THE Water Research FOUNDATION

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4729A

Mapping Climate Exposure and Climate Information Needs to Water Utility Business Functions

DENVER WATER

WUCA
Water Utility Climate Alliance

Mapping Climate Exposure and Climate Information Needs to Water Utility Business Functions

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Co-sponsored by:

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Water Utility Climate Alliance

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THE Water Research FOUNDATION

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Abstract and Benefits

Abstract:

The goal of this project was to develop a comprehensive, enterprise-level framework for understanding the exposure and sensitivities of water utility business functions to a changing climate and for accelerating the mainstreaming of climate considerations into utility management. The water utility business risk and opportunity framework was designed to be replicable for use by a range of utility sizes, impacts, and functions. Though this framework specifically focused on drinking water utilities, its approach has broader applicability across a variety of utilities. With this goal in mind, the Cadmus research team conducted interviews and virtual workshops with seven utilities to achieve the following:

1. Develop a suite of common water utility business functions.
2. Identify "critical" paths (defined below) within each business function to be analyzed.
3. Assess the potential risks and opportunities of climate drivers to affect the critical path of water utility business functions.
4. Compile relevant climate data and information for business functions.
5. Design a flexible and replicable framework and associated guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*.
6. Test the framework through four case-study utilities.

The methodology used to conduct this research included intensive desk research and virtual interviews, interactive and co-produced climate risk and opportunity mapping exercises, analysis of existing scientific data and information relevant to assess water utility business function risks and opportunities, the design of a replicable and easy-to-follow water utility business risk and opportunity framework and associated guidebook in collaboration with four utility case studies, and ongoing feedback from the project partners throughout the duration of the research project.

This research resulted in an improved understanding and lessons learned related to various business functions across multiple water utilities, key drivers for and barriers to assessing climate risks and opportunities, capabilities needed to support business function leaders through this process, the type of data and information needed to assess business function risks and opportunities at various scales, and a step-by-step framework for water utilities to map climate-related risks and opportunities across their business functions. Although this approach did not include a full-scale vulnerability assessment, it recognized the contributions of underlying vulnerabilities—including land use, economic conditions and aging infrastructure—as a starting point for the climate-related risk and opportunity conversation.

Benefits:

- This research furthers the understanding of how internal utility functions and activities, not commonly understood to be directly impacted by climate change, experience physical, financial, and resource impacts from acute and chronic changes in the climate.
- The *Water Utility Business Risk and Opportunity Framework* allows individual utilities to proactively consider climate-related risks and opportunities to their systems, customers, and communities.
- The framework is a simple, replicable approach that other utilities can follow, aided by the step-by-step guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*. Knowledge of climate change and related data sources, found throughout this report, greatly contribute to the effectiveness of this process.
- The framework remains consistent with existing water utility guidance documents from organizations such as The Water Research Foundation and the Water Utility Climate Alliance. The

framework helps water utilities identify and prioritize their core business functions in context with climate-related drivers, map climate-related risks and opportunities, and align their needs with the information required to undertake planning and implementation.

- The framework supports an enterprise-wide understanding of the exposure and sensitivity of water utility business functions to a changing climate; Phase 2 will test the framework with two WRF and WUCA utilities and provide suggestions for mainstreaming climate resilience throughout utility business functions. See “Next Steps” in the Executive Summary for details on Phase 2.
- The coproduction process used during this project spurs cross-utility team collaboration and improves communications across business function “silos;” this approach can be useful in multiple management and training contexts.
- This research and the framework development process has already led to some positive progress in risk identification and management for several of the partner utilities since the start of the project in 2018.

Keywords: Climate change, climate, climate drivers, extreme weather, risk, opportunity, business resilience, climate adaptation, climate data, climate vulnerability assessment, mainstream resilience

Contents

The following resource can be found on the 4729 project page of the WRF website, under Web Tools:

Climate Data and Information Spectrum for Case Studies

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Acronyms and Abbreviations

CIP	Capital improvement projects
CMIP	Coupled Model Intercomparison Project
CREAT	Climate Resilience Evaluation and Awareness Tool
EPA	U.S. Environmental Protection Agency
ESM	Earth System Model
EUM	Effective Utility Management
FEMA	Federal Energy Management Agency
GCM	General Circulation and/or Global Climate Model
NCA	National Climate Assessment
NYCDEP	New York City Department of Environmental Protection
PAC	Project Advisory Committee
R&O	Risk and opportunity
SLC DPU	Salt Lake City Department of Public Utilities
SDPUD	San Diego Public Utilities Department
SNWA	Southern Nevada Water Authority
TAG	Technical Advisory Group
WRF	The Water Research Foundation
WUCA	Water Utility Climate Alliance
WUPG	Water Utility Partner Group

Executive Summary

Water utilities provide potable water for use in homes, workplaces, schools, businesses, hospitals, and public buildings for drinking, cooking, showering and bathing, watering lawns and gardens, providing fire protection, and enabling industrial processes.

Water utilities face new and growing challenges in anticipating the risks (and opportunities) posed by climate change. Combined with seasonal, interannual, and decadal variability, climate change leads to more extreme events, such as heat waves, wildfire, drought, and flooding. These events impose a range of direct and cascading impacts and potential failures across multiple systems, sectors, and processes. That said, utilities already recognize the need to anticipate future conditions, including consideration of climate change—issues well documented in water utility guidance documents from organizations like The Water Research Foundation and Water Utility Climate Alliance.

This research project's goal was to co-design and test (through case studies) a replicable water utility business function climate risk and opportunity framework and associated guidebook with water utilities across the United States. In addition, the project provides insights on the types of available data that can be used to assess climate risks and the opportunities associated with particular water utility business functions. Through use of this framework and guidebook, an enterprise-wide understanding and prioritization of the exposure, sensitivities, and opportunities that water utility business functions face in a changing climate can be developed. In turn, this can accelerate the incorporation of climate considerations into everyday utility management.

The core benefits of using this framework include alerting business function managers and staff to emerging risks and opportunities associated with the intersection of climate drivers and the array of utility systems and functions. When these new and/or increased risk levels intersect with underlying vulnerabilities, such as deteriorating infrastructure and interdependent systems that may pose a common point of failure, the result may be catastrophic failures for large water utilities, with significant impacts on their surrounding communities. Energy, water, and healthcare system impacts resulting from these failures can place the people, businesses, and industries that rely on safe and reliable water at risk.

The Water Research Foundation (WRF), the project team, and other contributing partners supporting this research project clearly recognize that some water sector utilities include functions beyond drinking water, including wastewater, reclaimed water, and stormwater. These utilities have an even broader range of risks to manage. Due to funding and time constraints, the project's scope was primarily limited to drinking water functions and their critical pathways. However, the framework, guidebook, case studies, and findings can be readily used to assist other water sector utilities in preparing for, and responding to, Earth's changing climate.

This project investigated a range of water utility business functions and sub-functions, in addition to individual and cascading climate risks and opportunities, that may affect these business practices, including energy use and supply, capital investment decisions, purchasing and supply chain issues, asset management programs, employee and customer service issues, emergency management, and more, linking available and relevant climate data and information to those business functions. Limiting the consideration of climate change to the direct impacts of individual climate drivers on water supplies and infrastructure can "silo" climate change as an external, physical factor, preventing a full assessment of risks and opportunities across a water utility's core functions. Mainstreaming—including consideration of climate issues in all decision processes across the entire utility enterprise—requires a much more integrated view of systems and critical paths of business activities. Additionally, mainstreaming requires a more integrated system-based view as integration of these considerations into a broad array of activities must be strategically thought through to ensure that decisions address current and future risks and opportunities. Developing cross-functional expertise within a utility at scale requires collaboration, climate awareness, an understanding of the potential cascading impacts, and a broader perspective across all internal leadership.

Through this project, the team accomplished the following:

1. Developed a suite of common water utility business functions.
2. Identified "critical" paths and components for analysis within each business function.
3. Assessed the potential risks and opportunities of climate drivers to affect the critical path of water utility business functions.
4. Compiled relevant climate data and information for business functions.
5. Designed a flexible and replicable water utility business risk and opportunity framework and associated guidebook.
6. Tested the framework with four case-study utilities.

The methodology used to conduct this research included intensive desk research and virtual interviews; interactive and co-produced climate risk and opportunity mapping exercises; analysis of existing scientific data and information relevant to assess water utility business function risks and opportunities; the design of a replicable and easy-to-follow water utility business function climate risk and opportunity framework and associated guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*, in collaboration with four utility case studies; and ongoing feedback from the project partners (Table ES-1) throughout the duration of the research project.

Table ES-1. Project Partners.

Partner Name	Description	Organizations Involved
Water Utility Practitioner Group (WUPG)	WUPG members served as on-the-ground water utility experts, providing insights into the utility's core business functions, climate science and data needs, and decisions being made to enhance business resilience in the face of a changing climate. These utilities were selected as part of the project proposal process based on their interest, location, size, and utility complexity.	• Austin Water • City of Fort Collins Utilities • New York City Department of Environmental Protection • Salt Lake City Department of Public Utilities • San Diego Public Utilities Department • Southern Nevada Water Authority • Tampa Bay Water
Case Study Water Utilities	To explore the framework and process in more depth, four case study water utilities were selected, representing different geographic areas of the country, water sources, scopes of service, and size ranges, from relatively small to very large. All were enthusiastic about serving as a case study, and already do or will experience different impacts from climate change.	• City of Fort Collins Utilities • San Diego Public Utilities Department • Southern Nevada Water Authority • Tampa Bay Water
Technical Advisory Group (TAG)	To ensure the framework and end results were informed by a wide range of water utility practitioners and experts, a small group of technical advisors was recruited to supplement the team's expertise by providing in kind, overarching advice, guidance, and insight throughout the project's duration.	• American Society of Adaptation Professionals • Cascade Water Alliance • Western Water Assessment • Marie Pearthree, P.E. • Dr. Jeffrey Arnold • Dr. Missy Stults • Paul Fleming

This research resulted in an improved understanding of varying business functions across multiple water utilities, considerations for business functions to assess climate risks and opportunities, capabilities needed to support business function leads through this process, data and information types needed to assess business function risks and opportunities at various scales, a step-by-step framework for water utilities to map climate-related risks and opportunities across their business functions, and some positive progress in risk identification and management for several of the partner utilities since the start of the project in 2018. Although most of the utilities studied in this project were large, the framework proved useful regardless of the utility's size. For example, the same approach was used for Fort Collins and for larger utilities, such as Tampa Bay Water. In fact, the study found that the simpler the utility business functions, the easier it was to analyze the risks. For this reason, the research team found it helpful and more logical to map climate risks and opportunities to the core business functions' sub-components rather than the larger-scale core headline functions, which Table 1-1 shows in bold.

This project's next phase will include guidance on mainstreaming the framework into utilities' internal management practices to enhance overall resilience to climate change.

ES.1 Key Research Takeaways

These key takeaways represent a summary of overarching lessons learned throughout the research project and development of the framework.

> "When Hurricane Katrina hit the Gulf Coast more than a decade ago, our area had clear, blue skies and we thought we would not be affected by that disaster. However, our vehicle and generator fuel supplies were substantially diminished, and we were within one day of having those supplies cut off. With the increasing severity and frequency of extreme events, and the potential for greater global security challenges due to climate change, there is an increasing risk that water and wastewater utilities will experience more frequent and severe disruptions not only in the shipment, delivery, storage and stockpile of fuel supplies, but other critical services, materials, and supplies as well. Acquisition and supply chain issues are a good example of the 'secondary' business functions that will likely be impacted by our changing climate."
>
> *Patrick Davis,*
> *Orange Water and Sewer Authority*

- Most water utilities have not assessed climate change risks and opportunities from a business function perspective; rather, if considered at all, climate risks and opportunities usually focus on water supply and flood control issues. Those already assessing these risks have recently experienced significant impacts from extreme weather events that impacted their (or another utility's) ability to provide safe and reliable water to their customers.
- Mapping climate drivers and underlying conditions to critical decisions or requirements for business functions leads to a more integrated, systems-based understanding of risks and opportunities. This business-function oriented approach can lead to a more sophisticated analysis, ultimately affecting and providing the business case to reconsider priorities and strategic investments for utility management. The research team concluded that starting with the business function and understanding risks from that perspective proved more useful than starting analysis with the climate drivers.
- The process and conversations associated with mapping business functions were much more important than the maps themselves, which serve as means to an end. The primary outcomes of the mapping process included more collaborative relationships and improved communication across the business functions; cross-training, understanding of, and identification of impacts related to a complex issue within and across the utility enterprise; an improved understanding of relationships between climate risks and underlying vulnerabilities; explicit discussion of critical decisions or requirements for each business function; and thoughts about the actual conditions and significant

imperative for continuity levels of service and operation. Consequently, ongoing conversations of this type can be useful.

- Bringing an array of utility business function representatives together offers multiple benefits. In many cases, they may not have previously worked together closely, and joint exploration of these risks and opportunities builds relationships and capacity for future collaboration – for any complex issue the utility may face. Leadership and climate expertise within the utility for such assessments is also critical when working with business functions not regularly considering climate change as a factor in their decisions. These leaders and experts can help the business function leads navigate the daunting climate science and ask the key climate questions.
- A genuine need exists for guidance and implementation of integrated, long-range, capital improvement and financial planning for acute and chronic climate impacts across water utility business functions (mainstreaming risk and resilience). The research clearly indicated that not all water utilities currently integrate such planning processes and could benefit from more coordinated and aligned efforts.
- Knowing how to find the climate data and what data type, scale, and timeframe to use in evaluating business functions' risk and/or opportunity can prove daunting. The data synthesis developed for this project provides suggestions on how to deal with time, spatial scales, and other geographic considerations. Section 4.2 provides additional guidance for the type, scale, and timeframe of climate data.
- Anticipating extreme weather conditions can be far more challenging than identifying climate trends. Some utilities have internal climate experts (with some training in climate science and actively following climate-related developments) and/or sustained relationships with external climate experts (including scientists, consultants, or academics); others do not. Therefore, a range of sophistication and/or capacity exists in anticipating future climate conditions. Though even experts can be challenged in approaching these difficult questions, understanding the potential for extremes is very important to most utilities. Collaborating with scientists to understand how to manage uncertainties and generate useful data and information to provide anticipated ranges for extremes will be an ongoing need.[1]
- The co-production process is essential—the team could not have conducted this work without partner utilities sharing their knowledge of the ways that their utilities function. Conversely, external parties (the research team) asking the questions identified new topics not previously discussed, perhaps helping business function leads move to a more nuanced view of their business function's interdependence and of the potential for cascading risks and associated opportunities to enhance resilience.
- For almost every risk identified, a potential adaptation strategy or opportunity could minimize the risk's impacts. In many cases, the same strategy (e.g., advances in internal communications around building more robust infrastructure, hazard mitigation, human resources/community engagement systems to manage extreme events) could be used to address multiple potential problems, providing co-benefits for the water utilities.
- This climate risk-based business function assessment should be included as one element of a utility's comprehensive effective utility management (EUM) program.

