Levels

In accordance with this national guidance, two versions of formal heat stress standards were modeled to evaluate the cost to the five case study utilities. The first heat stress standard that was modeled represents a moderate standard similar to the current California standard and the second was a stricter version following OSHA's current guidelines. The first standard modeled a 10-minute break every two hours when the heat index is above 95°F. The second standard, based on current OSHA guidelines, models the strictest standard that could be enforced[15]. Under the strictest standard 15-minute, 25-minute, 35-minute and 45-minute breaks are given during an hour of work with Low, Moderate, High and Extreme Heat Index values. Daily Heat Index values were calculated for a baseline scenario and a suite of downscaled climate models to determine when the work/rest cycles would be enforced. The increase in Heat Index risk level contribute directly to an increase in worker breaks and thus decrease in anticipated worker productivity. Similarly, the potential for increased worker accidents was calculated based on increased temperatures and extreme heat events.

Looking across all climate models, it is estimated that there will be temperature increases across all five utility locations due to climate change. By 2030 the number of days seeing temperatures exceeding a range of extreme temperatures (90°F, 95°F, 100°F, 105°F, 110°F, and 115°F) increase from a week to over a month in some areas. In some locations, temperatures exceeding 100°F will significantly increase by double digits over the next half century. The projected average temperature increases from baseline for the climate models in 2030, 2050 and 2070 are illustrated in Figure 2, Figure 3 and Figure 4. As illustrated, the increase is not uniform across the sites but is present in each location. Please note that these increases represent the average values across all climate models and that more extreme values are projected by individual models.

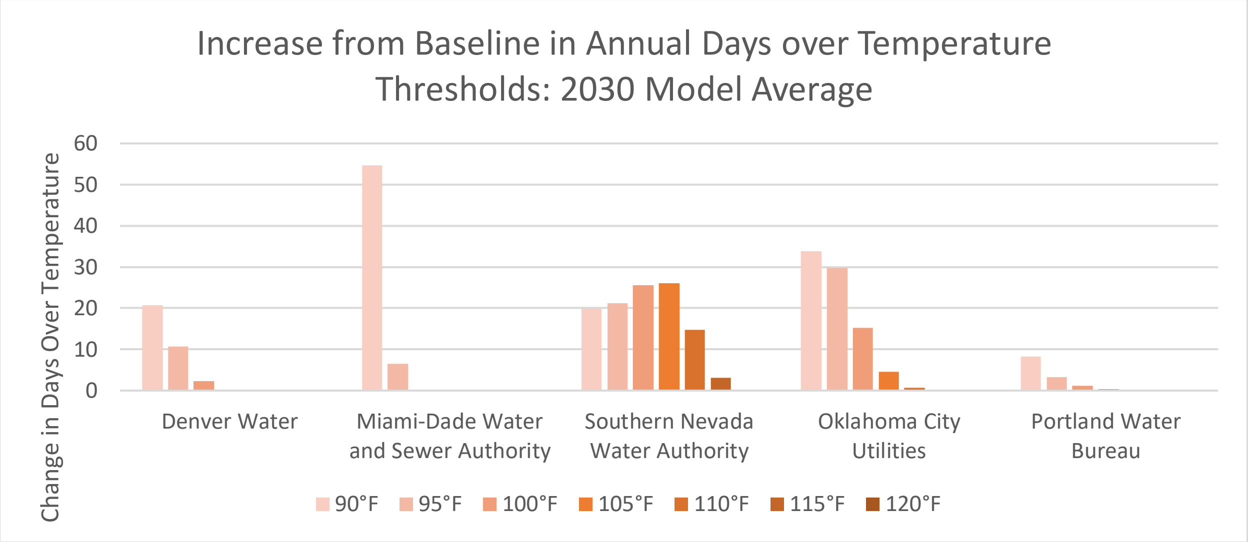

Figure 2 Increase from baseline in Annual Days Over Temperature Thresholds in 2030. Values shown represent the average values across all climate models and RCPs. More extreme values are projected by individual models.

