Climate Vulnerability and Risk Assessment

The Metropolitan Water District of Southern California

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SUSTAINABILITY
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INNOVATION

RINCON CONSULTANTS, INC.
Environmental Scientists | Planners | Engineers

Prepared by The Sustainability, Resilience, and Innovations Office

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Executive Summary

The Metropolitan Water District of Southern California (Metropolitan) has a legacy of forward-looking leadership that has for decades helped Southern California meet tomorrow's water challenges. Metropolitan's water sources and operation continue to be impacted by a changing climate. Metropolitan is working to ensure future water supply reliability for Southern California through investments in infrastructure, improved operations, and the development of an innovative One Water approach to manage the water cycle. To continue to adapt and drive investment, it is critical to assess the susceptibility of Metropolitans systems and operations to the shifting conditions related to climate change.

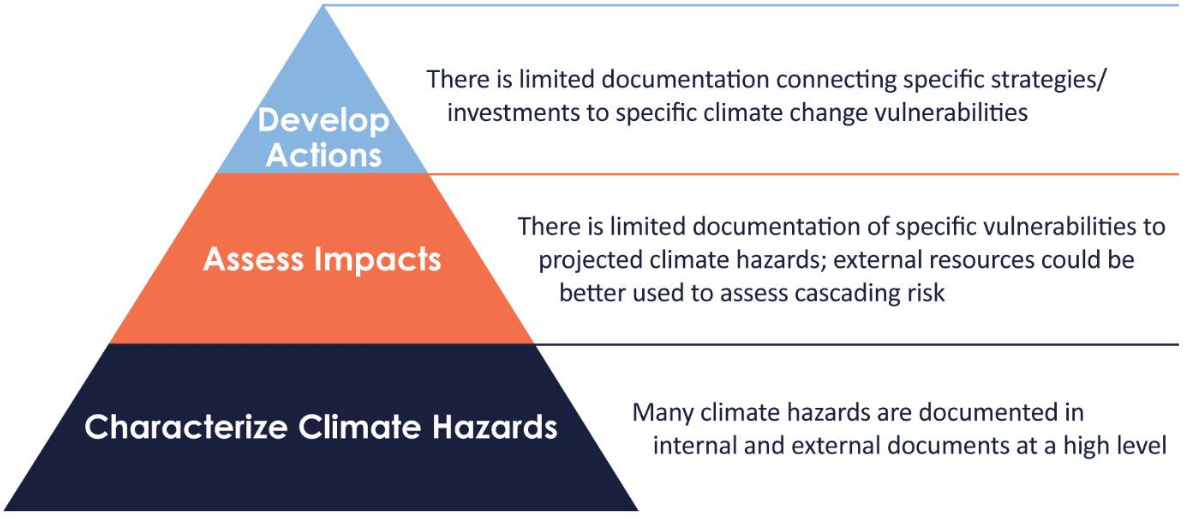
Metropolitan is currently developing a Climate Adaptation Master Plan for Water (CAMP4W), which will establish the framework for an adaptive management process to facilitate continued reliability and resilience in the face of a changing climate. To investigate how it is currently incorporating climate change risk into its planning and operational activities, Metropolitan has prepared a Climate Vulnerability and Risk Assessment (CVRA). The CVRA identifies how Metropolitan is currently managing risk associated with climate change and provide structural recommendations that will enable it to better adapt. Specifically, the CVRA provides recommendations to improve upon Metropolitan's:

1. Characterization of a broad range of climate hazards (e.g., wildfire, extreme heat, sea level rise, stronger storms, and drought events),
2. Assessment of vulnerabilities to Metropolitan's infrastructure, operations, workforce, and business model, and
3. Development of climate adaptation actions which can build Metropolitan's resilience to a changing new normal.

Key Findings and Recommendations

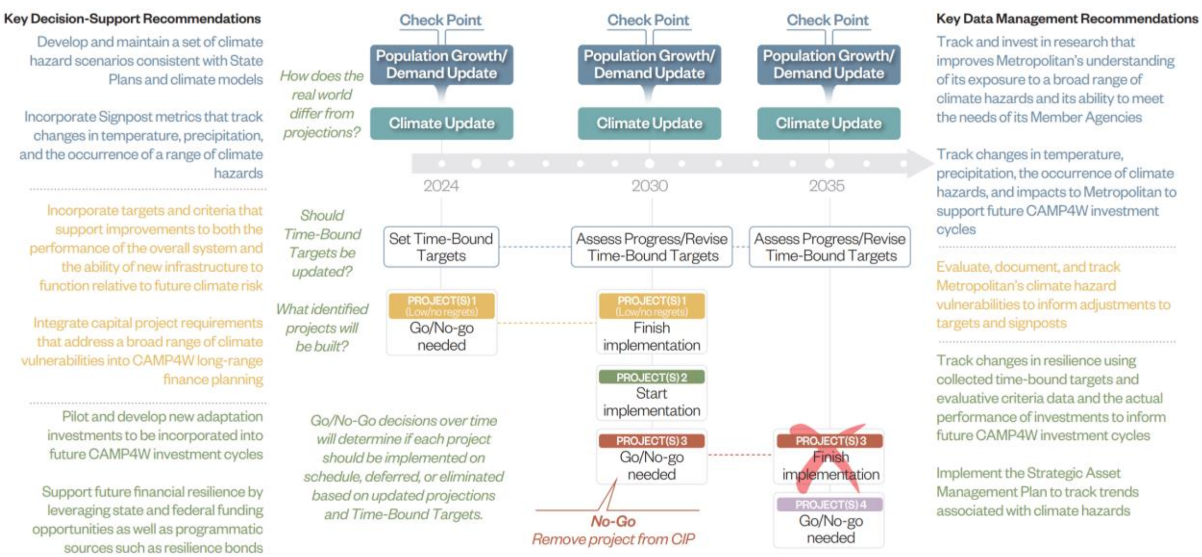
As graphically represented in Figure 1, many climate threats have been identified and characterized at a high level, but there is limited documentation of Metropolitan's specific vulnerabilities and even fewer documents identifying actions which address those vulnerabilities. As presented in Figure 1, many documents identify several types of climate hazards but include only a limited analysis of specific vulnerabilities. Limited information about systems impacts (e.g., the scale, timeframe, social, economic, and ecological repercussions) may result in a diminished capacity to identify specific solutions or strategies at the system/asset level. As an example, there is a lack of understanding of the (cascading) risks associated with impacts to the energy grid or to watersheds, both of which support Metropolitan systems and services. It is critical to understand and quantify the risks and associated actions to address vulnerabilities in order for Metropolitan to incorporate the full suite of actions and associated costs required to be resilient and reliable in the face of a changing climate into the CAMP4W process.

Figure 1 Summary of Literature Review Findings



Specific recommendations that directly support the development of CAMP4W are shown in Figure 2 and follow a consistent methodology of first characterizing climate hazards, then assessing vulnerabilities, and finally developing climate adaptation actions.

Figure 2 Key CVRA Recommendations for the CAMP4W Process



Characterize Climate Hazards. Recommendations (shown in Table 4) associated with this topic are intended to build on existing efforts in order to equip staff with the information required to effectively characterize the influence of climate change on weather events over time. CVRA Recommendations that directly support the CAMP4W process, include:

- Select, review, and update as necessary specific GHG emission scenarios in order to provide Metropolitan with a consistent set of underlying conditions to guide its adaptive management decisions. The CVRA proposes expanding upon Metropolitan's existing policy that identifies which climate change scenarios (e.g., RCP 8.5) will underpin Metropolitan's CAMP4W decision-making framework. The CVRA recommends that selection of climate change scenarios be reviewed and revised consistent with subsequent IPCC Reports, the National Climate

Assessment, and California's Climate Assessments to incorporate the best available science as it becomes available.

- Develop a broad set of localized climate hazard characterizations (including, but not limited to, wildfire, extreme heat, extreme precipitation, flood, landslide, and wind) to enable Metropolitan to track changes in risk over time and respond accordingly through CAMP4W. The CVRA proposes establishing a digital platform to track changes in the exposure of Metropolitan systems to characterized climate change hazards as well as changes in temperature and precipitation.
- CAMP4W Signposts enable Metropolitan to understand how underlying climate conditions, such as temperature, precipitation, and the occurrence of climate hazards change over time. This information is intended to inform future supply-demand analyses, climate hazard risk assessments, and resulting investment decisions. The CVRA proposes incorporating climate trends into selected CAMP4W Signpost metrics.

Assess Vulnerabilities. Recommendations (shown in Table 5) associated with this topic are intended to provide staff with the information required to effectively assess climate vulnerabilities and identify potential impacts. CVRA Recommendations that directly support the CAMP4W process, include:

- Climate change is projected to increase the frequency and severity of extreme conditions (heat, wind, precipitation, etc.) which will increase the risk of operational disruptions and asset damage. The CVRA proposes establishing a database that can be used to track the frequency and severity of emergency response events and impacts to Metropolitan operations (disruptions, costs, etc.) and infrastructure (age of asset, type of asset, damage or impact, costs). This information can be used to indicate if climate hazards are having a greater influence on Metropolitan infrastructure and operations over time and can inform future O&M and CIP decision making.
- CAMP4W Time-Bound Targets and Evaluative Criteria enable Metropolitan to identify and prioritize investments that increase its resilience. The CVRA proposes establishing targets and criteria which relate to types of investments that support both the overall resilience of Metropolitan's systems and/or investments that make specific elements of the system more resilient to climate hazards. Proposed Evaluative Criteria metrics should be based on the climate (and seismic) hazards which are most relevant to Metropolitan systems, available in the CAMP4W Year 1 Progress Report.
- Long-term finance planning through the CAMP4W process is intended to support Metropolitan's financial stability in the face of climate change. Understanding the financial impacts associated with bridging the supply gap identified in the IRP Needs Assessment will facilitate the iterative and adaptive methodology that is the cornerstone of the CAMP4W process. The CVRA proposes integrating capital project requirements to address climate hazard vulnerabilities into long-range financial planning so that the costs associated with adaptation are better represented in financial forecasts.

Develop Climate Adaptation Actions. Recommendations (shown in Table 6) associated with this topic are intended to provide staff with the information required to effectively develop adaptation actions and conduct robust vulnerability assessments. CVRA recommendations that directly support the CAMP4W process, include:

- CAMP4W investment decisions are intended to be reviewed and revised on a five-year basis. As projects are implemented, the associated Time-Bound Target and Evaluative Criteria data are intended to be revisited and revised as necessary to support this iterative decision-making process. The CVRA proposes establishing a database for tracking the actual performance of CAMP4W investments relative to their expected performance in order to guide future investment choices.
- There are additional potential resilience investments that can be considered in the future. The CVRA proposes projects and programs to address specific climate threat vulnerabilities which could be evaluated through CAMP4W for inclusion in future investment cycles.
- The continued resilience of Metropolitan's financial systems can be supported by increasing pathways for Metropolitan's to access to state and federal sources of funding as well as expanding partnership opportunities. The CVRA provides recommendations intended to inform future financial planning processes and increase pathways to access additional funds.

Deep-Dives

The CVRA also included deep-dive sessions with select internal groups to better understand how staff are currently characterizing, assessing, and addressing climate vulnerabilities on the topics of energy and water quality.

Power Supply Vulnerabilities Metropolitan's energy context is changing rapidly based in part on California's aggressive energy decarbonization efforts (e.g., increased electricity needs for electric vehicles and conversion of natural gas appliances to electric appliances), the rapid development of California's grid which Metropolitan influences and is influenced by, and the increasing scale of climate change impacts across the energy system. Interview participants identified several systemic adaptation options, including developing new Power Purchase Agreements (PPAs) and further diversification of Metropolitan's energy sources to better manage future grid instability and energy pricing. Increased use of large-scale PPAs may also offer increased financial flexibility by increasing Metropolitan's participation in the wholesale energy market, which would provide access to power when needed and the ability to sell the excess as an additional source of revenue. Upgrading Metropolitan's high-voltage transmission lines could mitigate operational risks while also generating revenue through transmission access charge and interconnection fees, which could then be used to support capital improvements to the transmission system. Metropolitan will have to consider changes to North American Electric Reliability (NERC) regulatory compliance levels before implementing these changes. The CRAPSP and Transmission Strategic Plan (TSP) will provide opportunities to address these risks to Metropolitan's high-voltage transmission system.

Water Quality Vulnerabilities. Participants agreed that climate change is likely to amplify the range of water quality challenges Metropolitan faces, which will increasingly strain water treatment operations moving forward. It is also possible more extreme conditions may exceed the current infrastructure's capability and staff's ability and capacity to balance the water quality characteristics of different flows across the system. Climate change may prompt the need for large-scale investments beyond what is currently needed for general repair and replacement. Furthermore, water quality regulatory standards have become more stringent over time, and this trend is expected to continue, making it more difficult to balance the source water and storage-based water quality conditions. In the future, it will be critical to identify impacts and build specific adaptations around the direct and cascading impacts on water quality associated with climate change.

Water Infrastructure Vulnerabilities (Data) The performance and condition of many of Metropolitan's assets are likely to degrade more rapidly as climate change amplifies the weather conditions that drive their exposure to climate hazards. At a foundational level, asset data is not currently managed in a holistic way across the organization that is consistent or complete at an agency-wide scale. Coordinating with the ongoing enterprise-wide approach to asset management is recommended to improve Metropolitan's ability to adaptively manage climate risks. Specifically, an Asset Management Policy, like the one proposed in the Strategic Asset Management Plan, should be developed and communicated to the entire organization. This will provide a systematic, proactive, and data-informed vehicle for efficiently maintaining, operating, and ultimately replacing assets and infrastructure.

Near-Term Recommendations

Near-term recommendations have been selected to address the most pressing needs by providing Metropolitan with information and tools to better characterize, assess, and address its climate vulnerabilities. Near-term recommendations from the CVRA are discussed below. Please refer to the Key Findings and Recommendations section for the full list of recommendations.

The CVRA makes three sets of recommendations, with each building upon the previous group. The first set of recommendations pertain to characterization of climate hazards and their potential impacts on the Metropolitan system. These recommendations will help Metropolitan collect the data needed for incorporating climate hazards into long-term planning. Near term recommendations for climate hazard characterization include establishing and maintaining a database of Metropolitan's climate hazard characterizations, regularly collecting the latest climate science, employing a digital platform to catalog and monitor climate hazard exposures and the occurrence of extreme events, and securing grant funding to conduct studies and support research that better characterizes climate hazards.

The second set of CVRA recommendations pertain to ways that Metropolitan can use the data gathered and maintained through the first set of recommendations to assess climate vulnerabilities, particularly related to future risk. Near term recommendations include funding, cataloging, and tracking specific vulnerability assessments across different asset and climate hazard typologies, revising design standards to mitigate projected asset vulnerabilities, and coordinating and streamlining future climate vulnerability assessments.

The third set of CVRA recommendations are intended to help Metropolitan staff develop and document adaptation actions informed through more robust vulnerability assessments. A near-term recommendation is to convene an annual climate risk summit with internal and external parties to identify vulnerabilities, opportunities for further assessment, and share best adaptation practices.

Finally, the deep dives provided valuable insights from staff across Metropolitan and were used to produce topical recommendations. The near-term power supply recommendations are to assess and address the vulnerabilities of Metropolitan's high voltage transmission infrastructure and assess opportunities for renewable power generation and energy storage to align with Metropolitan's decarbonization goals. The near-term water quality recommendations are to assess and address points of criticality in Metropolitan's water treatment facilities in anticipation of projected climate change impacts and invest in the ability to pilot new treatment processes and approaches that address anticipated climate impacts. Finally, the near-term recommendations for water infrastructure are to regularly evaluate trends in climate impacts on different types of assets to inform future adaptive design criteria and to coordinate with and sufficiently staff the existing inter-departmental asset management effort to develop an implementation strategy for Metropolitan's Strategic Asset Management Plan.

Conclusion and Next Steps

Improving Metropolitan's ability to adapt to climate change is an urgent focus and is expected to require continued attention. Climate science indicates certain trends are likely, and an Adaptive Management process, as defined throughout the CAMP4W process, is recommended. To manage climate change risk, Metropolitan needs a structured process for evaluating changes to its system and potential investments. These adjustments have the potential to increase Metropolitan's adaptive capacity and continue its critical mission to "provide… adequate and reliable supplies of high-quality water to meet present and future needs in an environmentally and economically responsible way."

The next steps for Metropolitan include:

- Initiating the near-term initial recommendations.
  - Funding and conducting feasibility and technical studies.
  - Convening a taskforce on energy diversification and power infrastructure along the CRA.
  - Developing and adopting an asset management data policy.
- Further deep dives into climate vulnerabilities.
  - Identifying climate risk signposts for CAMP4W Adaptive Management.
- Coordinating climate vulnerability risk assessments with member agencies.

1 Introduction

Changes in temperatures in California, and globally, are being driven by the accumulation of carbon dioxide and other heat-trapping gases emitted from human activities into the atmosphere. California has one of the world's most varied and volatile climates. Currently, temperatures are warming, heat waves and wildfires are more frequent, and precipitation has become increasingly variable. California has experienced a succession of dry spells, and with warmer conditions, the impacts of these droughts have increased, as observed across the state. Peak runoff in the Sacramento River occurs nearly a month earlier now than in the first half of the last century[1], and glaciers in the Sierra Nevada have lost an average of 70 percent of their area since the start of the twentieth century.[2] The Colorado River Basin's natural flow decreased by roughly the volume of Lake Mead during the 2000-2021 megadrought, increased aridification in snowpack regions resulting in water losses has occurred at roughly twice the rate of non-snowpack regions, and present day natural flows have declined by over 10% due to anthropogenic warming.[3] Metropolitan must therefore adapt its water supplies, infrastructure, operations, workforce and business model to the increasing threats posed by climate change in the form of extreme events such as wildfires, atmospheric rivers, extreme heat, drought, sea level rise, and more. More details regarding the best available science on climate change can be found in California's Fourth Climate Change Assessment[4] as well as the recently published Fifth National Climate Assessment.[5]

In recent years, several unprecedented climate events have occurred which directly impacted the Metropolitan Water District of Southern California's (Metropolitan's) water supply and operations, including record weather conditions (extended drought conditions and historic snow and rain in California and record drought conditions in the Colorado River system), and significant wildfires (ash, increased erosion and sedimentation, power disruptions and public safety power shutdowns, danger to staff). These extreme weather conditions as well as global climate science have presented Californians with a preview of the challenges ahead. Metropolitan recognizes climate change is here and is placing mounting pressure on its water supplies, infrastructure, operations, workforce and business model. To ensure the continued reliability of water supplies for the communities it serves, Metropolitan is taking steps to evaluate climate impacts as well as vulnerabilities and integrate climate and water resource planning with operations and financial planning in the Climate Adaptation Master Plan for Water (CAMP4W) process.

In addition to adapting its infrastructure, operations, water delivery, and storage capacities to meet the challenges posed by a changing climate, Metropolitan has also committed to reducing its operational carbon footprint through its recently adopted Climate Action Plan.[6] Metropolitan has

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[1] 2022. California Office of Environmental Health Hazard Assessment. Indicators of Climate Change in California, Snowmelt Runoff. https://oehha.ca.gov/media/epic/downloads/03snowmeltrunoff.pdf

[2] 2018. California Office of Environmental Health Hazard Assessment. Indicators of Climate Change in California, Glacier Change. https://oehha.ca.gov/media/epic/downloads/ips_gc2018.pdf

[3] 2023. Bass, Benjamin, Naomi Goldenson, Stafen Rahimi, Alex Hall. Aridificaiton of Colorado River Basin's Snowpack Regions Has Driven Water Losses Despite Ameliorating Effects of Vegetation. AGU Advancing Earth and Space Sciences. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022WR033454

[4] 2018, California Natural Resources Agency. California's Fourth Climate Change Assessment. https://www.climateassessment.ca.gov/

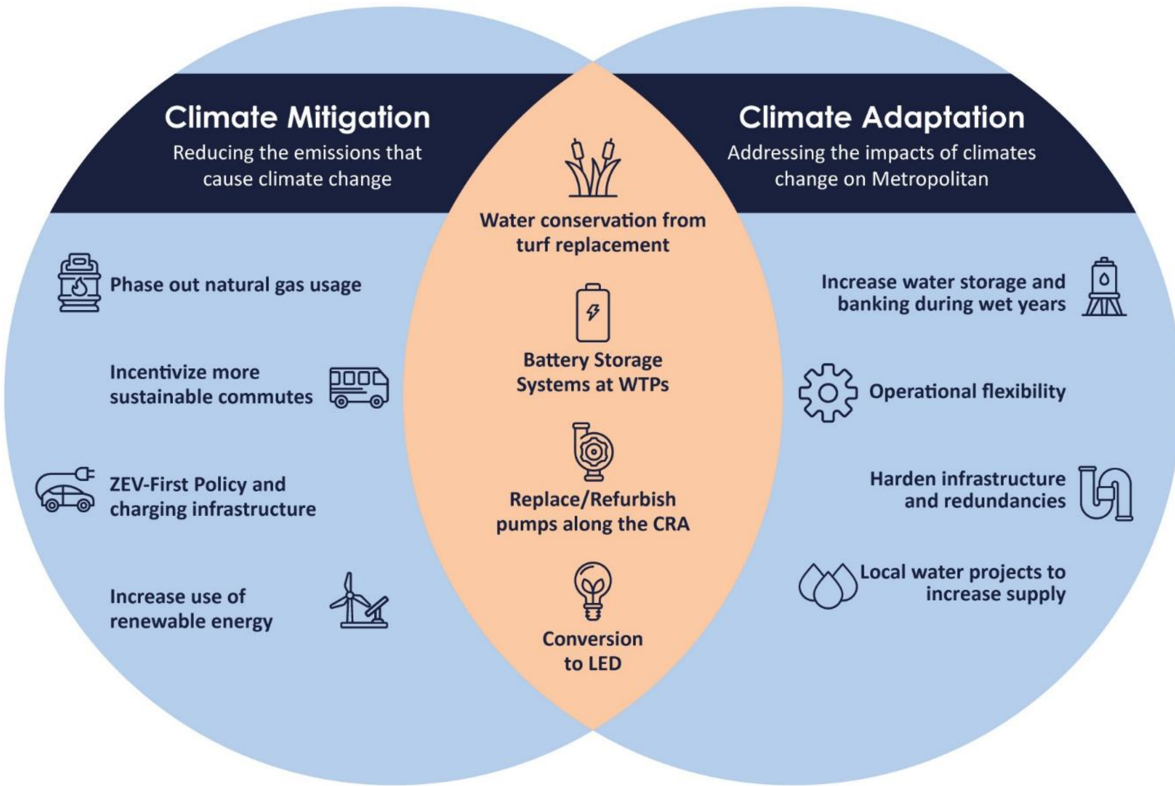
[5] 2018, U.S. Global Change Research Program. Fourth National Climate Assessment (NCA4). https://nca2023.globalchange.gov/

[6] 2022. Metropolitan Water District of Southern California. Cliamte Action Plan. https://www.mwdh2o.com/media/12469/final-cap.pdf

taken a leadership role in reducing greenhouse gas (GHG) emissions associated with its facilities and operations, also known as climate change mitigation, GHG mitigation, or climate action.

Historic and ongoing emissions in the atmosphere require climate adaptation strategies along with concurrent action by Metropolitan to reduce its own emissions. This dual approach towards climate resilience and GHG mitigation is critical for Metropolitan to adapt to the impacts of climate change and avoid disruption to its mission of providing reliable water supplies. Through critical planning and decision-making policies, which are being defined through the CAMP4W process and implemented through its existing Climate Action Plan, Metropolitan can invest in strategies that do both, representing the most efficient way to proceed as shown in Figure 3.

Figure 3 Resilience Framework



To navigate through the impacts of climate change, while continuing to provide a reliable and resilient supply of water to the communities it serves, Metropolitan is developing the CAMP4W. The CAMP4W process involves the following measures: establishment of an Adaptive Management process whereby Metropolitan will prepare for and respond to changing conditions; identification of critical Time-Bound Targets that will guide development needs; establishment of a comprehensive Climate Decision-Making Framework to facilitate integrating climate change into investment decisions; and development of updated business model options. This Climate Vulnerability and Risk Assessment (CVRA) is a critical component of the CAMP4W process as it provides a roadmap for Metropolitan to identify actions, programs, and projects that will address key vulnerabilities, and will support the Adaptive Management process. This forward-looking and integrated approach allows Metropolitan to adaptively manage its resources in a manner that accounts for the current and future challenges presented by climate change.

The analysis and recommendations included in this CVRA investigate how Metropolitan currently manages climate change risk, identifies key gaps, and provides structural recommendations for the future. The intent of this effort is to articulate a pathway for adaptive management of climate change by continuing to update methods of analysis and investing in infrastructure and operational adaptations in a manner that take into consideration changing future conditions. Through this increased adaptive capacity, Metropolitan will be better able to continue to provide its Member Agencies with adequate and reliable supplies of high-quality water.

Metropolitan's Mission Statement

To provide its service area with adequate and reliable supplies of high-quality water to meet present and future needs in an environmentally and economically responsible way.

1.1 Purpose

The purpose of the CVRA is to inform the CAMP4W process regarding Metropolitan's current process of managing the risks associated with climate change and to provide structured recommendations to enable Metropolitan to adapt to climate change moving forward. This report examines a range of climate impacts – from forecasted average impacts to extreme events – and serves several objectives, which include:

- Cataloging what is known about the influence of extreme climate events on Metropolitan's ability to fulfill its mission and serve its Member Agencies;
- Cataloging institutional knowledge, approaches, and understanding of climate threats, vulnerabilities, and adaptation options;
- Understanding Metropolitan's past approaches to incorporating climate change into policies and procedures;
- Identifying key gaps in Metropolitan's approaches to characterizing climate risks and vulnerabilities; and
- Identifying opportunities for Metropolitan to improve its management of climate risks moving forward.

2 Methodology

The initial step of this CVRA consisted of a literature review including both internal (i.e., Metropolitan) documents and external documents (i.e., local and regional documents developed outside of Metropolitan). The literature review developed an understanding of the current vulnerabilities, knowledge base, existing efforts and methods, and gaps as a basis for developing a resilience framework. SRI staff also convened several internal discussions with numerous staff on the topics of security, asset management, engineering, design, maintenance, and hazard mitigation.

Over 60 documents were reviewed and cataloged. The types and examples of documents included:

External Documents

- DWR Vulnerability Assessment & Plan
- CA Water Strategy & Plan
- CA 4th Climate Assessment & Studies
- Cap and Trade Proceeds Report
- SWP Plans & EIRs
- Watershed Assessments and Plans
- Utility Adaptation Plans and Vulnerability Studies
- Groundwater Sustainability Plans
- Local Vulnerability Assessments and Plans
- Wildfire Protection Plans

Internal Documents

- Integrated Resource Plan
- Climate Action Plan
- Urban Water Management Plan
- Energy Sustainability Plan
- Resource Vulnerability Study
- Strategic Asset Management Plan
- System Reliability Study
- Hydroelectric Feasibility Study
- Energy Management & Reliability Study
- Facility Wildfire Risk Reduction Plan

Additionally, surveys and charrettes with Metropolitan staff were conducted to receive feedback on a range of topics related to current procedures and analysis and risks and vulnerabilities on operations and infrastructure. Findings from each charrette were summarized in individual memorandums and detailed in Appendix C.

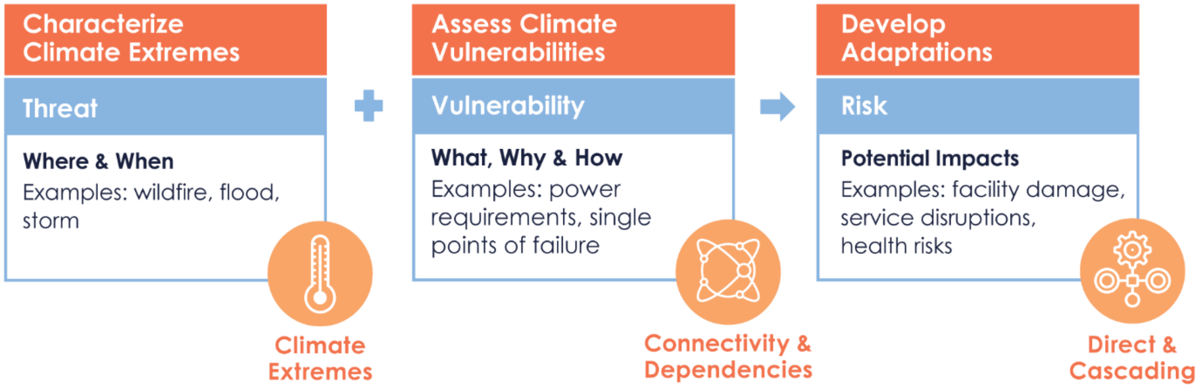
Documents were categorized in several ways, including whether they included specific actions, geographic scope, and types of water resource(s) they relate to. A summary of the literature review findings is included below. The complete list of reviewed documents is located in Appendix A.

The literature review was conducted using a risk assessment rubric (Figure 4). This structure was used to develop an understanding of the following:

1. Identification of analytical methods and data;
2. Characterization of regional climate extremes;
3. Assessment of facility and operational vulnerabilities to identified climate extremes; and
4. Development of adaptation strategies to reduce identified climate vulnerabilities.

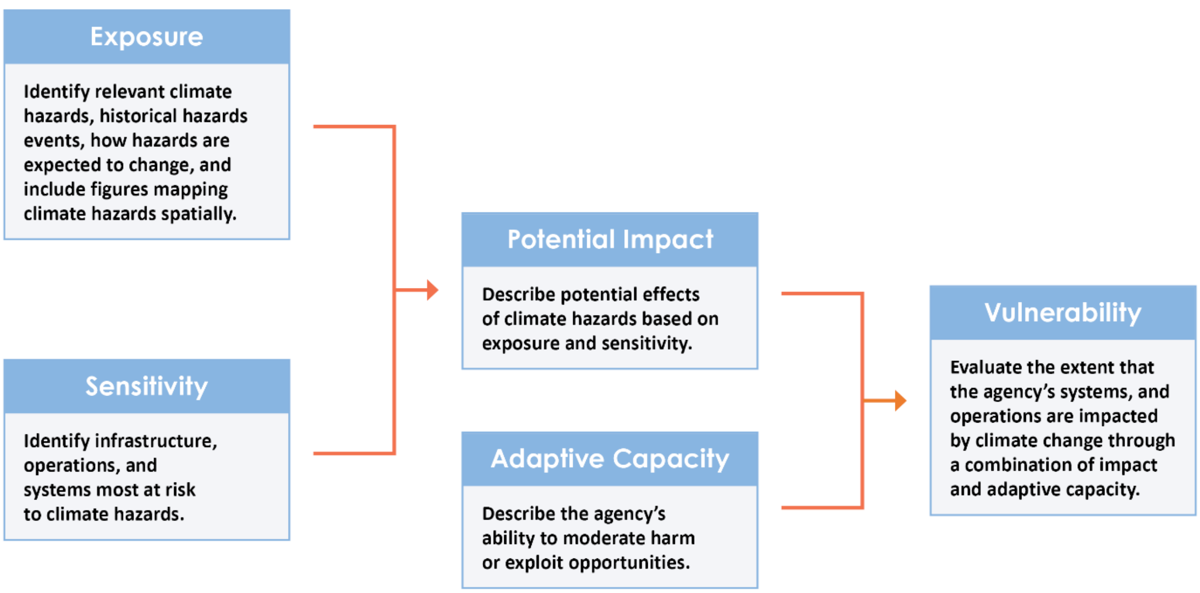
For the purpose of this analysis, threats represent different types of climate extremes, such as wildfire, extreme heat, stronger storms, and drought events. Vulnerabilities represent an understanding of how and why Metropolitan systems and operations can be affected by the various climate extremes. Risks represent the potential impacts of extreme climate events on Metropolitan infrastructure, facilities, services, and operations. Risk is evaluated by characterizing the threats posed by climate extremes and assessing the vulnerability of Metropolitan's systems and operations to those threats. Figure 4 depicts the relationship between threats, vulnerabilities, and risks as evaluated throughout this CVRA and is consistent with Metropolitan's general approach to assessing risk.