Based on the research objectives, the research team developed the key findings shown in Table ES-2, each of which is described in more detail in the subsequent chapters.

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[1] For useful climate data sources, review the climate information sources and types within the Risk and Opportunity Profiles (Appendix E).

Table ES-2. Summary of Key Findings.

Project Objective	Key Findings
Chapter 1: Compile a suite of water utility business functions	• **Key Finding 1-1:** Business functions and sub-functions vary across utilities • **Key Finding 1-2:** The level and frequency of collaboration varies across business functions • **Key Finding 1-3:** Extreme weather events and/or emergency response situations that significantly impact a water utility's continuity of operations present a driving force for cross-functional collaboration and strategic planning • **Key Finding 1-4:** Internal climate experts who can translate science into potential risks and opportunities for core business function leads are useful
Chapter 2: Map climate risks and opportunities by business function for four case studies	• **Key Finding 2-1:** Within the utilities studied, extremes drive actions on assessing climate-related risks and opportunities • **Key Finding 2-2:** The length of planning horizons varies across and within utilities making assessments and preparations for climate risks more difficult for utilities with short planning horizons • **Key Finding 2-3:** Improving or updating design standards and protocol to incorporate changing conditions is critical • **Key Finding 2-4:** Regulatory requirements can incentivize consideration of climate risk management within utilities • **Key Finding 2-5:** Decision-making under uncertainty remains a challenge • **Key Finding 2-6:** Leadership within the utility is critical to innovation and preparedness • **Key Finding 2-7:** Mainstreaming resilience across water utility business functions is in its infancy
Chapter 3: Co-produce a *Water Utility Business Function Climate Risk and Opportunity Framework*	• **Key Finding 3-1:** Most water utilities have not assessed climate change risks and opportunities from a business function perspective • **Key Finding 3-2:** Mapping climate drivers and underlying conditions to critical decisions or requirements for business functions leads to a more integrated, systems-based understanding of risks and opportunities • **Key Finding 3-3:** The process and conversations associated with mapping business functions prove much more important than the maps themselves, which serve as means to an end • **Key Finding 3-4:** Bringing an array of utility business function representatives together offers multiple benefits • **Key Finding 3-5:** A genuine need exists for guidance and implementation of integrated, long-range, capital improvement and financial planning for acute and chronic climate impacts across water utility business functions (mainstreaming risk and resilience) • **Key Finding 3-6:** Knowing how to find the climate data and what data type, scale, and timeframe to use in evaluating business functions' risk and/or opportunity can prove daunting • **Key Finding 3-7:** Anticipating extreme weather conditions can be far more challenging than identifying climate trends • **Key Finding 3-8:** The co-production process is essential • **Key Finding 3-9:** For almost every risk identified, a potential adaptation strategy or opportunity could minimize the risk's impacts • **Key Finding 3-10:** This climate risk-based business function assessment should be included as one element of a utility's comprehensive Effective Utility Management (EUM) program
Chapter 4: Identify relevant climate information sources and types by business function	• **Key Finding 4-1:** Information on climate extremes may require greater reliance on "data" information types • **Key Finding 4-2:** Spatial scales of interest may not match those of available information • **Key Finding 4-3:** Timeframes of interest may not match those for available information • **Key Finding 4-4:** Temporal scales of interest may not match those for available information • **Key Finding 4-5:** Low-risk tolerance and a desire to minimize disruption to utility functions leads to requiring "worst-case" plausible future climate trajectories for consideration • **Key Finding 4-6:** Use of downscaled climate projection data must consider information needs, decision context, and methodology limitations • **Key Finding 4-7:** Various online resources and information portals/hubs serve as collection points for several climate information sources and types • **Key Finding 4-8:** Existing climate services may help with information requirements and science translation

ES.2 Next Steps

Based on the outcomes of this project (Phase 1), the next phase (Phase 2) will test the framework with two Water Utility Climate Alliance (WUCA) member utilities and enhance the framework and guidebook to identify opportunities to accelerate the mainstreaming of climate considerations and resilience into utility management. To achieve this goal, the next steps in this second phase include:

1. Conduct a literature review and compare other climate-related risks, opportunity, and resilience mainstreaming frameworks to the water utility business risk and opportunity framework and identify how the framework relates to existing corporate and utility risk management processes or can be incorporated into existing processes;
2. Pilot test the framework for three and five critical business functions with two WUCA utilities, Denver Water and San Francisco Public Utilities Commission (SFPUC), through an interactive one- to two-day tabletop exercise (TTX) and workshop;
3. Expand the framework (version 1) to identify steps or opportunities useful in mainstreaming climate risks and resilience across select critical water utility business functions (version 2);
4. Update and enhance the *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate* to reflect lessons learned from testing the framework and identifying opportunities for resilience; and
5. Engage staff through the pilot testing and exercises and generate train-the-trainer materials to create awareness across Denver Water and SFPUC about climate-related risks and opportunities and measures to mainstream climate resilience through critical business functions.

Phase 2 of this project includes considerations for mainstreaming the framework. Having an outside facilitator—with an unbiased view of the utility—asking targeted questions led to fruitful discussions across business functions in each case study. The primary benefit appeared to come from asking questions that challenged preconceived notions of risk within the utility. Mainstreaming this approach will require adopting a deliberate method for including "what if" scenarios in the conversation to challenge "conventional wisdom," hence the testing of the updated framework through interactive tabletop exercises.

ES.3 Framework

A key output of this research project was the co-production of an adaptive, flexible, and tailorable water utility business risk and opportunity framework (Figure ES-1) that helps utilities define their focus for a risk and opportunity assessment, ask key climate questions, map climate impacts relative to mission-critical business functions, and pinpoint risks and opportunities across those business functions. The supplemental guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*, provides further details, images, and templates that utilities can use to map climate exposure and climate information needs to their core utility business functions, and, ultimately, understand cross-cutting risks and opportunities facing their business. Chapter 3 of this report provides additional details on the methodology, framework steps, key findings, and lessons learned. Based on the research team's expertise in assessing climate-related risks and opportunities across water and energy utilities, government agencies, and corporations, the framework steps were designed, tested, and synthesized as the research was conducted.

Figure ES-1. Water Utility Business Function Climate Risk and Opportunity Framework.

ES.4 Related WRF Research

- An Integrated Modeling and Decision Framework to Evaluate Adaptation (project 4636)
- Climate Change in Water Utility Planning: Decision Analytic Approaches (project 3132)
- Developing Robust Strategies for Climate Change and Other Risks (project 4262)
- Effects of Climate Change on Water Utility Planning Criteria and Standards (project 4154)
- Impacts of Climate Change on Honolulu Water Supplies and Planning (project 4637)
- Risk Governance: An Implementation Guide for Water Utilities (project 4363)
- Securing Value: Integrating Risk Governance With Other Business Functions in Water Utilities (project 4573)
- Water/Wastewater Utilities and Extreme Climate and Weather Events (project 4416)

CHAPTER 1

Compile a Suite of Water Utility Business Functions

The Cadmus research team identified a suite of common business functions that support the operation of large water utilities. The purpose of this task was to better understand the range of business functions across multiple water utilities and to start considering the various ways that climate risks and opportunities may affect their business functions. Staff not working on climate change daily, monthly, or even at all may not be aware of individual and cascading risks that climate change poses to their operations, facilities, reputation, staff, finances, and achievement of their overall mission.

By understanding the core decisions these people make on a day-to-day basis within their business function, the ways they interact with the other business functions across the utility, and the existing risk management processes they have in place, the team sought to identify climate data, information, and tools available to integrate into existing risk or strategic management plans, preparing the utilities for climate change and variability. Additionally, going through such an evaluation can enable a utility to identify information gaps and research needs, which may be met in collaboration with other utilities, other agencies, and external experts in climate science, adaptation, and mitigation.

1.1 Methodology

The methodology for developing a suite of water utility business functions involved close collaboration with seven Water Utility Partner Group (WUPG) members—utilities that were selected originally for the project proposal based on existing relationships, involvement in WUCA, experience with climate and extreme weather events, and utility size and geographical location.

1.1.1 The Water Utility Partner Group (WUPG) Members

The Water Utility Partner Group (WUPG) members include Austin Water, City of Fort Collins Utilities, New York City Department of Environmental Protection, Salt Lake City Public Utilities, San Diego Public Utilities, Southern Nevada Water Authority, and Tampa Bay Water.

For more background information on each of the seven water utilities participating in this process, please see Appendix E Water Utility Business Risk and Opportunity Profiles. The research team generated more in-depth profiles for the four case study utilities (City of Fort Collings, San Diego Public Utilities, Southern Nevada Water Authority, and Tampa Bay Water) and less detailed profiles for the three remaining utilities.

1.1.2 Technical Advisory Group (TAG) Members

In addition to the WUPG and to ensure the framework and end results were informed by a wide range of water utility and climate risk practitioners and experts, the research team recruited a small group of technical advisors that supplemented the team’s expertise by providing in kind, overarching advice, guidance, and insight throughout the project’s duration.

1.1.3 Desk Research

The research team conducted background research on the seven WUPG members through publicly available information (e.g., websites, reports, plans) to gather foundational information on the following:

- The utility's core and secondary business functions
- Recent climate- or extreme weather-related events in their jurisdictions and regions that impacted their operations and infrastructure
- Vulnerability, risk, or resilience assessments that identified climate risks and opportunities, and the climate data and information used to conduct the assessments
- Subsequent plans, reports, or programs developed to manage, prepare for, and respond to various climate-related risks and opportunities

The research team then compiled a preliminary list of water-specific and other utility core business functions and sub-functions within the seven WUPG utilities. During a kickoff call with the Cadmus research team's TAG and WUPG, the research team received feedback on the initial list of water utility business functions. During the stakeholder interviews, the research team received more detailed feedback from WUPG members and amended the business function list to reflect their suggestions.

1.1.4 Virtual Interviews

Using information gathered through the desk research, the Cadmus research team designed a detailed interview protocol with targeted questions for each WUPG member and their business function leaders. The interviews sought to understand core business functions for each utility, the existing and potential efforts and capacity to assess climate risks and opportunities, and the potential for cascading impacts across business units.

The questions and protocol were developed in consultation with the TAG and were sent to WRF and the Project Advisory Committee (PAC) for their review and input. WRF collected and compiled the PAC's feedback on questions and protocol, incorporating this into the final interview protocol and questions.

1.1.4.1 Interview Attendees—Business Function Leads

Before the virtual stakeholder interviews, the research team asked WUPG members to identify their core business function leads and to invite them to the interviews, ensuring cross-function collaboration and the ability to represent multiple perspectives. The interviews enhanced the understanding of the members' business functions, operations, roles, and responsibilities. WUPG utility business functions represented in the interviews included decision support and planning, finance, source water assessment, systems planning, human resources, maintenance and asset management, emergency management, operations, and water quality treatment, among other business functions.

The interviews focused on questions in two major areas—the utility's core business functions; and climate data and information the utility currently uses in making decisions.

1.1.4.2 Interview Questions: What Are the Core Business Functions in Your Utility?

To better understand WUPG members' utility business functions, the research team asked each stakeholder the following questions:

1) In preparation for this interview, we did some background research on the various business functions performed by utilities across the nation, including your own [see the business function list above]. When you think about your utility, are any major categories of business functions missing that we should include?

a) If yes, can you tell me a bit about what business functions are missing, what their responsibilities are, and why/how your utility works in this area?
b) Do you have an internal organizational chart that you can share with us that illustrates the organization of business functions across your utility? (If so, please share via email.)

2) Has your utility identified any regulatory or structural barriers to climate adaptation and/or other risk management innovations that you had hoped to implement?
3) During this background research, we also identified some subcategories within each of the core business functions we found across the nation. Did we miss any major subcategories?
4) At your utility (or unit within the utility), what key decisions are made? More specifically:
   a) Can you describe how decisions are made on a day-to-day basis?
   b) Is there a different process for long-term or policy decisions? If yes, can you please describe?
5) In advance of this call, we asked you to fill out a document highlighting the core business functions you as an individual regularly engage/work with. If you completed those sheets, can you bring them out now? Can you each briefly share your results?

The final question of the interview led WUPG members through an exercise to understand how the business function they represent aligns with the water utility's other business functions. The exercise was intended to encourage WUPG members to think about the interconnectedness of their utility's business functions. To complete the high-level business function-mapping exercise, interviewees were asked to fill out a circle diagram (such as that shown in Figure 1-1 and Figure 1-2) by indicating their business function or unit in the center circle. Interviewees were then tasked with writing the business functions with which they directly interact on a frequent basis in the adjacent (blue) ring. The next (grey) ring consisted of the business functions that the second group of business functions interacted with regularly, and the final ring (yellow) consisted of business functions that the grey group of business functions interacted with regularly. The goal of the exercise was to encourage participants to think about how they communicate, make decisions, and collaborate across business functions within the utility.

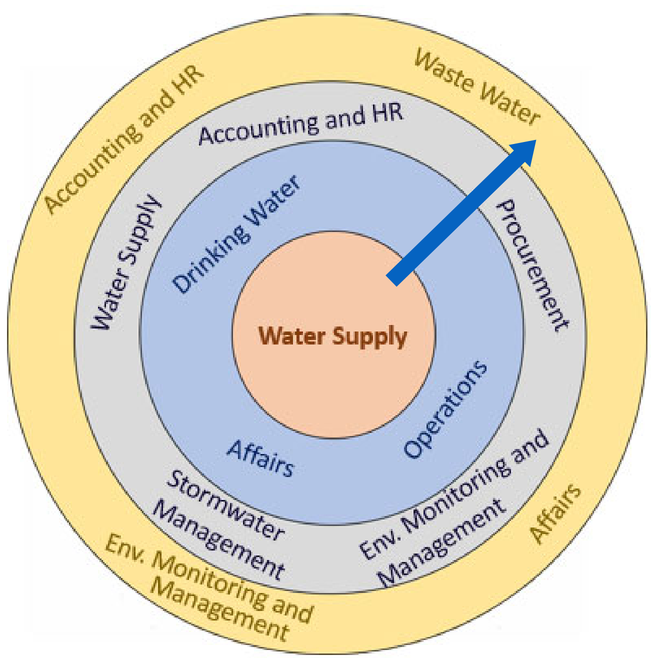

Figure 1-1. Example of Circle Diagram from San Diego Public Utilities Department.