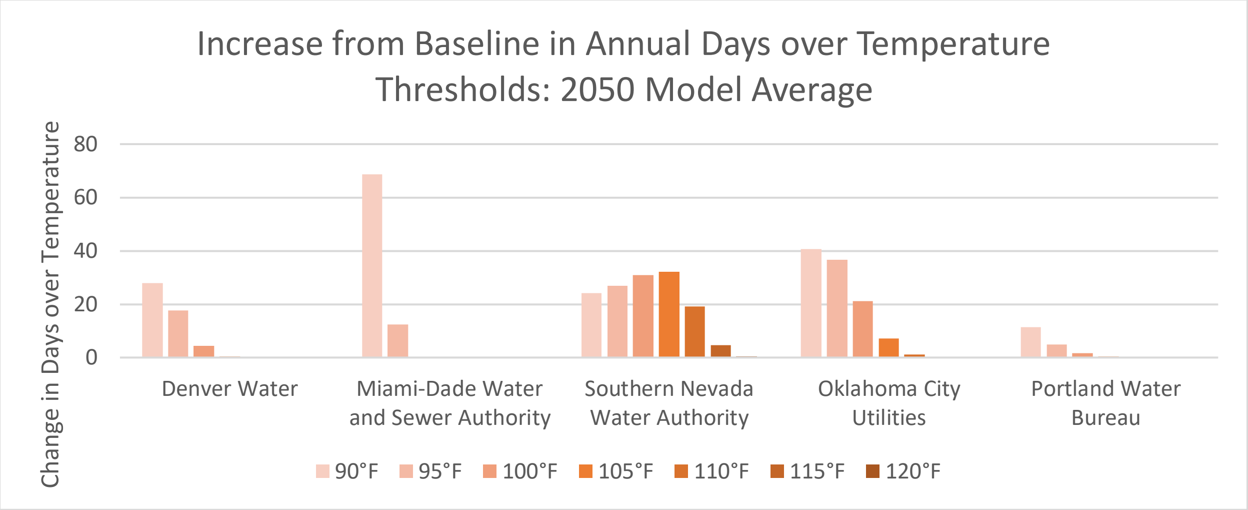

Figure 3: Increase from baseline in Annual Days Over Temperature Thresholds in 2050. *Values shown represent the average values across all climate models and RCPs. More extreme values are projected by individual models.*

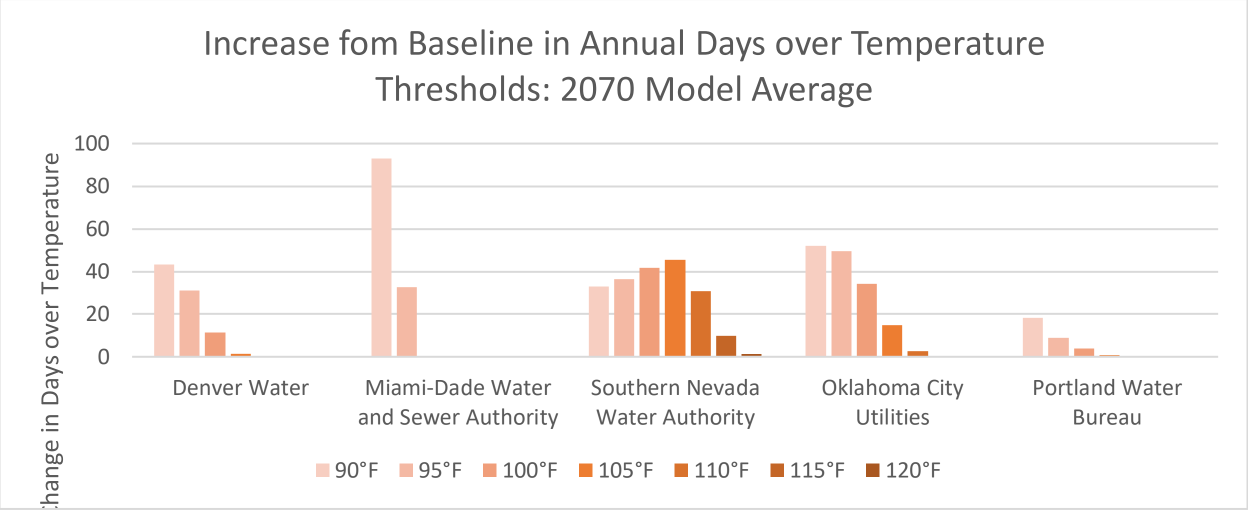

Figure 4: Increase from baseline in Annual Days Over Temperature Thresholds in 2070. *Values shown represent the average values across all climate models and RCPs. More extreme values are projected by individual models.*

In addition to these temperature changes, the projected Heat Index in several locations would place workers at high levels of risk if no adaptation measures are taken. These projected increases have ramifications for the health, safety and productivity of field workers, possible accidents, and worker safety in enclosed spaces.