Figure 4 CVRA Process Flow Diagram



The CVRA approach is also informed by the Vulnerability Assessment Process (Figure 5) as defined in the California Adaptation Planning Guide[7] and employed by the California Department of Water Resources.[8] California organizes a climate vulnerability assessment into a two-step process comprised of four elements. In this process, vulnerability is based on the potential impacts a system is facing and its adaptive capacity, which is its ability to moderate those impacts and exploit opportunities that present themselves. Potential impacts are based on a combination of a system's exposure and sensitivity to climate threats. In the context of the CVRA, Metropolitan's adaptive capacity can be improved through the actions it takes (e.g., capital investments, process improvements, shifts in operational capabilities).

Figure 5 California's Vulnerability Assessment Process



7 2020, California Governor's Office of Emergency Services. California Adaptation Planning Guide (Final, June 2020, Accessible version). https://www.caloes.ca.gov/wp-content/uploads/Hazard-Mitigation/Documents/CA-Adaptation-Planning-Guide-FINAL-June-2020-Accessible.pdf#search=adaptation%20planning%20guide

8 2019, California Department of Water Resources. Climate Action Plan III: Vulnerability Assessment. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAP-III-Vulnerability-Assessment.pdf?la=en&hash=7DF13A5B51C4B4FA808166C596F7EAE67ED58AC5 Climate Action Plan, Phase 3: Climate Change Vulnerability Assessment.

The CVRA approach is also aligned with Envision, a decision-making framework developed by Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure, a not-for-profit education and research organization. Envision offers guidance for physical infrastructure providers to assess and measure the extent to which a project contributes to sustainability across the full range of social, economic, and environmental indicators. The Envision framework includes 64 sustainability and resilience indicators, called 'credits', organized around five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Resilience.

During the initial charettes, staff identified two areas of study for more detailed analysis: energy and water quality. Staff conducted follow-on investigations of these topics through charettes with internal experts to better understand the following: how climate impacts manifested in recent years; how climate threats may impact operations in the future; what adaptations are occurring or needed; and what barriers exist to adaptation.

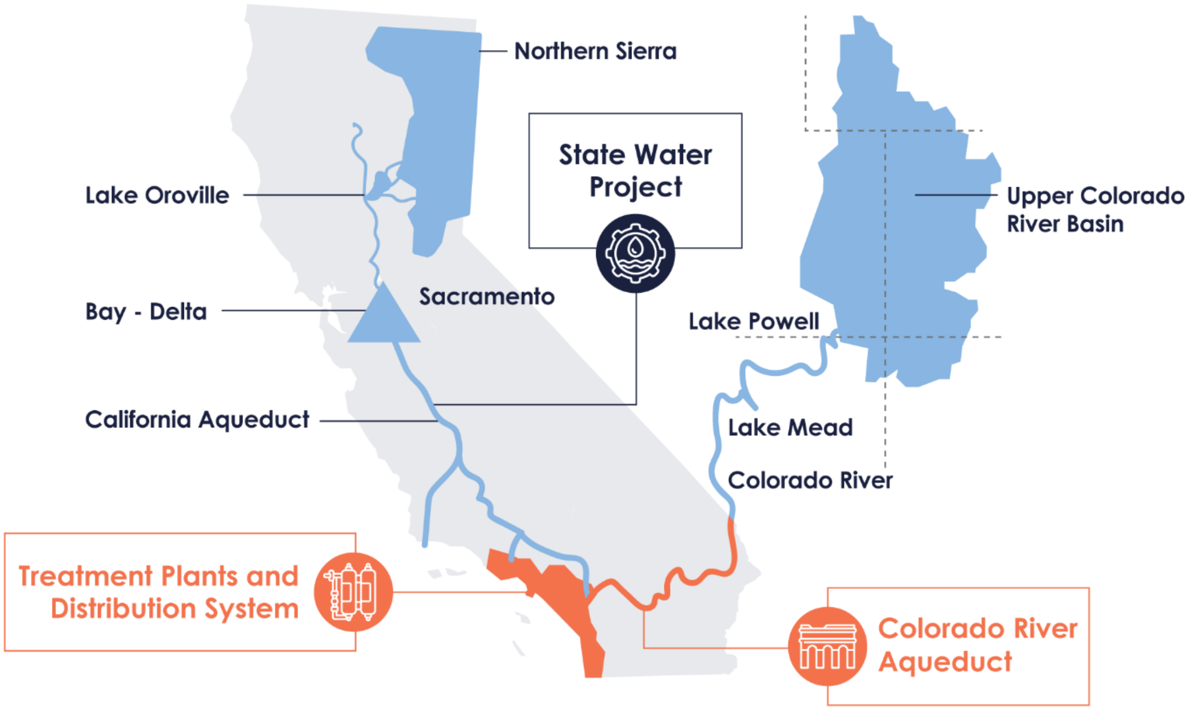
2.1 Employing a Systems-Based Approach

Metropolitan's ability to provide water to its Member Agencies relies on a collection of natural and built systems which span across thousands of square miles and across multiple states. The complexity of interactions between systems, such as the State Water Project (SWP), the Upper Colorado River Basin, and local supply sources, necessitates a systems-based approach to assessing climate risk. Climate impacts that affect one or more of these systems can influence Metropolitan's ability to deliver water, including systems beyond Metropolitan's direct control (e.g., SCE's power grid). Risks influencing Metropolitan's facilities and operations that are outside of its direct control are identified as cascading risks (rather than direct risks), such as risks associated with power grid reliability and resilience. By employing a systems-based approach which has been accomplished successfully by other agencies, Metropolitan will continue to be able to identify multi-benefit and/or cost-efficient adaptation options.[9] Figure 6 depicts Metropolitan's system of infrastructure that provides treated and untreated water supply to its Member Agencies. The CVRA assessment included the following components:

- Watersheds supporting Metropolitan water resources, including the Northern Sierra Nevada, the Sacramento Bay Delta, and the Upper Colorado River Basin;
- External infrastructure systems, including hydropower facilities, and various elements of the energy grid that powers water delivery systems;
- Metropolitan infrastructure and operations, including the Colorado River Aqueduct (CRA) system, the SWP (operated by California Department of Water Resources), distribution pipelines within its service area, power infrastructure, water treatment facilities, pump stations, and other facilities;
- Local water supplies developed and used by Member Agencies (e.g., groundwater, treated wastewater, desalinated water); and
- Demand for Metropolitan water through Member Agencies, including its agencies located in Metropolitan's SWP-dependent areas (the "SWP-Dependent Areas").

[9] As an example, New York City has saved $6 to $8 billion in 2023 dollars by making large-scale watershed management investments in the Catskill Mountains (the primary source of its water supply), even though the area is beyond the limits of its facilities, pipelines, and direct operational control, by avoiding construction of a filtration plant. See more here: https://www.ecosystemmarketplace.com/articles/ecosystem-services-in-the-new-york-city-watershed-1969-12-31-2/

Figure 6 Metropolitan's System Map



2.2 Climate Threats

Climate models indicate an increasing likelihood and magnitude of extreme climate events, which can be defined as a time and place in which weather, climate, or environmental conditions—such as temperature, precipitation, drought, or flooding—rank above a threshold value near the upper or lower ends of the range of historical measurements. Increased heat trapped in the atmosphere caused by increased GHG concentrations is leading to changes in the frequency and magnitude of climate extremes, because the additional heat amplifies weather conditions.[10] Research is demonstrating that climate change is resulting in more frequent, more intense, longer-lasting, or larger in scale extreme events beyond what has occurred historically.[11] Globally, there is evidence climate change has the potential to trigger major disruptions to water suppliers of the size and scale of Metropolitan. Recent examples include:

- The South African city of Cape Town recently experienced a 1 in 400-year drought event, which nearly resulted in a complete collapse of its water supply system. As a result, the city quadrupled its water rates and is investing more than $545 million (a third of its total municipal budget) in water infrastructure, groundwater extraction, and water efficiency. The City has also raised $54 million for a Green Bond that will fund key sustainability projects, including reservoir upgrades, pressure management, water re-use, and sewer and water system upgrades. These lessons-

[10] 2021. Gulev, S.K., P.W. Thorne, J. Ahn, F.J. Dentener, C.M. Domingues, S. Gerland, D. Gong, D.S. Kaufman, H.C. Nnamchi, J. Quaas, J.A. Rivera, S. Sathyendranath, S.L. Smith, B. Trewin, K. von Schuckmann, and R.S. Vose. Changing State of the Climate System. 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*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, doi:10.1017/9781009157896.004.

[11] 2020. National Oceanic and Atmospheric Administration (NOAA). What extreme event is there evidence that global warming has caused or contributed to? Climate.gov. Retrieved Month Day, Year, from https://www.climate.gov/news-features/climate-qa/what-extreme-event-there-evidence-global-warming-has-caused-or-contributed

learned underscore the critical importance of proactively understanding and investing in actions that enhance Metropolitan's resilience to the amplifying threat of extreme drought in California.

- One of the most extreme heat events ever recorded globally occurred in 2021 in the northwestern United States. The highest temperature recorded was 120 degrees Fahrenheit, and at least 36 locations in the western U.S. and another 38 in Canada tied or set all-time records for high temperatures. The heat event led to more than 650 deaths, damaged infrastructure including buckled roads and melted power lines. These lessons-learned underscore the critical need for Metropolitan to replace and refurbish infrastructure that is vulnerable to the amplified extreme climate conditions of today and establishing and incorporating design guidelines for new infrastructure based on future climate conditions rather than historic ones.
- Years of drought and extreme heat in the Mississippi Delta have decreased the river's flow, pushing salinity much further inland than normal. Smaller towns across the Mississippi Delta have employed emergency measures and some are contending with salinity levels that present a risk to people with conditions such as hypertension and kidney problems. As a result, in Fall 2023, a massive saltwater wedge moved up the Mississippi Delta and nearly cut off New Orleans' main source of drinking water. These lessons-learned underscore the critical importance of supporting measures that protect the SWP system from a similar event occurring in the Sacramento Delta, which could severely impair deliveries to Metropolitan and other SWP contractors.

The resulting effects on the atmosphere and ocean currents are driving new and more extreme weather patterns.[12] The threats included in the CVRA represent the different types of climate extremes being amplified by climate change, and include the following:

- **Extreme Heat Events** – Extreme heat events are prolonged periods of unusually high temperatures that can have significant impacts on the environment, public health, demand for water, and infrastructure. An extreme heat event or "heat wave" can be defined as a period of 5 or more days when the maximum temperature exceeds the 98th percentile (or is among the highest 2 percent) of historical daily maximums.[13] In California, the extreme heat event over the 10-day period from August 31 through September 9, 2022, set records for all-time high temperatures throughout the state, leading to a surge in heat-related hospitalizations and deaths, rolling electrical blackouts, and damage to essential infrastructure. In California, the daily maximum average temperature is expected to rise 4.4° to 5.8° Fahrenheit by mid-century and 5.6°F–8.8°F by late century. In the Northern Sierra region, an area where much of the state's water originates, extreme heat events are projected to occur four to ten times more often.[14]
- **Multi-Year Drought Events –** Drought is an extended period of abnormally low rainfall that can lead to water supply shortages, reduced soil moisture, and negative impacts on agriculture, ecosystem health and residential areas. The California drought between 2012 and 2017, coinciding with record warmth, led to record low snowpack and at the time, the most extreme

[12] 2021. Chen, D., M. Rojas, B.H. Samset, K. Cobb, A. Diongue Niang, P. Edwards, S. Emori, S.H. Faria, E. Hawkins, P. Hope, P. Huybrechts, M. Meinshausen, S.K. Mustafa, G.-K. Plattner, and A.-M. Tréguier. Framing, Context, and Methods. 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*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 147–286, doi:10.1017/9781009157896.003.

[13] 2017. California Natural Resources Agency. Cal-Adapt 2.0. https://www.adaptationclearinghouse.org/resources/cal-adapt-2-0.html

[14] 2021. California Governor's Office of Planning and Research. California Climate Adaptation Strategy, Resilience. from https://climateresilience.ca.gov/

drought since record keeping began in the late nineteenth century.[15] In 2014, at the peak of the drought, 58 percent of the state was experiencing exceptional drought conditions, the most extreme category of drought.[16] However, the drought from 2020-2022 is now considered the driest three-year period, surpassing the 2013-2015 record set during the previous drought.[17] Climate models project increasing temperatures and variable annual precipitation will lead to an increase in the number of multi-year drought events.

- **Extreme Precipitation and Wind Events** – A future with higher temperatures will lead to increases in the frequency of extreme wet and/or wind events, characterized by storms that are wetter, warmer, windier, stronger and/or occur over a shorter period of time. Atmospheric rivers (a common weather phenomenon in California that transports and drops dense streams of moisture) will drop between 25 and 45 percent higher hourly rates of precipitation by 2070.[18] Precipitation from atmospheric rivers drives much of California's water supply, contributing between 20 and 50 percent of California's annual water supply.[19] Though California is likely to receive similar amounts of annual precipitation in total, as compared to historical levels, the precipitation will likely fall in shorter and more intense events.[20] An increase in the strength and direction of wind events may also contribute to direct impacts or an increase in wildfire events.[21] Finally, as temperatures increase, more precipitation will fall as rain rather than snow, which will lead to changes in runoff patterns and increased flood potential.[22]
- **Wildfire Events –** Wildfires are characterized by uncontrolled and rapidly spreading fire that primarily spread in vegetated areas such as forests, grasslands, or shrublands. These fires can grow rapidly in size and strength, driven by climate-related factors such as warm weather conditions, low precipitation, strong winds, and availability of combustible vegetation. In recent years, the area burned by wildfire has increased drastically and fires are occurring at higher elevations and in coastal regions which have historically avoided wildfire impacts. In addition, many of California's wildfires are burning hotter and more forcefully than observed in recent history. In 2020, California experienced a record setting and devastating fire season, with over 4.3 million acres burned. The State predicts that by 2100, the average land area burned by wildfire will increase 77 percent and frequency will increase by 50 percent.[23]
- **Inland and Riverine Flooding** – Riverine flooding occurs when rivers and streams overflow due to heavy rainfall, snowmelt, or a combination of factors. The increased likelihood of consecutive and heavy precipitation events, in addition to sudden surges of snowmelt in response to higher temperatures, has made riverine flooding more common. Land use patterns, such as the

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15 2018. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. OEHHA Strategic Plan 2018-2022. https://oehha.ca.gov/media/strategicplan2018.pdf

16 2023.National Drought Mitigation Center. U.S. Drought Monitor. https://droughtmonitor.unl.edu/

17 2022. Department of Water Resources. New Water Year Begins Amid Preparations for Continued Drought (ca.gov) https://water.ca.gov/News/News-Releases/2022/Oct-22/New-Water-Year-Begins-Amid-Preparations-for-Continued-Drought#:~:text=The%20current%20drought%20from%202020%20to%202022%20is,all%20Californians%2C%20especially%20the%20State%E2%80%99s%20most%20vulnerable%20communities.

18 2020. Sciences Advances. Xingying Huang *et al.* Future precipitation increase from very high resolution ensemble downscaling of extreme atmospheric river storms in California. https://www.science.org/doi/10.1126/sciadv.aba1323

19 IBID

20 2023. California Governor's Office of Planning and Research. Summary of Projected Climate Change Impacts on California. https://climateresilience.ca.gov/overview/impacts.html

21 IBID

22 2016. U.S. Environmental Protection Agency. California's Climate Change Scoping Plan. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-ca.pdf

23 2018, California Natural Resources Agency. California's Fourth Climate Change Assessment. https://www.climateassessment.ca.gov/

prevalence of paved surfaces and impermeable infrastructure can exacerbate flooding by preventing the natural infiltration of water. California's 58 counties have all experienced at least one significant flood event in the past 25 years, resulting in loss of life and billions of dollars in infrastructure damage. A recent study indicates climate change has already doubled the chances of a disastrous flood happening in California in the next four decades, particularly in low-lying areas, such as much of Los Angeles County.[24]

- **Sea Level Rise and Coastal Flooding** – Sea level rise is already accelerating along California's coast and will continue to rise substantially over the twenty-first century, threatening coastal communities, natural resources, cultural sites, and infrastructure. The state's coastline is expected to experience between 1.1 and 1.9 feet of sea level rise by 2050 and between 2.4 and 6.9 feet by 2100.[25] Coastal storm events, when combined with projected sea level rise, will increase flood impacts on land. Rising sea levels may also cause salination of groundwater supplies and raise groundwater tables, impacting water quality and below-ground infrastructure. One-third of the water supply for coastal areas of Greater Los Angeles comes from local groundwater sources. Saltwater has already penetrated a part of the supply, and a significant part of the remaining supply is at risk.[26]
- **Landslide/Mass Movement** – Landslides and mass earth movements are a cascading climate risk that most often occur when loose rocks and soil are hit with intense precipitation. California's unique mountain geology means much of the state's steep terrain is still forming, meaning much of the material is loose and can easily be disturbed. High temperatures and prologued drought often lead to impermeable and hardened soils, so run-off precipitation can pick up debris as it falls, quickly turning into landslides and debris flows. Communities experiencing wildfires also may neighbor hillsides covered in loose debris, with no live vegetation to keep the soil in place. In winter 2023, consecutive atmospheric river events triggered numerous landslides, sinkholes, and other forms of debris hazard across California, resulting in 19 deaths.

More information on climate threats can be found using the following tools:

Extreme Heat – California Heat Assessment Tool: https://www.cal-heat.org/download

Drought – United States Drought Monitor: https://droughtmonitor.unl.edu/

Precipitation – Cal-Adapt: https://cal-adapt.org/tools/extreme-precipitation/

Flooding, Earthquake, Tsunami and Fire Risk – MyHazards: https://myhazards.caloes.ca.gov/

Landslide – California Department of Conservation: https://data.ca.gov/dataset/cgs-map-sheet-58-deep-seated-landslide-susceptibility

Sea Level Rise – United States Geological Survey: https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos

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[24] 2022. Huang and Swain. Climate change is increasing the risk of a California megaflood. American Association for the Advancement of Science. 2023. https://www.science.org/doi/10.1126/sciadv.abq0995.

[25] 2021. California Natural Resources Agency. Draft California Climate Adaptation Strategy. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Climate-Resilience/SAS-Workshops/Draft-CA-Climate-Adaptation-Strategy-ada.pdf

[26] 2002 United States Geological Survey.. Saltwater Intrusion in Los Angeles Area Coastal Aquifers—the Marine Connection. United States Geological Survey Fact Sheet 030–02. https://pubs.usgs.gov/fs/2002/fs030-02/.

2.3 Vulnerabilities

Vulnerability explains how and why a system is expected to be affected by different climate extremes. Different facilities, infrastructure, and processes may be more significantly impacted by certain climate extremes compared to others. For example, some facilities may be more vulnerable to wildfire risk or coastal flooding due to their location. Assessing vulnerability requires an understanding of how facilities and processes are connected to systems not operated by Metropolitan (e.g., the SWP) and Metropolitan-operated systems (e.g., reservoirs to pipelines, power distribution systems to pump stations). This enables staff to assess risk through an understanding of how impacts from climate threats can cascade across systems and influence the overall delivery of services.

Vulnerabilities to climate threats can also be exacerbated by existing challenges facing Metropolitan which are not necessarily and/or completely related to climate change but are potentially constraining the ability to manage climate change risks. Some of these challenges are summarized below:

- **Capital Investment Program Needs:** Aging infrastructure, such as dams, storage facilities, pipes, and other facilities are posing increasing challenges to water utilities. Aging infrastructure can also amplify climate hazard vulnerability. Climate change is anticipated to increase the number and scale of Capital Improvement Projects (CIP) and costs in coming decades. Metropolitan is projecting over $600 million in capital investments to address aging infrastructure in the two-year budget. Across the state, California Urban Water Agencies member agencies are expected to invest between $20 and $30 billion in capital improvements over the next decade.[27] To ensure capital investments are sized based on future conditions, capital improvement investments will need to be developed using adaptive management techniques. A CIP Risk Framework has been developed and is currently being used to help identify and support the prioritization of projects that address anticipated risks.
- **Shifting Workforce Dynamics:** Water utilities are grappling with workforce challenges due to an aging workforce, with about one-third of water sector employees expected to retire in the next decade. Significant numbers of retirees present the risk of losing institutional knowledge that could be difficult to replace. While Metropolitan has experienced a trend toward a younger workforce, succession planning remains crucial for specialized positions. Rapid technological changes also call for shifts in skills and specializations that will require specific investments in training, roles, and responsibilities.
- **Supply Variability - State Water Project Allocations:** Fluctuations in SWP deliveries significantly impact statewide water supply planning and pose challenges for Metropolitan's service reliability. SWP deliveries have shown an increase in variability over time, with annual deliveries ranging from 476 to 3,404 thousand-acre-feet between 2011 and 2020.[28] Environmental regulations aimed at protecting migratory fish species and threats like seawater intrusion, land subsidence, and extreme flood events will continue to complicate SWP deliveries.

[27] 2023. California Urban Water Agencies. Advancing California's Water Supply Strategy Fact Sheet. https://static1.squarespace.com/static/5a565e93b07869c78112e2e5/t/63efe25554956b32bee3b18f/1676665429100/CUWA_Advancing+CA+Supply+Strategy_Feb+2023+FINAL.pdf

[28] 2022. California Department of Water Resources. The State Water Project Final Delivery Capability Report 2021. https://data.cnra.ca.gov/dataset/2d836273-6b81-4f04-bd9e-bbe1a736a0a6/resource/5721288c-9553-477e-8738-774ea2ff537e/download/final_dcr_2021_signed_adafxro.pdf

- **Reduced Supply - Colorado River Flows:** Inflows into the Colorado River have been declining over the past century. Lake Powell and Lake Mead were nearly full when the Millennium drought started in 2000 and have been hovering around a third full in recent years. These reservoir conditions led to the first ever shortage declarations in the Lower Basin in 2021. But in 2022, even with shortages and other reductions occurring, Lake Powell and Lake Mead risked declining to critical levels.[29] Negotiations among Lower Basin states resulted in a voluntary agreement to conserve an additional 3 million AF until 2026.[30] This resulted in the lowest deliveries from Lake Mead in decades. Between mandatory reductions and voluntary conservation, the Lower Basin states took around 1.7 million acre-feet less than the Lower Basin's basic apportionment of 7.5 million acre-feet in 2023.[31] While conservation and recent above average snowpack in the Upper Colorado River Basin mitigated immediate effects, reduced inflow into the Colorado River system due to drought and climate change will require long-term solutions with all categories of water users taking significant cuts.
- **Power Availability, Reliability, and Cost:** Power availability and affordability are critical considerations for Metropolitan's long-term resilience strategy, with factors like decarbonization policies, hydropower constraints, and climate-vulnerable infrastructure affecting electrical power generation and access. Decreased water levels in Lake Mead and Lake Powell have reduced the availability of hydropower, necessitating investment in alternative power sources.[32] California's transition to a carbon-free energy grid by 2045 will significantly impact energy markets and pricing, potentially leading to increased electricity costs. Reduced water levels and flow into Lake Mead will affect the availability of low-cost power from hydropower plants, and extreme heat events will continue to strain the electric system and likely will result in outages.[33] Additionally, the planned shutdown of the Diablo Canyon Nuclear Power Plant[34] and the electrification of the grid (transition to electric vehicles and conversion of natural gas appliances to electric appliances) will reduce available baseload power, emphasizing the need for investment in renewable energy, storage, and grid upgrades.[35]
- **Water Demand/Conservation Initiatives:** Both structural (e.g., technological improvements such as low flow toilets or industrial/agricultural improvements) and behavioral conservation (e.g., behavioral changes such as turning off the tap) can have an impact on water use. Water usage in California varies among sectors, with agriculture using 40 percent, urban areas using 10 percent, and the environment using 50 percent of the water (Figure 7)[36]. Outdoor water use (i.e., irrigation) remains a significant part of total urban water consumption, offering opportunities

29 2023. US Bureau of Reclamation. https://www.usbr.gov/newsroom/news-release/3950

30 2023. National Association of Counties. Lower Basin States strike agreement to preserve water supply in Colorado River Basin. https://www.naco.org/news/lower-basin-states-strike-agreement-preserve-water-supply-colorado-river-basin#:~:text=Under%20the%20agreement%2C%20the%20three,with%20a%20foot%20of%20water.

31 US Bureau of Reclamation. https://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2023/forecast.pdf

32 2023. US Bureau of Reclamation. Near Term Colorado River Operations, Revised Draft Supplemental Environmental Impact Statement. https://www.usbr.gov/ColoradoRiverBasin/documents/NearTermColoradoRiverOperations/20231019-Near-termColoradoRiverOperations-RevisedDraftEIS-508.pdf

33 2013. US Department of Energy. US Energy Sector Vulnerabilities to Climate Change and Extreme Weather. https://www.energy.gov/articles/us-energy-sector-vulnerabilities-climate-change-and-extreme-weather

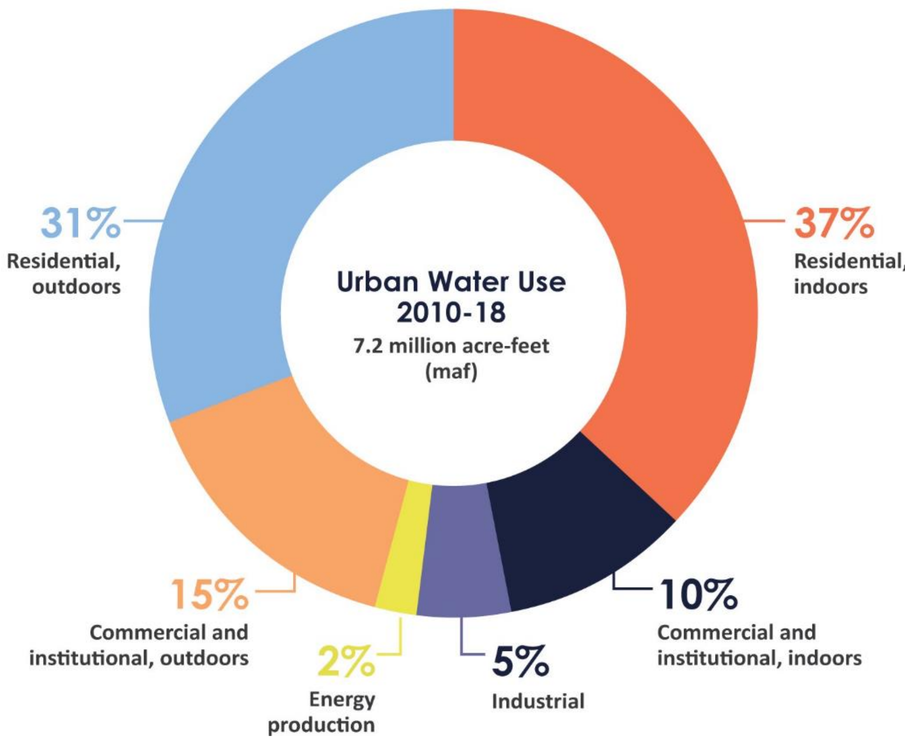
34 Note: Diablo Canyon has an exemption to operate thru 2025 while PG&E is seeking a 20 year extension to their permit. 2023. Michael Blood. Associate Press Article. California reactors win exemption in fight to keep running. https://apnews.com/article/nuclear-reactors-california-diablo-canyon-d66323cfe3743063c9446dd372652658

35 2021. Union of Concerned Scientists. Diablo Canyon is Shutting Down. Is California Ready? https://blog.ucsusa.org/mark-specht/diablo-canyon-is-shutting-down-is-california-ready/

36 2023. Public Policy Institute of California. Water Use in California. https://www.ppic.org/publication/water-use-in-california/

for cost-effective conservation.[37] The California Water Strategy aims to free up 500,000 AF of water annually through efficiency and conservation measures.[38] Proposed regulations may mandate conservation efforts by numerous cities and water agencies, potentially saving substantial amounts of water by 2030. Water utilities must consider the financial implications of increased conservation, and potential changes to business models, as reduced demand can lead to decreased revenue from rate collection.

Figure 7 California Urban Water Use, 2010–2018



- **Water Quality Regulations:** California's water quality regulatory environment is rapidly evolving, with the Total Maximum Daily Load (TMDL) program serving as a key framework under the federal Clean Water Act which regulates the discharge of pollutants into the waterways of the United States. Despite the adoption of 199 TMDLs addressing 1,426 impaired waterbody listings in California, more than 2,100 identified pollution listings still need to be addressed statewide, highlighting the ongoing challenges in maintaining and improving surface water quality across the state and the lack of source control measures that limit the introduction of pollutants into California's watersheds.[39] While source control measures that address TMDLs can provide water quality benefits on the supply side, water quality treatment requirements are also experiencing change. The United States Environmental Protection Agency proposed national maximum contaminant levels (MCL) for six per- and poly-fluoroalkyl substances (PFAS) in March 2023, potentially requiring water systems to test, notify the public, and reduce PFAS

37 IBID

38 2022. California Natural Resources Agency. California's Water Supply Strategy. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf

39 2016. California State Water Resources Control Board. The California Water Board Annual Performance Report. https://www.waterboards.ca.gov/about_us/performance_report_1516/plan_assess/11112_tmdl_outcomes.shtml

levels if they exceed proposed MCLs.[40] Arsenic is another example of a pollutant becoming more stringently regulated in drinking water. While these standards are not yet formally adopted, water utilities have started monitoring and enforcing PFAS standards. This will require new analytical methodologies and potentially require changes to water purification processes.

2.4 Risk/Potential Impacts

Potential climate change risks to Metropolitan facilities and operations include the effects of climate extremes based on identified vulnerabilities and their exposure to climate threats. Impacts are often in the form of service disruptions, infrastructure damage, and/or health and injury risks to staff. Consistent with other Metropolitan planning documents, the following categories have been used to assess potential impacts. Reviewed documents were cataloged based on whether they included an assessment of climate vulnerabilities relative to the following categories.