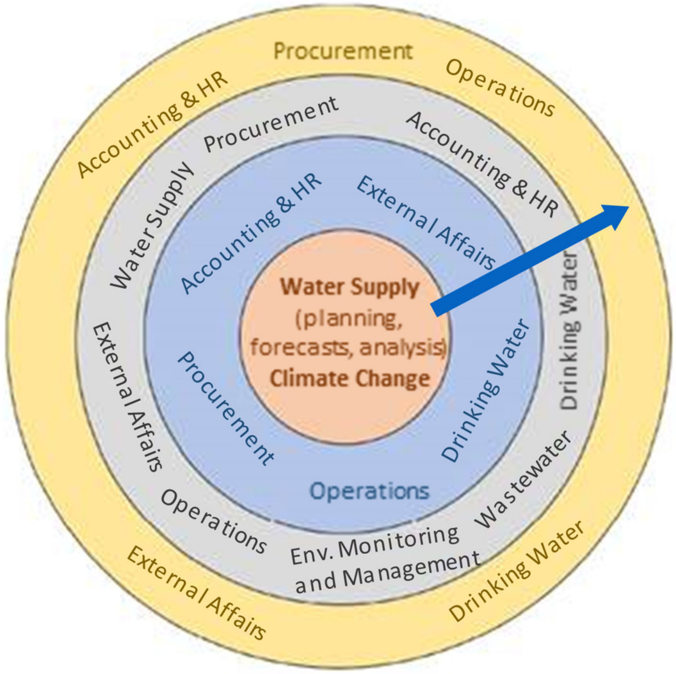

Figure 1-2. Example of Circle Diagram from City of Fort Collins Utilities.

1.1.4.3 Interview Questions: What Climate Data and Information Do You Currently Use for Decision-Making?

Once the Cadmus research team completed gathering the information about business functions and interactions, the interviewers asked the following questions about the ways that the utility and the business function representatives used available climate information to make decisions:

1) What sources or data did you use to compile your utility-specific climate information?
   a) Do you currently have information or tools to assist in identifying and assessing the likelihood and consequences of low-probability/high-impact events?
2) Do you have ongoing relationships with partners or consultants who assist you in finding or generating climate information?
3) What other processes does your utility have in place to identify, assess, and manage any type of risk or hazard (e.g., earthquakes, disease outbreaks, strong storms, cyber security, economic downturns)?
   a) Which business function conducts these assessments and manages the risks or opportunities?
   b) Does any business function specifically conduct assessments and work on managing climate risks or opportunities? If yes, how?
4) Have you engaged with other partners (e.g., utilities, community organizations, hazard mitigation planners, or government staff) on climate risk or opportunity assessments or on plans related to the risks your utility is facing? If yes, please describe the engagement and resulting output and/or outcome.
5) Has your jurisdiction/state taken any steps to adopt or promote policies and regulations to incorporate climate change into planning, policies, or decision-making, and, if so, has that driven actions within the utility? If yes, which business functions were involved?

1.1.5 Ongoing Feedback from Project Partners

In June 2018, the Cadmus research team completed the virtual stakeholder interviews with the seven WUPG members. During the interviews, the research team collected detailed notes, and then followed up with WUPG members to confirm the business function list and interview takeaways.

The resulting suite of water utility business functions remained a living list, reviewed and revised through subsequent PAC, WUPG, and TAG member exercises, feedback, and calls until the writing of this report began in mid-October 2018.

1.2 Suite of Water Utility Business Functions

Table 1-1 provides the full suite of water utility business functions, compiled in close collaboration with the PAC, WUPG, and TAG. Core business functions appear in bold, with sub-functions as bullets. Although no two utilities were organized the same way, the list represents the broad and complex range of water utilities' business functions, and some overlap may occur between function categories.

Table 1-1. Specific and Other Business Functions.

WATER-SPECIFIC BUSINESS FUNCTIONS				
Drinking Water	**Water Supply**	**Wastewater**	**Water/Environmental Monitoring and Management**	**Stormwater Management**
• Drinking water treatment (sub business function) • Drinking water distribution	• Conservation • Drought planning/water shortage stage management • Raw water/untreated irrigation water management • Seawater desalination • Recycled water/effluent management • Reservoir and surface water management • Groundwater management • Wholesale water supply	• Wastewater collection • Wastewater treatment • Biosolids management	• Groundwater and surface water quality/management • Watershed management/land management • Stream rehabilitation • Ocean water quality monitoring • Environmental monitoring • Environmental compliance	• Flood control • Drainage basins and infrastructure • Stormwater quality

OTHER BUSINESS FUNCTIONS					
Business Affairs, Accounting and Human Resources	**Procurement**	**Planning, Modeling, Forecasting and Analysis**	**External Affairs**	**Engineering, Design, and Construction**	**Operations**
• Contracts, business services, recordkeeping, and billing • Finance and insurance • Rate setting, charges and fees • Grant preparation and management • Human resources, employment, and staff training • Asset inventories and tracking	• Energy procurement and management • Procurement of goods and services	• Water supply planning • Water demand planning • Sustainability planning • Forecasting and analysis	• Customer service (residential, commercial) • Public education and outreach • Community relations and advocacy • Legal services, legislative and regulatory affairs • Cross-agency coordination • Communications • Emergency management/hazard mitigation	• Infrastructure planning • Construction	• Asset management • Infrastructure maintenance • Field operations • Meter reading and maintenance • Security (physical, computer, and data) • Information technology • Laboratory services

1.3 Key Findings

Drawing upon the initial desk research, interviews with the WUPG member and utility/business function representatives, and discussions with and feedback from the PAC and TAG, a list of several key findings was compiled.

1.3.1 Key Finding 1-1: Business Functions and Sub-Functions Vary across Utilities

Water utility business functions and sub-functions varied by utility size, geographical location, long-range planning priorities, regulatory conditions, and other factors. Some utilities have much broader mandates than others (e.g., including wastewater treatment as well as water supply and treatment). Some engage in regional water supply planning and delivery activities, while others operate independently. The following represent a few examples of the various ways that utility business functions prepare for climate change:

- Given San Diego's geographical location along the southwest coast of California, the utility has established a water supply contingency plan in consideration with drought impacts, sea level rise, and state-level requirements for hazard mitigation planning. The San Diego Public Utilities Department includes regional and multi-jurisdictional responsibilities and works in coordination with other entities (such as the San Diego Water Authority) on Integrated Regional Water Management. Key decisions regarding climate change at a project-management level are based on and in accordance with the City's Climate Action Plan and interpretation of goals set in San Diego Public Utilities Department's long-range planning documents. Risks or issues are identified on a weekly basis and are subject to internal staff meetings, discussions, or directives from senior management.
- San Diego Public Utilities Department's operations business function is responsible for conducting infrastructure vulnerability studies and managing impacts of extreme events (e.g., storms, earthquakes). Understanding underlying conditions and vulnerabilities proves crucial when planning for acute and chronic climate changes. San Diego's financial business function evaluates rate models, which include economic downturns.
- Over the past few years, Austin Water has experienced severe flooding events, which have resulted in damage to utility infrastructure and an extended boil water event. The utility's catastrophe insurance has provided some reimbursement for damage, but the extended drought from 2008–2016 impacted Austin Water significantly. Reduced water demand affected revenue and resulted in additional rate increases. This strained finances to the point that Bond Rating Agencies put the utility on a negative watch. Since that time, Austin Water's finances have stabilized, and the negative watch has been removed. In retrospect, Austin Water noted that, with stronger reserves or cash on hand, they could have absorbed some of these impacts.

Appendix C provides a few example organizational charts from WUPG members for this project.

1.3.2 Key Finding 1-2: The Level and Frequency of Collaboration Varies across Business Functions

The Cadmus research team found some utilities are relatively "siloed" internally, while others are more integrated and collaborative, even during normal operations. Key communicators and connectors within some water utilities can be identified and empowered to help navigate and overcome the effects of silos, thus promoting cross-utility collaboration.

- At Austin Water, many day-to-day decisions are made through the chain of command, with issues rising from workers to supervisors to managers to division managers and associate directors. The engineering services program communicates with all functional groups and other city departments daily. The water utility has a function-based organizational structure, but, in practice, staff work together in a matrix or cross-functional system to achieve business goals. In addition, Austin Water reported that multiple touchpoints span out from a central hub; that is, no one specific business function works in isolation. Instead, each function touches many others. For example, financial services provide support services to all business functions in the utility, through budget management, accounts payable, and financial planning.
- Fort Collins Utilities said staff has authority from the bottom up to take ideas and implement them (with approval from the director and the City Council). Fort Collins Utilities incorporates elements of matrix-style governance and independent decision-making. Fort Collins Utilities also reported that, from a water quality services standpoint, almost all business functions directly collaborate. These functions include water production, environmental and regulatory affairs, water resources, water

field operations, and wastewater reclamation. Staff members said they used the circle exercise to identify sub-functions to core business functions, finding they could reach only a third level (see Figure 1-2 for more information on these various levels)—an indication of the utility's interconnectedness.
- When confronting decisions related to risk management, all business functions at Southern Nevada Water Authority (SNWA) collaborate. Staff noted that the organization is collaborative and that different functions rely on each other. Currently, SNWA is going through a process of enterprise risk management implementation to break down silos and take a global look at risks across the organization.
- At San Diego Public Utilities Department, the internal business function units have not collaborated extensively on climate-related risks. Other units have not been internally integrated in the past. The City of San Diego is working to develop and improve across the spectrum of business functions.

1.3.3 Key Finding 1-3: Extreme Weather Events and/or Emergency Response Situations That Significantly Impact a Water Utility's Continuity of Operations Present a Driving Force for Cross-Functional Collaboration and Strategic Planning

The Cadmus research team found that many utilities maintain incident command structures or other cross-functional strategies, so business functions can coordinate smoothly in the face of significant emergency scenarios that impact the water utility's continuity of operations.

- Austin Water has established an incident command structure that, depending upon the resource requirements and other factors, in the event of a disaster or emergency, facilitates cross-functional collaboration. Over the last several years, major events for Austin Water have included short-term flooding and significant rains that occurred throughout the course of an entire year (e.g., in 2010, the utility lost $50 million, then went into a sustained drought, losing $100 million over a three-year period when water restrictions dramatically affected consumption). A major upstream flood in October 2018 significantly reduced drinking water treatment plant production and resulted in emergency conservation measures and a city-wide boil water notice. Extreme flooding events have also destroyed some wastewater infrastructure and periodically impede access to facilities. Austin Water has changed operations to accommodate adjustments in outdoor watering schedules. In the long term, Austin Water knows it will need to expand storage capacity within the distribution system and be prepared to issue emergency conservation measures more quickly if needed. Austin Water is now developing plans to improve facility access areas, so its facilities are more resilient to climate change risks. Due to flood damages, it has allocated funding from FEMA sources and has repaired damaged facilities to bring the system back to regular operation conditions. From a supply perspective (through conservation, demand management, and other approaches), Austin Water has worked closely with the Lower Colorado River Authority, the Texas Commission on Environmental Quality, and other regional partners to strengthen the water management plan guiding how the Lower Colorado River Authority manages surface water reservoirs. Through required five-year updates, the utility has been able to add protection to the reservoir storage supply in anticipation of future droughts. In November 2018, Austin's City Council adopted a groundbreaking 100-year water supply plan for Austin, called "Water Forward." This two-year planning effort includes cutting edge climate projection data for the 100-year planning period and a wide-ranging suite of strategies to address future climate scenarios.
- At New York City's Department of Environmental Protection (NYCDEP), the utility business functions are designed to respond to emergencies and crises, such as dam overtopping or a water main break. Hurricane Sandy served as a major driver in transforming decision-making. Even before that,

Hurricanes Irene and Lee devastated communities located in NYCDEP's water supply watershed. Despite turbidity events lasting for months after Hurricanes Irene and Lee, NYCDEP was able to continue its water delivery and meet drinking water standards due to major treatment enhancements/modifications. The most significant impacts from Hurricane Sandy were to NYCDEP's reservoirs from high winds leading to significant erosion, and to wastewater infrastructure from flooding. Water supply was only impacted minimally.

- Hurricane Irma forced Tampa Bay Water to decide which operations to shut down and which to keep running. Before Hurricane Irma landed, Tampa Bay Water switched its facilities to generators to preempt power issues and service interruptions. When Irma went from a Category 2 to Category 3, surface water treatment production was reduced in half, reducing projected supply. Tampa Bay Water could communicate effectively with its internal and external stakeholders and coordinate its responses at all utility levels.
- The response of the Salt Lake City Department of Public Utilities (SLC DPU) to emergency situations (such as algal blooms or extreme precipitation, both of which affected the utility significantly in 2017) affects almost all utility business functions due to requirements for a cross-functional strategy to communicate with the public, developing interim plans for operations, and ensuring enough staff are on hand to support the effort. On July 26, 2017, a 200-year storm event had a significant financial impact on SLC DPU in terms of property damage and liability. Nonprofit response organizations and regulators worked together, responding to the storm event with disaster relief and recovery strategies. The event's cascading impacts also affected operations as some infrastructure required extensive repairs. A flush of sediment into a river affected water quality for an extended time following the July 26 storm event. The effort also engaged the utility's communications team, and the utility conducted 14 interviews to communicate the event's impacts to the public. Procurement also was impacted as the utility had to rush in procuring disaster clean-up services. The utility incorporated planning for extreme events into its long-term and robust stormwater management programs.
- At Fort Collins Utilities, the core business functions of water utilities shifted as new positions and functions are required to respond to a major event or disaster in the city (e.g., an all-hands-on-deck situation). During an emergency, day-to-day staff functions may shift frequently. Staff who qualify as emergency experts also can be called upon for disasters beyond the City of Fort Collins' jurisdiction (such as the event affecting Larimer County [described below]).

For many utilities across the country, the need for a coordinated response to emergencies and disasters has become more obvious. However, despite the establishment of cross-functional strategies for coordinating responses to emergency situations, the research team found these strategies were not as prevalent in a "normal operations" context and proved rare within utilities whose continuity of operations had not been significantly impacted by an extreme weather event or emergency response situations. In addition, strategies to address future climate risks and opportunities across business functions may have to compete with other priorities.

- Although San Diego maintains a Climate Action Plan for emissions and carbon footprint reductions, it has not yet experienced extreme weather events of a significant magnitude. This, along with perceived ample water supply and the difficulty of translating climate change and extreme weather events impacts into measurable risks, are tasks that San Diego Public Utilities Department is still in the process of reviewing for changes in its internal policies or business functions to prepare or account for climate change. The San Diego Public Utilities Department, currently importing up to 85% to 90% of its water, is vulnerable to climate change, but has always made its water deliveries because its regional partnerships have worked to mitigate shortages.