Regarding productivity, the number of hours where breaks will be required is based on a heat stress standard and will increase significantly, resulting in costs that could potentially reach six figures for many of the five water utilities by 2030. These cost analyses were done for each case study but are not presented in the summary report. Closely related to this issue is the increase in number of heat-related accidents. If no adaptation procedures are put in place, it is projected that workplace accidents could increase 8% by 2030 and 17% in some case study locations by 2070.

In addition to these quantifiable impacts, workers in non-conditioned and/or confined spaces who are exposed to high ambient temperatures could experience an increased likelihood of accidents or health issues.

Personnel Adaptation Options

The potential effects on personnel can be balanced with proactive adaptation responses. As heat issues are the focus of this study, the following adaptation options should be considered to reduce personnel vulnerability to heat exposure. Many of the utilities included in this study have already adopted some of these adaptation measures.

1. A basic set of adaptations focus on work scheduling and worker comfort for outdoor workers. In terms of comfort, case study participants have found that providing outdoor workers with sufficient electrolytes and ice as well as providing cool locations for work breaks can make an immediate difference. Ice machines and water coolers should be placed at building locations where vehicles deploy. Employees with the greatest exposure should be provided with mobile shade devices (Awnings, umbrellas); all employees should have access to oversized hats, tinted safety glasses, neck shade, and cooling devices. Utilities may also consider adding cooling locations closer to the field sites where employees work.
2. A second focus should be on timing what types of work are prioritized during times of extreme heat. Specifically, maintenance and construction crews can shift work during extreme heat periods from heavy construction and trench work to hydrant repairs and main breaks – jobs that are cooler and wetter. These options can be introduced together with heat training and classes related to heat stress for all staff.
3. At a next level focusing on adopting new standards, utilities could focus on implementing a national heat stress standard, which would require utilities to follow a regulated work/rest cycle based on the Heat Index risk levels defined by OSHA. Implementing a standard work/rest cycle would help to avoid worker accidents as well as health and safety impacts from increased heat. While a standard work/rest cycle has been difficult for some organizations to achieve up to this point, the projected increase in temperatures should renew the effort to implement a strategy that conforms to suggested worker practices.
4. The implementation of a strict rest/work schedule may raise concerns of worker productivity. However, there are options to reduce this potential loss of productivity. Specifically, utilities could consider scheduling worker activities in a manner to reduce exposure to mid-day heat. For example, outdoor worker schedules could be adjusted to begin shifts earlier in the morning during cooler conditions. A shift in schedules would reduce the number of required breaks under any type of heat stress standard while also complying with a strict work/rest schedule.
5. Finally, utilities should determine which indoor and confined spaces lack air conditioning. These spaces, in turn, should be evaluated for air conditioning for the benefit of both maintenance workers and the equipment housed in these spaces. Areas of particular concern include electrical rooms and other areas that need to be serviced by workers using protective equipment.
6. It is also recommended that utilities monitor extreme heat conditions over time to understand how the conditions are changing. This could include recording the site-specific temperature experienced by a field crew for each day spent working, as well as increasing temperature monitoring efforts within buildings and throughout utility service areas and collections systems. Comparing actual conditions to the climate projections will help management develop timelines for implementing suggested adaptation strategies.

4.3 Facilities/Infrastructure

While personnel and the impact of heat on their safety was a consistent focus for all five case study water utilities, the focus on equipment and facilities differed between case studies. Facility analysis considered: 1) cooling requirements, 2) equipment impacts, and 3) facility structure impacts.

The range of facility assets and impacts considered are shown in Table 1. Scope varied by case study so not all facilities and impacts were studied in each.