- **Headwaters** refer to the source or beginning of a river, and the surrounding watershed or drainage area. Headwaters are often recognized as the origin of imported water supplies, like the SWP and Colorado River system. This category covers the watersheds rather than the infrastructure systems that provide imported water supplies to Metropolitan. Ecosystem changes in these areas influence the quantity and quality of water collected by imported water systems.
- **Imported water systems** refer to the infrastructure systems that convey imported water over long distances from their headwater sources to Metropolitan's service area. The SWP and the CRA are two primary systems that serve Metropolitan.
- **Local water supplies** refer to additional (or supplemental in some cases) water resources used by Metropolitan Member Agencies. Types of local water supplies include groundwater, treated wastewater, desalinated water, stormwater capture, and the Los Angeles Aqueduct.
- **Conveyance infrastructure** refers to Metropolitan's extensive network of physical structures and systems that transport water from imported water systems to their intended destinations, including pipelines, canals, pump stations, and aqueduct.
- **Distribution infrastructure** refers to the network of facilities and systems that deliver water to specific Member Agencies within Metropolitan's service area. This infrastructure includes water mains, distribution pipes, and pumping stations.
- **Owned land** refers to land and facilities owned by Metropolitan, including water treatment facilities, agricultural land, public rights-of-way, reservoirs, and conservation areas.
- **Treatment facilities** refer to infrastructure designed to treat water from natural sources, such as rivers, lakes, or groundwater, and make it safe for consumption or other purposes. The facility's primary goal is to remove contaminants, ensuring it meets water quality standards and is safe for human and environmental use.
- **Water storage infrastructure** refers to above- and below-ground tanks and reservoirs that store and manage water for future use.
- **Operations** refer to the internal processes, systems, and maintenance activities needed to provide water utility services.

40 2023. US Environmental Protection Agency. Proposed PFAS National Primary Drinking Water Regulation. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas#:~:text=On%20March%2014%2C%202023%20%2C%20EPA,known%20as%20GenX%20Chemicals)%2C%20perfluorohexane

- **Cascading impacts** refer to the various impacts that may occur sequentially as the result of an initial impact outside of Metropolitan's operational control (i.e., the domino effect). For example, a regional power disruption could disrupt Metropolitan operations.
- **Public impacts** refer to the positive or adverse effects that a decision or project has on the general public. This can include the opportunities for public engagement, increases in public awareness about water challenges, changes in water consumption, or new outcomes in public health.

2.5 Types of Adaptation Strategies

Adaptation strategies are the ways in which Metropolitan addresses its climate vulnerabilities and can be organized in several ways. At a high level, the literature review cataloged documents based on whether they included strategic guidance, policy guidance or programmatic guidance. Documents that provide strategic guidance indicated strategies which promote adaptation. Policy guidance documents recommended specific Metropolitan policies for promoting adaptation. Finally, programmatic guidance documents recommended programs and projects that support adaptation.

As an example, **California's Water Resilience Portfolio** is used by numerous water districts to align with State goals.[41] In this document, adaptation strategies are organized into four approaches:

1. **Maintain and Diversify Water Supplies** to enable flexibility as conditions change. Prioritizing regional supply diversification can take many forms and seeks to spread risk and achieve multiple benefits, such as increased water supply, restored habitat, improved public health, reduced energy consumption, and improved water quality.
2. **Protect and Enhance Natural Systems** to better balance competing demands for water and decrease potential investments in built infrastructure. Improving the natural systems can provide ecosystem benefits in the form of increased water supply, improved water quality, water storage, and flood protection.
3. **Build Connections** to foster more efficient regional solutions and acknowledge the cascading risks that cross jurisdictions, areas of responsibility, and different types of infrastructure. Partnerships can solve problems more cost effectively and provide the means to move water more effectively between physical locations where specific adaptation options are feasible. Similarly, different forms of interconnectivity provide more options to distribute water and manage variability and threats that affect a specific part of Metropolitan's system or sources.
4. **Be Prepared** to understand, make ready, respond, and recover from more frequent and severe emergencies induced by climate threats. This requires adaptation policies, knowledge, investments, and monitoring systems to proactively prepare for future climate conditions.

As another example, **the Water Utility Climate Alliance** has identified five essential climate change action areas that can help utilities effectively employ the right set of adaptation strategies and proactively manage risk over time, including engaging with interested parties, understanding climate science and its effects on systems, planning for future change, acting by implementing changes, or sustaining adaptation efforts.[42] The adaptation action areas include the following:

- **Understand** climate science, systems, and system vulnerabilities, risks, and opportunities;

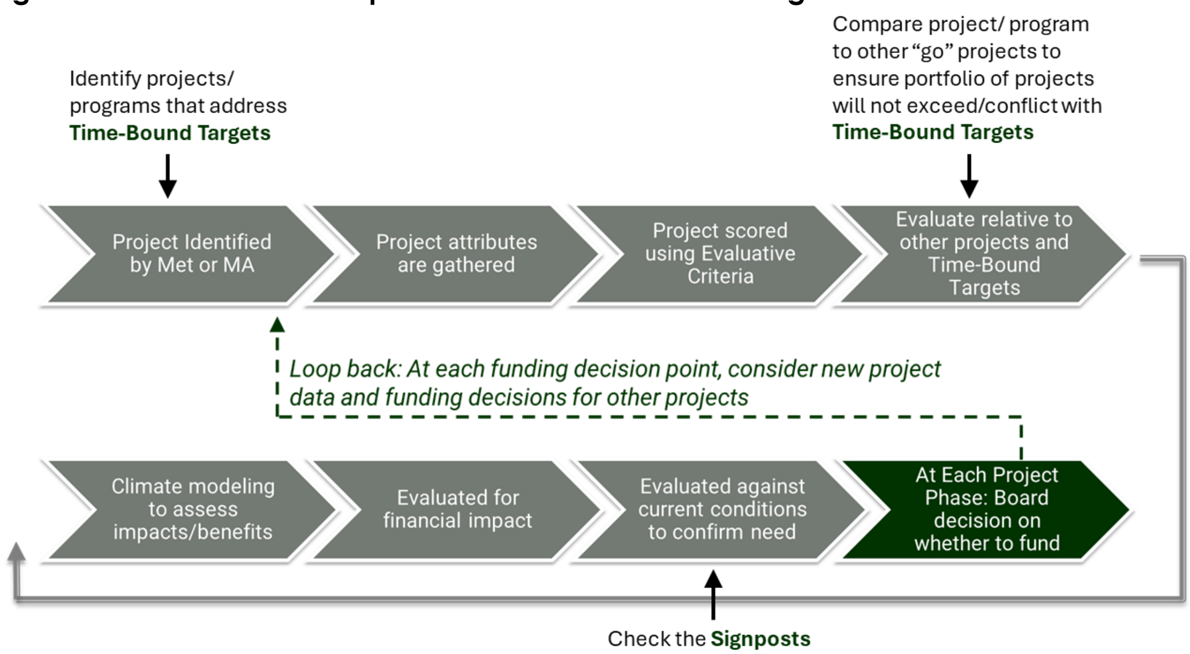
41 2020. California Natural Resources Agency. California Water Resilience Portfolio. https://waterresilience.ca.gov/wp-content/uploads/2020/07/Final_California-Water-Resilience-Portfolio-2020_ADA3_v2_ay11-opt.pdf

42 The Water Utility Climate Alliance. https://www.wucaonline.org/

- **Plan** for multiple futures and build capacity to manage climate hazards risks;
- **Engage** by motivating action, building connections with other organizations, and developing climate messages to partners and the public;
- **Implement** changes in assets and actions; and
- **Sustain** adaptation by monitoring conditions, developing funding, maintaining capacity, and managing expectations.

Many of the core elements of these two examples align with CAMP4W, where the Board's goals were defined through the process of developing CAMP4W Themes. These Themes are reflected in the Climate Decision-Making Framework, including Evaluative Criteria, development of Time-Bound Targets, and through the Adaptive Management process.

Figure 8 CAMP4W Draft Proposed Climate Decision-Making Framework



3 Results

Reviewed Authors and Sources

A total of 65 documents were reviewed, including 12 internal and 53 external documents. Internal resources included studies, plans, and strategies that relate to facilities and operations directly under Metropolitan's control. External resources relate to Metropolitan's water supplies, statewide conveyance infrastructure, and demand. Resources provided both general information (high-level considerations) and programmatic information (project and location-specific information).

Among the external resources reviewed, authors ranged across sector and scale. Authors included water agencies, energy utilities, counties, groundwater agencies, fire departments, federal agencies, and state agencies (Table 1). Authors provided a wide range of insights and technical information, pulling from both quantitative and qualitative data sources.

Table 1 Authors of External Documents, by Agency Type

Water Agencies
- Metropolitan Water District of Southern California
- Eastern Municipal Water District

Energy Utilities
- Southern California Edison
- San Diego Gas and Electric
- Southern California Gas Company

Counties
- County of San Diego
- County of Imperial
- County of Mono
- County of San Bernadino
- County of Orange
- County of Los Angeles
- County of Ventura

Groundwater Agencies
- Fox Canyon Groundwater Management Agency
- Pauma Valley Groundwater Sustainability Agency
- Main San Gabriel Basin Watermaster
- Santa Monica Basin Groundwater Sustainability Agency
- San Pasqual Valley Groundwater Sustainability Agency

California State Agencies
- California Energy Commission
- California Natural Resources Agency
- California Department of Fish and Wildlife
- California Department of Public Health
- California Ocean Protection Council
- California Air Resources Board
- California Delta Stewardship Council

Federal Agencies
- United States Bureau of Land Management
- United States Geological Survey
- United States Bureau of Reclamation

Fire Departments
- Riverside County Fire Department
- Orange County Fire Department

Miscellaneous
- Researchers
- Feather River Land Trust
- Western Riverside Council of Governments
- Colorado Water Conservation Board

Among Metropolitan-authored resources reviewed, documents had a wide range of focus areas including energy reliability, GHG inventories, infrastructure vulnerabilities and integrated resource planning. The scope of focus ranged as well, ranging from the high-level Resource Vulnerability Study, which did not cover individual facilities, to more detailed studies such as the IRP and the System Reliability Study. Additionally, plans such as The Energy Sustainability Plan and the Energy Management and Reliability Plan covered specific aspects of Metropolitan's system. There are also documents that relate to specific locations, such as the Fire Management Plan for Lake Mathews and the Hydroelectric Feasibility Study. Finally, the Water Shortage Contingency Plan is an example of a document focused on one specific type of climate risk (drought). A matrix of internal resources reviewed is provided in Table 2.

Table 2 Metropolitan Internal Documents Reviewed

Name of Plan	Year	Document Type	Strategy Level
Fire Management Plan for Lake Mathews	1994	Plan	Programmatic
System Reliability Study	2006	Assessment	Programmatic
Energy Management and Reliability Study	2010	Plan	Programmatic
Hydroelectric Feasibility Study	2010	Assessment	Project
Urban Water Management Plan	2016	Policy Document	General
Energy Sustainability Plan, Volumes 1 and 2	2020	Plan	Programmatic
Integrated Resource Plan; Phase 1: Regional Needs Assessment	2020	Strategy/Policy	General
Resource Vulnerability Study	2020	Assessment	General
Climate Action Plan	2021	Plan	Programmatic
Strategic Asset Management Plan	2021	Plan	Programmatic
Urban Water Management Plan	2021	Policy Document	General
Water Shortage Contingency Plan	2021	Plan	Programmatic

Characterized Hazards

A variety of climate hazards were included in reviewed documents, many of which have already had a direct impact on Metropolitan's services and operations (Figure 9). Drought and wildfire were discussed in depth and assessed at length in many of the reviewed documents. In contrast, wind and storm events and landslide events were the least-discussed in the reviewed documents. Because wind, storm, and landslide events typically have geographically-isolated impacts, it is likely internal planning processes did not have a mechanism yet for assessing the prevalence of and potential for district-wide hazards of these events. Among internal resources, the energy-related documents assessed hazards the most comprehensively, as a result of cascading climate risks. General and higher-level documents, like the Integrated Resources Plan, and the Resource Vulnerability Study, were more likely to identify and assess climate risks as tangible and relevant considerations in their respective planning purposes. Programmatic documents that identified specific projects were less likely to consider climate-related hazards. Because so much investment has been made to understand climate hazards by non-Metropolitan agencies, at a local, state and federal level, external resources are available to fill some gaps in Metropolitan's internal assessment of hazards. Table 3 identifies key climate threat assessment gaps in internal documents (e.g., wind, storm, and landslide impacts are only mentioned in two internal documents) and how external documents may help to supplement these gaps (e.g., four types of external documents address all of these impacts). Metropolitan is currently in the process of developing a Hazard Mitigation Plan, which may include a broader set of climate hazards.

Figure 9 Number of Documents that Characterized Specific Climate Hazards

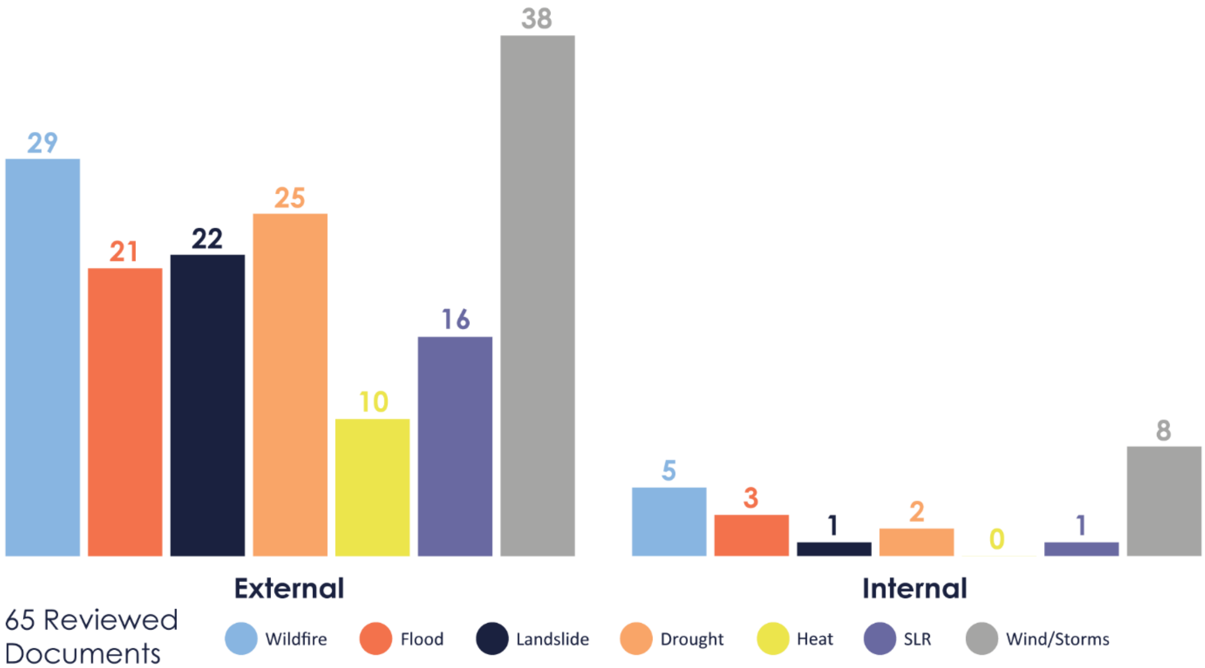


Table 3 Infrequently Mentioned Climate Threat Assessment Gaps Potentially Supplemented by External Sources

		Riverine Flood	Landslide/Mass Movement	Extreme Wind/Storms
Internal Docs	Climate Action Plan			
	Energy Sustainability Plan			x
	Hydroelectric Feasibility Study			
	Integrated Resource Plan			
	Urban Water Management Plan			
	Urban Water Management Plan			
	Energy Management and Reliability Study			
	Resource Vulnerability Study	x		
	Strategic Asset Management Plan			
	System Reliability Study			
	Fire Management Plan for Lake Mathews			
	Water Shortage Contingency Plan			
External Docs	Climate Change Vulnerability Assessments	x	x	x
	Basin Implementation Plans	x	x	x
	Statewide Water Plans	x	x	x
	Wildfire Protection Plans/Fire Plans	x	x	x

While internal documents reference several types of climate hazards, there are few that assess the influence of climate change on future risk. For example, historical drought conditions are discussed extensively in the IRP, but there is little discussion of how climate change may influence potential and repeated occurrences of acute (multi-year) drought events or more extreme drought patterns (increased variability). Future flood risk, atmospheric river risk, and the impact of climate change on the El Niño-Southern Oscillation (and associated patterns of extreme temperature and precipitation) are examples of climate hazards in need of better characterization. Having access to emerging science on climate hazards like these and the ability to conduct vulnerability assessments will enable Metropolitan to better assess its vulnerabilities to future climate hazards.

Assessed Vulnerabilities and Impacts

The assessment of vulnerabilities and impacts of climate hazards on Metropolitan infrastructure and operations included review of impacts to the human-made infrastructure and natural systems Metropolitan relies on. These systems include the CRA and SWP headwaters, purchased land, and treatment, storage, conveyance, and distribution infrastructure.

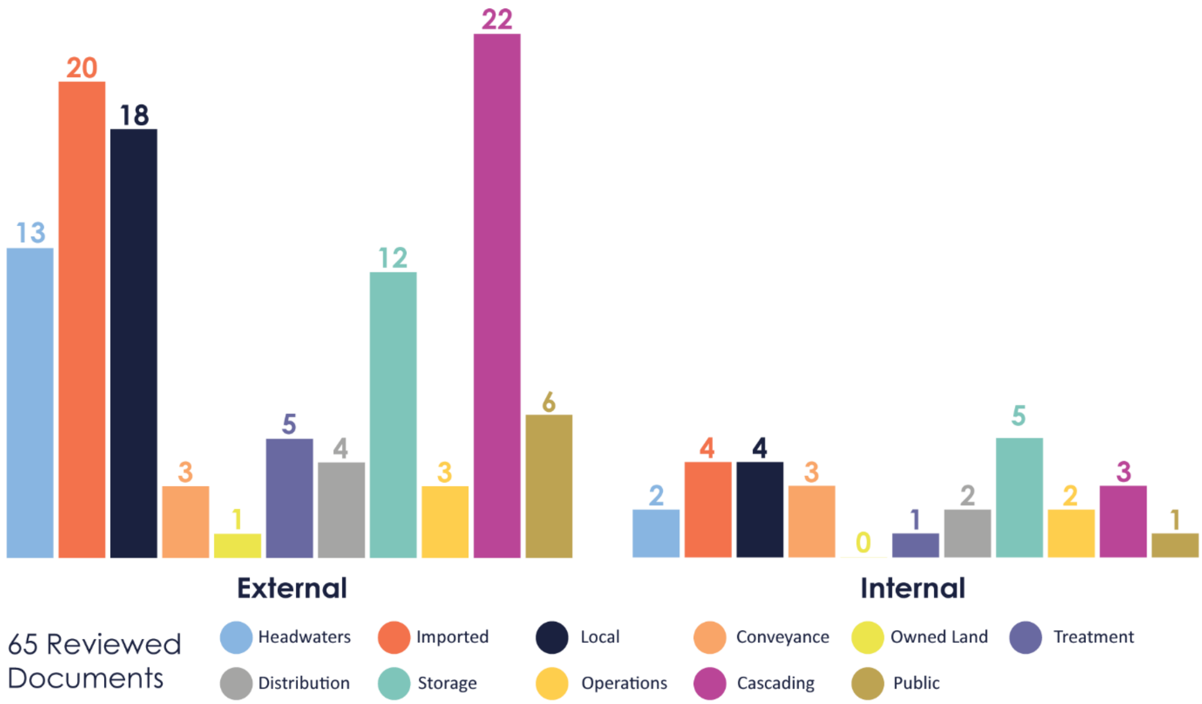
The Resource Vulnerability Study was the primary internal document that assessed a diverse range of climate risks in the most detail. The Energy Sustainability Plan also included an impact assessment of several climate threats but was limited in scope to energy infrastructure. The IRP Needs Assessment presented a broad collection of potential climate impacts. The analysis consisted of long-term, scenario-based water supply planning and the identification of the supply gap based on multiple future demand projections and climate change scenarios. While it evaluated water supply availability based on projected precipitation and drought scenarios, it did not evaluate the impacts of climate extremes on infrastructure and other assets.

The most discussed types of climate impacts were related to storage (n=5), imported water supply (n=4), and local water supply (n=4). There is little internal documentation of potential risks to land (including the delta islands, farmland in Palo Verde Irrigation District, parcels throughout the service area, etc.) owned by Metropolitan. These lands support related water resources, ecosystems, communities, and operations, and impacts from climate hazards can reduce water quality, impact sensitive species, and disrupt operations. Conversely, mitigating harm and implementing climate smart management of these lands can reduce potential impacts to related water resources, ecosystems, communities, and operations. External documents could supplement existing information by improving Metropolitan's understanding of potential cascading risks, particularly regarding the relationship between energy, land, climate and water resources systems that influence Metropolitan's services. Specific external documents that could supplement Metropolitan's understanding include countywide and municipal climate vulnerability assessments, watershed adaptation and resilience plans, and wildfire protection plans.

Similar to the characterization of climate hazards, the assessment of climate impacts was more likely to be included in general, high-level planning documents. Figure 10 provides an overview of the number of internal and external documents that included an analysis of different types of climate impacts.

While drought risk is included in the IRP, the analysis primarily characterizes annual supply limitations over time rather than acute events (such as a multi-year drought). Currently, vulnerabilities are most likely to be identified based on past experience rather than addressing them systematically using system-wide climate forecasts. These experience-based case studies are important for incorporation into system-wide risk assessment; however, system-wide climate adaptation planning must also be incorporated moving forward to try to plan for events not yet experienced by Metropolitan. An example of an experience-based case study occurred in January 2023 when heavy rains caused silt and debris to flow in Castaic Lake. The increased turbidity of the water stressed the ability of the water treatment plant to meet water quality compliance standards and increased operation and maintenance costs. Staff adapted to the extreme conditions by reducing flow, repurposing out-of-service basins, increasing coagulant dosage, and combining chlorine and ozone disinfection.

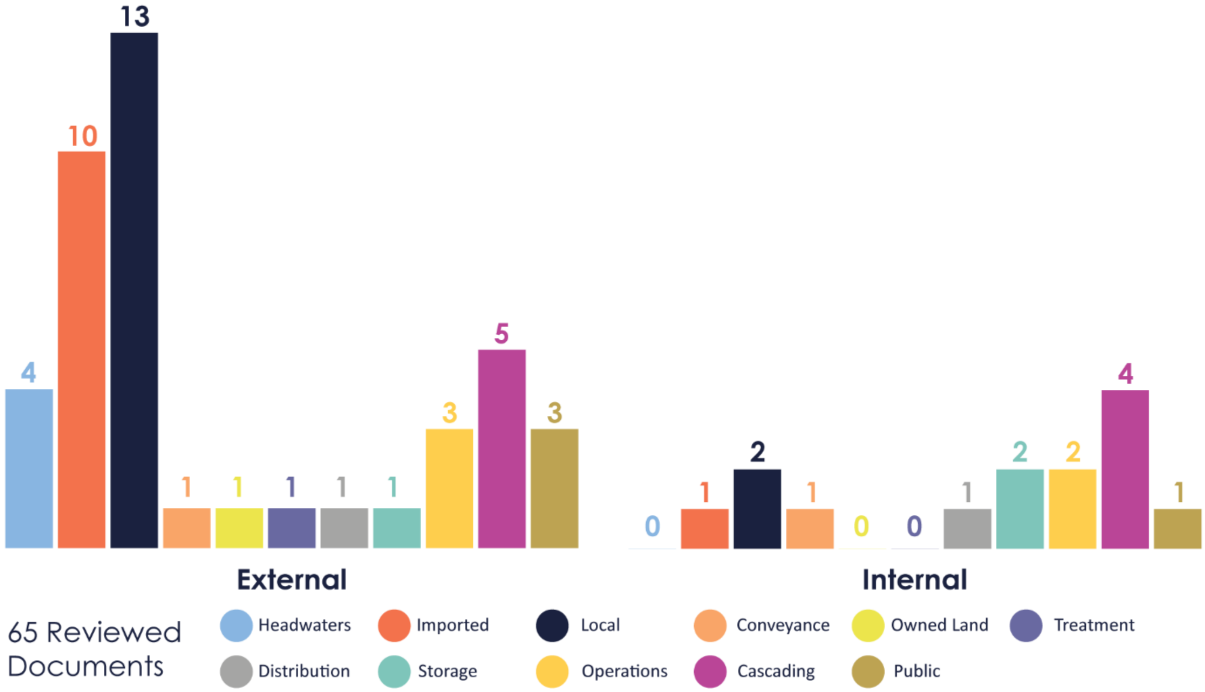
Figure 10 Number of Documents that Included an Assessment of Different Types of Climate Vulnerabilities



Climate Adaptation Actions Assessed: The review of adaptation actions focused on assessing the types of actions explicitly tied to alleviating a specific impact, and its associated climate threat. Overall, the review found a noticeable gap in identified adaptation actions linked to identified climate threats. External documents provided the most insight into potential adaptation actions. For example, the Climate Adaptation and Vulnerability Assessment conducted by SCE identified seven subtransmission substations and 140 distribution substations as vulnerable to freshwater flooding.[39] Based on this analysis, SCE then developed near-term flooding adaptation actions for all at-risk substations, which are cost- and time-effective and provide immediate resilience against flooding exposure, where feasible.

The California Water Plan provides a range of potential actions, though a more detailed analysis would be needed to apply these approaches to Metropolitan. Energy-related actions specific to climate threats were included in several internal documents. Actions related to cascading impacts and headwater impacts were assessed in some external documents. External documents, particularly those that address cascading risks, will likely supplement existing research. Figure 11 provides for an overview of the number of internal and external documents that included specific actions that address identified climate vulnerabilities.

Figure 11 Number of Documents that Include Specific Types of Actions



4 Key Findings and Recommendations

Overall, the literature review indicates many climate hazards have been identified and characterized at a high level, but there is less documentation of Metropolitan's specific climate vulnerabilities and even fewer documents which identify specific actions that build resilience to those vulnerabilities. As presented in Figure 12, internal documents do include analyses of some climate threats, but include very limited discussion of detailed actions that could address the impacts from those hazards. Understandably, with limited information about the scale, timeframe and social, economic and ecological repercussions of impacts, identifying meaningful solutions or strategies is challenging. Overall, the literature review indicates Metropolitan has more documentation characterizing high-level climate hazards, less documentation of its specific climate vulnerabilities, and a relatively low number of actions clearly associated with identified climate vulnerabilities. There are numerous external documents available which evaluate and programmatically address climate risks. These documents present potential opportunities for Metropolitan to understand cascading types of risks (factors like water quality degradation, power disruptions, and transportation infrastructure damage that could affect its water supplies, operational reliability, or demand).

Categories of recommendations that directly support the development of CAMP4W are described below. Recommendations are categorized in terms of the relevant vulnerability analysis step (threat + vulnerability → risk; see Figure 4) based on the following categorical types of recommendations:

- **Policy** recommendations are intended to establish a consistent basis for defining, incorporating, and updating climate change risk data and methodologies for use in internal planning and management processes.

- **Data management** recommendations are intended to provide staff with the information needed to track and update climate science and trends, the occurrence of climate threats, and adaptive features of Metropolitan's systems, including new investments.

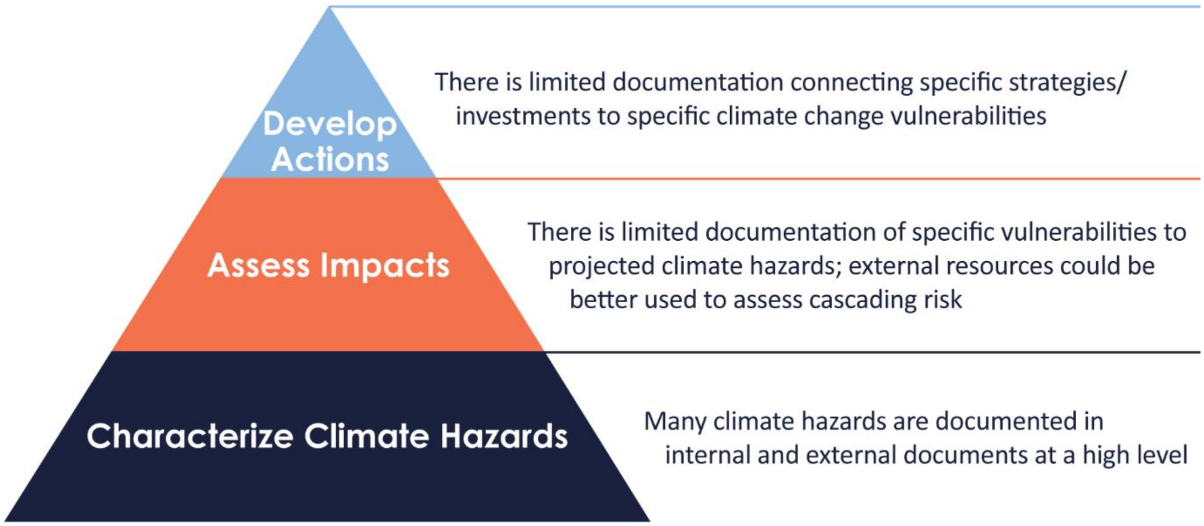
- **Decision-support** recommendations are intended to establish standardized approaches, define climate threat scenarios for stress test modeling, and inform findings from targeted vulnerability assessments.

- **Partnership** recommendations are intended to leverage coalition-based approaches, particularly in assessing and addressing cascading risks associated with Metropolitan's water resources and energy needs.

- **Funding** recommendations are intended to identify opportunities to support adaptation investments at-scale and take advantage of state, federal, and private funding opportunities.

Specific recommendations in these categories are described in Figure 4 and follow a consistent methodology of first characterizing climate hazards, then assessing vulnerabilities, and finally developing climate adaptation actions.

Figure 12 Summary Literature Review Findings



The recommendations included below contribute in part to credits that are part of the Climate and Resilience category of Envision. By implementing the recommendations, Metropolitan will have the necessary foundation to more closely align with Envision credits as part of an infrastructure project in the Climate and Resilience category.

4.1 Characterize Climate Hazards

There are several internal documents which characterize at least one type of climate threat influencing Metropolitan infrastructure and operations. Drought risk is the most extensively included climate threat and is included in 8 of 12 internal documents. Metropolitan also has a Water Shortage Contingency Plan that evaluates 6 standard water shortage levels.[43] The Resource Vulnerability Study, which focused on climate hazards to Metropolitan water supplies and infrastructure, includes the most comprehensive characterization, including: wildfire, extreme heat, sea level rise, extreme weather, and drought. The Energy Sustainability Plan also covers several climate threats, including wildfire, extreme heat, extreme weather, and drought. The most recent IRP includes scenarios that consider long-term changes in precipitation and temperature, rather than how infrastructure and operations will be impacted or influenced by the occurrence of more frequent and severe climate extremes (e.g., atmospheric river events, multi-year droughts, extreme heat events).

There are numerous reviewed external documents that include comprehensive characterization of climate hazards, including watershed vulnerability studies, groundwater management studies, and energy grid vulnerability studies. For example, SCE prepared a comprehensive Climate Adaptation Vulnerability Assessment (CAVA), which includes wildfire, extreme heat, sea level rise, and drought.[44] SCE is required to update its CAVA every 4 years, which presents Metropolitan with valuable insights into cascading energy risks. It also presents an opportunity to collaborate on better characterizing climate risks, considering the two organizations share a similar footprint. The same is

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43 2021. Metropolitan Water District of Southern California. Water Shortage Contingency Plan. https://www.mwdh2o.com/media/21648/water-shortage-contingency-plan-june-2021.pdf

44 2020. Southern California Edison. Adapting for Tomorrow: Powering a Resilient Future. https://www.edison.com/our-perspective/adapting-for-tomorrow

true for other external planning documents, such as Wildfire Protection Plans, Groundwater Sustainability Plans, and Watershed Climate Vulnerability Assessments, which all provide insights into climate hazards presenting direct or cascading risk to Metropolitan infrastructure and operations.