- Fort Collins has found it challenging to activate all its water utility business functions on climate change as it has yet to experience sufficiently significant extreme weather or sustained climate-related incidents within its jurisdiction. During flooding in 2013, Larimer County incurred $200 million in damages, whereas Fort Collins incurred only $700,000 in damages—a small enough expense that it was hard for the city to continue the momentum for coordinated disaster responses following the flood. In contrast, Larimer County, as well as Boulder and Boulder County, undertook a total reorganization as part of its recovery and resiliency effort. Although Fort Collins is exposed to wildfires, these events have not significantly impacted its water treatment plants. However, in direct response to the High Park Fire of 2012, City Council approved emergency funding to construct a pre-sedimentation basin. The basin came online in 2013 as a permanent part of our water treatment process. Furthermore, when people do their jobs well, the community may not see what it takes to prepare for or respond to an extreme event as the impacts are minimized by effective emergency response coordination measures.
- The City of Austin's Sustainability Office brought departments together to look at risks associated with wildfire, drought, and flooding. For Austin Water's Walnut Wastewater Treatment Plant, access issues have occurred during flooding events. Austin respondents noted that both of their wastewater treatment plants are near floodplain areas and that a bridge, maintained by a different entity, lies in the floodplain. During certain large flood events access to one of the plants is a recurring challenge. Their process illustrated that while raising the bridge height may not have been a priority for the transportation team, it was a priority for the water department. Austin Water found it very useful to think about how to prioritize actions across departments and business functions.

1.3.4 Key Finding 1-4: Internal Climate Experts Who Can Translate Science into Potential Risks and Opportunities for Core Business Function Leads Are Useful

For this project, the research team collaborated closely with each WUPG internal climate expert. These experts have knowledge, understanding, and insights into core operations and functions of their utilities as well as access to the latest scientific information about current and future climate conditions. They often maintain relationships with other business function leads from past collaborations. Generally, they have been trained or educated on the scale, type, and source of scientific data available and necessary for business functions to assess their future risks and opportunities. When internal climate experts collaborate with business function leads, the utility can develop a more comprehensive understanding of the risks that climate change poses to the enterprise. Climate experts, when armed with the knowledge of business function leads, have a translational capability to connect climate drivers to key risks and opportunities that their utility has experienced in the past, is challenged with today, and may face in the future.

Internal experts were critical to the process conducted in formulating the *Water Utility Business Risk and Opportunity Framework*. Through this project, the research team found cross-collaboration with the utility's existing climate experts to assess the key risks and opportunities to priority business functions proved useful and effective. However, the identified "climate expert" within utilities often is found in different parts of the utility structure.

- Austin Water's cross-divisional environmental staff work with internal staff in finance, development, legal, conservation, and public information as well as with partners outside of the utility, such as the Watershed Protection Department, Office of Sustainability, Austin Energy, and agencies that include the Lower Colorado River Authority, and the Texas Commission on Environmental Quality on climate considerations and other topics requiring cross-collaboration.

- Assessing and managing climate risks and opportunities at the Salt Lake City's Department of Public Utilities occurs within the executive function as some risks and opportunities require high-level attention and capacity exists in the director's office to handle these issues.
- The Cadmus research team found it useful to engage with experienced climate experts in conducting this project, but recognizes that many utilities do not have the capacity to hire such individuals. Climate experts, as described here, would have significant training in understanding climate processes, know how to use appropriate tools and data for projecting future conditions that may affect the utility and its community, and be well-versed in climate risk assessment. It is not a reasonable expectation for all utilities to have such expertise, especially smaller utilities. There are, however, multiple ways to overcome the lack of such expertise within a utility. For example, a utility could seek assistance from climate-related boundary organizations, such as NOAA's Regional Integrated Science Assessment teams or DOI's Climate Science Adaptation Centers; engaging with climate experts at local universities; working with professional organizations and local utilities that have the capacity to assist; hiring consultants; having a designated staff person attend in-person or online training sessions (thus becoming the designated go-to person for climate questions); and providing help in connecting with the right external "expert" person, tool, or organization to assist.

1.4 Lessons Learned

The Cadmus research team collected information from all seven WUPG members, incorporating feedback regarding organization and content from WUPG, PAC, and TAG members. This approach led to a comprehensive final list of 11 core business functions and nearly 51 sub-functions. While the project focused on drinking water utility business functions, several listed core functions apply to other water sector utility operations.

The Cadmus research team frequently emphasized that the business functions presented for feedback could not represent the exact organizational structure of each WUPG member. For the WRF project, WUPG members accepted this limitation, but they said, if they were to continue this effort individually, they would develop utility-specific lists of core and sub-business functions.

The team employed circle diagrams (illustrated in Appendix A) to encourage WUPG members to think about the interconnectedness of their utility's business functions. This exercise proved productive, primarily helping the utility team understand how well integrated their current business functions were or were not when it comes to addressing the impacts of climate change on the utility's critical business functions. The exercise also served as a useful icebreaker for some WUPG members—that is, an engaged water utility could use mapping of internal connections to inform future discussions by these business functions regarding climate-related risks and opportunities.

Reflecting on the interview questions, the research team realized that—prior to engaging in the circle diagram exercise—it would have been helpful to have explored the underlying vulnerabilities faced by specific utilities in greater detail and how core business functions are already affected by those issues. Given the compressed schedule, the research team asked the utilities to consider their own underlying vulnerabilities and key climate drivers, and then to select the business functions they wanted to map. Spending more time discussing those underlying vulnerabilities and key climate drivers before starting the mapping exercise would have helped more clearly pinpoint the respective utility's climate risks and opportunities.

CHAPTER 2

Map Climate Risks and Opportunities by Business Function

An initial engagement point for water utilities, relative to climate change, is in assessing how climate change may directly affect drinking water reliability and quality. This is only, however, the beginning of the conversation, provided a full assessment of climate-related risks and opportunities is considered across business functions. The approach includes considering how individual and cascading climate risks (and policy responses, both for adaptation and mitigation) may affect and should inform business practices, energy use and supply, capital investment decisions, purchasing and supply chain issues, asset management programs, employee and customer service issues, emergency management, and more. Limiting the consideration of climate change to direct impacts of individual climate drivers can isolate climate change as an external, physical factor, and impede the mainstreaming of the "climate question" across the entire enterprise of a utility.

> **The Climate Question:** How are the assets, people, resources, activities, and/or projects within your business function affected (either negatively [risks] or positively [opportunities] by climate change today and into the future?

Furthermore, it is important from a preparedness perspective to be ready for new kinds of challenges than those historically occurring in a specific utility. This means breaking out of existing expectations about risks and thinking more broadly about new risk sources and the possibilities of risks cascading through interconnected systems. This means utilizing "what if" scenario planning rather than framing the conversation around historic impacts. Long-range/long-term planning for climate and business function R&Os, funding, codes/standards, and more offer multiple benefits, including potentially building a more strategic, overall approach to planning, and integrating climate-related risks and opportunities into day-to-day operations.

2.1 Methodology

The Cadmus research team's methodology for mapping climate risks and opportunities to core business functions involved the following steps:

1. Conduct desk research to understand preliminary historic, current, and projected climate conditions.
2. Develop a straw-man list of business functions.
3. Establish common terminology and definitions.
4. Interview utility staff across the seven WUPG utilities.
5. Synthesize the climate risks and opportunities gathered from desk research and interviews.
6. Determine case study selection criteria to maximize the breadth of topics addressed.
7. Select four case study utilities from the seven WUPG members.
8. Develop a matrix of climate drivers, underlying conditions, and cascading impacts, and share that with the case study utilities.
9. Ask the case study utilities to identify their priority business functions for discussion, based on the matrix of climate drivers and on their assessments of their interactions with their underlying vulnerabilities.

10. Conduct an interactive co-production mapping exercise with the four case study utilities, and categorize overall risks and opportunities within the system.
11. Synthesize and finalize several business function map exercises with each case study utility, developing a climate risk and opportunity profile for each.

2.1.1 Desk Research on Preliminary Historic, Current, and Projected Climate Conditions

To establish a common foundation of climate conditions for the partner utilities and the business function representatives with whom the research team engaged, the research team researched publicly available online resources and documents provided by the partner utilities. The research team then summarized climate conditions using the utility-level, local, state, and regional resources listed in Table 2-1.

Table 2-1. Initial Climate-Related Resources.

Scale	Resource Type
Utility	Long-Range Water Resource Plans
	Urban Water Management Plans
	Water Supply and Demand Studies
	Climate Resilience Evaluation and Awareness Tool (CREAT) 2.0 (EPA, n.d.)
	Climate Change Sensitivity, Risk, or Vulnerability Assessments or Studies
	Integrated Modeling Projects
Local	Local University Climate Centers/Advisory Panels
	City or Community Resilience Assessments or Plans
	Local, City, or County Climate Action Plans
State	Technical State Climate Summaries (NOAA 2017)
	States at Risk Reports (Climate Central, n.d.)
Regional	Third National Climate Assessment (USGCRP 2014)
	Fourth National Climate Assessment, Volume 2: Impacts, Risks, and Adaptation in the United States (USGCRP 2018)*
	Fourth National Climate Assessment, Volume 1: Climate Science Special Report (USGCRP 2017)
** USGCRP 2018 – Volume 2 was not available during the analysis of data availability, but, given its relevance to this project, it is included in this final report as a reference for water utilities' use.*	

The research team also researched climate- and extreme weather-related events that had already occurred in the utility's jurisdictional area or in the region, and/or are projected or are likely to occur. This provided a foundation for the interviews and for the case study descriptions.

2.1.2 Develop a Preliminary List of Business Functions

The initial list of business functions came from reviewing the organizational charts of partner utilities (found on their websites). As no two utilities are organized the same way, the primary intent was to at least establish a placeholder for all major functions, whether the utilities agreed on which functions were considered "core." The utilities then had a starting point for selecting and adding to mapped business functions. Within each core function, sub-functions were identified.

2.1.3 Established Common Terminology and Definitions

Prior to the interviews, the research team collaborated with the TAG to identify common terminology and definitions for use in discussions with the water utility representatives. The Glossary at the end of this report lists the core terms used during the research project.

2.1.4 Interviews with Utility Staff

The Cadmus research team coordinated with each primary WUPG member contact to organize a meeting with staff members who represented the utility's various branches or business functions. The research team conducted a virtual, 1.5-hour interview with each partner utility, during which input was collected on the initial list of business functions, and utilities were asked about their experiences with climate events, its current use of climate data, barriers to climate adaptation, the degree of interest in climate resilience for the utility and the community, and other related topics.

Prior to the meeting, the research team asked attendees to use a circle diagram (Figure 1-1) to map interrelationships between their internal business functions. See Appendix A for an example interview packet that was provided to each of the seven WUPG members prior to interviews, for distribution to the interview attendees.

2.1.5 Synthesis of Risks and Opportunities

The research team relied on background research and on information from the interviews to synthesize each utility's climate risks and opportunities. Using the information, the research team selected the four utilities for case studies and prepared the risk and opportunity profiles for all the utilities (see Appendix E for high-level and more in-depth risk and opportunity profiles). The more in-depth profiles were developed for the four case study utilities.

Two approaches were considered for mapping business functions and associated climate risks and opportunities: (a) base the process on applicable climate drivers; or (b) base it on the utility's applicable business functions. Cadmus and the TAG decided to start with business functions, as this approach made those functions the focus of the conversation, leaving open the possibility of discussing additional stresses, climate drivers, and cascading effects that could interfere with critical path activities for that business function. It also reinforced the concept of mainstreaming or integrating climate considerations across water utility business functions and decisions.

2.1.6 Criteria for Selection of Case Studies

The criteria were intended to encourage a range of inputs from partner utilities and to maximize the possibility of applying this process to many future users, while minimizing the time and resources required to move into testing the mapping approach. Case study selection criteria included the following:

- The degree of interest expressed by the partner utility in serving as a case study
- A range of climate vulnerabilities
- Multiple regions across the U.S.
- Different utility sizes
- A varying degree of experience with climate risk, opportunity, and resilience issues
- Varying degrees of community engagement
- A range of different business functions/degrees of complexity of the business functions

2.1.7 Case Study Selection

Based on the case study selection criteria, four utilities were chosen—City of Fort Collins Utilities, San Diego Public Utilities Department, SNWA, and Tampa Bay Water. Besides representing different geographic areas of the country, the utilities use different water sources, provide very different scopes of service, and range from relatively small to very large. All were enthusiastic about serving as a case study and already do or will experience different climate change impacts.

2.1.8 Matrix of Climate Drivers, Underlying Conditions, and Cascading Impacts

In preparation for the case study mapping task, the research team developed an initial matrix with the core 11 business functions listed in Table 2-2, potential underlying conditions, climate drivers, risks, and opportunities. The research team distributed this matrix to the case study utilities to help them select three priority business functions for inclusion in the mapping exercise. The research team also requested feedback on the functions list.

In their approach, the research team did not want to limit the utility's selection of business functions by setting prior expectations about their risks and opportunities. The research team did, however, want to ensure that the utilities considered the full range of specific external climate drivers as well as climate impacts and cascading risks and opportunities. As each mapping exercise was intended to test a process for application by other utilities, the research team decided specific business functions mapped in each case were not critical, but the research team still sought to map a range of different business functions to test the approach.

2.1.9 Mapping Exercise with Four Case Study Utilities

The Cadmus research team remotely conducted the mapping exercise separately with each of the four case study utilities in 1.5-hour sessions via Skype. First, the research team discussed how the mapping exercise fit within the project process and timeline and shared the selection criteria used to determine the four case studies. The research team then explained the idea of climate drivers, cascading impacts, and risks and opportunities, as illustrated in Table 2-2. Next, via a PowerPoint graphic, the research team showed an illustration of how a business function, climate risk, and opportunity map could look, starting with procurement of the business function. The research team then worked through the utility's three selected business functions, mapping the business function, critical path components, climate drivers, cascading impacts, and resulting risks and opportunities in real time using PowerPoint (Appendix D includes the risk and opportunity maps prepared in partnership with each participating utility).

Each mapping exercise began by identifying critical facilities and capabilities necessary to successfully, safely, and efficiently conduct a business function. The research team then identified all climate drivers that might interfere with the critical path of these functions and discussed climate impacts that could limit continuity of service, disrupt efficiency of operations, or result in harm or unsafe conditions for employees. Finally, the research team discussed these effects' larger risks to the utility and its community, and how the utility could limit these risks or turn them into opportunities through preparedness, resilience, and strategic management measures.

Following the mapping exercise, the research team shared the revised versions of three selected business function maps with the partner utility and asked for feedback and improvements. Table 2-2 shows selected critical business functions for the four case study utilities.

Table 2-2. Selected Critical Business Functions and Associated Sub-functions Prioritized by the Four Case Study Utilities.