Impacts on Facility Type			
Facility Type	**Cooling Requirement Considerations**	**Equipment Impacts**	**Structural Impacts**
Water treatment plants	Changes in cooling demand and associated cost	Reduction in motor and MCC lifespan and associated increased cost of replacements	Reduction in roofing lifespan
Water pump stations			
Recycled water system and recycling plants			
Office buildings			
Wastewater pump stations			
Wastewater treatment plants			
Pumping plants			
Confined spaces	None		None
Parking lot structures	None	None	Reduction in asphalt lifespan

Table 1 Summary of analyses performed for each facility type within the scope of this study.

Cooling Requirements

Increases in temperature will result in additional cooling costs for facilities. The amount of additional cooling required is based on changes in cooling degree days. CDDs, a metric used to quantify the amount of cooling required at a specific location based on daily temperatures above a specific baseline temperature[16]. Each degree above that temperature represents one cooling degree day. The greater the number of cooling degree days, the greater the amount of cooling a building will need. By analyzing the historical data against the projected temperatures, the study determined an increase in projected CDDs and thus an increased cost of meeting this demand. Figure 5 demonstrates the CDD values projected for both scenarios RCP 4.5 and RCP 8.5 for the three utilities in the study that included conditioned facilities in the scope and opted to analyze the impact of rising temperatures on their cooling demand.

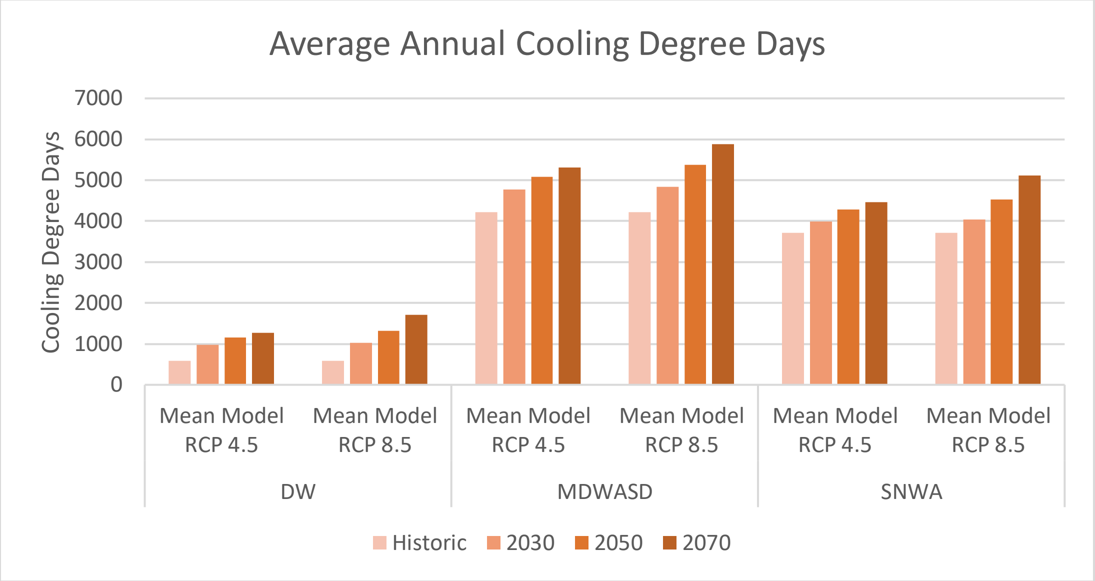

Figure 5 Increases in Average Annual Cooling Degree Days at the three utilities that included conditioned facilities in the scope and opted to analyze the impact of rising temperatures on their cooling demand.

Cooling Demand Adaptations Options

As cooling demands increase due to rising temperatures, a trend that is already being seen in some locations, enhancing existing cooling systems is one adaptation option, while facilities without cooling systems may require the installation of new systems. In either case, the new system design must account for the future increased cooling demands, as illustrated in Figure 5. The impact of this increase in cooling demand will specifically require utilities to examine:

- Office buildings
- Treatment plants
- Equipment spaces where ambient temperatures will exceed operating thresholds
- Areas with confined spaces

A cooling system analysis is recommended to determine the magnitude of increased cooling capacity necessary to meet increased cooling loads. As part of the cooling system analysis, it is recommended that utilities consider upgrading aging and inefficient cooling systems/equipment, including chillers and air handling units, to equipment with progressive efficiency ratings, which will help to offset additional cost of cooling. Emphasis should be placed on equipment that is near the end of its useful life with efficiencies that are below the latest energy codes and design guidelines.