4.1.1 Recommendations for Improving Characterization of Climate Hazards

The following recommendations are intended to provide staff with the information required to effectively characterize the influence of climate change on hazard events. Recommendations (Table 4) cover several types of options, including policies, partnerships, research, databases, decision-support, tools, analyses, and modelling efforts. Near-term recommendations (1-1, 1-4, and 1-7 are highlighted in blue. Implementation of these recommendations at a project-level would align most closely with Envision CreditS CR 2.2 Assess Climate Change Vulnerability and CR 2.3 Evaluate Risk and Resilience.

Table 4 Characterize Climate Hazard Recommendations

No.	Description	Type	Rationale
1-1	Incorporate direction to establish and maintain a database of climate hazard characterizations into existing climate policy, which will be reviewed and revised as necessary in alignment with Metropolitan's selection of a Representative Concentration (or Shared Socioeconomic) Pathway as California Climate Change Assessment is regularly updated.	Policy	▪ Establish consistency for future studies and plans. ▪ Avoid missing important climate hazard considerations in future studies and plans. ▪ Support the CAMP4W process by establishing which climate scenarios underpin the resilience decision-making framework.
1-2	Invest and/or partner in research that provides more advanced characterization of key climate threats, specifically to understand how climate hazards are projected to change over time and vary by location (e.g., future flood risk, future atmospheric river events, extreme wildfire events).	Partnership, Decision Support	▪ Improve ability to assess future exposure to climate hazards. ▪ Leverage other organizations with similar geography and intersecting interests (such as SCE).
1-3	Establish and maintain a catalog of studies that characterize advancements in the understanding of the influence of climate change on relevant natural hazards.	Data Management	▪ Establish consistent and adaptive knowledge base for future studies and plans.
1-4	Establish and employ a digital platform to record or catalog significant impacts related to the occurrence of extreme events and then institute an annual review by multiple departments to determine if adjustments need to be made to avoid future impacts.	Data management, Decision-support	▪ Consistently associate the appropriate set of potential climate extremes with specific infrastructure and operations. ▪ Facilitate an Adaptive Management process as defined in CAMP4W to allow Metropolitan to adjust to changing conditions and adjust future investments.
1-5	Incorporate climate trends, such as changes in temperature and precipitation and climate	Decision-support	▪ Facilitate an Adaptive Management process as defined in CAMP4W to

No.	Description	Type	Rationale
	hazard occurrence data into the CAMP4W Signpost metrics.		allow Metropolitan to adjust to changing conditions and adjust future investments.
1-6	Develop “stress test” scenarios designed to replicate projected future climate hazards for system modeling (e.g., how much precipitation would trigger failure conditions and where or what extent and duration of a power outage would trigger failure conditions and where).	Decision-support	▪ Ability to develop more robust vulnerability assessments associated with climate hazards amplified by future climate change (e.g., future wildfires, consecutive atmospheric river events).
1-7	Secure grant funding to support existing or new studies and research that better characterizes climate hazards.	Funding	▪ Improve ability to assess future exposure to climate hazards. ▪ Leverage other organizations with similar geography and intersecting interests (such as SCE).
1-8	Develop systems model inclusive of Metropolitan and Member Agency facilities to better understand regional and local water supply availability under future climate scenarios and stress test scenarios.	Partnership, Decision-support	▪ Develop a comprehensive understanding of water supply availability using a uniform methodology and assumptions. ▪ Better understand Member Agency dependance on Metropolitan’s imported supplies under climate stressed conditions.

4.1.2 CAMP4W Integration

Several “Characterize Climate Hazard” recommendations are designed to directly support the CAMP4W process, including:

- Selecting, reviewing, and updating as necessary specific GHG emission scenarios will provide Metropolitan with a consistent set of underlying conditions to guide its adaptive management decisions. **Recommendation 1-1** affirms establishing a policy that identifies which climate change scenarios (e.g., RCP 8.5) will underpin Metropolitan’s CAMP4W decision-making framework. The Board of Supervisors identified the RCP 8.5 scenario to underpin the CAMP4W process in September of 2023. This selection is recommended to be reviewed and revised consistent with subsequent IPCC Reports, the National Climate Assessment, and California’s Climate Assessments in order to incorporate best available science as it becomes available.
- Spatially relating specific Metropolitan infrastructure and systems to a consistent set of characterized climate hazards will enable Metropolitan to track changes in risk over time and respond accordingly through CAMP4W. **Recommendation 1-4** proposes establishing a digital platform to track changes in the exposure of Metropolitan systems to climate change hazards and changes in temperature and precipitation.
- CAMP4W Signposts enable Metropolitan to understand how underlying climate conditions, such as temperature, precipitation, and the occurrence of climate hazards are changing over time. This information is intended to inform future supply-demand analyses, climate hazard risk assessments, and resulting investment decisions. **Recommendation 1-5** proposes incorporating climate trends into the set of CAMP4W Signpost metrics.

4.2 Assess Vulnerabilities

Most of the internal documents characterizing specific types of climate hazards include some form of vulnerability assessment. Since most of the internal documents are focused primarily on drought, the resulting vulnerability analyses are largely focused on supply and storage risks with some attention to potential changes in conveyance or storage that could reduce general drought risk (i.e., reduced annual supply conditions over time). The Resource Vulnerability Study was developed as a high-level screening tool that ranks types of facilities relative to different types of climate hazards. As a result, the document covers a wide range of impacts on different types of facilities. This analysis is high level and does not look at specific infrastructure/facility vulnerabilities. The Energy Sustainability Plan includes an assessment of specific conveyance and distribution infrastructure as does the System Reliability Study, which identifies the potential effects of different types of conveyance outages and failures. While the System Reliability Study does not connect types of failures with climate hazards, expanding upon this study and utilizing the structure of the analysis could be a useful approach for assessing the impact of climate risks on system reliability.

Metropolitan is currently underinvesting in the types of studies that assess the climate vulnerabilities of its existing infrastructure and operations. One of the key reasons is that its current funding model includes these types of studies under each department's operations and maintenance budget. Historically, these budgets are often the first to be eliminated when Metropolitan balances its operational needs with limited resources. As a result, Metropolitan is behind on numerous studies that would enable it to better assess its climate vulnerabilities. Establishing a separate funding mechanism could help alleviate this bottleneck and provide Metropolitan with the information it needs to better address its increasing climate vulnerabilities.

There are numerous external documents which characterize different climate threats, as discussed in the preceding section. Some of these documents also include an assessment of vulnerabilities related to cascading risks to Metropolitan. Wildfire Protection Plans include an assessment of wildfire risk to watersheds providing different Metropolitan water supplies. The SCE CAVA includes an assessment of power infrastructure vulnerabilities to climate change that may affect Metropolitan's ability to power its facilities. Watershed Climate Change Assessments for the Colorado and Sacramento River Basins include an assessment of water supply vulnerabilities that influence Metropolitan's water supplies. Metropolitan is also in the process of developing a Strategic Infrastructure Resilience Plan (SIRP), which will establish a framework for assessing and improving the ability of its water and electric power systems to withstand, adapt, and recover from hazard events. While Metropolitan has taken numerous steps to better move water from different source supplies in more directions, there is additional potential to support the resilience of water supplies that are received by Metropolitan, which may be more economically efficient than additional infrastructure investments.

4.2.1 Recommendations for Assessing Vulnerabilities

The following recommendations (Table 5) are intended to provide staff with guidance toward developing policies, programs, and initiatives that will better allow Metropolitan to effectively assess climate vulnerabilities, particularly related to projected future risk. Near-term recommendations (2-3, 2-5, 2-11, and 2-12) are highlighted in blue. Implementation of these recommendations at a project-level would align most closely with Envision Credits CR 2.2 Assess Climate Change Vulnerability, CR 2.3 Evaluate Risk and Resilience, and CR 2.4 Establish Resilience Goals and Strategies.

Table 5 Assess Vulnerabilities and Potential Impacts Recommendations

No.	Description	Type	Rationale
2-1	Establish a policy that defines and requires an integrated climate vulnerability assessment standard to be coordinated by SRI for evaluating the different types of infrastructure (either existing or new), consistent with State guidance and best practices by supporting organizations such as WUCA.	Policy	▪ Establish consistency for future vulnerability assessments and industry best practices. ▪ Location and hazard specific vulnerability assessments are needed across treatment, conveyance, distribution, supply, storage, power, and owned land/habitat.
2-2	Identify partnership opportunities between Metropolitan and Member Agencies and/or among Member Agencies to support vulnerability assessments, identify local vulnerabilities, and/or better understand Member Agency dependance on Metropolitan during extreme conditions.	Partnership, Decision-support	▪ Reduce cascading risks between Metropolitan and Member Agencies. ▪ Support resilience of Member Agencies. ▪ Provide a standard methodology and consistent approach to characterizing climate hazards and assessing vulnerabilities, including how Metropolitan organizes its systems.
2-3	Create a fund under the SRI Office to support, catalog, and track specific climate vulnerability assessments across the different types of assets (e.g., energy, water treatment, conveyance).	Database	▪ Build Metropolitan's understanding of its climate change vulnerabilities. ▪ Directly link assets with the vulnerability assessments that support adaptation actions. ▪ Establish a baseline data tracking process for new assets following capital project completion.
2-4	Catalog and track specific emergency response/recovery events, including data regarding costs, staff time, affected facilities and types of climate hazards. Consider this metric as a CAMP4W Signpost.	Database, Decision-support	▪ Increase understanding of vulnerabilities and emergency management costs from climate hazards. ▪ Facilitate an Adaptive Management process as defined in CAMP4W to allow Metropolitan to adjust to changing conditions and adjust future investments. ▪ Inform improvements to the emergency management/response planning process.
2-5	Establish new or modify existing design standards for new assets to mitigate vulnerabilities identified for each asset class and location with the overall lifespan of the asset and potential future climate conditions in mind.	Policy, Decision-support	▪ Designing with climate data that is accurate only at the beginning of a asset's life – or, as is often the case, based on historical data from 10-30 years before it was built – poses significant risks. ▪ Establish methodology for developing more resilient projects in the face of climate change.

No.	Description	Type	Rationale
2-6	Coordinate and/or partner with external parties to assess vulnerabilities related to cascading risks (e.g. power disruptions or water quality emergencies).	Partnership, Decision support	▪ Understand specific cascading vulnerabilities. ▪ Develop value propositions for co-investments in infrastructure or other types of investments that reduce cascading hazard risk to Metropolitan systems.
2-7	Supplement existing studies (Integrated Resource Plan, System Reliability Study, etc.) with 'stress test' analyses to understand system performance relative to extreme climate hazard scenarios (Recommendation 1-6).	Decision-support	▪ Understand the conditions in which climate extremes will lead to failures to help staff orient funding to improve operational resilience.
2-8	Anticipate increased annual budget allocations for a greater number of emergency management/response events.	Funding	▪ Existing climate literature indicates an increase in the frequency and severity of climate hazard events (i.e., weather whiplash).
2-9	Develop "Infrastructure Resilience" Time-Bound Target and Evaluative Criteria scoring metrics in order to support policy and resource management goals.	Decision-support	▪ Facilitate an Adaptive Management process as defined in CAMP4W to allow Metropolitan to adjust to changing conditions and adjust future investments.
2-10	Integrate and align CAMP4W assessment framework with CIP risk framework so that capital project requirements address identified vulnerabilities and are incorporated into long-range financial planning to encapsulate all reliability and resilience costs beyond drought.	Funding	▪ Integrates findings into financial assessments of rates and business models to incorporate the potential impacts of multiple climate hazards ▪ Alignment between the CAMP4W and existing CIP Risk framework
2-11	Coordinate with the existing inter-departmental asset management working effort to develop an implementation strategy for Metropolitan's Strategic Asset Management Plan that incorporates climate action goals.	Data management	▪ Enable staff to evaluate trends in climate impacts on different types of assets and better inform future adaptive design criteria.
2-12	Coordinate and streamline the various ongoing assessments (e.g., the Local Hazard Mitigation Plan, Strategic Infrastructure Resilience Plan, Water Quality Resiliency Study, Risk and Resilience Assessment, Energy Sustainability Study, etc.), regularly update assessments (e.g., Fire Management Plan for Lake Mathews), and incorporate the best available climate science from state and federal sources.	Decision-support	▪ Efficient resource allocations and cross-plan consistency in support of infrastructure plans that enable Metropolitan's system to perform better under future climate conditions.

4.2.2 CAMP4W Integration

Several "Assess Vulnerabilities" recommendations are designed to directly support the CAMP4W process, including:

- Proposed CAMP4W Signposts may enable Metropolitan to understand how climate conditions are changing over time. This information is intended to inform future supply-demand analyses, climate hazard risk assessments, and resulting investment decisions. **Recommendations 1-4 and 2-4** establish a databases and digital platforms that can be used to track the frequency and severity of emergency response events and impacts to Metropolitan infrastructure and operations. This information can be used to indicate if climate hazards are having a greater influence on Metropolitan infrastructure and operations.

- CAMP4W Time-Bound Targets and Evaluative Criteria help Metropolitan to identify and prioritize investments that increase its resilience. **Recommendation 2-9** establishes targets and criteria which relate to types of investments that support both the overall resilience of Metropolitan's systems and/or investments that make specific elements of the system more resilient to climate hazards, including their reliance on externally operated systems such as the SWP. The proposed Evaluative Criteria metrics are based on the climate (and seismic) hazards which are most relevant to Metropolitan systems and are detailed in the CAMP4W Year 1 Progress Report.
- Long-term financial planning through the CAMP4W process is intended to support Metropolitan's financial stability in the face of climate change. Understanding the financial impacts associated with bridging the supply gap identified in the IRP Needs Assessment will facilitate the iterative and adaptive methodology that is the cornerstone of the CAMP4W process. **Recommendation 2-10** integrates capital project requirements to address climate hazard vulnerabilities into long-range financial planning so that the costs associated with adaptation are better represented in financial forecasts.

4.3 Develop Climate Adaptation Actions

In the face of climate change and changing relationships between member agencies and Metropolitan, additional measures must be taken to evolve Metropolitan's infrastructure and systems to function as needed. This indicates the need to better show connectivity between investments, specific climate vulnerabilities, and future investments. The IRP is limited to looking at average low water supply conditions rather than acute drought events and other types of climate hazards. The Energy Sustainability Plan does include actions addressing direct operational risks to wildfire, extreme heat, extreme weather and drought. Internal documents did not identify any strategies related to treatment facilities or owned land, implying a need for greater understanding of how these components might be impacted, and mechanisms for avoiding impact.

There are numerous external documents that include robust adaptation options. External documents tend to be topical and focus on one or two of the impact/action categories used in the literature review. At a very high level, the California Water Plan and Water Resilience Portfolio documents provide insights into the type of actions that support individual agency adaptation. However, these concepts would need to be contextualized by Metropolitan for individual projects. External watershed adaptation/resilience plans include actions for the headwaters context. These actions could reduce cascading risk on the topics of water quality, water supply (quantity), and invasive species. There are also documents, such as groundwater sustainability plans, local vulnerability assessments, and wildfire protection plans, which include actions addressing risks to local water supplies that supplement water provided by Metropolitan to its Member Agencies. Some of these studies also identify risks to water storage options (groundwater, reservoirs, etc.). Some local vulnerability studies and groundwater sustainability plans also articulate actions which address demand-side vulnerabilities.

The key identified gap is existing and planned investments, including CIPs, largely do not demonstrate Metropolitan's ability to adapt to future climate conditions. While the CIP Risk Framework includes attributes that could be used to prioritize adaptation investments, it has yet to be used for project selection. Implementation of the Tactical Asset Management Plan would also support the identification of projects that support adaptation. When layered on top of other challenges facing Metropolitan vulnerabilities (e.g., increasing capital investment needs, grid reliability), this presents significant future risk in terms of potential for more frequent and severe service disruptions and associated financial insecurity. If Metropolitan's systems are not evolved to function under future climate conditions, the likely result is increased spending on emergency response and recovery, increased capital improvement costs, and increased staff focus on response and recovery. The same holds true for cascading risks identified through external studies. Some of the actions identified in the external plans present potential co-benefits to Metropolitan. These are potential investments that may provide financial efficiency compared with Metropolitan addressing the issues unilaterally.

4.3.1 Recommendations for Climate Adaptation Actions

The following recommendations are intended to provide staff with the information required to effectively develop and document adaptation actions informed through robust vulnerability assessments. As staff are able to develop robust vulnerability assessments, it is recommended they have the means to develop and pilot new approaches, secure new funding sources, track trends and progress, weigh adaptation actions against one another for maximum effectiveness and efficiency, and implement actions that provide adaptation benefits to Metropolitan. Metropolitan also has an opportunity to address risks to its systems as well as those that cascade to its Member Agencies. By doing so, it puts itself in a more robust position to provide greater and more resilient value as a service provider. A near-term recommendation (3-9) is highlighted in blue. Implementation of these recommendations at a project-level would align most closely with Envision Credit CR 2.6 Improve Infrastructure Integration.

Table 6 Develop Actions Recommendations

No.	Description	Type	Rationale
3-1	Catalog the implementation of investments that support adaptation/resilience using the Time-Bound Targets and Evaluative Criteria relative to their actual performance to inform future CAMP4W investment decisions.	Database	▪ Determine which climate hazards are relevant and how the project has been developed or designed to address identified risks. ▪ Track investments that mitigate risk.
3-2	Build on Metropolitan's exploratory work with Blue Forest in the Feather River Watershed to (the primary source of State Water Project supply) by evaluating the potential role and benefits of a resilience bond partnership. The key steps would include cataloging potential actions and associated ecosystem services, establishing an ecosystem service valuation methodology, identifying additional beneficiaries (as potential partners), and determining whether a sufficiently beneficial payment/finance structure providing sufficient value to stakeholders and investors can be established.	Funding, Partnership	▪ Alleviate funding and staffing constraints. ▪ Provide opportunity for substantial progress through a programmatic approach.
3-3	Establish an adaptation pilot program that enables the development of novel adaptation approaches, including adaptive design features and/or multi-benefit solutions, by securing funding, establishing partnerships, and other resources to test and pilot new methods.	Decision-support	▪ Enable staff to innovate and develop new adaptation approaches before conditions become too severe to transform. ▪ Articulate cost-benefit tradeoffs to demonstrate value.

No.	Description	Type	Rationale
3-4	Maximize federal, state, local and private funding opportunities by establishing a database of potential funding sources to be reviewed against proposed projects given the funding that may be available to support climate resilience and mitigation actions.	Database, Funding	▪ Improve the ability of staff to monitor grant opportunities. ▪ Connect the project development process with funding opportunities.
3-5	Develop, pilot, and implement partnerships for addressing water supply and power cascading risks. Employ external vulnerability data to identify cascading climate hazard vulnerabilities. Co-develop analyses that assess the financial and operational benefits of adaptation actions outside of Metropolitan's system which reduce risk to Metropolitan's system. Identify funding strategies for implementing identified actions.	Partnership	▪ Address vulnerabilities associated with cascading risks. ▪ Leverage external resources through joint investments. ▪ Potentially reduce the cost of adaptation.
3-6	Develop, pilot, and implement partnerships for addressing water supply-related climate risks to Member Agencies, such as those serving State Water Project-dependent and disadvantaged communities. Employ external vulnerability data to identify cascading climate hazard vulnerabilities. Co-develop analyses that assess the financial and operational benefits of adaptation actions by Metropolitan. Identify funding strategies for implementing identified actions.	Funding, Partnership	▪ Reduce risk to Member Agencies. ▪ Provide a potential vehicle for addressing Member Agencies' vulnerabilities through the Local Resource Program.
3-7	Coordinate with other agencies, Water Utility Climate Alliance, State Water Project and Colorado River users, and Member Agencies to identify and promote adaptation best practices, tools, analyses, and methods. Track actions successfully employed by other agencies and incorporate the options into the adaptation pilot program.	Partnership	▪ Incorporate lessons learned and successful pilot programs from other agencies, and promote Metropolitan's leadership among water utilities.
3-8	Consider and incorporate the implications of more extreme climate hazards and more variable water supply conditions into financial modeling and develop financial strategies that account for climate change implications associated with extreme events.	Funding	▪ Adapt Metropolitan's financial stability as its role and the cost of service evolves due to climate change. ▪ Effectuate CAMP4W objective to integrate financial, climate and water resource planning.
3-9	Hold an annual climate risk summit with different internal and external parties to identify vulnerabilities and opportunities for further assessment and the development of innovative options and funding.	Partnership	▪ Engage with staff across and outside the organization to gain a better understanding of climate vulnerabilities. ▪ Incorporate data from recent experiences to improve Metropolitan's understanding of vulnerabilities. ▪ Promote Metropolitan's leadership among water utilities.

4.3.2 CAMP4W Integration

Several "Develop Actions" recommendations are designed to directly support the CAMP4W process, including:

- CAMP4W investment decisions are intended to be reviewed and revised on a five-year basis. As projects are implemented, the associated Time-Bound Target and Evaluative Criteria data are intended to be revisited and revised as necessary to support this iterative decision-making process. **Recommendation 3-1** establishes a database for tracking the actual performance of CAMP4W investments relative to their expected performance in order to guide future investment choices.
- There are additional potential resilience investments that can be considered in the future. Recommendations in this section that address specific climate threat vulnerabilities can be evaluated for incorporation into future CAMP4W investment cycles, including **Recommendations 3-2, 3-3, 3-5**, and **3-6**.
- The continued resilience of Metropolitan's financial systems can be supported by **Recommendations 3-2, 3-4**, and **3-8**. These recommendations are intended to increase Metropolitan's access to state and federal sources of funding as well as to expand partnership opportunities with external organizations. **Recommendation 3-8** is intended to inform future financial planning processes with additional information regarding trends in spending that relate to climate hazards.

5 Deep-Dives

SRI staff partnered with several internal groups to better understand how staff are currently characterizing, assessing, and addressing climate vulnerabilities. These deep-dive sessions were comprised of a set of in-person meetings on the topics of energy and water quality.

Prior to each meeting, participants were provided with a survey (Appendix C). The survey questions were also provided in paper form during each meeting. Meeting notes on each theme are provided in Appendix D. The structure of the discussions on each theme were generally organized as follows.

1. What is the most significant climate extreme-related disruption you have observed in the past 5 years?
2. What is the most significant climate extreme-related disruption you anticipate in the next 5 years and beyond?
3. If climate extremes become more frequent and intense, what effects do you anticipate?
4. What are some short-term actions Metropolitan can take to address priority vulnerabilities?
5. What are some long-term actions Metropolitan can explore to address priority vulnerabilities?
6. What are the key constraints and barriers to implementing short- and/or long-term actions?

5.1 Power Supply Vulnerabilities

Metropolitan's energy context is changing rapidly based in part on California's aggressive energy decarbonization efforts (e.g., increased electricity needs for electric vehicles and conversion of natural gas appliances to electric appliances) and the increasing scale of climate change impacts across the energy system. Metropolitan requires a significant amount of energy to deliver water to its Member Agencies. The electricity required for pumping along the CRA is highly variable. During periods of drought there tends to be significantly more pumping, which results in a higher energy demand. In high-pumping years the CRA pumping operation can make up the largest proportion of Metropolitan's electricity needs (for example, in 2022 wholesale energy purchased for CRA pumping represented approximately 97 percent of Metropolitan's total electricity use). Historically, hydropower produced at Lake Mead and Lake Havasu have provided about half of the CRA's energy needs. In recent decades, water levels within Lake Mead and Lake Havasu have declined and water managers are increasingly concerned the reservoirs could fail to reach "minimum power pool" levels—where water could drop below the hydropower intakes, preventing energy generation altogether. Lower reservoir levels have already required Metropolitan to purchase more of its electricity from the open market, which is more expensive and carbon intensive. Frequent and severe extreme heat events, floods, and wildfires associated with climate change are likely to create additional vulnerabilities to Metropolitan's purchased energy and its energy infrastructure, which includes significant high-voltage transmission infrastructure. Metropolitan's CRA transmission system has lasted beyond the industry average life span of 50 years. Though Metropolitan's transmission O&M team are doing an extraordinary job to keep the aging system running reliably to this point, the risk of asset failures is increasing due to age of the assets. More extreme or more frequent heatwaves, wildfires and windstorms would put much higher stress on the aging transmission asset exacerbating associated risks.

The projected increase in power transmission for California's grid in coming years is also expected to increase the vulnerability of Metropolitan's high-voltage transmission system. Major power projects in development could impose approximately 6 gigawatts of additional power in the coming decade to California, which will potentially influence Metropolitan’s transmission system (e.g., Southwest Intertie Project-North and TransWest Express Transmission Project). Metropolitan’s current approximately 300 MW transmission system could experience significantly more stress and operational challenges. Higher transmission loads on the grid could put additional stress on Metropolitan's transmission lines, substations, and other infrastructure components. This increased stress can lead to accelerated wear and tear, increasing the likelihood of equipment failures and disruptions in service. Secondly, if the system is not adequately upgraded to handle the increased power transmission, there is an increased risk of overloading certain components. Overloading can cause equipment to overheat, leading to failures and potentially triggering cascading failures across the grid. These vulnerabilities will also be exacerbated by the increased extreme heat, precipitation, and wind risks associated with climate change.

Energy deep-dive participants included representatives from the Water Energy Climate Sustainability Core Team (WECS), comprising staff from a wide range of Metropolitan roles and functions. This reflects the broad distribution of responsibilities associated with managing power throughout the organization (i.e. Engineering, WSO, Legal, Administrative Services) and the bureaucratic challenge in adapting to a rapidly changing energy landscape. There were 17 distinct responses from a combination of the pre-session surveys and in-session worksheets.

In addition to the deep-dive session with the WECS Core Team, Metropolitan partnered with the US Environmental Protection Agency with support from the Cadmus Group to conduct a climate change risk assessment of energy infrastructure associated with the Colorado River Aqueduct system. The assessment used the EPA’s Climate Resilience Evaluation and Awareness Tool (CREAT) to examine extreme heat and drought-related risks to power generation as the priority climate threats (assuming RCP 8.5) to the CRA water conveyance system, and how each could negatively impact operational resilience. The analysis considered how changing climate conditions may influence MWDSC’s operational resilience and the utility’s ability to supply water to its Member Agencies.

The CREAT analysis results suggest that all three scenarios evaluated (power infrastructure upgrades, investments in renewable power generation, and a transition to variable frequency drives) have a positive cost-effectiveness that varies between climate scenarios. In particular, the VFDs and Power Upgrades adaptation plans are shown in the report to have the highest proportional risk reduction to plan cost. The Renewable Energy adaptation plan produces an average monetized risk reduction, but the relatively high annualized plan cost makes choosing to implement the plan less clear. Additionally, there may be benefits that are not captured under the study’s purely economic analysis that may drive the cost-effectiveness and resiliency value of the adaptation plans and climate scenarios. The complete report with detailed results and more information about the three investment scenarios is provided in Appendix D.

Key inputs from the deep-dive session are shown below. Priority recommendations are highlighted.

Extreme Heat

Characterize Climate Hazards ➡	Assess Vulnerabilities ➡	Develop Actions
▪ Increased likelihood of future power supply disruptions	▪ Potential damage to energy infrastructure such as pumps and transformers	▪ Battery storage and other types of uninterruptable power solutions, where

▪ Increased potential for heat-related staff illness, particularly on the CRA ▪ Increased wholesale energy prices	▪ Water service disruptions ▪ CRA emergency spills ▪ Rate increases ▪ Zero emission vehicle fleet disruptions ▪ Health impacts, particularly in confined spaces or when wearing confined safety gear	feasible to reduce the effects of power disruptions ▪ Evaluate and, as feasible, develop renewable power generation, including potentially through Power Purchase Agreements (PPAs) ▪ Variable Frequency Drives to reduce energy demand ▪ Explore an organizational consolidation of power systems responsibilities across the district ▪ Updated staff safety protocols to provide greater ventilation, cooling, and reduced exposure to heat ▪ Adjusted work scheduling to reduce exposure to extreme conditions

Wildfire

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Increased likelihood of future power supply disruptions ▪ More frequent and extreme wildfires	▪ Damage to facilities and infrastructure, particularly those in highest risk locations ▪ Water service disruptions ▪ Zero emission vehicle fleet disruptions	▪ Infrastructure hardening ▪ Battery storage and other types of uninterruptable power solutions, where feasible ▪ Diversification of energy sources

Drought

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Reduced supply of hydroelectricity from Lake Mead and Lake Powell ▪ Increased reliance on wholesale energy market leading to increased energy costs ▪ Increased need for pumping	▪ Rate increases	▪ Power Purchase Agreements to control energy price increases ▪ Diversification of energy sources to spread risk

Extreme Weather/Flooding

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ More extreme precipitation, wind, and associated natural hazards like flooding and landslides	▪ Extreme flooding in the Delta could stop State Water Project deliveries for significant periods of time, creating salinity control problems ▪ Facility damage, including to the CRA ▪ High-voltage transmission line damage	▪ Changes to infrastructure design criteria ▪ Investments in flood control infrastructure (along the CRA, or upgrading levee systems in the bay-delta for example) ▪ Investments in data management systems along transmission lines ▪ Battery storage and other types of uninterruptable power solutions, where feasible

	▪ Increased emergency response costs (equipment, staff, contractors, etc.)	▪ Diversification of energy sources to spread risk ▪ Increased capacity and R&R investment in high voltage transmission infrastructure

In summary, Metropolitan is likely to be exposed to a greater likelihood of more frequent and extensive power disruptions, wholesale energy pricing instability, and wholesale energy price increases. Participants anticipate the need to increase efforts to identify specific energy infrastructure and facilities vulnerabilities. Participants are also interested in finding ways to increase the speed and flexibility of Metropolitan's feasibility study and procurement processes to keep pace with the rate of change in this hazard context. This will enable staff to incorporate adaptative (multi-benefit) design features more effectively into the CIP projects most exposed to projected climate hazards.

In response to this quickly evolving context, participants identified several systemic adaptation options, including developing new Power Purchase Agreements (PPAs) and further diversification of Metropolitan's energy sources to better manage future grid instability and energy pricing. Increased use of large-scale PPAs for renewable energy may also offer increased financial flexibility by increasing Metropolitan's participation in the wholesale energy market, which would enable it to have access to power when needed and sell the excess as an additional source of revenue. Developing energy (or pump) storage options are also opportunities for cost savings. Finally, PPAs connected through Metropolitan's high-voltage transmission lines may also provide additional income through connection fees that could be used to support capital improvements to the system. These are classic examples of the State's definition of adaptive capacity in that they reduce potential harm, while exploiting opportunities that provide Metropolitan with financial and operational stability. It should be noted that any such investment would require careful consideration of changes to NERC compliance levels as well as potential operational and resource impacts.

5.2 Water Quality Vulnerabilities

There are numerous potential water quality impacts associated with climate change which build on the issues staff are already contending with. In any given year, staff must balance a range of source water quality characteristics based on climate conditions, hydrology, and other factors. There is a certain amount of flexibility built into Metropolitan's system enabling staff to balance conditions, such as alkalinity, turbidity, heavy metal accumulation, emerging contaminants and regulations, extended nitrification events, and harmful algal blooms. This flexibility is limited by the capability of chemical processes, infrastructure connectivity, infrastructure investment, adequate staff resources and the physical capacity of its various facilities.