City of Fort Collins Utilities	San Diego Public Utilities Department	Southern Nevada Water Authority	Tampa Bay Water
Stormwater Management Forecasting, water quality management, design and maintenance of collection and storage infrastructure, floodplain management, land use planning and development, regulation	**Drinking Water Treatment and Delivery** Treatment facilities, facility maintenance, pipelines, physical and chemical treatment of raw water, remedial treatment for impaired water, reuse of municipal effluent, stormwater runoff quality, upstream watershed conditions	**Administration** Customer care and field services, Environmental, Health, and Safety and security, human resources, information technology, public services	**Physical and Cyber Security** Communications, physical plant management, information technology, detection, sensors, supervisory control and data acquisition systems (SCADA)
Asset Management Lifecycle analysis, service levels, reliability, maintenance standards, infrastructure development, mapping, strategic planning, data collection	**Water Supply (Key Function: Operational considerations within San Diego's local storage/reservoir system)** Water supplies, groundwater rights, reservoir water supply and storage agreements with county, water rights agreements with Colorado River water, prioritization process for water purchases, native water, imported water prices, water supply availability	**Engineering and Operations** Energy management, engineering, infrastructure management, operations, resources and facilities, water quality and treatment	**Drinking Water Treatment and Distribution** Incoming water quality, treatment facility capacity, treatment technology, distribution system, storage, treatment type (physical and chemical), monitoring, desalination
Engineering and Design Surveying, sizing, layout, design standards	**Staff Experience and Training** Staff operations, risk protocols, operating manuals, capital improvements management, engineering training and protocols, staff outreach, projections, scenarios, integrated long-range planning	**Finance** Accounting, financial services, purchasing and rate structures	**Engineering, Design, and Construction** Construction standards, construction specifications, constructability of assets, site selection, design standards, material selection, useful life analysis, physical construction

Figure 2-1 provides a visual representation of climate data resources available for consideration for the business function mapping of each case study utility. Each case study utility's name is on the left-hand side of the figure, is the name of each case study utility, and within each row is the number of existing climate data resources, sorted by climate topic.

Figure 2-1. Climate and Business Function Mapping Matrix.

Tampa Bay Water	Precipitation	Temperature	Drought	Storms	Flooding	Sea Level Rise / Storm Surge	Tropical Cyclones	Air
	29	24	11	7	7	12	9	7
Fort Collins Utilities	Precipitation	Temperature	Drought	Wildfire	Storms	Runoff		
	36	28	16	12	9	13		
San Diego PUD	Precipitation	Temperature	Drought	Wildfire	Humidity			
	40	29	17	14	4			
Southern Nevada Water Authority	Precipitation	Temperature	Drought	Wildfire	Storms	Flooding		
	36	27	17	10	7	7		

Represent number of available resources by water utility and climate driver (available as of Dec 2018)

2.2 Key Findings

Along with the utility partners, the research team concluded that the methodology provided a useful starting place for utilities to identify climate-related risks and opportunities associated with their specific business functions and to explore how these interrelate. The research team also concluded that the more narrowly defined the selected business function (e.g., a subset of a core function), the easier mapping would be and the more meaningful the results. For some utilities, core business functions are so large and all-encompassing that the mapping exercise looked like spaghetti. In contrast, focusing on a narrower set of activities prompted a very productive conversation about significant risks that staff might not have considered and opportunities that otherwise might not have been identified.

> "All projects with opportunities for cross-departmental brainstorming sessions provide value to Utility planning efforts. This research process was no exception. It created the venue for targeted conversations around the risks of climate change to individual business unit operations, highlighting the need for coordinated efforts across all Utility departments."
>
> *Meagan Smith,*
> *City of Fort Collins Utilities*

During conversations with utility representatives for all four case studies, participants were very engaged in the process and learned from each other as well as from the research team. In fact, the research team learned of certain climate risks the research team did not know of previously, such as the effect of salt spray from larger tropical storms on water utility infrastructure in Florida. The research team also learned of opportunities the research team had not considered, such as Las Vegas having less risk associated with flooding as facilities are enclosed, with no open reservoirs in the water and sewer delivery system. The key findings described below include information gathered from all seven water utilities, with more details drawn from the four case study utilities.

> "This project helped SNWA think beyond water supply impacts. It helped us think more broadly about how risks to the organization can change from climate change."
>
> *Keely Brooks,*
> *Southern Nevada Water Authority*

2.2.1 Key Finding 2-1: Within the Utilities Studied, Extremes Drive Actions on Assessing Climate-Related Risks and Opportunities

Extreme events serve as a driving force in decision-making when faced with a changing climate.

- Fort Collins has not experienced many significant climate-related incidents, making it difficult for the city to focus on issues of extreme climate events within the utility. However, due to suffering through the High Park fire in June 2012 and a flood in September 2013, Fort Collins Utilities has embarked on a Water Supply Vulnerability Study, which will model impacts of various climate futures on its current supply portfolio.
- Hurricane Sandy served as a driver in transforming the NYCDEP's thinking about climate change risks. Although NYCDEP was already studying climate-related risks before Hurricane Sandy, the storm demonstrated a magnitude of impact that they anticipated for the far future, rather than 2012.
- In recent years, Austin Water has experienced two major climate extremes that have impacted multiple business functions. Though major floods damaged utility infrastructure, the utility's catastrophe insurance fortunately covered some financial damages. A catastrophic upstream flood in October 2018 significantly reduced drinking water treatment plant production and resulted in emergency conservation measures and a city-wide boil water notice. Extreme drought from 2008–2016 substantially reduced water demand and associated revenues, which in turn necessitated additional rate increases. Finances were sufficiently strained that bond rating agencies put Austin Water on a negative watch. Since that time Austin Water's finances have stabilized, and the negative watch has been removed. In retrospect, Austin Water notes that, if it had had stronger reserves or cash on hand, it could have better absorbed some of these serious financial impacts.

2.2.2 Key Finding 2-2: The Length of Planning Horizons Varies across and within Utilities Making Assessments and Preparations for Climate Risks More Difficult for Utilities with Short Planning Horizons

Planning horizons vary between utility business functions within the same utility, and utilities have adopted different approaches to long-range and capital planning. These differing approaches require differing climate information timeframes.

- The San Diego Public Utilities Department has made important strides in implementing long-range and climate focused projects within Capital Improvement Plans/Programs (CIPs). Climate Change management and planning is rapidly advancing under the umbrella of the City of San Diego's Climate Action Plan, it's new Department of Sustainability and the other long-range planning efforts being led by the Public Utilities Department.[2]
- For financial planning purposes, like many utilities, Austin Water typically does not conduct financial projections much beyond five years into the future and does not plan financially for the longer term (e.g., 50 to 60 years into the future), except for securing low interest state and federal loans with 30-year terms. In November 2018, Austin's City Council adopted a groundbreaking 100-year water supply plan for Austin, called "Water Forward," with a wide-ranging suite of strategies based on cutting edge climate data projections.
- Climate change information is critical for longer-term planning, and while extremes are already more substantial compared to historic periods, most climate change projections focus on changes in

[2] As of March 2019, San Diego Public Utilities Department expanded its master planning and prioritization process from near-term readiness to longer-term readiness.

average conditions rather than extremes. Utilities that do not consider longer-term conditions may not recognize the full range of risks or plan their infrastructure to withstand increasing impacts over time.

2.2.3 Key Finding 2-3: Improving or Updating Design Standards and Protocol to Incorporate Changing Conditions Is Critical

Utilities have identified improving and updating design standards to reflect future climate conditions as a core strategy to adapting to climate change. One Water LA 2040[3] acknowledges the importance of innovative design standards to mitigate exposure to climate vulnerabilities.

- At Fort Collins Utilities, engineers needed more than knowing "floods are going to get more extreme" to integrate future climate considerations into design standards. They know climate modeling is not an exact science, but they are hoping research can give them not just a trend for Colorado but more specific quantitative data about the Front Range so they can make the case for adaptation action to decision makers and the city council.
- Climate change projections for New York City were developed in 2008 but were not sufficient as a catalyst to make the impacts seem real until Hurricane Sandy hit. As a result, NYC has been changing design standards to minimize future risk. In April of 2017, New York City's Mayor's Office of Recovery and Resiliency published its first Climate Resiliency Design Guidelines (Mayor's Office 2018), which provides instructions for integrating resilient design into historic infrastructure. The goal of these Guidelines is to incorporate climate data projections in the design of city projects to mitigate the hazards New York City faces in a rapidly changing climate. NYCDEP also issues its own guidelines for DEP infrastructure that aligns with the citywide guidelines.

2.2.4 Key Finding 2-4: Regulatory Requirements Can Incentivize Consideration of Climate Risk Management within Utilities

Regulatory requirements can be key drivers of decision making for climate change.

- Stormwater and wastewater planning and activities undertaken by the NYCDEP are driven by the need to maintain adequate draining and by Clean Water Act; therefore, all resources go toward ensuring water quality in New York's harbor is compliant and proper stormwater management is in place for areas that experience frequent flooding. This requires consideration of changing climate conditions on water quality and drainage, since ability to meet standards and drainage criteria is affected by the increased intensity of rainfall, etc.
- SLC DPU is looking to build additional green infrastructure to mitigate flash flood risks and recognizes there is also a water quality opportunity to mitigate the contributions of pollutants to waterways that are not meeting beneficial use requirements. The utility is trying to find co-benefits in long-term planning and risk management work. Meeting water quality standards into the future will be increasingly difficult due to the impacts of changing temperatures, the need to treat harmful algal blooms, etc.
- San Diego Public Utilities Department acknowledges California's Integrated Regional Water Management grant programs and policies drive climate action related activities.

[3] One Water LA 2040 is a plan developed by the City of Los Angeles to identify fiscally- and environmentally-responsible water planning solutions in the face of a changing climate.

2.2.5 Key Finding 2-5: Decision-Making under Uncertainty Remains a Challenge

Utilities are challenged by the need to make decisions in the face of considerable uncertainty about future climate conditions.

- SNWA is concerned that infrastructure will be at risk if temperatures in 50 years exceed the current planning projections. Increasing global temperatures have reduced snowmelt runoff and precipitation such that Lake Mead's recent water levels are the lowest in its history. SNWA's pumping stations at Lake Mead are still operational, but this infrastructure will fail if Lake Mead's water levels continue to fall.[4] Additionally, operations staff will be unable to endure outdoor temperatures, and people may leave the valley because it is essentially uninhabitable. It will be difficult to plan for the cascading impacts of changes of this magnitude.
- Tampa Bay Water is striving to fully integrate climate change considerations into its water supply planning and modeling efforts. The plans and models evaluate a range of hydrologic conditions, water demand projections, sea level rise and storm surge projections, and associated uncertainties to inform future decisions and investments. Making decisions under uncertainty and communicating about the decisions to the public continue to be a challenge.

2.2.6 Key Finding 2-6: Leadership within the Utility Is Critical to Innovation and Preparedness

Leadership and climate expertise within the utility is critical. Leaders and experts can help the business function leads navigate the daunting climate science and encourage staff to ask difficult climate questions[5] and consider actions that go above and beyond current regulatory expectations.

- In New York City, decisions and actions taken by utility managers are generally driven by complying with regulations. When they are requested to take "voluntary actions," they tend to be driven by objectives that the city has put into place to make the city more resilient, which may come from the Commissioner, Mayor's Office, or both. The One NYC[6] plan, for example, is New York City's plan to become the most sustainable and resilient city in the world. Ensuring compliance with the resilience standards set by OneNYC and the Mayor's office requires that the utility managers follow city resiliency design guidelines to ensure that investments are developed above the floodplain and consider future sea level rise. Many of these voluntary actions were spurred by Hurricane Sandy, such that the agencies are developing their own design guidelines, but some actions were already underway by internal leadership.
- Assessing and managing climate risks and opportunities at the Salt Lake City's Department of Public Utilities occurs within the executive function because some risks and opportunities require high level attention.
- Austin Water has quarterly leadership retreats, during which utility leaders from the supervisor level and above meet and discuss the business plan for the utility. Most recently, they produced the Austin Water 2020 plan, which gives a roadmap for the near-term focus. In November 2018 the Austin City Council adopted the Water Forward (100-year water supply plan). This groundbreaking plan contains a wide-ranging suite of water supply strategies, designed to address multiple climate scenarios that are based on cutting edge climate data projections.

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[4] Data regarding Lake Mead is from Southern Nevada Water Authority's "2018 Water Resource Plan & Water Budget." https://www.snwa.com/assets/pdf/water-resource-plan.pdf

[5] The "climate question" is defined in Chapter 2.

[6] One NYC is New York City's plan to become "the most resilient, equitable, and sustainable city in the world" by institutionalizing resilient construction throughout the city. https://onenyc.cityofnewyork.us/

- The range of climate-related expertise varies dramatically across the utilities interviewed; those with climate-related expertise clearly had an advantage over other utilities from the perspective of integrating future climate risks into decision processes.

2.2.7 Key Finding 2-7: Mainstreaming Resilience across Water Utility Business Functions Is in Its Infancy

Although water utilities are advancing their understanding and assessment of climate change impacts to the hydrologic cycle and ecosystems related to their water sources and reservoirs, integrating resilience across water utility business functions is still in its infancy. Mainstreaming climate considerations into existing organization-wide processes such as emergency management, budget, capital planning, safety, etc. is an effective method of institutionalizing longer-term climate change risk and resilience into water utility business functions. Instead of creating separate climate resilience functions and policies, it is widely believed to be more effective to integrate these considerations into existing processes to enhance the overall service delivery and operations of the water utility. Most water utility business function leads (excluding functions related to environmental management, water conservation, ecosystem services, etc.) are at the initial stages of understanding the risks associated with acute and chronic changes in the climate. Mainstreaming climate considerations and resilience throughout water utility business function processes is a crucial next step and one that will take careful thought, strategic consideration, and innovative financing mechanisms for implementation. Phase 2 of this effort will develop approaches to mainstreaming climate risk and resilience throughout critical water utility business functions. Nevertheless, the research team believes the framework and guidebook offer a good foundation for this effort.

2.3 Lessons Learned

The research team found that conducting desk research prior to the interviews and mapping exercises was helpful in establishing a foundation of information for the discussions, including ensuring a shared understanding of historic, current, and future climate risks and opportunities and resources.

- Shortly after the interviews, the research team began designing the framework and realized that starting with the water utility business functions during the mapping exercise, instead of using the traditional method of starting with the climate drivers, would allow identifying the risks and opportunities to be driven by the critical path to ensure continuity of service within business functions. This allowed a much more innovative conversation and discussion of topics that had not previously been identified within many of the utilities
- Our approach allowed the utilities to select the three business functions they sought to test through the framework; ideally, a broader conversation about underlying risks would have been useful prior to selecting functions to be discussed. Given time constraints, however, it would have been challenging to select the business function for discussion and to match various climate impacts to specific business functions.

- Following the mapping exercise, the research team realized how valuable it would have been to conduct a more in-depth discussion with the utilities on how to identify underlying vulnerabilities and think of them in context with their business functions along with additional stresses associated with climate change. As climate change poses a threat multiplier to existing conditions, additional information regarding the current state of assets, policies, programs, and other elements that allow business functions to operate effectively and efficiently, along with the stresses these business functions are currently under, would have helped all parties better understand the broader context.