A cooling system analysis should be complemented, and in most cases preceded, by an analysis of the associated facility as the susceptibility of an indoor facility's temperature to change in response to changing outdoor air temperature can be reduced using various building improvements.

- A facility analysis should include evaluation of the potential for indoor temperatures to be monitored to determine whether the cooling system, if present, is providing the necessary and expected cooling effect. If elevated temperatures are seen, or temperatures show a trend of increasing, evaluation of the cost/benefit of installation of additional cooling capacity is recommended. If no cooling system is present, temperature monitoring will allow for temperature trends to be established and for the prioritization of facilities most in need of a new cooling system.

- The susceptibility of an indoor facility's temperature to change in response to changing outdoor air temperature can be reduced by various building improvements, including installing additional envelope insulation, tighter air sealing to prevent infiltration of outdoor air, and pre-conditioning ventilation air that is brought into the space. Utilities should evaluate the cost/benefit of retrofitting existing facilities with such features to minimize heat loads, especially those facilities that show high susceptibility to indoor temperature changes in response to outdoor temperature changes. Utilities can also consider updating their engineering specifications for new construction with the aim of minimizing heat loads from outdoor temperature in new facilities.
- At times when the space temperature setpoint (temperature for which the cooling system is sized and set to maintain) is higher than the outdoor air temperature, an airside economizer can be used to circulate untreated outdoor air to help cool the space**.** This strategy is commonly used to save energy in comfort cooling applications where the space would be maintained at the cooling setpoint during airside economizer operation. However, in spaces where comfort is not a priority (mechanical spaces, pump rooms, etc.), an airside economizer *may* be able to be used to achieve indoor space temperature lower than the cooling setpoint during periods where the outdoor air temperature is at some temperature below the cooling setpoint (depending on fan capacity).

Equipment

This portion of the study quantified the relationship between ambient operating temperature, defined as the temperature within which the equipment operates, and equipment lifespan in the context of future projected trends in rising outdoor air temperature. The ambient operating temperature within which electrical equipment operates is a key factor in its lifespan. As ambient temperature increases the expected lifespan of the equipment decreases, and vice versa. Motors, Motor Control Centers (MCCs) and Variable Frequency Drives (VFDs) were the primary focus of this study because of the critical role they play in water utility operation.

Motors contain a variety of components (bearings, rotor, stator, insulation, etc.)[17] that each fail for a variety of reasons (voltage imbalance, over/under voltage, temperature, moisture, vibration, dirt, corrosive fumes, improper or insufficient maintenance, etc.)[18]. For the purposes of this study, the effect of temperature on motor winding insulation was analyzed. The analysis focused on motor winding insulation because temperature is a key reason for its failure, leading to potential motor failure, and because insulation is exposed to the highest temperatures of any motor component and therefore is most susceptible to temperature increases[19].

The relationship between temperature and electrical equipment lifespan is based on the industry standard "10-degree rule." This rule says, for every 10°C (18°F) rise in operating temperature, the motor insulation lifespan is reduced by a factor of one-half[18]. Similarly, for every 10°C (18°F) fall in operating temperature the motor insulation lifespan is increased by a factor of two. Motor lifespan was calculated by applying this relationship to the baseline and projected hourly ambient operating temperature profiles under the assumption that at the rated ambient operating temperature of 104°F the motor's lifespan is 20,000 hours[20]. The 10-degree rule can also be applied to Motor Control Centers (MCCs) and Variable Frequency Drives (VFDs)[21,22].

Impacts of extreme temperature on motor lifespan were quantified using the 10-degree rule described above for each hour and then converted to annual values for 12 hour-per-day and 24 hour-per-day operation. The motor lifespan values were then used to calculate the total number of replacements per motor expected for each of the 20-year analysis periods associated with the baseline (1990-2009), 2030

(2021-2040), 2050 (2041-2060) and 2070 (2061-2080). This information was combined with motor quantity and motor value information to estimate the quantity and cost of replacements for each facility over the 20 years corresponding to each time period.

Motor and MCC Lifespan Reduction Adaptation Options

High ambient operating temperature is a major factor in the reduction of lifespan for motors and related equipment. In the context of the projected rise in outdoor temperatures, facilities that see the greatest increase in the quantity of equipment replacements, on a per-motor-basis, are those whose indoor temperature changes most readily in response to a corresponding change in the outdoor air temperature. In such facilities, the result is a general trend towards hotter ambient operating temperatures and therefore a reduction in motor lifespan.