There was consensus among participants that climate change is likely to amplify the range of different water quality characteristics in a given year, making operations more challenging in future. More extreme conditions may also exceed the infrastructure's capability and staff's ability to balance the water quality characteristics of different flows across its system.

For example, in the Summer and Fall of 2023, Metropolitan had to manage the most severe and extended nitrification event recorded in Metropolitan's system. Nitrification is a common phenomenon whereby nitrifying bacteria that are always present in chloraminated water systems convert ammonia to nitrite. These bacteria are naturally occurring, are not considered pathogens, and nitrite is not considered a contaminant. However, if nitrification is left unchecked it can create a runaway feedback loop where chloramine decay releases ammonia which promotes the proliferation of ammonia oxidizing bacteria, which increases nitrite levels. This then leads to nitrite reacting with the chloramine and leads to further ammonia release and disinfectant loss. If this runaway effect continues without intervention, the loss of disinfectant can allow growth of potentially harmful bacteria that could pose a potential public health threat. Metropolitan switched from free chlorine to chloramines (chlorine mixed with ammonia) as the primary disinfectant in June 1985 as approved by the State Department of Health Services in 1983. This change reduced disinfectant byproducts in the system but was also correlated with widespread periodic episodes of nitrification. Metropolitan conducted research on nitrification and water quality and optimized chlorine dosing at 2.5 mg/L and established an optimal ratio of chlorine to ammonia at approximately 5:1, with variation if responding to a nitrification episode.

Numerous factors can contribute to nitrification events but the two primary factors are long detention times and warmer water temperatures. Detention times refer to the length of time water spends in the distribution system. In the Summer and Fall of 2023 very low demand led to increased detention times along with warm Summer and Fall temperatures. These conditions were exacerbated by tropical storm Hilary, all contributing to the severe and extended nitrification event in the second half of 2023. During this event, over 30 percent of samples were over the designated action levels 1 and 2 (nitrite levels of >0.01 mg/L and >0.02 mg/L, respectively), which was, by far, the highest percentage recorded at Metropolitan over the last two decades of monitoring. To manage this event Metropolitan started to flush water in August on the west side of the system and Orange County. By the peak period of the event, Metropolitan was flushing 24 locations. Metropolitan also held daily meetings, had 50 special sampling locations, took well over 1,700 dedicated samples, and relied on more than 100 staff working over 21,000 hours with much of that being overtime, across numerous teams and in coordination with affected member agencies. Operational changes included optimizing disinfectant to minimize free ammonia, increasing pH to help stabilize chlorine residual, reducing SWP blend going into the Diemer plant from 85 percent to 25 percent, and turning off ozone at the Diemer plant. These around-the-clock efforts from staff and system flexibility allowed for this event to be effectively managed without any public health risks as chlorine levels were maintained. Lower demand and climate driven warming trends and increased likelihood of tropical and other severe storms will contribute to extended nitrification events occuring more in the future.

The CAMP4W draft climate decision-making framework for water quality impacts characterizes the climate-induced nitrification impact as “increased demand for chlorine and microbial activity such as nitrification in the distribution system”. Near term actions identified in the draft CAMP4W decision-making framework include enhanced monitoring, modeling, and deployment of predictive management tools and an update to the nitrification action plan and response indicators, slated for completion by the end of 2025.

Climate change may push needed investment past what is required for general operations and maintenance and instigate a need for capital investment in additional infrastructure to address all water quality vulnerabilities. Furthermore, water quality regulatory standards have become more stringent over time and this trend is expected to continue, making it more difficult to balance the source water and storage-based water quality conditions. In the future it will be critical to identify impacts and build specific protections around the direct and cascading impacts associated with climate change.

Severe Storms/Runoff

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Increased turbidity, which can be exacerbated in wildfire affected areas ▪ Elevated runoff into source tributaries and reservoirs ▪ Faster snow melt, which is exacerbated by warmer temperatures ▪ More variability in incoming water supply and water quality conditions	▪ Water supply disruptions or limitations associated with turbidity ▪ Limited treatment flexibility ▪ Extended detention times are sometimes needed ▪ Flood damage to facilities/infrastructure ▪ Low alkalinity conditions (SWP supplies) can require additional treatment/blending	▪ Pilot new treatment processes/approaches ▪ Investment in flood control infrastructure ▪ Monitoring system investments ▪ Further diversify/blend source water options ▪ Additional flexibility in treatment facilities to handle increased water quality and quantity fluctuations

Warming/Extreme Heat

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Increased bacterial/algal growth in source waters and reservoirs, can lead to taste and odor issues, and potentially hypoxia ▪ Increased growth of ammonia oxidizing bacteria in distribution system ▪ Load shedding/power disruptions to treatment facilities ▪ Work delays due to extreme heat	▪ Increased treatment time and costs ▪ Increase chlorine demand, increased costs due to operational changes and staff time to manage extended nitrification events ▪ Partial or complete facility shutdowns due to power loss ▪ Partial or complete facility shutdowns due to bacterial/algal growth	▪ Pilot new treatment processes/approaches ▪ Update nitrification action plan and response indicators ▪ Monitoring system investments ▪ Further diversify/blend source water options ▪ Uninterruptible power solutions

Wildfire

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Taste and odor issues ▪ Increased turbidity (see Severe Storms/Runoff) ▪ Facility Access ▪ Poor air quality ▪ Power disruptions to treatment facilities	▪ Customer Complaints ▪ Increased treatment costs ▪ Water service disruptions ▪ Service disruptions ▪ Staff safety	▪ Pilot new treatment processes/approaches ▪ Monitoring system investments ▪ Infrastructure hardening ▪ Battery storage and other types of uninterruptable power solutions, where feasible ▪ (Wildfire) Operational contingency plans

Drought

Characterize Climate Hazards ⟹	Assess Vulnerabilities ⟹	Develop Actions
▪ Reduced supply conditions ▪ Water quality changes associated with reduced flows/increased demand ▪ Hypoxia in reservoirs and lakes	▪ Higher Total Dissolved Solids resulting in treatment challenges ▪ High bromide levels, which impact Disinfection Byproduct formation	▪ Pilot new treatment processes/approaches ▪ Monitoring system investments ▪ Further diversify/blend source water options

▪ Increased demand for treated water	▪ Limited treatment flexibility (inability to handle large swings in demand)

In summary, Metropolitan is likely to be exposed to a greater likelihood of more frequent and intense influent water quality issues. Wildfires, drought, and extreme weather events coupled with warming and extreme heat will increase the variability of water quality in Metropolitan's water supplies. Treatment facilities and operations have evolved over time to provide staff with significant flexibility in terms of level of treatment and ability to blend water from different sources. Climate change is likely to place additional stress on the ability of existing systems to accommodate future variability. For example, if harmful algal blooms become more frequent and severe, Metropolitan may be unable to draw water from certain reservoirs for extended periods of time, which may further stress its ability to deliver treated water.

There are also additional structural factors facing Metropolitan's water treatment systems. Demand for Metropolitan treated water has decreased, particularly over the past 20 years. This has created larger swings in demand over relatively short periods of time (in response to wet and dry year swings), which further stresses water treatment systems and the ability to accommodate increasing swings in water quality. Requirements from water quality regulations is also expected to increase treatment costs and require additional treatment processes.

Staff have identified several adaptation options that may provide resilience benefits across the range of potential climate impacts. Staff need the facilities and resources to pilot new treatment processes and approaches that may enable them to adapt to future water supply conditions and handle increased variability. Opening a demonstration plant, for example, could provide these capabilities. Staff also need to further develop monitoring systems to inform process changes in response to extreme conditions. Staff are interested in conducting detailed vulnerability assessments for specific facilities and reservoirs to better understand critical failure thresholds. This will enable them to better develop systemic approaches to future extremes.

5.3 Water Infrastructure Vulnerabilities

Asset management is generally defined by the American Water Works Association as a coordinated set of activities within an organization to realize overall value from all assets through stronger governance and accountability. It is the combination of management, financial, economic, engineering, and other practices applied to all assets with the objective of providing the required level of service at an acceptable level of risk at an optimal life cycle cost.[45]

Asset management is a vital element of Metropolitan's ability to adaptively manage climate risks. It provides a systematic, proactive, and data-informed vehicle for efficiently maintaining, operating, and ultimately replacing assets and infrastructure. This approach minimizes the risk of unforeseen events, including those caused by different types of climate hazards, through a better understanding of the age, condition, and maintenance history of assets.

The performance and condition of many of Metropolitan's assets are likely to degrade more rapidly as climate change amplifies the weather conditions that drive their exposure to climate hazards. Robust asset management processes that are connected to all phases of an asset's life cycle (i.e.,

45 2018. Asset Management Definitions Guidebook. https://www.awwa.org/Portals/0/AWWA/ETS/Resources/AMGuidebook.pdf?ver=2018-12-13-100101-887

design, installation, maintenance, and ultimately replacement) are therefore an essential element of Metropolitan's ability to adapt to climate change.

Data is not currently managed at Metropolitan in a holistic way that is consistent or complete at an agency-wide scale. Different departments often employ different and largely disconnected data management structures and systems. Metropolitan uses a Computerized Maintenance Management System (CMMS) called Maximo to track labor and issue maintenance work orders against a catalog of equipment or structures in service that need maintenance while using other systems for engineering, design, operation or financial tracking. The Strategic Asset Management Plan sets the goal to interconnect disconnected data management systems while clarifying which system is authoritative for the disparate elements and assets.

Asset Management staff developed an agency-wide Strategic Asset Management Plan (SAMP) that would enable a shift toward a more complete asset catalog, establishes a standardized rubric for tracking assets and their attributes, establishes standardized procedures for data collection, and connects all phases of an asset's life cycle through a single system. Incorporation of a comprehensive asset replacement database would inform the design and purchase of new equipment, hastening and simplifying the design process. Alignment between the various groups and departments at Metropolitan is needed to realize this vision, which will enable it to more nimbly track and proactively manage changes in the condition of assets attributed to climate change.

6 Conclusion

Improving Metropolitan's ability to adapt to climate change is an urgent focus and is expected to require continued attention. The next steps for Metropolitan include initiating the near-term initial recommendations outlined in this CVRA, such as funding and conducting feasibility and technical studies, convening a taskforce on energy diversification and power infrastructure along the CRA, and developing and adopting an asset management data policy. Additional next steps include conducting further deep dives into climate vulnerabilities, coordinating climate vulnerability risk assessments with member agencies, and identifying climate risk signposts for CAMP4W Adaptive Management. Climate science indicates certain trends are likely, and an Adaptive Management process, as defined throughout the CAMP4W process, is recommended.

To manage climate change risk, Metropolitan needs a structured process for evaluating changes to its system and potential investments. These adjustments have the potential to increase Metropolitan's adaptive capacity and continue its critical mission to "provide… adequate and reliable supplies of high-quality water to meet present and future needs in an environmentally and economically responsible way."

Appendix A

Reviewed Documents

Doc #	Source	Context	Document Name	Year
E01	External	CA-DWR	Climate Action Plan Phase III: Climate Change Vulnerability Assessment & Adaptation Plan	2019
E02	External	CA-NRA	California Water Plan	2018
E03	External	CA-DWR	Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project	2019
E04	External	CA-CEC CA-NRA	Climate Change Risk Faced by the California Central Valley Water Resource System	2018
E05	External	CARB	Cap and Trade Auction Proceeds Annual Report 2022	2022
E06	External	Vicuna & Dracub	The Evolution of Climate Change Impact Studies on Hydrology and Water Resources in California	2006
E07	External	CA-DFW	A Rapid Assessment of the Vulnerability of Sensitive Wildlife to Extreme Drought	2016
E08	External	CA-NRA CA-OPC	State of California Sea-Level Rise Guidance 2018 Update	2018
E09	External	Groves	Developing and Applying Uncertain Global Climate Change Projections for Regional Water Management Planning	2008
E10	External	US-BLM	Climate Change Vulnerability Assessment for Colorado Bureau of Land Management	2015
E11	External	CO-WRW	Wildfire Ready Watershed Map of Colorado (Image only)	2022
E12	External	CO-CWCB	Colorado Basin Implementation Plan (BIP) Vol.2 - Full Length Plan	2022
E13	External	CO-CWCB	Colorado Water Plan (state)	2023
E14	External	Orange County Fire Authority	Orange County County-wide Community Wildfire Protection Plan (CWPP)	2017
E15	External	Riverside County Fire Dept	CAL FIRE/Riverside County Fire Unit Strategic Fire Plan	2022
E16	External	San Bernardino Inyo and Mono Counties	San Bernardino Inyo Mono Unit Strategic Fire Plan	2022
E17	External	Ventura County	Ventura County Community Wildfire Protection Plan	2010
E18	External	San Diego and Imperial Counties	San Diego Imperial Unit Strategic Fire Plan	2022
E19	External	SCE	Southern California Edison Climate Adaptation and Vulnerability Assessment	2022
E20	External	CA-CEC	Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Options for San Diego Gas and Electric	2018
E21	External	SDGE SoCalGas	Risk Assessment and Mitigation Phase (RAMP) Report of San Diego Gas and Electric and Southern California Gas Company	2016
E22	External	SDGE	San Diego Gas and Electric Sustainability Update	2022
E23	External	SDGE	San Diego Gas and Electric RAMP Climate Change Adaptation Chapter	2016
E24	External	CA-CEC	Potential Climate Change Impacts and Adaptation Actions for Gas Assets in the San Diego Gas and Electric Company Service Area	2018
E25	External	SoCalGas	Case Studies of Natural Gas Sector Resilience	2019
E26	External	SMB GSA	Santa Monica Subbasin Groundwater Sustainability Plan	2022

Doc #	Source	Context	Document Name	Year
E27	External	SB GSA	Spadra Basin Groundwater Sustainability Plan San Gabriel Valley	2022
E28	External	SPVB GSA	San Pascal Valley Groundwater Sustainability Plan	2021
E29	External	Eastern Municipal Water District	Groundwater Sustainability Plan for the San Jacinto Groundwater Basin	2021
E30	External	Pauma Valley GSA	Upper San Luis Rey Valley Groundwater Sustainability Plan, Pauma Valley, SD County	2022
E31	External	Fox Canyon GMA	Pleasant Valley Groundwater Sustainability Plan	2019
E32	External	Fox Canyon GMA	Las Posas Valley Groundwater Sustainability Plan	2019
E33	External	Fox Canyon GMA	Oxnard Subbasin Groundwater Sustainability Plan	2021
E34	External	CA-DWR	Draft Environmental Impact Report for Long-Term Operation of the California State Water Project	2019
E35	External	CA-DWR	Appendices for the Draft Environmental Impact Report for the Long-Term Operation of the California State Water Project	2019
E36	External	CA-CEC	Mean and Extreme Climate Change Impacts on the State Water Project	2018
E37	External	Orange County	County of Orange & Orange County Fire Authority Local Hazard Mitigation Plan - public review draft	2021
E38	External	CA-DPH	Climate Change and Health Profile Report, Orange County	2017
E39	External	LA County	Los Angeles County Climate Vulnerability Assessment	2021
E40	External	San Bernardino County	County of San Bernardino Climate Change Vulnerability Assessment	2018
E41	External	San Diego County	County of San Diego Vulnerability Assessment and Adaptation Report	2021
E42	External	Ventura County	Ventura County General Plan Climate Change Chapter, Section B.2 Climate Change Adaptation and Resilience Strategy	2018
E43	External	Watersheds Coalition of Ventura County	Appendix L: Watersheds Coalition of Ventura County Integrated Regional Water Management Plan - 2019 Amendment Climate Change Vulnerability Assessment	2019
E44	External	Western Riverside Council of Governments	Vulnerability Assessment, Western Riverside County	
E45	External	Fire River Land Trust	After the Burn: Emergency Response, Feather River Fire Response Plan	2020
E46	External	USGS	Watershed Scale Response to Climate Change - Feather River Basin, California	2004
E47	External	Gershunov et al.	Precipitation Regime Change in Western North America: The Role of Atmospheric Rivers	2019
E48	External	Smith et al.	Wildfire Effects on Water Quality in Forest Catchments: A Review with Implications for Water Supply	2011
CE49	External	U.S. Bureau of Reclamation	American River Basin Study	2022
E50	External	U.S. Bureau of Reclamation	American River Basin Study Appendix B: Development of Future Climate and Hydrology Scenarios	2022

Doc #	Source	Context	Document Name	Year
E51	External	Delta Stewardship Council	A Risk Management Approach to Delta Water Supply Vulnerability	2019
E52	External	Dettinger et al.	Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900-2099	2004
E53	External	Ficklin et al.	Effects of projected climate change on the hydrology in the Mono Lake Basin, California	2012
M01	Internal	Metropolitan	Climate Action Plan	2021
M02	Internal	Metropolitan	Energy Sustainability Plan - Volume 1	2020
M03	Internal	Metropolitan	Energy Sustainability Plan – Volume 2	2020
M04	Internal	Metropolitan	Hydroelectric Feasibility Study	2010
M05	Internal	Metropolitan	Integrated Resource Plan; Phase 1: Regional Needs Assessment	2020
M06	Internal	Metropolitan	Urban Water Management Plan (2015)	2016
M07	Internal	Metropolitan	Urban Water Management Plan (2020)	2021
M08	Internal	Metropolitan	Energy Management and Reliability Study	2010
M09	Internal	Metropolitan	Resource Vulnerability Study	2020
M10	Internal	Metropolitan	Strategic Asset Management Plan	2021
M11	Internal	Metropolitan	System Reliability Study	2006
M12	Internal	Metropolitan	Fire Management Plan for Lake Mathews	1994
M13	Internal	Metropolitan	Water Shortage Contingency Plan	2021

Appendix B

Deep-Dive Surveys

SUSTAINABILITY
RESILIENCE
INNOVATION

CAMP4W and the Water Energy Climate Sustainability (WECS) Core Team Meeting

Name | *Title* | *Department*

AGENDA:

1. Welcome & Introductions (10 minutes)
2. Purpose of Climate Vulnerability Risk Assessment and of this meeting (15 minutes)
3. Review Survey Results (15 minutes)
4. Overview of discussion questions (5 minutes)
5. Lunch (30 minutes)
6. Discussion
   1. Impacts of more frequent climate extremes (10 minutes)
   2. Prioritizing vulnerabilities (10 minutes)
   3. Actions (20 minutes)
   4. Constraints & Barriers (20 minutes)
7. Review and Wrap-up (15 minutes)

Survey Questions

What is the most significant climate extreme-related disruption to Metropolitan's water quality facilities/operations that you have observed in the past five years?

What is the most significant climate extreme-related disruption to Metropolitan's water quality facilities/operations that you foresee in the next five years and beyond?

Visioning Future Climate Impacts:

If climate extremes become more frequent and intense, what would the effects be on Metropolitan's WQ facilities and operations?

Prioritizing Vulnerabilities:

Order the vulnerabilities we have discussed from highest to lowest priority

Short- and Long-Term Actions:

What are some short term actions Metropolitan can take to address priority vulnerabilities?

What are some long-term actions Metropolitan can explore to address priority vulnerabilities?

Key Constraints and Barriers:

What are the key constraints and barriers to implementing short and/or long-term actions?

CAMP4W and the Water Energy Climate Sustainability (WECS) Core Team Meeting

SUSTAINABILITY RESILIENCE INNOVATION

Name | *Title* | *Department*

AGENDA:

1. Welcome & Introductions (10 minutes)
2. Purpose of Climate Vulnerability Risk Assessment and of this meeting (15 minutes)
3. Review Survey Results (15 minutes)
4. Overview of discussion questions (5 minutes)
5. Lunch (30 minutes)
6. Discussion
   1. Impacts of more frequent climate extremes (10 minutes)
   2. Prioritizing vulnerabilities (10 minutes)
   3. Actions (20 minutes)
   4. Constraints & Barriers (20 minutes)
7. Review and Wrap-up (15 minutes)

Survey Questions

What is the most significant climate extreme-related disruption to Metropolitan's power facilities/operations that you have observed in the past five years?

What is the most significant climate extreme-related disruption to Metropolitan's power facilities/operations that you foresee in the next five years and beyond?

Visioning Future Climate Impacts:

If climate extremes become more frequent and intense, what would the effects be on Metropolitan's power facilities and operations?

Prioritizing Vulnerabilities:

Order the vulnerabilities we have discussed from highest to lowest priority

Short- and Long-Term Actions:

What are some short term actions Metropolitan can take to address priority vulnerabilities?

What are some long-term actions Metropolitan can explore to address priority vulnerabilities?

Key Constraints and Barriers:

What are the key constraints and barriers to implementing short and/or long-term actions?

Appendix C

Deep-Dive Meeting Notes (Water Quality Design Charrette Summary, Water and Energy Design Charrette Summary, Asset Management Charrette Summary)

Water Quality Design Charrette Summary

Meeting Details:

Location: Weymouth Water Treatment Plant

Date/Time: July 26, 2023, 12:00 PM – 2:30 PM

Attendees: water quality leads, water treatment facility managers, research leads, compliance leads, process leads

Key Themes/Takeaways:

There are numerous potential water quality impacts associated with climate change building on the issues that staff are already contending with. In any given year, staff must balance a range of source water quality characteristics based on climate conditions, hydrology, and other factors. There is a certain amount of flexibility built into Metropolitans system that enables staff to balance conditions, such as alkalinity, turbidity, heavy metal accumulation, emerging contaminants and regulations, harmful algal blooms, etc. This flexibility is limited by the capability of chemical processes, infrastructure connectivity, infrastructure investment, and the physical capacity of its various facilities. There was consensus among charrette participants that climate change is likely to amplify the range of different water quality characteristics in a given year, which will make operations more challenging in the future. It is also possible that more extreme conditions may exceed the infrastructure's capability and staff's ability to balance the water quality characteristics of different flows across its system. Additionally, increased pressures are being placed on Metropolitan's, member and neighboring agencies/facilities that are forced to shut down or don't have capacity to build in added resilience to climate change. Climate change may push needed investment past what is required for general operations and maintenance and instigate a need for capital investment in additional infrastructure. Furthermore, water quality regulatory standards have been becoming more stringent over time and this trend is expected to continue, which will make it more difficult to balance the source water and storage-based water quality conditions. In the future it will be critical to identify impacts and to build specific protections around the direct and cascading impacts associated with climate change.

Survey Question Summaries:

12 distinct respondents from both the survey and charrette worksheets.

Climate Impact Experience

What is the most significant climate extreme-related disruption to Metropolitan's water quality facilities/operations that you have observed in the past five years?

Key Climate Hazards:

a. Severe Storms/Elevated Runoff n=7 response
b. Warming/Extreme Heat n=4 responses
c. Wildfire n=4 responses
d. Drought/Extreme Drought n=3 responses

Notes: majority consider sever storm and associated runoff to be the most significant climate related impact.

Key Impacts:

e. Severe Storms/Elevated Runoff
    i. **Inflows after wildfire with elevated turbidity**. Severe storms following wildfire have resulted in record high turbidity events as runoff carries loose sediment into source water reservoirs. Turbidity increases brings concerns regarding microbial indicators and pathogens, such as Cryptosporidium. High turbidity water requires additional coagulant and longer sedimentation times. This resulted in the WTP needing to be operated far outside its design specifications and required solutions to novel problems to keep the plant online and meeting water quality objectives (ex. Castaic Lake experienced increased turbidity and coliform levels).
    ii. **Wastewater overflow from treatment plant**. Partially treated wastewater ended up in Silverwood Lake as a result of overflow during a severe storm (atmospheric river event).
    iii. **Elevated runoff into source tributaries/reservoirs**. Extreme storms events have resulted in elevated runoff into source water reservoirs. That runoff brings additional contamination and turbidity.
    iv. **Large volumes of snow and fast melting from higher temps** has resulted in large volumes of low alkalinity water during very wet years (like 2023). This impacted treatment operations and inorganic analysis of WQ. Low alkalinity water is more difficult to treat, makes it harder to remove turbidity, and increases the corrosiveness of the water. To date, the District has been able to maintain alkalinity levels within its standards by blending low alkalinity water with higher alkalinity water from the CRA. Lake Perris, which is where MWD received water from the SWP is a critical point in the system. It can be affected by harmful algal blooms, which could, among other implications, make it more difficult for staff to manage low alkalinity.
    v. **Regulatory impacts.** Current water quality regulations don't account for conditions associated with climate change**.** Sample analytical lags, new analytical procedures, sample locations and detection limits are getting more difficult to manage.

f. Warming/Extreme Heat
    i. **Increased water temperatures support bacterial/algal growth.** Warmer waters support increased growth of microbes and algae which can increase contaminants including algal toxins, and cause odor and taste issues. There has been increased cyanobacteria blooms this year. These impacts in turn increase treatment costs. Lake Perris has historically been affected by harmful algal blooms (there was a Cyanobacterial bloom this year, 2023).
    ii. **Power disruptions and load shedding during heat waves** can result in O_3 plant shutdown in order to save electricity. O_3 not wired to emergency power. The treatment facilities rely on a significant amount of power to operate.

g. Wildfire
    i. **Taste & odor issues**.
    ii. **Increased turbidity.** See Severe Storms/Elevated Runoff section above.
    iii. **Danger, road access, and poor air quality affecting WTP staff/operations.** Nearby wildfires caused poor air quality at the WTP and in the control rooms. The wildfire

resulted in a) staff not being able to access the plant due to road closures, and b) concerns for staff safety and the potential to evacuate/abandon/shut down the plant.

h. Drought/Extreme Drought
   i. **Reduced supply leading to higher Total Dissolved Solids/Electrical Conductivity**. Reduced/low water supply conditions combined with increased demand from customers, more pump-in waters, and higher salinity water results in treatment challenges due to high TDS/EC.
   ii. **Increased bromide impacting Disinfection Byproducts (DBP) analysis**. During drought events high bromide results from the SPW were observed which impacted the analysis of DBPs (THMs, HAAs, and bromate).
i. General Impacts/Trends:
   i. **Multiple events can overwhelm capacity**.
   ii. **Increased nutrients and contaminants in source waters**.
   iii. **Highly variable water supplies** resulting in:
      1. Operating facilities at very high or very low flows,
      2. Increased nitrification in low flow areas, and
      3. Keeping equipment in operable condition when it is not used for years at a time.
   iv. Regulatory impacts- Groundwater pumping results in increased arsenic levels. MCL for arsenic continues to drop down towards detection levels.
j. Structural:
   i. **No real time data**. It takes 3 days to test water after sample collection.
   ii. **Increased turbidity requires increased coagulant to remove**.
   iii. **Decreased water demand and impacts from an increase in lower flow conditions.**
      1. Lower flows through plants requiring replacement of equipment that can adjust flows and feed chemicals at a greater turndown.
      2. Lower flow through piping and reservoirs creating decay in water quality (nitrification & lower disinfection residuals).
      3. Equipment and facilities out of service and dry for longer periods of time causing UV degradation and drying out of materials.
      4. Systems are sized for large quantities of water. Treated water has a shelf life, when water sits in the system it degrades and must be repumped through treatment.
      5. Requires internal system redundancy or connectivity for source water
   iv. **Neighboring water agencies could “go down”**.
   v. **Member Agencies purchasing less MWD treated water**.

Anticipated Climate Impacts

What is the most significant climate extreme-related disruption to Metropolitan’s water quality facilities/operations that you foresee in the next five years and beyond?

Key Climate Hazards:

a. Severe Storms/Elevated Runoff n=6 responses
b. Drought/Extreme Drought n=5 responses

c. Warming/Extreme Heat n=3 responses
d. Wildfire n=1 responses

Anticipated Future Impacts:

e. Severe Storms/Elevated Runoff
   i. **Extreme precipitation events**
   ii. **Flooding**
f. Drought/Extreme Drought
   i. **Extreme droughts**
g. Warming/Extreme Heat
   i. **Harmful algal and cyanobacterial blooms**
   ii. **Work delays due to extreme heat**. Challenges to completing operations and maintenance work during the summer due to higher temperatures.
h. Wildfire
   i. **Increased turbidity after wildfire and storms**. Compounds severe storm/elevated runoff risk
i. General Impacts/Trends
   i. **Demand shifts**. Increase in water conservation causing longer water age in the distribution system that's designed for higher demand.
   ii. **"Weather Whiplash" and seasonal extremes**. Increase variability in precipitation, including more frequent prolonged dry spells and atmospheric rivers, creating more inconsistency in supply volume and water quality, requiring more flexibility in treatment to address the different issues that arise. This may compound with seasonal extremes such as higher temperatures and heat waves in the summers.
   iii. **Increased water quality issues.** Increases in turbidity, bacteria, algae, salinity. Drops in alkalinity. Changes to lake patterns. Increased salinity of CRW. Changes to Water Quality due to conditions changing in Lake Mead.
   iv. **Difficulty forecasting equipment and facility needs**. Source water changes and varying water demands with the complication of forecasting the proper equipment and facility needs to move and treat the water within our existing system.
   v. **No deoxygenation at lower levels of Perris**. Links to other issues. Allowable manganese levels. Arsenic, PFAS, perchlorate all are more tightly regulated.
   vi. **Non emergency impacts**. Variability related to climate change may not necessarily be considered an emergency but still require added investment to manage/mitigate. Difficult to justify investment for non emergencies.
j. Structural
   i. Ability to fund all desired Capital Improvement Projects
   ii. Ability of the system as configured to handle increased variability and various types of water quality impacts happening concurrently
   iii. Power disruptions can halt ozone treatment and other critical processes
   iv. Chemical suppliers must be certified creating a weak point in the supply chain. The chemical market is small, chemicals for treatment are produced in Louisiana. When there

are hurricanes it can disrupt the supply chain, potentially causing issues with having adequate chemical supplies.

Increased Future Climate Impacts

If climate extremes become more frequent and intense, what would the effects be on Metropolitan's WQ facilities and operations?

Anticipated Future Impacts:

a. Extreme Heat
    i. **More frequent Power disruptions impacting treatment**. Grid capacity issues requiring MWD to shed power, stopping ozone treatment of water.
    ii. **Increased temps leading to increased microbial growt**h. Increased water temperature leads to increased algae blooms, increased algae toxins, increased oxygenation issues, increasing treatment requirements and costs. There is huge potential to disrupt operations if key reservoirs are very significantly impacted.
b. General Impacts/Trends
    i. **Variability in water supply quantity and quality**. Changes in water quality can be sudden and extreme (such as with turbidity, algae, and bacteria). Treating low flows is very difficult, as is differing water quality (need chemical feed system adjustments (mixing)). The lack of consistent and reliable water supply creates most of the WQ issues identified.
    ii. Changes in demand. Low demand of water = nitrification in distribution system
    iii. **Extended detention times to address water quality deterioration**.
c. Structural
    i. **System Flexibility**. The system is built for specific quality and quantities of water. It has been flexible enough for staff to find solutions when challenging conditions occur. However, the future system may need additional flexibility in order for staff to handle future extremes and amplified water quality impacts.
        1. Climate change impacts are not necessarily related to on single threat. Rather the overall variability related to climate change is the biggest issue.
        2. Low demand of water = nitrification in distribution system
        3. Lack of available storage. Insufficient reservoir storage.
        4. Turn down of plants, chemical feed systems. Turn down is 10:1, while 20:1 is what is needed.
        5. Treatment ability for end limit capacity (high and low). Rated capacities.
    ii. **Member agencies are moving away from Metropolitan water**. Member agencies are purchasing less water treated by Metropolitan; however, they expect Metropolitan to be a backup source of water. This can create large changes in demand in short periods of time.