> "What was an eye opening for us through this project, was that we were able to see potential climate change impacts into different business functions that we may not have thought about before. We typically tend to concentrate climate change impact assessments on demand and supply. But it is much more than that."
>
> *Tirusew Asefa, Tampa Bay Water*

- Guidance is still needed about ways to think about climate change within all decision processes (mainstreaming) rather than as one or more discrete external drivers, and about ways to deal with uncertainties associated with extreme weather risks and opportunities.
- Lastly, it is important to ask the right questions. Having conducted the initial phase of the research, the team concluded that some preliminary work completed was more useful than other components. In a co-production mode, it was possible to develop an evolving understanding of which questions proved truly critical. The framework included three central questions, presented for reference:
  - What are existing sources of vulnerability in the system?
  - What are the climate change drivers you are already most worried about?
  - How do existing vulnerabilities and climate issues drive critical business functions?

CHAPTER 3

Co-produce a Water Utility Business Risk and Opportunity Framework

Based on the research gathered and described in the previous two chapters, the Cadmus research team co-produced an adaptive, flexible, and tailorable *Water Utility Business Risk and Opportunity Framework* that helps utilities define their focus for a risk and opportunity assessment, ask key climate questions, map climate impacts relative to mission-critical business functions, and pinpoint risks and opportunities across those business functions. The supplemental guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*, provides further details, images, and templates that utilities can use to map climate exposure and climate information needs to their core utility business functions, and, ultimately, understand cross-cutting risks and opportunities facing their business.

3.1 Methodology

Section 2.1 describes the methodology used to co-produce the *Water Utility Business Risk and Opportunity Framework* with the four selected case study utility partners.

3.2 Framework Steps

The following step-by-step framework is designed for individual utilities' use in exploring climate risks and opportunities associated with their business functions. Although this process seems very straightforward, one pitfall to avoid arises from failing to recognize biases among staff engaged in this exercise.

Biases and Assumptions
Overcoming climate biases and assumptions is critical to gauging the full impact of climate on utility business functions. There is a need to consider "What if" climate impacts beyond recent experience.

For example, it is very difficult for people to become aware of their own assumptions and/or preexisting biases about elements most at risk. This occurs partly due to most people assuming that future risks will be similar to past risks, but this can be an erroneous assumption. Though particular impacts have occurred in the past makes them very likely to occur in the future, the changing nature of institutions, communities, infrastructure, and communication systems—not to mention climate change impacts—makes it important to remain open to potential future risks, opportunities, and impacts that look very different from those today.

For this framework to function most effectively, personnel engaged in the conversation should adopt a "what if?" scenario planning approach and consider that possible system failures may be triggered by new kinds of events, both locally and in remote locations, that result in cascading effects from linkages in systems and the supply chain. Preparedness means imagining the unimaginable, considering the possibility of low-probability, high-consequence events as well as multiple, high-probability events happening simultaneously. Exploring these ideas in the context of imagining a future not yet arrived can be thought-provoking and rewarding, even if some possible futures seem very unlikely now. Understanding the array of possible future risks helps in identifying individual or multiple approaches that increase resilience.

This framework is presented as a "Plan-Do-Check-Act" approach: users follow the framework to plan risk management and resilience improvements, take action and track trends, check progress towards resilience improvements, and act to revise the plan accordingly. The framework is an iterative process, designed to be used quarterly, annually, or as deemed necessary to analyze all potential underlying conditions, climate impacts, and associated risks and opportunities for priority business functions, keeping in mind, however, that priority business functions may also evolve over time.

Adaptive resilience can be developed through replicating this exercise on a regular basis to explore elements changed since the last event, whether underlying conditions, climate, staff capacity, climate expertise, new regulations, or other factors. Each time new personnel are added to the conversation, a new set of perspectives and ideas can lead to new outcomes, so it is worth experimenting to gauge how outcomes differ with various personnel groups within a utility.

Although the framework leads to identifying risks and opportunities for use in strategic planning and prioritization activities, it stops short of moving into selection and implementation of adaptation options. That said, the research team offer a well-sorted listing of data and resources that can be used to take next steps in defining specific climate risks, opportunities, and adaptive pathways relevant the utility's specific needs and conditions. The data sources were selected in response to identification of climate drivers expected to impact business functions, as analyzed within the four case study utilities. These data are provided in spreadsheet *Climate Data and Information Spectrum for Case Studies*, which can be found on the 4729 project page of the WRF website. Please refer to the supplemental guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate,* for more details, images, and templates associated with the framework that utilities can use alongside the steps described below. Figure 3-1 provides a visual representation of the Water Utility Business Risk and Opportunity Framework.

Figure 3-1. Water Utility Business Function Climate Risk and Opportunity Framework.

3.2.1 Step 1: Define Focus for Risk and Opportunity Assessment

This critical step in the analysis starts with the full array of business functions, but then narrows the conversation's scope to specific business functions for in-depth analysis. It is very important that participants avoid discussing only business functions that they know best or those recently under scrutiny, considering that those functions that may be "beneath the radar" but quite fundamental to utility operations—and hence a high priority. In addition, the case study experience found it much easier and clearer to do mapping exercise when focusing on sub-functions rather than on the utility's core business functions. Core functions often include subcomponents that experience climate stresses very differently, and the resulting map may prove less useful (as noted previously, more like spaghetti than a series of logical flows) if only the core functions are mapped.

3.2.1.1 Step 1a: Identify All Water Utility Business Functions and Sub-functions

Using the suite of water utility business functions compiled, identify business functions relevant to your utility's activities, noting that if some are present but clearly peripheral to the utility's mission, you may not wish to emphasize them.

3.2.1.2 Step 1b: Identify a Cross-Functional Team of Representatives

Considering the business functions selected, compile a cross-functional team of leaders familiar with the underlying conditions, inner workings, regulatory requirements, and strategic processes of those functions. To the extent feasible, select participants with very different backgrounds and training, and some familiarity with the way the utility currently functions. It is essential to also include a representative who is considered a "climate expert" or someone familiar with the impacts of climate change to the various business functions and the cascading implications. This representative can ask the climate questions and help navigate the climate data, information, and impacts space for the other team members who may not be as familiar with how climate change can affect the utility business functions.

3.2.1.3 Step 1c: Identify Existing Resources, Expertise, and Capacity for Risk Assessment and Management

In conversations with the gathered cross-functional team, identify existing resources, plans, risk assessments, and strategic plans that may be useful in assessing current and future preparedness for climate-related events as well as in potentially recognizing climate-related opportunities. If necessary, provide team members a list of resources for review before initiating conversations, ensuring a familiar organization-wide baseline. Conduct initial conversations about risks to key business functions that require further analysis.

3.2.2 Step 2: Address Key Questions

In this step, participants explore underlying vulnerabilities within a utility's geographic region along with its political and economic context, and its previous experiences with extreme weather or climate-related events. This way, participants consider how critical business function paths may be affected by such factors. It is important to build a joint understanding of these factors, as this will help in prioritizing which business functions will be considered in the mapping exercise.

3.2.2.1 Step 2a: With the Team, Discuss the Underlying Vulnerabilities within Their Business Functions

Climate change tends to act as a threat multiplier, exacerbating existing climate conditions and underlying vulnerabilities. If the assessed business functions have underlying conditions to start with (e.g., aging infrastructure, limited human capacity, political issues), it is important that the team understands these from the start. This allows an assessment of the way's climate change may exacerbate the conditions or create new conditions problematic to the utility's mission. Discuss historic vulnerabilities, experiences, and events affecting continuity of service, utility functions, and the health, safety, and welfare of employees and community members. Explore "what if" scenarios, including changing policy and physical impacts, that seem improbable now, but which address long-term risks that could impact the utility's business functions.

3.2.2.2 Step 2b: Discuss What Climate Change-Related Drivers You Already Care about Most

Once the team has a clear understanding of underlying conditions for each business function under assessment, climate drivers appearing to pose the highest initial concern for the business function can be layered in. These may include climate drivers such as sea level rise, extreme heat, poor air quality, wildfires, drought, flooding, and strong storms. Think about drivers that have affected the utility in the past as well as drivers affecting utilities in your region and drivers that may pose issues in the future.

3.2.2.3 Step 2c: Discuss How the Underlying Vulnerabilities Identified above Might Intersect with Climate Drivers You Already Know About, Leading to Impacts for Business Functions

Upon identifying the various underlying conditions and climate drivers of concern, map the two and discuss how they intersect. This involves considering direct and cascading climate impacts on—for example—business function operations, facilities, assets, employees, and supply chains. Table 3-1 outlines some example business functions and impacts mapped with the case study utilities:

Table 3-1. Example Business Functions and Associated Climate Impacts.

Business Function	Impacts from Climate Change
Administration	• Intensity of heat and flood events from extreme storms put employees and communication systems at risk
External Affairs	• Increased need to apply for hazard mitigation and resiliency funding • Following major events, External Affairs is called upon to communicate to public, state, Federal, and municipal decision-makers • Opportunities to communicate with customers and disclose each utility's future planning processes
Employee Education	• Uncertainties about future climate conditions can impair a utility's ability to consider risks in large-scale planning
Engineering Design, Construction, and Operations	• Wildfires, extreme heat, and drought require more energy and costs to pump and treat water before distribution to customers • Failure to consider climate change projections in design and throughout master planning could have serious impacts on critical business functions and the ability to meet demand • Cost-effective management of equipment requires robust material analyses as climate-related uncertainties persist • Cascading impacts from flooding and algal blooms have affected operations as infrastructure has required extensive repairs
Physical and Cyber Security	• Field electronics and servers are sensitive to increased heat, humidity, and precipitation
Finance	• Intensity of drought and unstable economic futures resulting from extreme temperatures in the region could reduce the utility's consumer base due to inhospitable living conditions • Bond rating impacts are associated with revenue loss from drought restrictions
Asset Management	• Increased frequency of extreme climate-related events may increase asset maintenance and replacement costs • Infrastructure cracking and failure may result from aridification
Procurement	• Major events spur a rush to procure disaster clean-up services to respond to infrastructure challenges
Business Affairs	• Extended drought and conservation efforts reduce water demand and impact revenue, resulting in required rate structure adjustments
Environmental Monitoring and Management	• Increased difficulty in balancing Clean Water Act compliance and adaptation measures • Increased spending to comply with the Safe Drinking Water Act
Stormwater Management	• Storm surge and sea level rise impact flood mitigation measures and a utility's stormwater system capacity • Precipitation intensity puts utility stormwater management systems at risk
Drinking Water Treatment and Delivery	• Sea level rise threatens water quality and existing delivery structures • Water quality and delivery become increasingly risk-prone as temperatures and storms become more intense
Water Supply	• Water supplies are increasingly exposed to pollutants from wildfires and high temperatures
Wastewater Treatment	• Employees have difficulty accessing major wastewater treatment plants during large flooding events
Planning, Modeling, Forecasting, and Analysis	• Utilities may need to consider a broader array of future conditions in planning, including changes in precipitation, temperature, and evaporation projections • Long-term climate projection trends and extremes may change

3.2.3 Step 3: Identify Key Risks Relative to Mission-Critical Business Functions; Select Business Functions Requiring Further Analysis

Prioritize the list of business functions considering how the intersection of underlying conditions and climate drivers might affect them. Consider the full range of activities necessary to allow for institutional excellence, a healthy work environment, positive relationships with the community, environmental stewardship, fiscal responsibility in the short and long term, and continuity of service. The following steps can be executed at an organization-wide level or by smaller teams, if diverse expertise is included in the discussion, so risks can be addressed comprehensively.

3.2.3.1 Step 3a: Identify the Critical Path Activities, Functions, and Equipment for Each Business Function

Thinking through the activities required to conduct each business function selected for analysis over a variety of time horizons (e.g., daily, weekly, monthly, annually), consider the following:

- Critical decisions, facilities, or processes required to deliver services, products, or resources to your customers
- Potential failure points and what functions can "make or break" the capacity to perform this service
- Whether employees must travel to a certain location or be at a particular location to ensure continuity of operations and services to customers
- The type of equipment required
- Whether computers and sensors are required that may be affected by a power supply disruption resulting from climate-related or extreme weather events (e.g., heat wave, high wind and storms, flooding, other similar factors)

List all critical path activities, functions, and equipment required over multiple time horizons, both on a day-to-day basis and in the face of extreme weather events for the business function under analysis to operate effectively, efficiently, and safely.

3.2.3.2 Step 3b: Map Business Functions to Underlying Conditions, Climate Drivers, and Associated Impacts

Taking each critical path item individually, discuss the underlying vulnerabilities and the ways climate drivers might exacerbate those conditions over time. It is critical for the team to take a systems approach for this step as so many business functions must work together to maintain continuity of service. Additionally, successful water delivery requires energy, transportation, land use, and other resources and considerations when thinking about the lifecycle of this process. Using boxes and arrows (as in Figure 3-1), show critical pathways that identify multiple impacts from individual drivers, and then map the cascading effects from interactions between drivers and impacts. Repeat this process until you have discussed all mission-critical business functions selected.

3.2.4 Step 4: Identify and Prioritize Risks and Opportunities Across Business Functions

This step involves pulling together collective learning across analyses of individual business functions to build an integrated list of risks and opportunities that can feed into strategic planning, human relations, communications, engineering, finance, and operations considerations (among others).

3.2.4.1 Step 4a: Compare Climate Drivers, Impacts, and Risks across Business Functions and Establish a Risk Priority List That Includes Considerations from All Mapped Risks

Establish a priority risk list to guide decision-making and planning activities. These priorities can be established based on the number of functions that are at risk due to a particular climate impact, and/or the likelihood, intensity or magnitude of climate risk factors that have been identified. These can be used as motivators across the utility, encouraging a “supply-chain” view of the way’s climate considerations penetrate all components of business activities and produce cascading impacts.

3.2.4.2 Step 4b: Identify the Opportunities to Manage Impacts

Develop a list of existing opportunities to manage risks (e.g., hazard mitigation plans, interconnection agreements) as well as additional risk management opportunities. Further, discuss ways to take advantage of climate change adaptation to accomplish co-benefits (e.g., improved habitat preservation options, recreation opportunities, health outcomes that could be associated with risk management efforts). Look for ways that asking the “climate question” can offering advantages to the utility (e.g., perception as a leader in the community, attracting more young professionals to work at the utility, positioning leadership to influence broader outcomes [such as recovery planning] if/when future extreme events occur).

Moving into implementation, evaluate the ways that managing risks and opportunities can be mainstreamed into day-to-day utility operations (rather than being considered as outside of normal business function activities), and plan to revisit this conversation regularly to assess lessons learned and new impacts arising since the last conversation.

3.3 Key Findings

As discussed in the Executive Summary, through co-development of this framework with the partner utilities, the research team identified the following key findings:

3.3.1 Key Finding 3-1: Most Water Utilities Have Not Assessed Climate Change Risks and Opportunities from a Business Function Perspective

Rather, if considered at all, climate risks and opportunities usually focus on water supply and flood control issues. Those already assessing these risks have recently experienced significant impacts from extreme weather events that impacted their (or another utility’s) ability to provide safe and reliable water to their customers.