Ambient operating temperature was calculated within water utility facilities based on historical and projected outdoor air temperatures depending on the type of cooling system present in the facility. In general, ambient temperatures in facilities with active cooling systems increased the least in response to rising outdoor temperatures, which led to less degradation of motor lifespan and therefore less increase in replacement costs. In contrast, unconditioned and outdoor facilities saw the largest increase in ambient temperatures due to rising outdoor temperatures, leading to more degradation of equipment lifespan and more increase in replacement costs.

Adaptation options for extending equipment lifespan include a combination of obtaining heat-tolerant equipment as well as controlling the ambient operating temperature. The adaptation options for reducing cooling demand, discussed earlier in this report, can be used to control the ambient temperature. For equipment specific adaptations, the following can be considered:

- To prolong motor lifespan as ambient operating temperatures increase, utilities can investigate cost/benefit of rewinding existing motors with a higher insulation temperature rating, which will increase the winding lifespan. Utilities can also investigate the installation of new motors with higher insulation temperature ratings, which can tolerate higher operating temperatures. However, it is important to note that a motor's rated operating temperature is made up of three components: ambient temperature, internal temperature rise, and hot spot allowance. It is possible that a motor with a higher insulation temperature rating may operate at a higher internal temperature, leaving no increase in allowable ambient temperature[18]. Therefore, when specifying new motors with higher insulation temperature ratings, it is essential to first determine, with the manufacturer and specifying engineer, the allowable ambient operating temperature of the motor. A cost/benefit analysis can then be undertaken weighing the additional upfront cost versus the cost savings from any extension in the motor lifespan due to the increased allowable ambient operating temperature.
- Motors can overheat and prematurely fail due to several factors in addition to ambient operating temperature, and these factors should be mitigated. These factors include dirt, improper and/or imbalanced voltage, frequent start/stop cycles, and others[18]. Therefore, monitoring of the operation and maintenance schedules of each motor is recommended to optimize the motor lifespan.

Again, it is recommended that utilities monitor ambient operating conditions and outdoor conditions over time to understand how the conditions are changing. Comparing actual conditions to the climate projections will help management develop timelines for implementing suggested adaptation strategies.

Facility Structure

The impact on facility structures considered roofing system damage resulting from increased temperatures. A temperature-based lifespan analysis was performed in the study based on roofing system information provided by the utilities. For asphalt-based roofs, thermal oxidation is a primary factor in the aging process. For every 18°F rise in temperature, the rate of thermal oxidation approximately doubles, leading to a shorter roofing lifespan[23]. For TPO roofing systems, higher temperatures assist photodegradation which leads to a shorter roofing lifespan[24]. These relationships were modeled to estimate the degradation rates of each roofing system.

Roof System Degradation Adaptation Options

Increases in temperature will result in additional roofing system damage. Specifically, as detailed previously, increased temperatures can result in thermal oxidation or photodegradation depending on the type of roof. In either case, the degradation of the roof coatings will result in reduced capacity of the roofing material to adequately perform to required specifications. Offsetting this degradation is essential to avoid increased repair and replacement costs for the roofing systems.

To avoid additional roof replacement costs multiple adaptation strategies can be put into place. The goal of each of the strategies is to reduce the surface temperature of the roofing system.

- For current roofing systems a cool coating can be applied to accomplish a lower surface temperature. A cool roof is one that has been designed to reflect solar radiation and absorb less heat. These systems can be made from highly reflective paint, tiles, shingles or sheet coverings. The cost to coat a functioning roof varies, but averages about $2.00 per square foot. A cool roof coating/alternative can also be applied when the roof system is being replaced. The cost to include a paint coating as part of a roof replacement varies from $0 to $1.90 per square foot.
- Cooler roofing systems will provide other benefits such as energy savings and HVAC equipment savings. These benefits should also be considered when evaluating the payback period for cool roof adaptation.