Priority Vulnerabilities

Charrette Question 2: Order the vulnerabilities we have discussed from highest to lowest priority.

Key Vulnerabilities:

a. **Inconsistent water supply**. Both the amount and consistency of water supply.

b. **Long-term deterioration of water quality**, with the possibility that water sources will never return to “normal”.
c. **Short-term changes in water quality** due to sudden/extreme influxes of water or demand for water.
d. **Power disruption** and grid capacity issues
e. **Flexibility of distribution system**. Limited/restricted service areas from the WTPs
f. **Flexibility of facilities**. Facilities are designed and built for very specific throughputs and have difficulty adjusting to variation.
g. **Approval process for preparation/adaptation**. It is difficult to get approvals for adaptation projects when there is not currently an emergency.
h. **More pump-in activity along the SWP**. Lower quality water (water with elevated contaminants) may enter aqueducts as a result of more frequent drought years.
i. **DPR water sources and unknowns**. MWD will get DPR water in several years, need to figure out how to monitor it.
j. **Ground banked water quality**. New water quality challenges associated with using ‘banked’ groundwater to supplement traditional surface water supply.
k. **Low reservoir levels** can lead to issues with low dissolved oxygen content.
l. **Low alkalinity and reliance on Perris**. Increased instances of low alkalinity water in wet years and a reliance on Perris to deal with low alkalinity. Perris → 4 tiers – deoxygenation

Needs/Proposed Solutions:

m. **Additional source water options** to help adapt to changes in supply related to climate change.
n. **Adapt infrastructure for treatment issues**. Treatment infrastructure adjustments needed to deal with low flows, low alkalinity water, high turbidity, additional regulatory requirements, corrosive (low alkaline) water.
o. **Water quality testing plant**. Ability to develop, test, and pilot new approaches
p. **Equipment readiness**. Need to have equipment ready for various water quality issues.
q. **Facility flexibility**. Need to build in more flexibility into facilities to accommodate fluctuations in water quality, quantity, contaminant levels, turbidity, demand, etc.

Potential Adaptive Actions

Charrette Question 3: What are some short-term actions Metropolitan can take to address priority vulnerabilities?

n=8 responses

Short-term adaptations identified:

a. **Reopen WQ pilot plant/open a demonstration plant.** Develop testing facilities to identify techniques to treat water during extreme water quality conditions and to develop testing for different scenarios in extreme weather. Processes to be investigated include ozone, oxygenation, and how to treat cyanotoxins.
b. **Fund development, piloting, and implementation of new techniques and processes.**
c. **More staffing/redundancy**, flexible staffing that allows response to changes.
d. **Polymer addition for alkalinity.**

e. **Manage variability in the system.**
f. **Prioritization of adaptive infrastructure projects.**
g. **Increasing plant turn down capabilities.**
h. **Change water rate structure.**
i. **Real-time monitoring** to help treatment process match and adjust to changing water quality.

What are some long-term actions MWD can explore to address priority vulnerabilities?

Long-term adaptations identified:

a. **Develop more options for water sources and water treatment.**
b. **Develop more flexibility in conveyance and distribution of treated water.**
c. **Pilot plant to test treatment chemicals.**
d. **Systems specific and facility specific vulnerability assessments,** including assessments of different reservoirs and water treatment plants.
e. **Additional ancillary WTPs to handle high or low demand.**
f. **Prioritize resiliency** in projects, processes, and research.
g. **Booster chlorination in distribution system**
h. **"Looping system"**
i. **Develop vulnerability analysis on a per system basis to better understand needs**
j. **Infrastructure adaptation projects.**
k. **Water monitoring** to manage the variability that comes with flexibility in source water. Tracking water quality as more groundwater recharge and ground banking occurs.

Constraints and Barriers to Adaptation

What are the key constraints and barriers to implementing short and/or long-term actions?

Barriers and Constraints on Adaptation:

a. **Staffing.** Do not have enough redundancy in staff. Need enough staff with the right expertise.
b. **Funding.** Inadequate funding for projects and process improvements. Many adaptation projects have a long time before there is a return on investment.
c. **Future Member Agency violations -** support
d. Political will.

Additional Notes:

- Chemical supply costs are impacted by weather.
- The distribution system cannot take full supply.
- Metropolitan acts as an insurance company.
- Member agencies are choosing lower cost water options rather than water from Metropolitan, but at the cost of depleting groundwater.

Water and Energy Design Charrette Summary

Meeting Details:

Location: Room US.2-450

Date/Time: July 24, 2023; 11:00 AM – 1:30 PM

Invitees: Water Energy Climate Sustainability Core Team Members

Key Themes/Takeaways:

Metropolitan's energy context is changing rapidly based in part on California's electrification initiatives and the increasing scale of climate change impacts on the energy system. Metropolitan requires a significant amount of energy to deliver water to its Member Agencies. The Colorado River Aqueduct (CRA) pumping operation represents the largest proportion of Metropolitan's energy needs (~98%). Historically, hydropower produced at Lake Mead and Lake Powel have provided about half of the CRA's energy needs. However, in recent decades, water levels within Lake Mead and Lake Powell have been declining and water managers are increasingly concerned that the reservoirs could fail to reach 'minimum power pool' levels – where water could drop below the hydropower intakes, preventing energy generation altogether. Lower reservoir levels have already required Metropolitan to purchase more of its electricity from the open market, which is more expensive and carbon intensive. Future climate conditions and increasing electrification of operational infrastructure are likely to increase demands from the grid, which could result in higher energy costs and more frequent power disruptions. More frequent and severe extreme heat events, floods, and wildfires associated with climate change are likely to create additional vulnerabilities to Metropolitans purchased energy and its energy infrastructure which includes a high-voltage transmission across the desert.

Key vulnerabilities identified by design charrette participants included lack of diversity and resilience in sources of electricity, variability in and increasing electricity costs, and workforce issues including too few staff in some areas, lost institutional knowledge, and not enough redundancy. Potential adaptive actions identified during the charrette that could take place in the short-term included: building more Battery Storage, hiring emergency contractors, or retaining retiring workforce, workforce training, peer to peer learning with other utilities, and an internal education campaign to garner support from staff and the Board to implement strategic adaptation measures. Long-term adaptive actions identified by charrette attendees included: proactively identifying and addressing weak points in MWD systems, rebuilding transmission systems, diversification of energy sources, upgrading to variable speed pumps, developing new ways to fund adaptation projects, in line energy storage, and modifications to MWD's rate structure. Key identified operational constraints include: a procurement process that is struggling to keep pace with the rate of climate change, an increasing Capital Improvement Projects (CIP) budget, and staffing shortages (particularly on the CRA).

Survey Question Summaries:

Session invitees were provided with a survey in advance of the session. Session participants were provided with a paper version of the survey. Staff received 17 distinct respondents from both the survey and charrette worksheets, which are referenced in the sections below.

Climate Impact Experience

What is the most significant climate extreme-related disruption to Metropolitan's power facilities/operations that you have observed in the past five years?

Key Climate Hazards:

k. Extreme Heat	n=7 responses
l. Drought/Extreme Drought	n=5 responses
m. Wildfire	n=3 responses
n. Flooding	n=1 response
o. Cold	n=1 response

Key Impacts:

p. Extreme Heat
   i. **Decreased pumping:** Increased energy demand during heat waves, for example, in August 2020, CAISO issued Energy Emergency Alerts resulting in Metropolitan reduced pumping on the CRA in order to support the alleviation of constrained capacity conditions of the power grid. Energy Emergency Alerts are often coordinated, and responses can be mitigated at Copper Basin, for example, where pumping was reduced to shed 150 MW of power. There can also be financial reasons to reduce power loads under these conditions due to the wholesale price of energy.
   ii. **Power outages**, power grid capacity issues, especially when extreme heat events last for long periods of time.
   iii. **Electricity rate spikes**/increased costs during periods of high demand.
   iv. **Pausing ozone disinfection:** Ozone disinfection is stopped for specific periods of time to reduce water treatment plant energy demand.

q. Drought/Extreme Drought
   i. **Reduced supply of hydroelectricity.** Reduced water in the Colorado River and Lake Mead behind the Hoover Dam leads to reduced hydroelectricity production. This directly impacts the operation of CRA pumping plants or requires that Metropolitan spend more on wholesale power to make up the difference.
   ii. **Increased need to pump.** Low hydropower capacity is often associated with periods of higher demand for CRA water. This is associated with the larger drought context. When SWP supplies are low (i.e., during multi-year droughts) Metropolitan Member Agencies tend to rely more on water provided through the CRA.
   iii. **Increased electricity cost.** Wholesale energy prices can become very high in the summer months, particularly during extreme heat events. This can create a financial burden for Metropolitan, particularly if hydropower generation is limited at Lake Powell and Lake Mead.

r. Wildfire
   i. **Power outages prevent EV charging.** Public Safety Power Shutoffs (PSPS) due to high wildfire risk conditions, can lead to power outages that electric vehicle fleet recharging, and may be particularly problematic if there has not been enough notice to charge vehicles ahead of time or if there isn't onsite battery storage.

s. Flood
    i. No specific impacts mentioned in responses.
t. Cold
    i. **Electricity rate spikes**. Electricity rate spikes that can occur during cold periods.

Anticipated Future Climate Impacts

What is the most significant climate extreme-related disruption to Metropolitan's power facilities/operations that you foresee in the next five years and beyond?

Key Climate Hazards:

k. Extreme Heat n=6 responses
l. Wildfire n=5 responses
m. Drought/Extreme Drought n=5 responses
n. Extreme precipitation/flooding n=4 responses
o. Cold/Extreme Cold n=2 responses

Anticipated Future Impacts:

p. Extreme Heat
    i. **Increasing strain on/disruptions to electrical grid**.
        1. **Compounded by increasing electrification** efforts, further increasing the frequency of capacity deficits, affecting both retail and wholesale power.
        2. **More frequent disruptions to pumping** as a result of grid capacity issues requiring reduced power demand.
    ii. **Extended use of backup power.** Grid-related shortages may cause MWD facilities to operate on backup power systems for extended periods of time (2-3 days or more).
    iii. **Heat illness risks to staff.** Future increases in extreme heat events may result in increased risk and incidence of heat stress and exhaustion of Metropolitan staff, particularly in the desert, Inland Empire, and Jensen areas while performing operations and maintenance work.
    iv. **Power disruptions along the CRA.** A catastrophic loss of power to any of the CRA pump station facilities would trigger an uncontrolled release of water, which has regulatory compliance implications.
q. Wildfire
    i. **Infrastructure-based Power Disruptions**. Wildfire may damage electrical infrastructure such as transmission lines, causing power outages.
    ii. **More Frequent PSPS's**. As severe wildfire conditions become more frequent, PSPS's may become more frequent, affecting MWD power system operations and the SWP. PSPS's could also knock out Member Agency local supplies placing a sudden large demand on MWD treatment plants and distribution system.
r. Drought/Extreme Drought
    i. Power generation from Hoover/Parker Dams is threatened.
    ii. Decreased pumping. When Lake Mead/Hoover is full it can provide up to 5 pump flow. Currently they can only provide 4 pump flow, requiring purchase of more supplemental power. This could become further constrained in the future.

s. Extreme precipitation/flooding
    i. **Power Disruptions.** More frequent disruptions to power grid.
    ii. **SWP salinity issues.** Extreme flooding in the Delta could knock out the SWP for months to years due to lingering elevated salinity levels.
t. Cold/Extreme Cold
    i. **Increased energy costs.** Periods of high-priced power in cold winters when natural gas prices are high.

Increased Future Climate Impacts

If climate extremes become more frequent and intense, what would the effects be on Metropolitan's power/WQ facilities and operations?

Key Climate Hazards:

d. Drought n=2
e. Flooding n=2
f. Extreme Heat n=1

Anticipated Future Impacts:

g. Drought
    i. **More Damage to energy infrastructure**. This could also include increased operations and maintenance costs and other types of capital expenses.
    ii. **Increased cost of power.** Decrease or loss of hydroelectricity production would result in MWD having to purchase power, increasing electricity costs.
        1. **Cascading impact: Increased water prices**. Having to purchase more power on the open wholesale market could contribute to further rate increases.
h. Flooding
    i. **CRA infrastructure damage.** Desert flash floods cause issues with the canal and the desert power infrastructure, CRA erosion. This may become more likely if storms become more frequent and extreme.
    ii. **Response and recovery costs.** Things like purchasing sandbags, mitigation erosion and scouring, etc. can be expected to occur more frequently.
i. Extreme Heat
    i. **Increased need for wholesale energy needs** in order to offset reduced hydropower generation at Lake Powell and Lake Mead.
    ii. **Fuel pump issues.** Conditions could exceed operational thresholds.
j. Not hazard-specific impacts:
    i. Power outages
    ii. Microbursts/extreme wind events
    iii. Required to reduce number of pumps in operation at intake and Gene, could cause catastrophic failure.
    iv. More restricted CRA flows
    v. Inflexibility with CRA operations also PURE

Priority Vulnerabilities

Order the vulnerabilities we have discussed from highest to lowest priority.

Key Vulnerabilities:

r. **Loss of power/more expensive power** – CAISO capacity issues in CA, surge prices. Loss of hydroelectricity → Lake Mead hitting Deadpool/below minimum power pool would be catastrophic, still likely to decline. Less power production from Hoover and Parker Dams.

s. **Workforce issues:**
  i. Constraints
  ii. Security
  iii. HVCA for CRA facilities
  iv. Only 5 linemen
  v. Availability of contractors

t. **Extreme heat events**

u. **Flooding/flash floods and extreme flooding**

v. **Drought**

w. **Extreme weather events (various)**

Potential Adaptive Actions

What are some short-term actions that Metropolitan can take to address priority vulnerabilities?

Short-term adaptations identified:

j. **Battery Storage.** Hedging → Building more and larger battery storage areas to store power generated. (currently have 3: Skinner, Jensen, Weymouth)

k. **Workforce flexibility.** Emergency contractors in place for power or retain retirees.

l. **Workforce training.** Increased training on how to address impacts from different extreme weather events.

m. **Peer to peer learning.** Facilitate discussions with other utilities, partners, and peer groups, perhaps in Australia or Israel, to understand how adaptation is approached and energy costs are managed/offset. Perhaps discuss desalination projects?

n. **Fuel pump vapor locks** that can better function under higher temperature conditions.

o. **Education campaign.** Share experiences, forecasts, challenges and opportunities with Board members and employees to get people on board.

What are some long-term actions that Metropolitan can explore to address priority vulnerabilities?

Long-term adaptations identified:

p. **Proactively identifying weak points in MWD systems.** Identify and address or prepare for likely points of failure. For example, a transmission system failure along the CRA could take many months to restore power.

q. **Rebuild transmission systems.** Consider revisiting design parameters for more extreme future conditions.

r. **Diversification of energy sources**. Consider spreading risk across different energy sources.
s. **Increased role in the wholesale energy market**. Explore the possibility of generating power that could either be used by MWD or sold on the wholesale market. This could provide direct resilience benefits as well as financial benefits.
t. **Opportunities to connect to the CRA system**. Explore the possibility of allowing energy producers to connect to CRA high-voltage transmission lines. This opens up opportunities to potentially fund CIP projects through associated fees and secure PPAs to better control energy costs.
u. **Variable Frequency Drives (VFDs).** Explore energy efficiency options by employing VSD pumps, which could theoretically achieve the same flow using less power.
v. **Budgeting for adaptation projects.** Consider the effect of climate change on future operations and maintenance budgets.
w. **In line storage.** Opportunities to increase storage across Metropolitan water conveyance and distribution systems.
x. **Flexibility in MWD's rate structure** in order to unlock additional investment opportunities that are currently constrained.
y. **Power Purchase Agreements** could help to control likely substantial increases in future energy prices.
z. **Uninterruptible Sources of Power/Diversification** in order to minimize the impacts of localized power outages.

Constraints and Barriers to Adaptation

What are the key constraints and barriers to implementing short and/or long-term actions?

Barriers and Constraints on Adaptation:

e. **Slow procurement process.** The procurement process is at least 2 years, but conditions are changing faster than that and expected to further intensify as a result of climate change.
f. **Gaps in knowledge**.
g. **Linking CIP & rates**. There is a perception that projects are desire-based. Establishing a clearer link between resilience benefits of CIP projects and climate risks to delivery of service.
h. **Design and spatial constraints.** Ex: variable speed pumps → could upgrade fixed speed pumps; however, intake of the drive is difficult in certain areas, currently not enough space to build them in → MWD would risk spillage because there isn't unlimited storage down river.
i. **Power cost and availability.** Government sometimes requires reduction in power usage. CAISO power can be expensive.
j. **Converting from analog to digital.** The CRA is largely an analog system, which is becoming more difficult to maintain and can constrain employing technologies and methodologies that are digital.

Additional Recorded Notes:

- How to be more agile and adaptive?
- How is MWD expressing value?
- Back to the key why for Metropolitan - making sure core functions are resilient
- Cost center → profit center
- Diversification → uncertainty
- low-cost flexibility
- monetize transmission (capacity, premiums[?])
- energy contracts for power

Asset Management Charrette Summary

MEETING DETAILS:

Location: Weymouth Treatment Plant, Water Quality Lab

Date/Time: January 31, 2024; 11:30 AM – 1:00 PM

Invitees: Ricardo Hernandez, Victor Erikson, Courtnay Roland, Alan Villaverde, Silvia Lanza, David Sadamoto, Amparo Munoz, Christopher Gabelich, Adrian Hightower, Eric Vaughan (Rincon)

KEY THEMES/TAKEAWAYS:

Data is not currently managed in a way that is consistent at the organizational level. As a result, it is difficult to track trends, understand how conditions may change in the future, and how asset management may need to adapt as the climate changes.

Maximo is significantly underutilized. Data is largely managed differently by different departments. There are numerous work arounds in order to simplify work flows (e.g., scheduling and tracking PM, tracking condition assessment data, etc.

There is need to develop more collaborative work flows for managing the life of assets and connecting all the associated asset data. Without this, there is a risk of missing key trends in asset condition and how asset management is resourced.

The group seems to have a good vision for a holistic system that identifies key risks, tracks changes in the condition of assets over time, and informs the CIP selection process with this information, but would need a broader mandate to execute this vision and possibly changes in how asset management is resourced.

MEETING NOTES:

Adrian began the discussion by reviewing the CAMP4W process and how the CVRA is supporting it.

Staff have developed a risk scoring rubric and tool connected with the capital project submission process. The idea behind the scoring rubric is to incorporate risk reduction into the prioritization process. This could be an effective way to reduce risk over time.

One of the key identified challenges to the risk scoring rubric is the consistency of the data. How can the data be consistently applied when different staff and individual perceptions of risk may make it difficult to effectively evaluate risk to individual project submissions. That has resulted in skepticism about the effective use of the tool.

One solution that was attempted in the most recent CIP cycle was to review each submission and to request edits to the scoring as needed. This ideally should make the data a little more consistent through review. However, the scoring has not, to date, been used in the prioritization process.

Asset Management is currently working with a consultant to run an optimization routine on the latest set of projects to determine how to maximize risk reduction given budgetary constraints (max annual spending limits) and potentially resource constraints.

Staff discussed issues with the alignment of data between different departments. They reported that, in general, most departments keep their own information and this is often done in different ways. For example, engineering data is organized by project and this is where you can find the design specs, submitted preventative maintenance requirements, etc.

Staff discussed that there is not a one-to-one relationship between physical and virtual assets. In an ideal scenario, there is a direct match between these, but this is not the case. One of the main reasons for this is that Maximo is not directly used by all departments. As a result, there is no single depository for asset data.

One of the issues raised is that there is no organization-wide mandate to follow a unified process for developing and maintaining asset data and related information such as condition assessment, work order histories, and time spend on different work orders.

For example, some staff just enter in a general work order and then complete multiple specific work orders. As a result, it is not possible to align time spent on different work orders.

Staff have been conducting criticality assessments at the individual facility scale to identify where single points of failure present the greatest risk of a more systemic failure. This is reported to take several months and gets into very specific detail at the facility scale. This is a potentially interesting process to consider perhaps at a larger scale for the concept of determining points of criticality related to climate extremes.

Staff also mentioned that Veolia (previous work experience) incorporated climate risks into PM/WO scheduling. For example, outdoor work in the summer was scheduled to avoid the heat of the day.

Staff have expended a great deal of effort, including trainings) to secure better use of Maximo, but there has been resistance because some groups prefer alternate approaches, like using an Excel worksheet to track data.

Staff also noted that condition data is very difficult to find. For example, they report that the install dates are typically blank in Maximo. It is difficult to determine some of the most basic condition data within the system. There is desire to be able to use asset data to monitor trends and adjust but this is difficult without

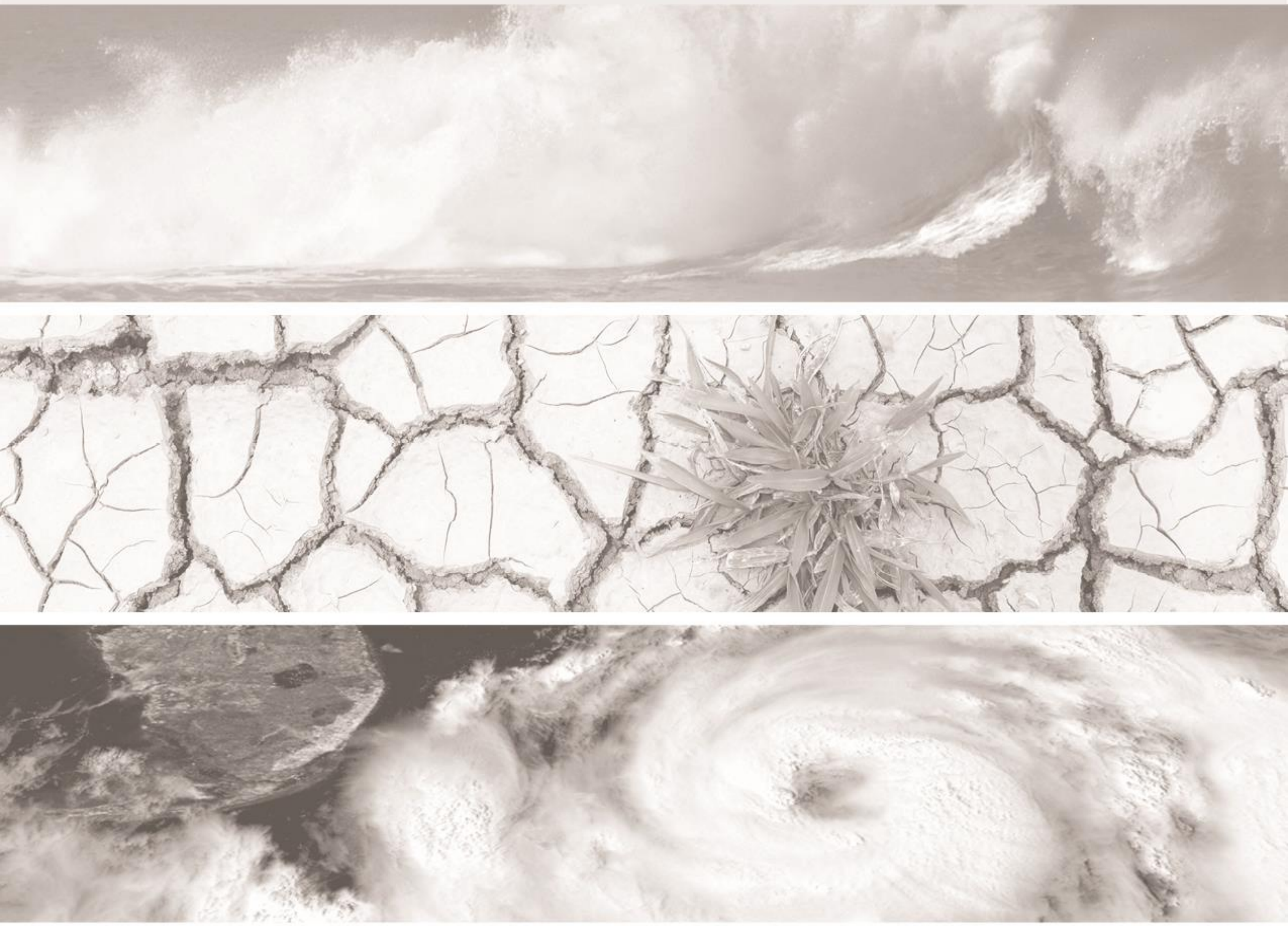
Staff would like to see a uniform approach to asset management so that there is more consistency, it is easier to track information, and make adjustments as conditions change. Staff would also like to see better feedback between the condition of different assets, the risk that R&R needs pose to overall service delivery (i.e. critical points of failure), and how CIP projects are scored/prioritized.

Appendix D

EPA CREAT Report

CLIMATE RESILIENCE EVALUATION AND AWARENESS TOOL (CREAT) EXERCISE REPORT

METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA (MWDSC)



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July 2023

EXECUTIVE SUMMARY

Metropolitan Water District of Southern California (MWDSC) is a regional water wholesaler that supplies water to over 19,000,000 consumers across 26 public water agencies in Southern California. MWDSC works in collaboration with multiple state, tribal, and international authorities in the region to determine water allocations from the Colorado River.

From February through June 2023, representatives from MWDSC participated in a series of calls, webinars, and an onsite visit to conduct a climate change risk assessment. Using the U.S. Environmental Protection Agency (EPA)'s Climate Resilience Evaluation and Awareness Tool (CREAT), MWDSC assessed the resilience of its Colorado River Aqueduct (CRA) system and operations to cascading climate threats. The CREAT assessment brought together individuals from MWDSC and EPA (**Appendix A**: Exercise Participants) to think critically about potential climate impacts, prioritize assets, consider adaptation options, and compare monetized risk reduction across plans and climate scenarios. This exercise served as an introduction to CREAT's capabilities and is expected to provide a foundation for MWDSC to conduct further analysis using the tool.

Figure 1: MWDSC's Iron Mountain Pumping Plant

For the purposes of this exercise, MWDSC examined extreme heat and drought-related risks to power generation as the priority climate threats to the CRA water conveyance system, and how each could negatively impact operational resilience. Both threats were explored under three climate scenarios, accounting for changing climate conditions: a historical baseline climate scenario, a moderately hotter climate scenario, and an extreme heat climate scenario. MWDSC opted to utilize values from CREAT's historical temperature datasets, which featured customized climate metrics. Throughout the analysis, MWDSC considered how changing climate conditions may influence MWDSC's operational resilience and the utility's ability to supply water to its member agencies.

The participants evaluated the effectiveness of existing resilience strategies and technologies, and those identified as feasible options for mitigating risk were then compiled into a Current Measures adaptation plan. Proposed adaptation plans in CREAT are intended to identify strategies that reduce the impact of climate change and improve MWDSC's capacity to respond and recover from these impacts. Ultimately, MWDSC decided upon a Power Upgrades Plan, a Renewable Energy Plan, and a Variable Frequency Drive (VFD) Plan.

MWDSC quantified the reduction in risk from each plan by monetizing consequences and assessing the reduction in risk between climate scenarios and adaptation plans.

The CREAT analysis results suggest that each plan would have a clear range of cost-effectiveness that varies between climate scenarios. In particular, the VFDs and Power Upgrades adaptation plans have the highest proportional risk reduction to plan cost, with an average of >$45 million and >$90 million in potential risk reduction, compared to an annualized implementation costs of under $1 million and $5 million, respectively. The Renewable Energy adaptation plan produces an average monetized risk reduction of >$105 million, but the relatively high annualized plan cost of over $12 million makes choosing to implement the plan less clear for MWDSC, particularly if the utility is uncertain in the climate scenario they are planning for. Additionally, MWDSC may want to evaluate benefits that are not captured under a purely economic analysis to determine the cost-effectiveness and resiliency value of some adaptation plans and climate scenarios. This is particularly relevant for baseline and moderate climate scenarios, which have broader ranges of uncertainty for the return on investment with each adaptation plan. The CREAT assessment conveyed the effectiveness of the tool for resilience planning and demonstrated how MWDSC could run additional CREAT analyses based on future data and anticipated impacts.

SOUTHERN CALIFORNIA

July 2023

BACKGROUND

Utility Overview

Metropolitan Water District of Southern California (MWDSC) supplies water to over 19,000,000 people across 26 individual water agencies in Southern California. MWDSC primarily imports water through the California State-managed State Water Project (SWP), and the Colorado River Aqueduct (CRA), which delivers water through a series of aqueducts from Lake Havasu. Within the CRA, MWDSC has an estimated daily flow of 892.15 million gallons per day (MGD).

MWDSC has concerns about the increasing duration and intensity of extreme heat events over the past two decades in the Southern California region. These extended heat events, in combination with drought, have raised concerns for current water infrastructure and supply methods. In cooperation with state agencies and contractors, MWDSC is currently in the process of assessing system-wide climate vulnerability through a threat gap analysis to improve operational resiliency and planning capacity.

Colorado River Aqueduct Overview

The Colorado River Aqueduct (CRA) is a raw drinking water conveyance system that supplies communities across Southern California. The 242 miles of built aqueduct is supported through five pumping stations and three reservoirs. MWDSC procures much of its energy for the CRA through a combination of long-term power supply agreements with the Hoover and Parker Dam hydroelectric facilities, and procurement from the open electricity market to meet excess demand.

The CRA crosses regions of California experiencing extreme heat which will become worse with climate change, and these challenges are compounded by periodic extreme drought. In addition, water allocations from the SWP can be limited by State water authorities such as the Department of Water Resources (DWR), which increases system reliance on the CRA. Operators and utility staff have expressed concerns that increasing frequency and duration of extreme heat events could threaten operational sustainability and degrade system infrastructure, which is nearing a century of continued use. Failure of certain CRA components due to extreme heat could result in a reduction of available water supply to MWDSC customers.

MWDSC is susceptible to additional reliability challenges as a result of climate change. Water levels within Lake Mead and Lake Havasu are declining and water managers are concerned that the reservoirs could reach ‘dead pool’ levels – where water could drop below the hydropower intakes, preventing the energy turbines from spinning. The threat of ‘dead pool’ conditions is a significant power reliability hazard for the CRA. Lower reservoir levels have already required MWDSC to purchase more of its electricity from the open market, which is more expensive and carbon intensive. These changes have created friction with MWDSC’s carbon emission goals from the utility’s Climate Action Plan. Future climate conditions and increasing grid electrification may increase demands from the grid, which may force MWDSC to reduce or turn off their grid electricity to limit electricity load on the grid and prevent grid strain.

The CRA’s power transmission equipment also faces some significant threats in a changing climate. Originally built in the 1930s and 1940s, some of the transformer equipment relies on older technologies, and is at an operational disadvantage when compared to modern analogs. The needs of the power transmission equipment, and other original equipment along the CRA, require MWDSC to maintain an active backlog of parts that are no longer produced in the event of a component failure, which provides only a limited degree of system resiliency.