3.3.2 Key Finding 3-2: Mapping Climate Drivers and Underlying Conditions to Critical Decisions or Requirements for Business Functions Leads to a More Integrated, Systems-Based Understanding of Risks and Opportunities

This business-function oriented approach can lead to a more sophisticated analysis, ultimately affecting and providing the business case to reconsider priorities and strategic investments for utility management. The research team concluded that starting with the business function and understanding risks from that perspective proved more useful than starting analysis with the climate drivers.

3.3.3 Key Finding 3-3: The Process and Conversations Associated with Mapping Business Functions Prove Much More Important than the Maps Themselves, Which Serve as Means to an End

The primary outcomes of the mapping process included the following: more collaborative relationships and improved communication across the business functions; cross-training, understanding of, and identification of impacts related to a complex issue within and across the utility enterprise; an improved understanding of relationships between climate risks and underlying vulnerabilities; explicit discussion of critical decisions or requirements for each business function; and thoughts about the actual conditions and significant imperative for continuity levels of service and operation. Consequently, ongoing conversations of this type can be useful.

3.3.4 Key Finding 3-4: Bringing an Array of Utility Business Function Representatives Together Offers Multiple Benefits

In many cases, they may not have previously worked together closely, and joint exploration of these risks and opportunities builds relationships and capacity for future collaboration – for any complex issue the utility may face. Leadership and climate expertise within the utility for such assessments is also critical when working with business functions not regularly considering climate change as a factor in their decisions. These leaders and experts can help the business function leads navigate the daunting climate science and ask the key climate questions.

3.3.5 Key Finding 3-5: A Genuine Need Exists for Guidance and Implementation of integrated, Long-Range, Capital Improvement and Financial Planning for Acute and Chronic Climate Impacts across Water Utility Business Functions (Mainstreaming Risk and Resilience)

The research clearly indicated that not all water utilities currently integrate such planning processes and could benefit from more coordinated and aligned efforts.

3.3.6 Key Finding 3-6: Knowing How to Find the Climate Data and What Data Type, Scale, and Timeframe to Use in Evaluating Business Functions' Risk and/or Opportunity Can Prove Daunting

The data synthesis developed for this project provides suggestions on how to deal with time, spatial scales, and other geographic considerations. Section 4.2 provides additional guidance for the type, scale, and timeframe of climate data.

3.3.7 Key Finding 3-7: Anticipating Extreme Weather Conditions Can Be Far More Challenging than Identifying Climate Trends

Some utilities have internal climate experts (with some training in climate science and actively following climate-related developments) and/or sustained relationships with external climate experts (including consultants or academics); others do not. Therefore, a range of sophistication and/or capacity exists in anticipating future climate conditions. Though even experts can be challenged in approaching these difficult questions, understanding the potential for extremes is very important to most utilities. Collaborating with scientists to understand how to manage uncertainties and generate useful data and information to provide anticipated ranges for extremes will be an ongoing need.[7]

3.3.8 Key Finding 3-8: The Co-production Process Is Essential

The team could not have conducted this work without partner utilities sharing their knowledge of the ways that their utilities function. Conversely, external parties (the research team) asking the questions identified new topics not previously discussed, perhaps helping business function leads move to a more nuanced view of their business function's interdependence and of the potential for cascading risks and associated opportunities to enhance resilience.

[7] For useful climate data sources, review the climate information sources and types within the Risk and Opportunity Profiles (Appendix E).

3.3.9 Key Finding 3-9: For Almost Every Risk Identified, a Potential Adaptation Strategy or Opportunity Could Minimize the Risk's Impacts

In many cases, the same strategy (e.g., advances in internal communications around building more robust infrastructure, hazard mitigation, human resources/community engagement systems to manage extreme events) could be used to address multiple potential problems, providing co-benefits for the water utilities.

3.3.10 Key Finding 3-10: This Climate Risk-Based Business Function Assessment Should Be Included as One Element of a Utility's Comprehensive Effective Utility Management (EUM) Program

As the most widely recognized water sector utility management program in the country, EUM helps utilities comprehensively assess current operations and identify a path to improving in key areas that are the highest priorities. As the climate continues to change and the intensity of extreme weather events increase, it will be important for water utilities to utilize this climate risk-based business function framework within their EUM program to ensure climate risks are integrated when assessing current and future operations and capacity.

3.4 Lessons Learned

Through co-development of this framework, the team learned several lessons. The first relates to the time required to conduct this analysis using the framework. Once the research team designed the framework in collaboration with the utilities, they spent 1.5 hours with each case study utility's mapping exercise, exploring three of their priority business functions.

Outside of this "experimental" mode, conducting this kind of exercise meaningfully within utilities will require significant internal preparation time to gather the foundational information regarding a broader suite of business functions, prioritizing the functions, and identifying the climate drivers that have or may affect the functions. Depending on the number of business functions a utility decides to assess, considerable staff time and effort could be required to brainstorm the various impacts possibly resulting from climate change and identifying various risks and opportunities that each business function may encounter.

The research team expects that utilities using this framework will be better able to identify and screen their priority business functions for initial climate drivers of most concern to those business functions; so relevant and appropriate data and information can be located to inform decisions needed to manage impacts from a changing climate.

In addition, a utility can use/apply this framework for other purposes, such as the following:

- Prioritizing mission-critical business functions and day-to-day decisions, services, needs, and processes
- Educating other business function leaders about underlying conditions and the ways climate change may exacerbate these conditions or create new issues in the future
- Fostering collaboration and communication across business functions that may not always collaborate, and identifying points of common risks or opportunities

These are but a handful of benefits and opportunities that the framework presents for utilities.

CHAPTER 4

Identify Relevant Climate Information Sources and Types by Business Function

Following the mapping exercise for the four case study utilities, described in Chapter 2, the Cadmus research team compiled an array of corresponding climate information and developed a method for high-level categorization of this information. The task's purpose was to provide a suite of potentially useful information sources and types for use in understanding and evaluating climate-related risks in addition to identifying opportunities by business function and facilitate finding those with greater advantages or appropriateness of use, whether in general or technical contexts.

4.1 Methodology

The team selected sources based on its experience with and knowledge of climate information, focusing initially on operational resources providing coverage at a national level, and then on resources at regional and state levels. These sources provide qualitative and quantitative information relevant to key risks and opportunities. Information ranged from national, regional, and state assessment reports to climate projection datasets based on state-of-the-art modeling efforts. Including a diversity of sources and types helps ensure sufficient available information to address the various kinds of water utility climate-related issues.

In creating the four arrays (one for each case study), the research team chose to represent potentially useful climate information as a sampled and pragmatic list (rather than an exhaustive one due to the large number of potential sources continues to increase. All selected data and tools are available online to facilitate access to information. The research team then generated a high-level categorization of potential climate information, based on clustering (or concentration) of information characteristics.

4.2 Summary of Relevant Climate Information and Its Categorization

All entries of potentially useful climate information for each of the four case studies are included in the spreadsheet *Climate Data and Information Spectrum for Case Studies*, which can be found on the 4729 project page of the WRF website. Each entry includes the following: attributes of climate stressors or impacts to which it pertains; timeframe (defined below); the information resource's name, online location, brief description, and any additional notes. Summaries of climate information sources and types by individual climate stressors and impacts for each of the case studies include risk and opportunity profiles for the representative case study (Appendix E).

The research team identified three high-level characteristics that helped in categorizing types of potentially useful climate information. This first involved separating entries in the climate information arrays into two types: "data" (including observations or model output from sources requiring end users to download, process, analyze, and visualize data to generate the needed climate information); and "derivative" (sources providing existing analysis, synthesis, or interactive tools for climate data). In some instances, a source provides both types of climate information. The "data" and "derivative" labels are not standard in the field, but they nonetheless characterize an apparent and important difference in climate information types and ease of use. Note: this categorization is done explicitly in the profiles only; not in the climate data spreadsheet.

The research team found a second characteristic useful for categorizing climate information—spatial scale. In context with the four case studies, the research team decided to define broadscale information as having a resolution coarser than that approximately provided at the county level (greater than an area roughly 100 kilometers by 100 kilometers). Fine-scale information includes information with a higher resolution, approximately finer than the county level, and often less than a roughly 50 kilometer by 50 kilometer area. Some sources provide climate information at both of these general spatial scales.

A third characteristic used to cluster climate information was the time periods for which it is available (provided in the *Climate Data and Information Spectrum for Case Studies* spreadsheet and in the Water Utility Business Risk and Opportunity Profiles [Appendix E]):

- Historical Averages or Conditions (Historical) typically cover the past several decades or several centuries (for paleo data) and may extend to recent months, weeks, or days
- Recent or Current Conditions (Recent) reflect those from the past few weeks, months, or years to the present
- Short-term Future Conditions (Short-term) include information such as daily forecasts as well as weekly, monthly, and seasonal outlooks
- Long-term Future Conditions (Long-term) consist of projections extending over several decades

4.3 Key Findings

This typology facilitates finding potentially useful climate information providing water utilities' different decision contexts, given one cannot know in advance exact questions that utilities want to answer. To identify the most relevant climate information sources and types from such lists, water utilities must first break down individual and linked impacts and risks (as initially developed in the mapping exercise) into more detailed components that lead to clearly defined questions and corresponding information requirements. Some overarching considerations related to this include the following:

- Further resolving information requirements may include consideration of attributes such as "skill" or accuracy (for example, forecasts and outlooks that can be tested and/or calibrated against actual weather/climate conditions), spatial scales, timeframes, temporal scales, and types of uncertainty (for example, climate change projections) inherent to these questions.
- Attributes of available, potentially useful climate information may not match those of a specific question and require reframing the question or generating new data.
- Effectively gathering, assessing, and using climate information from disparate sources. The subject-matter expertise and technical skills required to do this can pose challenges, given the ever-increasing amount of data available and the methods for accessing it, as can keeping up with frequent international, national, and regional assessments.
- Not all climate information or risk-related questions requires highly complex or technical data. The answers to some questions can derive from knowledge of trends or understanding the physics of climate drivers (e.g., how higher temperatures influence evaporation).

General guidance follows to help end users utilize climate information referenced in the climate data spreadsheet or in individual utility risk and opportunity profiles. Additional discussion on using climate change information for water management and planning exists in several recent publications, including those from WUCA, the Research Applications Laboratory at the National Center for Atmospheric Research (Vano et al. 2018), the U.S. Bureau of Reclamation (USBR 2016), and the U.S. Environmental Protection Agency Region 9 and California Department of Water Resources (EPA and CDWR 2011).

4.3.1 Key Finding 4-1: Information on Climate Extremes May Require Greater Reliance on "Data" Information Types

In the climate data spreadsheet and the case studies' risk and opportunity profiles (Appendix E), the research team organized climate information sources and types by individual climate stressors and impacts (e.g., drought, precipitation, temperature). During interviews and mapping exercises for the case studies, however, water utility staff often mentioned more specific aspects of such climate variables (e.g., changes in the frequency, magnitude, or intensity of extreme events). Although some sources listed in the spreadsheet and profiles provide "derivative" climate information on these aspects, it is possible that end users will need to rely more on sources providing "data" to generate the desired, more-specific climate information. Compiling climate information from this latter type is more time and skill intensive.

4.3.2 Key Finding 4-2: Spatial Scales of Interest May Not Match Those of Available Information

Sources listed in the climate data spreadsheet and risk and opportunity profiles (Appendix E) provide climate information with spatial resolutions ranging from broad (greater than approximately 100 kilometers) to fine (less than approximately 50 kilometers). The finest spatial scale corresponds to information based on historical or recent station data. Measurement stations, however, can be sparsely or irregularly located throughout a region. Relatively fine-scale and spatially continuous (or gridded) data offer a possible substitution, available at resolutions of approximately 5 kilometers, regardless of timeframe (Weiss and Crimmins 2016). A few products have even finer resolution (e.g., gridded forecasts issued by the National Weather Service). The issue of the information scale versus the decision scale arises as a frequently cited issue in connecting science, decision-making, and stakeholder requests for more "useful" information (National Research Council 2010).

4.3.3 Key Finding 4-3: Timeframes of Interest May Not Match Those for Available Information

For the climate data spreadsheet and the risk and opportunity profiles, the research team classified individual climate information resources into the four timeframes: Historical, Recent and Current, Short-Term Future, and Long-Term future. In contrast to possible temporal overlaps in products classified as Historical or Recent, a gap exists in temporal coverage of forecasts (e.g., predictions) after the Short-Term Future category (e.g., daily to weekly forecasts, and weekly, monthly, and seasonal outlooks). Information in the Long-Term Future category (climate change projections) does not represent forecasts, but rather plausible future conditions (see Key Finding 4-5). Thus, this gap corresponds to a lack of climate information that forecasts conditions over the next one to several years (e.g., annual, multiannual, and multidecadal predictions). The ability to make skillful forecasts on these timescales is currently a relatively new, quickly developing scientific field, commonly requested by stakeholders as an important information need (for example, by the U.S. Department of the Interior, Bureau of Reclamation).

Typically, for financial planning purposes, Austin Water uses data projecting financials five years into the future for both operating financial forecasts and capital budgeting purposes. Utilities uncommonly establish financial plans for 50 to 60 years into the future. Recently, Austin Water's systems planning team began working closely with the finance team to develop revenue projections that align with other planning goals that the utility hopes to accomplish in addition to revenue growth. Utilities such as Austin Water may, however, face difficulties in finding applicable climate information to inform financial planning decisions across business functions.

4.3.4 Key Finding 4-4: Temporal Scales of Interest May Not Match Those for Available Information

Most sources listed in the climate data spreadsheet and risk and opportunity profiles provide climate information with temporal resolutions in daily, weekly, monthly, seasonal, annual, decadal, or multidecadal levels (hourly data are uncommon). Daily data from measurement stations provide a typical information type with a relatively frequent time step. Station data, however, may present issues related to length and record completeness that can hinder their use in water utility applications requiring information about past or recent and current conditions. Temporally complete, gridded, daily data are available as an alternative source of such climate information (Weiss and Crimmins 2016).

4.3.5 Key Finding 4-5: Low-Risk Tolerance and a Desire to Minimize Disruption to Utility Functions Leads to Requiring "Worst-Case" Plausible Future Climate Trajectories for Consideration

Many information sources appearing in the climate data spreadsheet and risk and opportunity profiles (under the Long-Term Future timeframe category) are based on climate projection data. Initially, these data derive from general circulation and/or global climate models (GCMs) and earth system models (ESMs).

These complex numerical models represent myriad physical processes in and interactions between different components of Earth's climate system, including atmosphere, ocean, cryosphere, and land surface. In addition to serving as tools that improve scientific understanding of Earth's current climate, they prove fundamental in calculating potential climate changes over global to sub-continental spatial scales, based on "natural" forcings (e.g., solar output and volcanic eruptions) and "human" forcings (e.g., greenhouse gas emissions).