Parking Lot Degradation Adaptation Options

Asphalt surfaces are vulnerable to increases in temperature. Specifically, asphalt binders are rated to a certain temperature and when that threshold is crossed, the surface is weakened resulting in cracking and rutting. The temperature when this softening occurs is related to the historical temperature in a specific area, therefore increases in temperature can cause weakening of the surface in any geographic location. For this reason, all study sites are susceptible to this degradation based on projected temperature increases.

The primary adaptation option available to reduce asphalt degradation is to upgrade the binder to one that meets the new operating temperatures. This should be done when the parking lot requires resurfacing. Until that point in time an enhanced repair schedule should be put in place to account for increased cracking in the asphalt.

5. Conclusion

In summary, a warming climate has many deleterious effects on water utility personnel and facilities/assets, some of which are climate specific, and some of which are universal to all locations. These impacts are likely to be felt by the utilities within the next decade, if not immediately, and thus adaptation options should be considered in the near term as well as in the longer-term strategic planning process. Preemptive planning can help to mitigate the impact that rising temperatures have on utility personnel, assets, and facilities.

The results included in this report are for temperatures averaged over all models and scenarios, meaning that the possibility exists for actual future temperatures to be more extreme than shown. As such, water utilities must monitor future temperatures and decide how they will adapt to varying degrees of temperature change.

For personnel, the projected increase in temperatures will result in health, productivity, and budgetary impacts. From a health perspective, it will be necessary to reduce exposure to extreme heat scenarios. This will require alternative shift options, changes in maintenance schedules, and increased cooling options for enclosed and confined spaces. From a productivity perspective, increased break times as well as potential increases in workplace accidents could have both a financial impact as well as a morale impact on individual locations.

For assets, a broad range of impacts are possible due to increased temperatures. Roofing and parking lot degradation are direct results of increased temperatures on materials. Increased cooling demand will have widespread consequences on cooling systems by both requiring additional cooling capacity in existing systems as well as introducing cooling into areas that previously did not require such mechanical equipment. Finally, increased temperatures have the potential to reduce the operating lifespan of critical equipment such as motors. In order to counteract these impacts, it is essential that the repercussions of a warming climate be factored into all future plans and projects undertaken by utilities. New design approaches will need to be developed, new materials will need to be considered, and new norms will need to be observed.

The combination of personnel and asset impacts makes increasing temperatures a serious concern for every utility. Many of these impacts stem from the relative increase in temperature from historical norms, rather than the absolute magnitude of future temperatures, making any geographic location susceptible to the issues covered in this report. Additionally, as these impacts are projected to occur within a decade, the timeframe to address these impacts must be sooner rather than later. As such, it is recommended that analyses such as the ones in this study be undertaken at any location where climate models project increases in temperature. The results and subsequent adaptation options will help secure worker safety improvements, financial savings and the ability of water utilities to continue to provide their essential services to the populations they serve.

Appendix A: Utility Case Study Contacts

Utility	Contact Name	Email
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Southern Nevada Water Authority	Keely Brooks	Keely.Brooks@snwa.com

Appendix B: Personnel, Facility and Infrastructure Adaptation Strategies

Impact	Adaptation Strategies
Extreme heat effect on outdoor workers and personnel	Providing outdoor workers with sufficient electrolytes and ice as well as providing cool locations for work breaks
	Ice machines and water coolers should be placed at building locations where vehicles deploy
	Employees with the greatest exposure should be provided with mobile shade devices
	Utilities may also consider adding cooling locations closer to the field sites where employees work
	Timing what types of work are prioritized during times of extreme heat
	Implementing a standard work/rest cycle
	Scheduling worker activities in a manner to reduce exposure to mid-day heat
	Utilities should determine which indoor and confined spaces lack air conditioning
	Utilities should monitor extreme heat conditions over time
Changes in cooling demand and associated cost	Monitor indoor air conditions and outdoor conditions
	Building envelope and façade improvements
	HVAC retrofitting for higher efficiency
	Airside economizer
	Update engineering specifications for new construction
Reduction in motor and MCC lifespan and associated increased cost of replacements	Monitor ambient operating conditions and outdoor conditions
	Rewinding existing motors with a higher insulation temperature rating
	Installation of new motors with higher insulation temperature ratings
	Monitor operation and maintenance schedules of each motor
Reduction in roofing lifespan	Install cool roofing system
Reduction in asphalt lifespan	Upgrade asphalt binder grade

End Notes

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