ASSESSMENT

Exercise Process

From February through June 2023, representatives from MWDSC participated in a series of webinars and a three day onsite visit to conduct a climate change risk and resilience assessment of potential adaptation plans to mitigate the consequences of climate threats on the CRA. To better understand the potential consequences to the utility's infrastructure and operations, MWDSC assessed threat information using the U.S. Environmental Protection Agency (EPA)'s Climate Resilience Evaluation and Awareness Tool (CREAT)[1]. The CREAT assessment brought together individuals from MWDSC, Rincon Consultants, California Department of Water Resources (DWR), EPA, and the Water Infrastructure Finance and Innovation Act (WIFIA) Center to think critically about potential climate hazards, plan for risk reduction measures, work to quantify potential monetary costs, and explore funding avenues for risk reduction across adaptation plans and climate scenarios (**Appendix A**: Exercise Participants).

CREAT provides climate projection data within a risk assessment framework to help utilities understand climate change, assess risks from climate-related threats, and evaluate potential adaptation options for implementation. Within CREAT, users assess consequences from climate-related threats that can impact utility assets and operations and assess the benefits of implementing adaptation options to protect those assets and operations. At the end of a CREAT assessment, users can explore monetary values that compare the risk reduction obtained by implementing adaptation plans against the cost of implementing the adaptive measures. As a decision support tool, CREAT also enables users to evaluate the likelihood of climate change scenarios occurring and how that can affect the cost-effectiveness of adaptation options. The results of a CREAT assessment provide information utilities can use to inform future investments and long-term planning.

CREAT Assessment

To begin the CREAT process, the MWDSC team defined seven current climate concerns that have the potential to shape the agency's resiliency planning for the exercise:

- **Water Supply Management** – Ensuring the supply of water from the CRA system is delivered efficiently and cost-effectively and will not impact the financial bottom line of MWDSC under alternate climate scenarios.
- **Interdependent Sector Reliability** – Relations between the CRA and infrastructure that it depends on, as well as infrastructure that depends on it (e.g., pumping stations, Parker/Hoover dams.)
- **Ecosystem / Landscape Management** – In managing CRA assets and plans, MWDSC must consider endangered species in some actions the utility takes. For example, there is a desert tortoise population that impacts MWDSC's ability to do construction. The additional vulnerability of the desert landscape to storms is crucial to the utility.
- **Natural Disasters** – Similar to Ecosystem / Landscape Management, storms and flooding can impact the ability of MWDSC to access its assets in emergency situations.
- **Sector Water / Service Needs** – Economic sectors of the service area depend on reliable service from the utility. Agricultural, service, and manufacturing sectors each rely on stable access to water.
- **Population / Demographic Changes** – The CRA infrastructure is remote, and the utility experiences challenges employing a large base of staff in the region.

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[1] EPA Climate Resilience Evaluation and Awareness Tool, available at: https://creat.epa.gov.

- **Water Quality Management** – Studying the impacts of precipitation and flow on water quality is important to MWDSC for future operations.

The CREAT assessment was informed by these concerns, emphasizing the potential impact of climate change on infrastructure, resiliency, and operations through 2035. Using CREAT, MWDSC was able to plan and develop a comprehensive overview of their system's resilience to projected changes in climate focused on the cascading impacts of extreme heat. From this perspective, MWDSC customized resiliency plans and strategies considerate of the agency's gap analysis efforts and Climate Action Plan.

Historical and Projected Climate Information

CREAT provides data for historical and projected climate conditions that users can incorporate into scenarios to help them understand how threats are driven by climate change. Users build these climate scenarios by selecting different potential future conditions defined by changes in various climate metrics, including the following:

- Average annual or monthly temperature
- Average annual or monthly precipitation
- Severity of intense precipitation events
- Surface Water Levels and water availability
- Coastal Sea Levels

Changes in these climate variables may exacerbate existing issues while also creating new problems for the utility. While all Global Circulation Models (GCMs) project warming, the projected changes in temperature vary widely across the 38 GCMs used to generate climate projections in CREAT. Some models project moderate temperature increases for a given location, while others project more extreme conditions for the same location. Across the Southwestern region of the United States, many of the model projections show the potential for increasing departures in the average temperature, with summer months producing more total high-heat days. CREAT provides averages of projected data selected from 38 GCMs to provide data for moderate and extreme heat climate scenario conditions at a resolution of 0.5 x 0.5-degree grid cells (approximately 30 x 30 miles). The list of models used in CREAT is provided in **Appendix B**: Models Used in Developing Climate Data. The models provide a variety of climate conditions that illustrate the range of potential changes; no set of conditions is more likely to occur than another.

Baseline Climate Scenario

The default values in the Baseline Climate Scenario used in CREAT are generated from historical observed climate data, and from non-CREAT datasets selected by MWDSC to capture climate threats. Externally sourced data included values based on planning assumptions (described in more detail in

Appendix C: Methodology for Projected Climate Data in CREAT):

- Temperature – Average annual and monthly conditions are derived from the Parameter-elevation Regressions on Independent Slopes Model[2] (PRISM) dataset using historical observed data from 1981 to 2010.
- Extreme Heat Days (> 115°F) – Determined based on 98th percentile values for daily high temperatures in the hotter parts of MWDSC's system. This value was chosen since it is a level of temperature where staff safety can be compromised if staff are exposed to this level of heat for too long.
- Lake Level at Lake Mead – Lake Level at Lake Mead was determined based on current MWDSC emergency planning thresholds. These levels were based on lake levels that would show "dead pool" levels and just above "dead pool" levels.
- Peak Daily Power Demand – Averaged based on planning values from a 2022 report published by the California Energy Commission that anticipated growth in electricity consumption across Southern California for 2045, and then extrapolated for the 2035 planning timeframe.
- State Water Project (SWP) Allocation – Allocations based on historic and projected allocations of water from the SWP.

Additional details on the development of historical climate conditions and extreme events are provided in the CREAT 3.1 Methodology Guide, available on the CREAT website[3].

The Baseline Climate Scenario is populated with values from CREAT using the sources provided in **Appendix C**: Methodology for Projected Climate Data in CREAT, but the user is also given the option to provide customized data. MWDSC compared CREAT default values (PRISM data from 1981-2010) to those data available; specifically, the 6th California State Climate Assessment, internal MWDSC emergency preparedness planning values, and other values based on conversations with operational staff during the onsite visit were utilized. The team analyzed some of the water level data generated by the Lower Colorado Group to deduce historical trends for flow rates and reservoir levels in Lake Mead.

MWDSC determined that days with temperatures exceeding 100°F and 115°F would be appropriate to consider for potential climate scenarios within this assessment, as areas surrounding CRA infrastructure often hit or exceed these levels during summer months. The team made edits to the CREAT default values produced by the tool and included 25 days over 115°F under the Baseline Climate Scenario.

Table 1 shows the selected Baseline Climate Scenario values drawn from a combination of the default CREAT data and customized category entries. The weather station selected for the CREAT default data (MWDSC's Gene Pumping Plant) comes from its proximity to Gene Wash Reservoir, an area representative of MWDSC's climate planning conditions for operations and the beginning point of the CRA.

Projected Climate Scenario

In addition to the Baseline Climate Scenario, two potential climate scenarios were created based on projected climate data: the Moderate Climate Scenario and Extreme Heat Climate Scenario. MWDSC intended for these

[2] PRISM Climate Group, Oregon State University. Available online at: http://www.prism.oregonstate.edu/
[3] CREAT 3.0 Methodology Guide is available at https://www.epa.gov/crwu/creat-risk-assessment-application-water-utilities

scenarios to encompass values representative of realistic 'moderate' and 'worst-case' heat-related climate benchmarks.

All climate scenarios were forecast out to the timeframe of 2035, to show short-term potential impacts to infrastructure and to align with near-term planning processes. The Moderate Climate Scenario assumed a steady increase in the average temperature (2.36°F increase in the average annual temperature), and an increase in the number and intensity of extreme heat days (10 additional days > 115°F) by 2035 compared to the Baseline Climate Scenario. The Extreme Heat Climate Scenario projected for an even hotter scenario overall (2.7°F increase in the average annual temperature), and a sharper rise in extreme heat days (25 additional days > 115°F) by 2035.

Table 1 provides a summary of climate data that was used in the CREAT assessment. For the projected changes in extreme heat events, the value shows the anticipated increase for the projected temperature parameter of the same return period. MWDSC chose a combination of default CREAT data and customized entries for both baseline and projected climate scenarios.

Table 1. Historical and Projected Climate Data for the MWDSC Assessment

	BASELINE CLIMATE SCENARIO		MODERATE CLIMATE SCENARIO		EXTREME HEAT CLIMATE SCENARIO	
Measurement	Value	Source	Value	Source	Value	Source
Average Annual Temperature	71.33 °F	CREAT	2.36 °F increase	CREAT	2.7 °F increase	CREAT
Average May Temperature	77.46 °F	CREAT	2.29 °F increase	CREAT	2.64 °F increase	CREAT
Average June Temperature	86.57 °F	CREAT	2.29 °F increase	CREAT	2.65 °F increase	CREAT
Average July Temperature	92.59 °F	CREAT	2.31 °F increase	CREAT	2.58 °F increase	CREAT
Average August Temperature	91.15 °F	CREAT	2.7 °F increase	CREAT	3.28 °F increase	CREAT
Average September Temperature	84.89 °F	CREAT	2.61 °F increase	CREAT	3.61 °F increase	CREAT
Number Of Hot Days Over 100 °F (Annual)	107 days	CREAT	130 days	CREAT	133 days	CREAT
Extreme Heat Days (> 115°F)	25 days	MWDSC	35 days	MWDSC	50 days	MWDSC
Lake Level at Mead	1047 feet above mean sea level (MSL)	MWDSC	1000 feet above MSL	MWDSC	940 feet above MSL	MWDSC
Peak Daily Power Demand	50 gigawatts	MWDSC	72.5 gigawatts	MWDSC	72.5 gigawatts	MWDSC
State Water Project Allocation	35%	MWDSC	35%	MWDSC	5%	MWDSC

Threat Definitions

The CREAT assessment is built around specific climate change threats of concern identified by the utility. MWDSC described two priority threats for the assessment: 1) Extreme Heat: intended to capture extended and intensified heat events and utility consequences, and 2) Power Generation: intended to capture increasing challenges associated with procuring reliable electricity for the CRA. The team developed customized definitions for these threats as follows:

Extreme Heat

Baseline Climate Scenario

- Climate change will increase temperatures across ecosystems, which causes concerns about the functioning of infrastructure and the ability of staff to perform their work functions within the system. CRA staff are required to work under extreme heat situations indoors and outdoors frequently during summer operations, including conducting maintenance on transmission lines, as needed. In addition, staff are required to work in confined spaces at times in protective gear. Historically, these extreme heat days typically occur in June, July, and August.

Moderate Climate Scenario

- Climate change will increase temperatures across ecosystems, which causes concerns about the functioning of infrastructure and the ability of staff to perform their work functions within the system. CRA staff are required to work under extreme heat situations indoors and outdoors frequently during summer operations, including conducting maintenance on transmission lines as needed. Staff are required to work in confined spaces at times in protective gear. These extreme heat days are expected to triple in frequency up to 35 days per year. The concern is where staff are exposed to extreme heat days for consecutive days where there is little cooling in the evening.

Extreme Heat Climate Scenario

- Climate change will increase temperatures across ecosystems, which causes concerns about the functioning of infrastructure and the ability of staff to perform their work functions within the system. CRA staff are required to work under extreme heat situations indoors and outdoors frequently during summer operations, including conducting maintenance on transmission lines as needed. Staff are required to work in confined spaces at times in protective gear. These extreme heat days are expected to triple in frequency up to 50 days per year. The concern is where staff are exposed to extreme heat days for consecutive days where there is little cooling in the evening.

Power Generation

Baseline Climate Scenario

- The threat that Metropolitan Water District is concerned about is the ability to generate and procure power including through hydropower and from the grid. Historically, MWDSC has had requests to reduce load on the electric grid during hot weather and under high-demand scenarios. MWDSC has been able to meet this request the majority of the time but has had instances where water demand required infrastructure to remain online. As a baseline, MWDSC is expected to increase electricity use while at the same time reducing GHG emissions in alignment with MWDSC's climate action plan.

Moderate Climate Scenario

- The threat that Metropolitan Water District is concerned about is the ability to generate and procure power including through hydropower and from the grid. MWDSC expects to have requests to reduce load on the electric grid during hot weather and under high-demand scenarios. MWDSC may not be able to meet this request if demand for CRA water increases, which may cause constraints on electricity availability to the CRA. As a baseline, MWDSC is expected to increase electricity use while at the same time reducing GHG emissions in alignment with MWDSC's climate action plan.

Extreme Heat Climate Scenario

- The threat that Metropolitan Water District is concerned about is the ability to generate and procure power including through hydropower and from the grid. MWDSC expects to have requests to reduce load on the electric grid during hot weather and under high-demand scenarios. MWDSC may not be able to meet this request if demand for CRA water increases, which may cause constraints on electricity availability to the CRA. As a baseline, MWDSC is expected to increase electricity use while at the same time reducing GHG emissions in alignment with MWDSC's climate action plan.

The definitions for the Extreme Heat threat considered both infrastructure integrity and staff health due to the threat of increasing temperatures exceeding 115F. The definition for the Power Generation threat added consideration of the expectations for MWDSC to shed energy load, while simultaneously anticipating a rise in power consumption.

Economic Consequences

The risk assessment framework in CREAT guides users through assigning levels of economic consequences they would experience if climate change threats were to occur, and then adjusting those consequences if they were to be reduced through the implementation of adaptation options that protect utility assets.

CREAT provides economic consequence data related to four preset categories that capture the range of impacts a water utility may experience from a climate-related threat:

- **Utility Business Impacts** – Operating revenue loss evaluated in terms of the magnitude and recurrence of service interruptions. Consequences range from long-term loss of expected operating revenue to minimal potential for any loss.
- **Utility Equipment Damage** – Costs of replacing the service equivalent provided by a utility or piece of equipment evaluated in terms of the magnitude of damage and financial impacts. Consequences range from complete loss of the asset to minimal damage to the equipment.
- **Environmental Impacts** – Evaluated in terms of environmental damage or loss, aside from water resources, and compliance with environmental regulations. Consequences range from significant environmental damage to minimal impact or damage.
- **Source/Receiving Water Impacts** – Degradation or loss of source or receiving water quality or quantity evaluated in terms of recurrence. Consequences range from long-term compromise to no more than minimal changes to water quality or quantity.

MWDSC additionally created two customized economic consequence categories to capture relevant risk reductions:

- **Staff Safety** – Exposure of staff to extreme heat days. Consequences range from significant staff health concerns to minor threats to staff safety. Can also consider the loss in work hours due to staff being unable to work during extreme heat events.
- **Purchasing of Power** – Dependence on the purchasing of grid power to ensure operations run as scheduled. Consequences range from full reliance on grid power to no more than minimal reliance on the open market for electricity.

Under MWDSC's current operations, it has no significant concerns that could be monetized under the Source/Receiving Water consequence category. As such, MWDSC elected to monetize the following economic consequence categories: Utility Business Impacts, Utility Equipment Damage, and Environmental Impacts. The MWDSC team chose to keep the default definitions for each consequence level.

Consequence Cost Ranges

Based on historical cost and expenditure data from utilities of similar size and economic condition, CREAT provides default cost ranges within each category that represent Low, Medium, High, and Very High impacts to the utility. The economic data is based on water sector survey data and calculated using the utility type (drinking water vs. wastewater), population served, total daily flow, public or private ownership, and financial condition. The CREAT-provided values can be revised by a user to better relate to the utility's financial data. MWDSC determined that the default range of economic values for each impact level (Low to Very High) were not appropriate for the economic consequence categories and opted to customize the data.

MWDSC revised the consequence cost ranges for the consequence categories by increasing the ranges of the "Low", "Medium", "High", and "Very High" consequence levels. These decisions were made after a discussion with MWDSC's asset management team and relevant operational staff about the ways in which different thresholds of events could affect the CRA, and costs that each scenario may incur. In the future, MWDSC's team could further refine the consequence cost ranges for each category to allow for greater differentiation between baseline and potential climate scenario costs.

The categories and monetary ranges associated with each level of consequence can be found in **Table 2.**

Table 2. MWDSC Economic Consequences Matrix

Consequence Categories	Levels			
	Low	**Medium**	**High**	**Very High**
Utility Business Impacts	Operating revenue loss evaluated in terms of the magnitude and recurrence of service interruptions. Consequences range from long-term loss of expected operating revenue to minimal potential for any loss.			
	Minimal potential for loss of revenue or operating income	*Minor and short-term reductions in expected revenue*	*Seasonal or episodic compromise of expected revenue or operating income*	*Long-term or significant loss of expected revenue or operating income*
	$0 - $1,000,000	$1,000,000 - $10,000,000	$10,000,000 - $100,000,000	$100,000,000+
Utility Equipment Damage	Costs of replacing the service equivalent provided by a utility or piece of equipment evaluated in terms of the magnitude of damage and financial impacts. Consequences range from complete loss of the asset to minimal damage to the equipment.			
	Minimal damage to equipment	*Minor damage to equipment*	*Significant damage to equipment*	*Complete loss of asset*

Consequence Categories	Levels			
	Low	Medium	High	Very High
	$1,000,000 - $5,000,000	$5,000,000 - $15,000,000	$15,000,000 - $50,000,000	$50,000,000+
Environmental Impacts	Evaluated in terms of environmental damage or loss, aside from water resources, and compliance with environmental regulations. Consequences range from significant environmental damage to minimal impact or damage.			
	No impact or environmental damage	*Short-term damage, compliance can be quickly restored*	*Persistent environmental damage*	*Significant environmental damage*
	$1,000,000 - $5,000,000	$5,000,000 - $14,000,000	$14,000,000 - $28,000,000	$28,000,000+
Staff Safety[4]	Exposure of staff to extreme heat days. Consequences range from significant staff health concerns to minor threats to staff safety. Can also consider the loss in work hours due to staff being unable to work during extreme heat events.			
	No more than minimal threats to staff health and safety (0 hours per week missing)	*Temporary threats to staff health and safety (1-8 hours per week missing)*	*Seasonal or episodic threats to staff health and safety (8-48 hours per week missing)*	*Long-term, significant threats to staff health and safety (48-96 hours per week missing)*
	0 hours	1 – 8 hours	8 – 48 hours	48 – 96 hours
Purchasing of Power	Dependence on the purchasing of grid power to ensure operations run as scheduled. Consequences range from full reliance on grid power to no more than minimal reliance on the open market for electricity.			
	No more than minimal reliance on grid power for electricity. Less than 10% of power from the grid. Running between 3 and 4 pumps	*Some reliance on grid power for electricity. Between 10 and 25% power from the grid. Running 5-6 pumps*	*Moderate reliance on grid power for electricity. Between 25 and 40% power from the grid. Running 7 pumps*	*Significant reliance on grid power for electricity. More than 40% power from the grid. 8 pumps running.*
	$7,500,000 - $18,750,000	$18,750,000 - $30,000,000	$30,000,000 - $56,250,000	$56,250,000+

[4] Upon completion of this exercise, MWDSC decided that this category should be altered to focus more on health concerns of the staff.

Regional Economic Consequence Assessment

Often in risk assessments, financial consequences extend solely to the entity that is conducting the risk assessment. When studying public utilities, however, the impact of climate risks often extends to those who rely on a public utility for their services. Regional economic consequences within CREAT include lost revenue from businesses and industries in the utility's area that cannot operate due to water or wastewater service disruptions. Due to the scale of the regional population, MWDSC opted not to consider regional economic consequences, as the values generated would likely not accurately reflect the scale of utility consequences.

Public Health Consequences

In a risk assessment framework, most experts have chosen to try to separate out the potential economic impact of death and injury. AWWA and other standard development organizations have included public health consequences to define economic consequences in the context of risk mitigation to help justify investment. MWDSC determined that for the purposes of this assessment, public health consequences were not relevant to the threats as they are defined.

Risk Assessment and Adaptation Options

CREAT risk assessments are conducted on pairs of utility assets and climate change threats. For this assessment, MWDSC explored Extreme Heat and Power Generation impacts to the Colorado River Aqueduct System, as shown in **Table 3**. Using CREAT, MWDSC was able to assess the consequences the utility may experience through a given climate event with their current capabilities and the risk reduction of different adaptation plans that could be implemented in the future.

The Colorado River Aqueduct (CRA) was selected as the primary asset for assessment because: 1) state-wide water supply challenges in California mean that the CRA is providing an increasing share of MWDSC's supplied water; and 2) if aqueduct infrastructure were to fail, utility-wide operations would be significantly compromised.

Table 3. MWDSC Asset/Threat Pairs with Relevant Consequence Categories

CRITICAL ASSET	PAIRED THREAT(S)	CONSEQUENCE CATEGORIES
Colorado River Aqueduct System *MWDSC relies heavily on the CRA to supply water to Southern California. The CRA provides on average 1.2 M acre feet of raw water annually to Southern California through 242 miles of tunnels.*	Extreme Heat; Power Generation	Utility Business Impacts Utility Equipment Damage Environmental Impacts Staff Safety Purchasing of Power

To investigate potential risk reduction, MWDSC evaluated both Existing Adaptive Measures and Potential Adaptive Measures. Existing Adaptive Measures are grouped into a "Current Measures" adaptation plan in CREAT that represents MWDSC's current resiliency practices and capabilities. It is not necessary for the team to include the costs for Existing Adaptive Measures, given that the figures are not used in the Risk Assessment calculations (since they are considered as sunk costs and are not used in determining costs for Potential Adaptive Measures or Adaptation Plans). The utility could opt to add costs for these Existing Adaptive Measures if it would be helpful for accounting purposes or to capture previous and current investments in measures that increase climate resilience. MWDSC captured estimated costs for its annual CRA system shutdown, a maintenance and repair program for electrical infrastructure, a spare parts warehouse, and staff safety training measures.

Through discussions on actionable system improvements, MWDSC compiled and evaluated three adaptation plans, which include potential adaptive measures that could mitigate asset risk. Each potential adaptive measure is evaluated in **Table 4.** MWDSC Potential Adaptive Measures and Associated Annualized Costs Given the high costs associated with each potential adaptive measure and MWDSC's desire to utilize assessment results to make the planning and business case for resilience efforts, the measures are incorporated into mutually exclusive options under separate adaptation plans. The detailed adaptation plans and associated annualized costs are shown in **Table 5**.

The titles and descriptions for each adaptive measure are provided in **Appendix D**: Existing and Potential Adaptive Measures; Existing Adaptive Measures are defined in **Table D-1.** Existing Adaptive Measures for Extreme Heat and Power Generation in the Colorado River Aqueduct System, and Potential Adaptive Measures are defined in **Table D-2.** Potential Adaptive Measures for Extreme Heat and Power Generation on the Colorado River Aqueduct System**.**

Table 4. MWDSC Potential Adaptive Measures and Associated Annualized Costs

POTENTIAL ADAPTIVE MEASURES	POTENTIAL ADAPTIVE MEASURE ANNUAL COST
Renewable Energy Supplies	$200,000,000
Variable Frequency Drives	$24,000,000
Power System Upgrades	$50,000,000

Table 5. MWDSC Adaptation Plans and Associated Annualized Costs

ADAPTATION PLAN	ADAPTATION PLAN TOTAL COST
Renewable Energy	$12,566,019
VFDs	$893,961
Power Upgrades	$4,679,087

As the projected consequence costs within CREAT are considered on an annual basis, MWDSC calculated equivalent annualized costs for each potential adaptive measure. The cost calculation considers initial capital outlay, expected lifespan, discount rate/cost of capital (%), and annual operations and maintenance (O&M) expenses. MWDSC used assumptions from its Capital Improvement Plan (CIP), and information relayed through a WIFIA program presentation to decide on a 4% discount rate. MWDSC additionally interviewed system staff to deduce typical operational lifespans and anticipated O&M costs for each potential adaptive measure (**Table 6**).

Table 6. Equivalent Annual Cost Calculator for Potential Adaptive Measures for MWDSC

PARAMETER	Renewable Energy Supplies	Variable Frequency Drives	Power System Upgrades
Initial Capital Outlay	$200,000,000	$12,000,000	$2,200,000
Expected Lifespan	30	30	20
Discount Rate/Cost of Capital (%)	4	4	4
Annual O&M	$1,000,000	$200,000	$1,000,000
Equivalent Annual Cost	$12,566,019	$893,961	$4,679,087

The MWDSC team input annual O&M costs based on consultation with operating staff and estimates derived from previous utility experience. Economic consequence values can be edited upon receipt of supplemental information, allowing MWDSC to scale costs as more operating information becomes available.

CREAT Assessment Results

CREAT guides users through a risk assessment for each asset/threat pair across the defined scenarios. Each assessment considers the implementation of a specific adaptation plan. The assessment results for each potential adaptation plan can be compared to the results from the assessment of the Current Measures plan to show the benefits of implementing the adaptation plan. During the risk assessment, MWDSC evaluated the potential risk reduction offered by each adaptation plan relative to the cost of implementing that plan for each defined climate scenario (Baseline, Moderate, and Extreme Heat). For each climate scenario and adaptation plan, MWDSC selected the expected impact level (Low to Very High) in the Economic Consequences Matrix (see **Table 2.** MWDSC Economic Consequences Matrix). The Baseline Climate Scenario and Current Measures adaptation plan are considered the case against which to evaluate the potential benefits of individual adaptation plans. By definition, adaptive measures should decrease consequences and MWDSC determined anticipated levels of impact assuming an adaptation plan was implemented. The monetary values were summed across all categories to calculate total consequences of the Extreme Heat and Power Generation threats impacting the critical asset (the CRA).

Through evaluating the Current Measures plan under either the Moderate or Extreme Heat Climate Scenarios, MWDSC can understand potential consequences if the climate were to change but the utility were not to implement an adaptation plan. The assessment of each adaptation plan provides the total reduction of risk (in dollars) that MWDSC may experience after implementing potential adaptation plans, both for the historical events as defined in the Baseline Climate Scenario, and for the projected changes defined in the Moderate or Extreme Heat Climate Scenarios. Potential risk reduction is achieved through the implementation of adaptation plans, and by evaluating the change in expected impact level or consequences for each plan and comparing the results with those for Current Measures in each scenario. The assumptions underlying the team's determination of consequence levels are described in **Appendix E**: Consequence Assumptions.

CREAT calculates monetized risk reduction from the asset/threat pair assessment to characterize the difference between current and potential future risk to utility assets and resources, with and without adaptation. Monetized risk reduction is the change in total consequences considering the increased capabilities of assets to withstand the impacts from threats following the implementation of an adaptation plan. For example, the estimated annual risk reduction resulting from implementing the Power Generation plan under an Extreme Heat Climate Scenario could be as great as $70,000,000. This is compared to an annualized cost of around $4,679,087. By comparing the cost of implementation to the associated benefits, MWDSC can determine the cost-effectiveness of implementing adaptation plans. Adaptation plan cost, potential economic consequences, and monetized risk reduction for each adaptation plan are shown in

Table 7. Adaptation Plan Costs and Associated Monetized Risk Reduction.

Table 7. Adaptation Plan Costs and Associated Monetized Risk Reduction

ADAPTATION PLAN		BASELINE CLIMATE SCENARIO		MODERATE CLIMATE SCENARIO		EXTREME HEAT CLIMATE SCENARIO	
NAME	COST	TOTAL CONSEQUENCES	RISK REDUCTION	TOTAL CONSEQUENCES	RISK REDUCTION	TOTAL CONSEQUENCES	RISK REDUCTION
Current Measures (No Change)	$0	$60,750,000 - $128,250,000	N/A	$96,000,000 - $233,500,000	N/A	> $232,500,000	N/A
Power Upgrades	$4,679,087	$52,750,000 - $108,250,000	$0 - $14,000,000	$64,000,000 - $134,500,000	$20,000,000 - $111,000,000	> $128,500,000	> $70,000,000
Renewable Energy	$12,566,019	$23,000,000 - $69,500,000	$11,250,000 - $85,250,000	$37,000,000 - $113,500,000	$32,500,000 - $146,500,000	> $85,000,000	> $110,000,000
VFDs	$893,961	$41,500,000 - $82,000,000	$0 - $65,500,000	$45,500,000 - $92,000,000	$10,000,000 - $182,000,000	> $112,250,000	> $35,000,000

CREAT results suggest that implementation of the Power Upgrades, Renewable Energy, and VFDs Adaptation Plans would not be cost effective in terms of monetized risk reduction under the Baseline Climate Scenario. However, the risk reduction benefits increase substantially under both the Moderate and Extreme Heat Climate Scenarios, with the latter having a more definite business case for implementation. The increase in risk reduction under the projected climate futures suggests that the plans increase system resilience under the defined climate scenarios.

For example, the Renewable Energy adaptation plan varies in risk reduction across each potential climate scenario in **Figure 2, Figure 3,** and **Figure 4**. For each adaptation plan, the range of values for total consequences for Current Measures ("No Change") and potential adaptation plans are shown, as well as total monetized risk reduction and adaptation plan cost. As scenarios become more extreme, the anticipated monetized risk reduction scales in step.

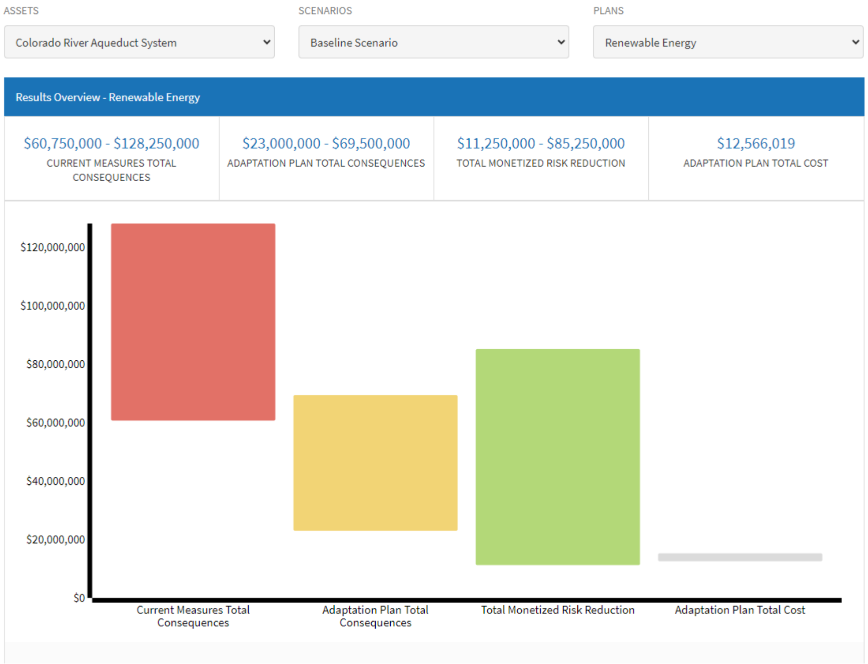

Figure 2. Monetized Risk Reduction for Colorado River Aqueduct System Renewable Energy Plan under a Baseline Climate Scenario

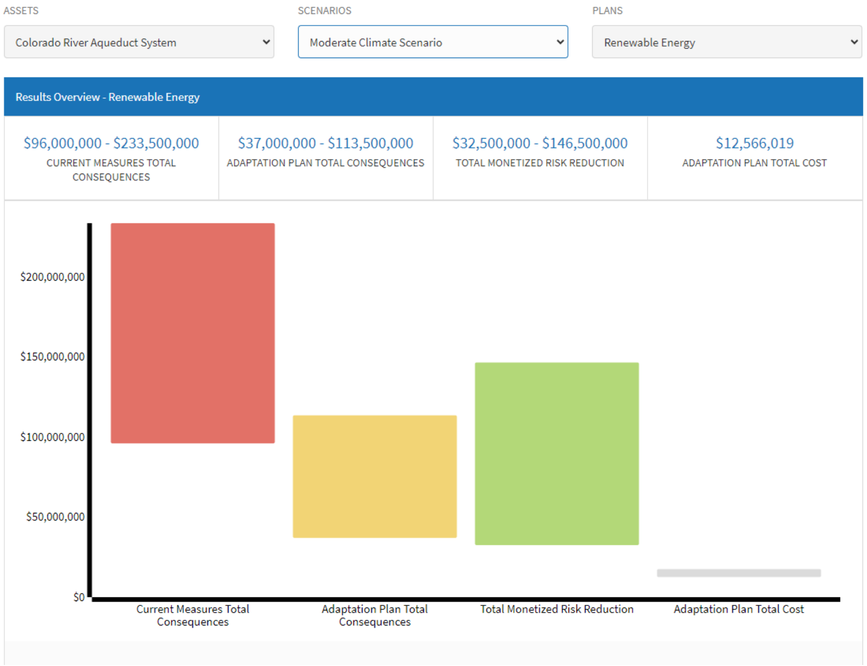

Figure 3. Monetized Risk Reduction for Colorado River Aqueduct System Renewable Energy Plan under a Moderate Climate Scenario

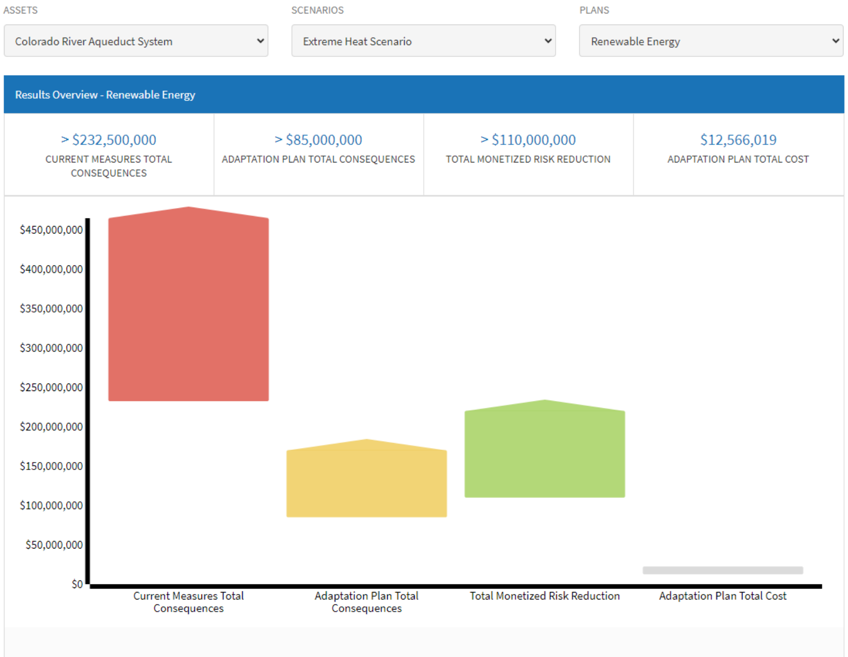

Figure 4. Monetized Risk Reduction for Colorado River Aqueduct System Renewable Energy Plan under an Extreme Heat Climate Scenario

Likelihood Sensitivity

CREAT enables users to consider additional results of their analysis to support decision making, including how the likelihood of a climate change scenario occurring will impact the cost effectiveness of implementing an adaptation plan. In CREAT, scenarios and threats are considered "conditional," where likelihood is assumed to be 100%. **Figure 5, Figure 6,** and **Figure 7** show how scenario likelihood can alter cost effectiveness. The Renewable Energy plan likelihood analysis shows how certainty in a climate scenario can sway the recommended threshold for implementation.

Table 8. Description of Likelihood Sensitivity Categories

LIKELIHOOD SENSITIVITY CATEGORIES	DESCRIPTION
Red - Wait and See	The range of implementation costs of the plan exceed the entire range of possible risk reduction for the threats in the scenario, with a negative return on investment.
Orange - Consider Implementing Plan	The range of implementation costs for the selected plan overlap with the range of possible risk reduction for the threats in the scenario, with uncertain return on investment.

Green - Implement Plan	The range of implementation costs of this selected plan is below the entire range of possible risk reduction for the threats in the scenario, with a positive return on investment.

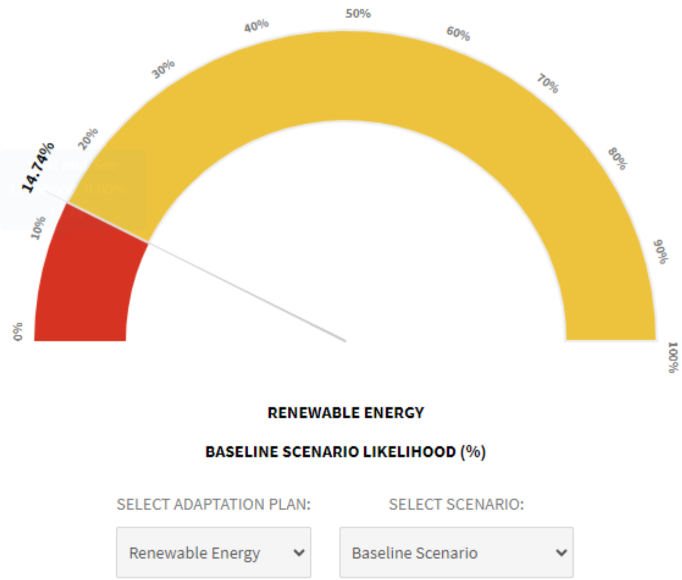

Figure 5. Likelihood Range for Analysis of Renewable Energy Plan under a Baseline Climate Scenario

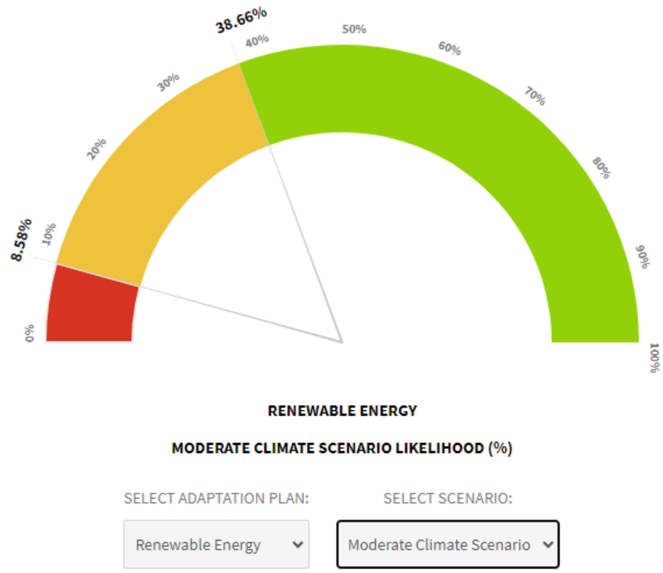

Figure 6. Likelihood Range for Analysis of Renewable Energy Plan under a Moderate Climate Scenario

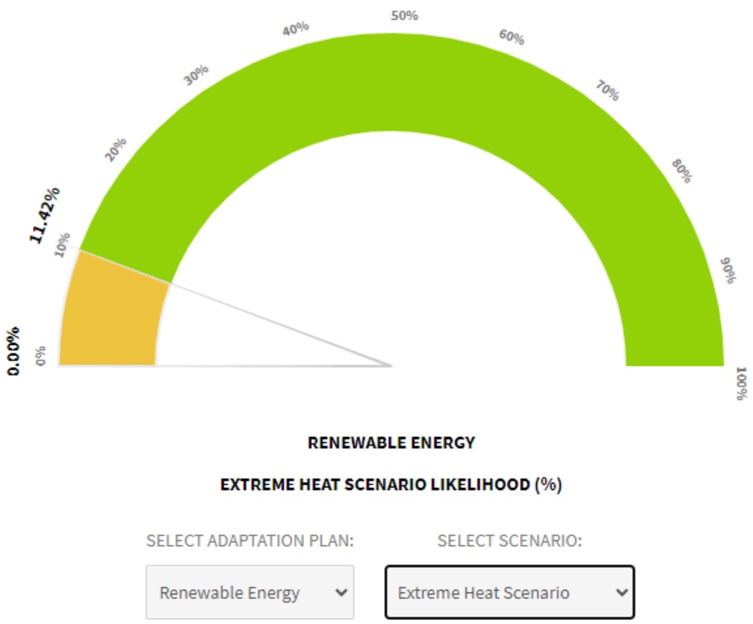

Figure 7. Likelihood Range for Analysis of Renewable Energy Plan under an Extreme Heat Climate Scenario

The red "Wait and See" range represents the range in which the cost to implement the selected plan exceeds the entire range of possible risk reduction for the threats in the selected scenario. In this range, there would be a negative return on investment for implementing the adaptation options.

The orange "Consider Implementing Plan" range represents the range in which the cost to implement the selected plan overlaps with the range of possible risk reduction for the threats in this scenario. In this range, there would be an uncertain return on investment for implementing the adaptation options. For plans with significant orange ranges, additional benefits gained from implementing these adaptation options should be considered before implementing this adaptation plan, or additional assessments, with potential increases in risk reduction, could support the decision regarding implementation.

The green "Implement Plan" range appears for a range of scenario likelihood in which the costs to implement the selected plan are below the entire range of possible risk reduction for the threats in this scenario. In this range of likelihood, the adaptation plan is cost effective to implement, since there would be a positive return on investment. The monetized risk reduction alone provides adequate benefit to support the decision to implement this plan.

If considering only the cost of the Renewable Energy Plan and the magnitude of risk reduction, MWDSC must achieve at least $12,566,019 in risk reduction for the adaptation plan to be cost-effective. Looking at the plan's risk analysis under the Baseline Climate Scenario (**Figure 2**), the tool suggests that MWDSC would have challenges justifying the investment, since the risk reduction potential is less than or comparable to the annualized plan cost. The likelihood analysis indicates that if MWDSC is less than 14.74% certain that the climate scenario will occur, they should not implement the plan (**Figure 5**). If MWDSC is more than 14.74% confident the climate scenario would occur, however, the likelihood analysis suggests that the utility consider if there are additional benefits to the adaptation plan that may not be captured within a financial analysis, as the plan may have a positive return on investment when additional factors are considered.

The projected climate scenarios further alter the potential cost-effectiveness for each adaptation plan. The Extreme Heat Climate Scenario risk analysis for the Renewable Energy Plan (**Figure 4**) shows a wider range of potential risk reduction that exceeds the $12,566,019 annualized adaptation plan cost. The likelihood scenario (**Figure 7**) indicates that if the utility is more than 11.42% confident of this scenario occurring the analysis suggests that there is a business case for this adaptation plan, and the utility should adopt the measure to mitigate financial risk and build resilience.

NEXT STEPS

This CREAT exercise was intended to demonstrate CREAT's functionality and capability, help MWDSC better understand how to utilize the tool, and build additional resilience capabilities to support the utility's evaluation of adaptation options. Throughout this process, EPA's team guided MWDSC staff in understanding the features of the tool and ways it could be applied across the organization to integrate resilience planning and assess additional threats to the system including flooding and extreme storms.

In order to improve the accuracy of the current demonstration assessment results, MWDSC can revisit data and assumptions made throughout the exercise, including threats to staffing, and continue to refine the data in each module. The existing and Potential Adaptive Measures include customized definitions, and all Potential Adaptive Measures have cost estimates. While no further refinement is necessary at this time to complete the assessment, additional climate threats, assets, and adaptive measures can be explored and assessed by the utility. This framework can be applied to SWP infrastructure and to additional aspects of the CRA to support larger planning efforts within the utility, such as addressing infrastructure and operational changes.

MWDSC expressed that the powerful outcomes of the exercise were compelling to its team, including the Risk Analysis and Likelihood Sensitivity Analysis. MWDSC expressed interest in working with EPA's CRWU team in the future to demonstrate the usefulness of the CREAT tool to its board and staff to showcase some of the findings. The tool fits within MWDSC's existing resiliency planning framework, and future CREAT assessments focused on other pertinent threats like flooding could be utilized to inform MWDSC's Capital Improvement Plan or other long-term planning efforts.

APPENDIX A: EXERCISE PARTICIPANTS

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APPENDIX B: Models Used in Developing Climate Data

MODEL NAME	STORM SCALARS	SOURCE / INSTITUTION
ACCESS1_0		Australia, Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM)
ACCESS1-3	X	
BCC-CSM1_1		China, Beijing Climate Center, China Meteorological Administration
BCC_CSM1_1_M		
BNU_ESM		China, College of Global Change and Earth System Science, Beijing Normal University
CANESM2	X	Canada, Canadian Centre for Climate Modelling and Analysis
CCSM4	X	USA, National Center for Atmospheric Research (NCAR)
CESM1_BGC	X	USA, Community Earth System Model Contributors
CESM1_CAM5		
CMCC_CM	X	Italy, Centro Euro-Mediterraneo per i Cambiamenti Climatici
CMCC_CMS	X	
CNRM_CM5	X	France, Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique
CSIRO_Mk_3_6	X	Australia, Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence
EC_EARTH		EC-EARTH consortium
FGOALS_G2		China, LASC, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University
FGOALS_S2		China, LASC, Institute of Atmospheric Physics, Chinese Academy of Sciences
GFDL_CM3		USA, NOAA General Fluid Dynamics Lab
GFDL_ESM2G	X	
GFDL_ESM2M	X	
GISS_E2_H		USA, NASA Goddard Institute for Space Studies
GISS_E2_H_CC		
GISS_E2_R		
GISS_E2_R_CC		
HADGEM2_AO		Korea, National Institute of Meteorological research/Korea Meteorological Administration
HADGEM2_CC		UK, Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2_ES	X	
INMCM4	X	Russia, Institute for Numerical Mathematics
IPSL_CM5A_LR	X	France, Institute Pierre Simon Laplace
IPSL_CM5A_MR	X	
IPSL_CM5B_LR	X	
MIROC_ESM	X	Japan, Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC_ESM_CHEM	X	
MIROC5	X	
MPI_ESM_LR	X	Germany, Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)
MPI_ESM_MR	X	
MRI_CGCM3	X	Japan, Meteorological Research Institute
NorESM1_M	X	Norway, Norwegian Climate Center
NORESM1_ME		

APPENDIX C: METHODOLOGY FOR PROJECTED CLIMATE DATA IN CREAT[5]

The climate information available in CREAT provides a snapshot of how changes in climate might exacerbate current concerns. In addition to the national and international assessments synthesized in CREAT, historical observations and model projections are organized for users to review and select as part of their scenarios.

Historical Climate Conditions

CREAT provides historical climate data for temperature and precipitation to help users assess current risk as part of their Baseline Climate Scenario. Average annual and monthly conditions are sourced from the Parameter-elevation Regressions on Independent Slopes Model[6] (PRISM) dataset based on observations from 1981 to 2010. Data available from the Climate Research Unit[7] are used in places where PRISM data were unavailable, such as in Alaska, Hawaii and Puerto Rico. The resultant dataset covers all U.S. states and Puerto Rico at a 0.5-degree resolution in latitude and longitude.

Historical Extreme Events

Historical data on extreme events, including both temperature and precipitation, are based on time-series analysis of the data available from the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center climate stations[8]. Data for historical extreme precipitation events are representative of each station.

For intense precipitation events, time series of historical daily precipitation data from 11,010 stations were reviewed and converted into annual maxima time series for 24-hour precipitation. Any station with data available during 1981 through 2010 was included.

Historical hot days, those days with daily maximum temperature over 90 and 100°F, were calculated using historical daily maximum temperature data from 8,150 stations. These stations were selected from the same stations used for intense precipitation based on a minimum of 95% completeness for April through October daily observations from at least one calendar year in the period of observation.

Projected Climate Conditions

CREAT provides projected changes from Global Climate Models (GCMs) as available from the Coupled Model Intercomparison Project, Phase 5 (CMIP5)[9] which is the same data used to support the IPCC Fifth Assessment Report.[10] Data provided in CREAT were from model simulations employing Representative Concentration Pathway 8.5, a higher trajectory for projected greenhouse gas concentrations to support assessments looking at higher potential risk futures.

CREAT uses an ensemble-informed approach to derive meaningful choices from the results of 38 model runs[11] for each 0.5 by 0.5 degree location. This approach involves generating a scatter plot of normalized, projected changes in annual temperature and precipitation by 2060 for all models. Statistical targets were calculated based on the distribution of these model results and the five models closest to those targets were averaged to

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[5] Adapted from the CREAT Methodology Guide, available at: https://creat.epa.gov.
[6] PRISM Climate Group, Oregon State University. Available online at: http://www.prism.oregonstate.edu/.
[7] Data set available at: http://catalogue.ceda.ac.uk/uuid/2949a8a25b375c9e323c53f6b6cb2a3a.
[8] For more information on NOAA climate stations, see: http://www.ncdc.noaa.gov/data-access/land-based-station-data.
[9] World Climate Research Programme Coupled Model Intercomparison Project available at: http://cmip-pcmdi.llnl.gov/cmip5/.
[10] IPPC Fifth Assessment report available at: https://www.ipcc.ch/report/ar5/.
[11] List of models used in analyses provided in Appendix B: Models Used in Developing Climate Data

generate each projection (**Figure C-1**). The targets were designed to capture a majority of the range in model projections of changes in annual temperature and precipitation, as follows:

- Warmer and wetter future conditions: average of five individual models that are nearest to the 95th percentile of precipitation and 5th percentile of temperature projections;
- Moderate future conditions: average of five individual models that are nearest to the median (50th percentile) of both precipitation and temperature projections and
- Hotter and drier future conditions: average of five individual models that are nearest to the 5th percentile of precipitation and 95th percentile of temperature projections.

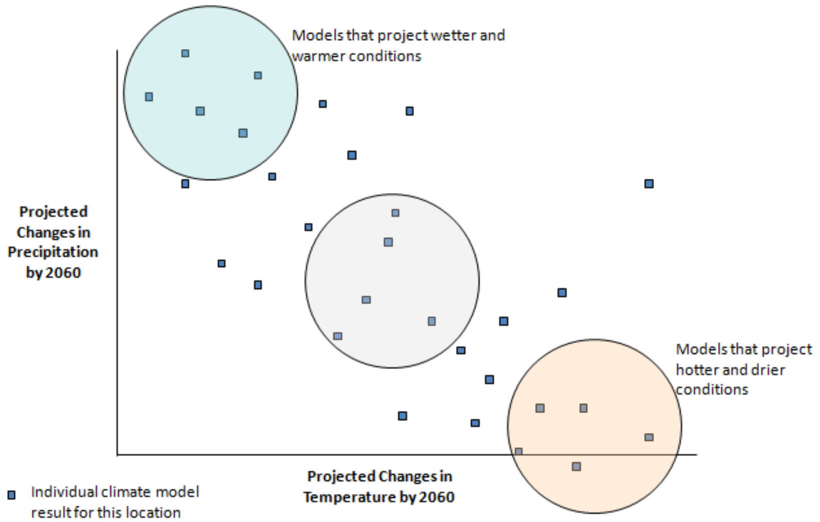

Figure C-1. Illustration of Ensemble-informed Selection of Model Projections to Define Potential Future Conditions

Once the models for each projection were selected, these models were ensemble-averaged to calculate annual and monthly changes for temperature and precipitation. CREAT selects the most appropriate data to match the defined planning horizon from two available data sets – one for 2035, which is based on projection data for 2025–2045, and one for 2060, which is based on projection data for 2050–2070. The selection of the appropriate CREAT-provided time period is based on the End Year defined by the user during the time period selection. If the End Year is 2049 or earlier, the 2035 data are selected; otherwise, CREAT selects the 2060 data set.

Projected Extreme Events

CREAT also provides projections of extreme heat in terms of the new total number of hot days following the projected shift in temperature. The projected changes in hot days were linked to the models selected for projected changes in average temperature and precipitation. The change in monthly average temperature for April through October for the analysis location was added to the daily time series from that station to generate a new time series for each projection. The number of hot days was then calculated using the same method employed for historical hot days to generate projected number of hot days.

Similar to the development of model projections of changes in average temperatures and precipitation, CREAT uses an ensemble-based approach to identify a range of possible changes in total storm precipitation (**Figure C--2**). A subset of the GCMs used earlier (22 of the 38 models) provide scalars or changes in precipitation per degree of warming, for storm events of the same return intervals as the historical storms provided in CREAT. Each model provides a different scalar for each return interval based on model-projected daily precipitation patterns.

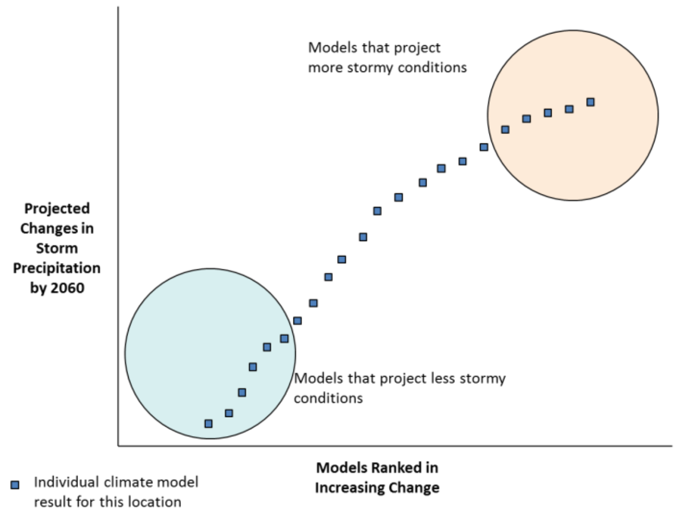

Figure C-2. Illustration of Ensemble-informed Selection of Model Projections to Define Potential Future Storm Conditions

The scalars from these models were ranked based on the scalars for the storm events with a 5-year return interval. The use of 5-year storm events to rank the models was based on the assumption that water sector utilities dealing with intense storm events are often more concerned with more frequent storm events. Ensembles of five models were selected as describing a “Stormy Future,” which are the highest models and a “Not as Stormy Future,” which are the lowest models. In each case, these models were averaged to provide two model projections available to users.

APPENDIX D: EXISTING AND POTENTIAL ADAPTIVE MEASURES

Table D-1. Existing Adaptive Measures for Extreme Heat and Power Generation in the Colorado River Aqueduct System

EXISTING ADAPTIVE MEASURE	DESCRIPTION	TOTAL COST
CRA System Shut Down	This system requires annual shut down to address system infrastructure. During this time the aqueduct infrastructure receives necessary upgrades/maintenance and inspection to ensure reliability.	$2,600,000
Maintenance and Repair Program for Electrical Infrastructure	Metro Water institutes a regular maintenance and repair program for electrical infrastructure supporting the CRA, including inspections that occur every two months, and repairs as needed based on visual inspections. Additionally, support staff conduct aerial surveys of the transmission system to identify any infrastructure risks on a regular basis. This cost needs to be verified.	$25,000,000
Spare Parts Warehouse	The operations team has a warehouse and backlog for spare parts for CRA infrastructure. These parts are no longer manufactured and hard to find. Having them on hand reduces time that infrastructure needs to be offline for repairs, increasing system resiliency.	$100,000-$500,000
Staff Safety Training	CRA staff have safety protocols and training that help focus on safely operating the system. This training reduced the risk of staff shortages in the desert due to injury. Currently this training does not include risks from climate change.	$50,000-$200,000

Table D-2. Potential Adaptive Measures for Extreme Heat and Power Generation on the Colorado River Aqueduct System

POTENTIAL ADAPTIVE MEASURE	DESCRIPTION	ESTIMATED ANNUAL COST
Renewable Energy Supplies	This project includes developing renewable energy supplies for the Colorado River Aqueduct so that there is less reliability on the power system. This will include solar energy and power storage to run some of the equipment in the event of power failures.	$12,566,019
Variable Speed Pumps	This cost is the estimate for six pumps across CRA infrastructure. This estimate is not final and will be revised by Met.	$893,961
Power System Upgrades	This project includes significant upgrades to the power transmission system supplying power to the CRA infrastructure including sensors to identify location of impacts to towers, increased capacity of transmission lines, replacing transmission towers, increasing physical security, replacing circuit breakers. This cost is an estimate and will be revised by Met	$4,679,087

APPENDIX E: CONSEQUENCE ASSUMPTIONS

The risk assessment of the Current Measures and Adaptation Plans for Extreme Heat and Power Generation impacts to the Colorado River Aqueduct System relied on the assumptions outlined below.

The Environmental Impacts category was assumed to be Low for the Baseline Climate Scenario, Low for the Moderate Climate Scenario, and Medium for the Extreme Heat Climate Scenario. MWDSC made this projection, as its team staff expressed that they did not have sufficient background to consider the monetary consequences associated with environmental regulation noncompliance.

Asset: Colorado River Aqueduct System
Threat: Extreme Heat
Plan: Current Measures

- Baseline Climate Scenario
  - Purchasing of Power: High
    - The high amount of monetized risk ($30,000,000 - $56,250,000) accounts for the assumption that MWDSC would need to purchase electricity from the open market on a more regular basis without sufficient upgrades.
- Moderate Climate Scenario
  - Staff Safety: High
    - Assuming that increased temperatures will raise the number of lost-time incidents related to heat and maintaining operational safety for employees.
    - Risk is not monetized but measured in lost hours. Additional consideration should be given to potential work safety compliance fines under these conditions.
- Extreme Heat Climate Scenario
  - Utility Equipment Damage: Very High
    - Assuming that increases in annual temperatures can cause larger power conveyance system failures, and damage pumping equipment along the CRA.
  - Utility Business Impacts: Medium
    - Assuming an increase in procurement challenges for water supply, and a substantial increase in the baseline price of electricity needed to operate CRA infrastructure.

Plan: Power Upgrades

- Baseline Climate Scenario
  - Utility Equipment Damage: Low
    - Assuming that the upgrades to the power conveyance system mitigate some of the maintenance needs of current infrastructure, decreasing the likelihood of a larger equipment failure.
- Moderate Climate Scenario
  - Utility Equipment Damage: Low
    - Assuming that the upgrades to the power conveyance system mitigate some of the maintenance needs of current infrastructure, decreasing the likelihood of a larger equipment failure.
- Extreme Heat Climate Scenario
  - Staff Safety: High
    - Staff will likely continue to face an increase in exposure to health and safety threats with the adaptation plan implemented, with some limited mitigation of exposure hazards (48-96 hours).
  - Purchasing of Power: Very High
    - Assumes that MWDSC will continue to face power procurement challenges with the conveyance technologies implemented.

Plan: Renewable Energy

- Baseline Climate Scenario
  - Staff Safety: Medium
    - Assuming that staff would continue to experience lost-hour incidents caused by heat at a moderate frequency, with limited mitigation provided (8-16 hours).
- Moderate Climate Scenario
  - Utility Business Impacts: Low
    - Assuming that a moderate increase in temperatures would not have a substantive impact on the CRA's ability to supply water, or cause any undue increase in the amount of spillage of lost water along the aqueduct.
- Extreme Heat Climate Scenario
  - Purchasing of Power: Low
    - Assuming that an independent green energy capability would eliminate much of the CRA's current reliance on external electricity, and mitigate consequences significantly.

Plan: VFDs

- Baseline Climate Scenario
  - Purchasing of Power: Medium
    - Assumes that the increased efficiency of the VFDs does not mitigate consumption needs on a significant enough basis that there is no longer a need for energy purchased from the open market.
    - The Medium consequence range captures sufficient consequence levels under both the Baseline and Moderate Climate Scenarios.
- Moderate Climate Scenario
  - Utility Business Impacts: Low
    - Assuming that a moderate increase in temperatures would not have a substantive impact on the CRA's ability to supply water, and that VFDs would sustain current business efficiency conditions for the aqueduct.
- Extreme Heat Climate Scenario
  - Purchasing of Power: Very High
    - Assumes anticipated increase in heat and energy consumption is not offset by VFD efficiency, and MWDSC is required to purchase substantial amounts of electricity from the open market.
    - Discussions explored the potential of increasing the number of VFDs as an option, which would increase the existing annualized estimated cost for this adaptation plan.

Threat: Power Generation

Plan: Current Measures

- Baseline Climate Scenario
  - Utility Business Impacts: Low
    - Assumes the amount of water spilled by the CRA in operations is relatively low on consideration of Power Generation challenges, and would not have significant economic consequences for MWDSC.
    - Discussions determined the amount of water spilled would likely not be impacted across the climate scenarios.
- Moderate Climate Scenario
  - Utility Equipment Damage: High
    - Assumes the potential for significant disruptions to transmission line equipment, which may require a partial rehabilitation of one of the CRA's 230 kV transmission lines.
- Extreme Heat Climate Scenario
  - Maintaining Staff Safety: Very High

        - Assumes increasing needs to rotate staff from extreme heat conditions, and place limitations on exposure when working on power equipment outdoors and in confined spaces during extreme heat events.

Plan: Power Upgrades

- Baseline Climate Scenario
    - Environmental Impacts: Low
        - Assumes that upgrades to transmission infrastructure will increase operational efficiency, offsetting power generated from outside of MWDSC's primary hydropower suppliers, limiting the likelihood for a violation.
- Moderate Climate Scenario
    - Purchasing of Power: High
        - Assuming that increases in heat will increase power consumption year-round, forcing MWDSC to procure additional energy from the open market.
        - Impact levels scaled across climate scenarios, reflecting the potential for increased consumption needs.
- Extreme Heat Climate Scenario
    - Staff Safety: Medium
        - Assumes staff will experience an increase in exposure to health and safety threats, through the new equipment would likely reduce the amount of service time needed, limiting lost time incidents to 1-8 hours.

Plan: Renewable Energy

- Baseline Climate Scenario
    - Utility Equipment Damage
        - Assumes that rate of equipment wear would remain the same due to only the source of power changing, and not the transmission equipment itself.
        - Threat scales up depending on scenario as power consumption increases.
- Moderate Climate Scenario
    - Environmental Impacts: Low
        - Assumes that deployment of renewable energy capacity would reduce MWDSC's existing emissions impact, and decrease the likelihood that the system is out of compliance with state emissions regulations.
    - Staff Safety: High
        - Assumes that benefits from reducing staff exposure when servicing legacy equipment are offset by the increased need to clean and maintain renewable energy equipment.
- Extreme Heat Climate Scenario
    - Purchasing of Power: Low
        - Assuming that an independent green energy capability would eliminate much of the CRA's current reliance on external electricity, and mitigate generation challenges significantly.

Plan: VFDs

- Baseline Climate Scenario
    - Utility Equipment Damage: Low
        - Assumes that implementation of scalable VFDs would decrease existing wear on the legacy pumps within each plant.
- Moderate Climate Scenario
    - Environmental Impacts: Low
        - Assuming that VFDs will incur increased efficiency, and reduce the likelihood that the power system exceeds any environmental compliance regulations.
- Extreme Heat Climate Scenario

- Purchasing of Power: High
  - Assumes that the efficiency gains are limited in scope, and that MWDSC would likely still need to increase its procurement of energy from the open market to make up the difference in consumption needs.