Despite being incredible tools, GCMs and ESMs remain limited by computational resources and by incomplete, but improving, scientific knowledge. For instance, increasing computing power has led to finer spatial resolutions in models, but it remains insufficient to resolve local information (see Key Finding 4-6). Incomplete scientific understanding of phenomena in the atmosphere, ocean, cryosphere, and land surface and how these interact can reduce the ability to accurately model Earth's climate and thus potential climate change impacts at global, regional, and local spatial scales. Uncertainty in projections of future climatic conditions that stem from both aspects will continue to decrease over time, as technology and science evolve.

Uncertainty in future climatic conditions projections also results from the inability to know what future greenhouse gas emissions will be (directly related to human activities and success in transitioning to renewable energy supplies and/or sequestering carbon from the atmosphere). To address this, modeling studies use a range of plausible future trajectories of human forcings as scenarios, pathways, or targets to project possible future changes. In general, low-risk tolerance requires considering projections based on higher greenhouse gas emissions levels or worst-case scenarios, particularly for decision horizons beyond the middle of this century.

As models have improved over the past number of years, evaluations of different model generations have taken place through Coupled Model Intercomparison Projects (CMIPs). The most current and available climate projection data derive from CMIP5. Use of information sources based on CMIP3 data, the second-most recent CMIP effort, remains valid, partly because CMIP3 data have been highly evaluated and CMIP5 results are not dramatically different. Further details on climate projection data can be found in the *Climate Science Special Report: Fourth National Climate Assessment, Volume I*

(USGCRP 2017) and through online resources, such as the Cal-Adapt website (Reich 2018) developed by the California Energy Commission.

4.3.6 Key Finding 4-6: Use of Downscaled Climate Projection Data Must Consider Information Needs, Decision Context, and Methodology Limitations

Even the most advanced GCMs and ESMs currently provide climate projection data at spatial scales that are probably too coarse (50–100 kilometers or greater) for many water utility applications. Downscaling, or translating GCM and ESM output to finer spatial scales, offers an approach for resolving this mismatch between global- and continental-scale climate information and the more regional and local features of interest to end users. Many information sources appearing in the climate data spreadsheet and risk and opportunity profiles (under the Long-term Future timeframe category) refer to downscaled climate projection data.

Statistical and dynamical are the two main downscaling techniques. The former can be based on several different methods to determine statistical relationships between coarse-scale GCM and ESM output and fine-scale observations over an historical period. Applying these relationships to coarse-scale GCM and ESM output over future periods produces fine-scale climate projection data with resolutions often less than 10 kilometers. The latter uses coarse-scale GCM and ESM output to drive regional climate models that simulate the same physical processes in global models at finer spatial scales, producing projection data with resolutions typically ranging from 10 to 50 kilometers. Dynamical downscaling offers advantages when understanding local conditions' dynamics is important, as when considering convective precipitation or significant topography changes.

Both downscaling techniques carry unique advantages and limitations that can impose tradeoffs between availability, accuracy (correct results), and precision (spatial resolution level). For instance, as statistically downscaled climate projections are less computationally demanding than those based on dynamical downscaling, data availability (based on number of GCM and ESM models used as input, number of scenarios, and temporal coverage) is more extensive than for dynamically downscaled projections. Statistically downscaled data, however, explicitly assume by their construction that relationships between coarse-scale model outputs and fine-scale historical observations will not change in the future.

Given what is known about climate change drivers, assuming historical statistical relationships between observations and model outputs will remain constant is questionable. This may affect how well these data project average and extreme values. That said, recent improvements to statistically downscaled information, such as those provided in the Localized Constructed Analogs (LOCA) dataset (Pierce et al. 2014) have overcome some of the limitations from statistical downscaling.

Understanding the advantages and limitations of downscaling techniques is important when selecting model outputs from these data sources and interpreting whether and how to use the analysis results. As different downscaling methods and different GCMs and ESMs have varying strengths and weaknesses, consideration of their use must take place in the context of the clearly defined motivating question. Central to this is the ability of a particular methodology to simulate climate stressors or impacts of concern.

Research communities' standardized comparisons of different downscaling techniques remains in the initial stages, though robust results are availing in the context of identifying which global-scale models best represent which physical processes over regions. Further details on downscaled climate projection data, including additional discussions on uncertainties of different approaches, can be found in the

Fourth National Climate Assessment (USGCRP 2017), an earlier National Climate Assessment report on modeling and downscaling (USGCRP 2010), and a recent publication from the Research Applications Laboratory at the National Center for Atmospheric Research (Vano et al. 2018).

4.3.7 Key Finding 4-7: Various Online Resources and Information Portals/Hubs Serve as Collection Points for Several Climate Information Sources and Types

Sources and types of climate information appearing in the climate data spreadsheet and risk and opportunity profiles represent a sampled and pragmatic—rather than exhaustive—list. Additional resources exist, and many agencies are developing more and better information. One online collection point with such information is the National Oceanic and Atmospheric Administration's Climate Resilience Toolkit (NOAA 2018), a continually updated resource designed to help people find and use tools, information, and subject matter expertise to improve management of climate-related risks and opportunities. Several climate information sources and types listed in the spreadsheet and profiles are included in the toolkit as components of a water resources dashboard. Guides for water utilities regarding drought response and recovery and flood resilience are also available in the toolkit.

4.3.8 Key Finding 4-8: Existing Climate Services May Help with Information Requirements and Science Translation

Several federal and state government- and university-based organizations have the expertise to help water utilities develop specific applications, answer questions, or select applicable climate information from various sources and types. This may prove particularly important when considering uncertainties of measurements and model outputs, and how such uncertainties might affect information use.

For example, some of these agencies and programs include the following:

- Land-grant colleges and universities, as part of the Cooperative Extension System, have climate science specialists and research scientists on staff to help stakeholders identify and use relevant climate information.
- The U.S. Department of Agriculture supports six "Climate Hubs" that can connect stakeholders with climate information, particularly in the context of forest and range management and agricultural crop production.
- The U.S. Department of the Interior supports eight regional and one national Climate Adaptation Science Centers, all linked to universities, and all providing research funding for specific projects to benefit resource managers.
- Several NOAA line offices, including the Climate Program Office, provide access to climate-related data and support. Six Regional Climate Centers for the United States and Puerto Rico are operational climate information providers, developing and supplying sector-specific and value-added data products.
- The National Weather Service has 122 offices that deliver forecasting services to support water management and to enhance climate services to help adaptation to related risks.
- The NOAA Climate Program Office funds 10 Regional Integrated Sciences and Assessments (RISA) programs that provide services, products, and tools to enhance use of science in decision-making. Climate information from two of these RISA programs (California-Nevada Applications Program [CNAP] and Western Water Assessment [WWA]) appears in the climate data spreadsheet and risk and opportunity profiles.
- The U.S. Climate Resilience Toolkit (Figure 4-1 presents a website screenshot) provides a consolidated online map of regional and locally focused science centers across the nation, available

to help organizations, companies, and utilities understand the science behind climate change and provide resources to enhance resilience to climate-related changes and impacts.

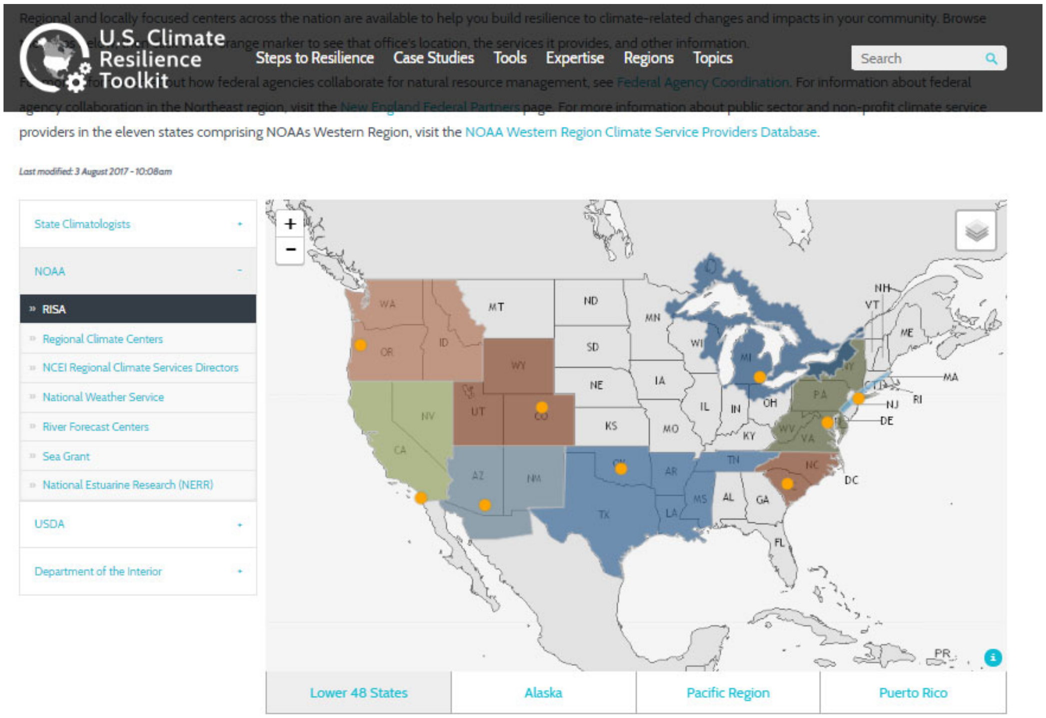


Figure 4-1. U.S. Climate Resilient Toolkit—Regional and Locally Focused Science Centers.
Source: U.S. Federal Government, 2014.

Water utilities can collaborate with many of these agencies and programs to improve existing climate information, based on utility decisions, needs, and capabilities.

4.4 Lessons Learned

The separation of climate information by types, spatial scales, and timeframes offer one example of categorizing and subsequently filtering applicable sources for different water utility topics and discussions. The research team recognizes that the spatial-scale categories developed for the four case studies and county sizes varies tremendously across the country. In future applications of the current framework, water utilities can substitute other domains of interest, such as watershed boundaries or service areas, to differentiate broad- and fine-scale climate information and to update this important attribute of a potential sources list. The research team recommends contacting one or more of the climate service centers indicated above for assistance in identifying information available using different geographic boundaries.

The approach to categorizing climate information sources and types is flexible. After using this information to effectively filter climate information and find best matches to business function issues, it may be necessary to adjust the classification approach as appropriate. Furthermore, as entries in the four case studies do not provide an exhaustive list of climate drivers or data sources, water utilities may add new sources that present new and relevant dimensions by which to classify climate information.

Individual climate stressors and impacts are not necessarily independent from one another. In fact, they commonly link. For example, precipitation amounts and drought, and tropical storm intensities and storm surge. Consequently, climate information sources and types listed under one stressor and impact may be applicable for another. Similarly, individual climate stressors and impacts may not always occur in isolation. Therefore, it is important to consider the coincidence of two or more climate stressors and impacts and the subsequent and potentially compounding effects on multiple business functions. Extreme heat, drought, and wildfire are one possibility of simultaneous hazards (AghaKouchak et al. 2018).

CHAPTER 5

Conclusions and Next Steps

The *Water Utility Business Risk and Opportunity Framework* is a simple, replicable approach that utilities can follow, aided by the step-by step supplemental guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate*. The framework helps water utilities of multiple sizes to identify and prioritize their core business functions, map climate-related risks and opportunities to the capabilities of those functions and align their needs with information required to move into planning and implementation. The framework supports an enterprise-wide understanding of the exposure and sensitivity of water utility business functions to a changing climate. The risk and opportunity profiles provide examples of framework applications in the real world, with user-friendly terminology for each of the four case studies in depth and for the three additional WUPG members at a higher level (Appendix E).

With the framework and guidebook now available to help enterprise risk managers and business function leads navigate this process, business function leads are encouraged to partner with climate experts (in-house or from external partner agencies) in using this framework. Utility managers can help champion this effort by connecting the internal working capacity and knowledge of business functions with either internal or external translational science capacity.

This research resulted in an improved understanding of varying business functions across multiple water utilities, approaches for business function managers to assess climate risks and opportunities, capabilities needed to support business function leads through this process, sources and types of data and information available to assess business function risks and opportunities at various scales, and a step-by-step framework for water utilities to map climate-related risks and opportunities across their business functions. This research also furthers the understanding of how physical climate drivers intersect with underlying water utility vulnerabilities across a variety of business functions.

Through this research, it was found that most water utilities have not yet assessed the risks and opportunities of climate change from a business function perspective. This occurred for several reasons, including the following: not having experienced a significant-enough climate impact to their operations, facilities, or employees to justify the analysis; competing priorities and limited resources; lack of regulatory requirements to assess the impacts; and the abundance of climate data in various types, spatial scales, and timeframes, presenting challenges in knowing which to use to evaluate what business function risk and/or opportunity.

If a given utility does not have an in-house climate expert, multiple ways exist to access the appropriate expertise, as described in this report. Among these are reaching out to local climate science centers, universities, and professional societies for help in understanding how to manage uncertainties in climate science and in generating useful analyses of existing and future risks.

Based on the outcomes of this project (Phase 1), the next phase of this project (Phase 2) will test the Framework with two WRF and WUCA member utilities and enhance the Framework and Guidebook to begin identifying opportunities to accelerate the mainstreaming of climate considerations and resilience into utility management. See “Next Steps” in the Executive Summary for more details on Phase 2.

APPENDIX A

Example Interview Briefing Packet and Questions

Water Utility Interview Briefing: San Diego Public Utilities

Interview Date: Tuesday, May 29th, 2:00-3:30pm

Contents

Project Background

The goal of this research project is to co-design and test (through case studies) a replicable Water Utility Business Function Framework and associated Guidebook, *Water Utility Business Risk and Opportunity Framework: A Guidebook for Water Utility Business Function Leaders in a Changing Climate,* with water utilities. Ultimately, this project will help to create an enterprise-wide understanding and prioritization of the exposure, sensitivities, and opportunities that water utility business functions face in a changing climate.

- Objective 1: Develop a suite of water utility business functions.
- Objective 2: Identify individual, interrelated, and cascading climate risks and opportunities by business function.
- Objective 3: Compile an array of available information to understand and evaluate climate-related risks and opportunities by business function.
- Objective 4: Map business function implications to climate information.
- Objective 5: Develop case studies to test the framework and generate a final report.
- Objective 6: Develop lessons learned and guidance for using the business function climate risk and opportunity framework.

Climate Risks and Resources for the Southwest Region and San Diego

According to data and information gathered from scientifically reputable sources (e.g., the Third National Climate Assessment [NCA3; USGCRP 2014], draft Fourth NCA [NCA4; USGCRP 2017], and Climate Central [n.d.]) and the San Diego Public Utility website, the Southwest region of California and San Diego is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Projected regional temperature increases, combined with the way cities amplify heat will pose increase threats and costs to public health, and disruptions to water supplies will exacerbate those health problems.	NCA3[1]
	Heat-associated deaths and illnesses, vulnerabilities to disease, and other health risks to people in the Southwest increase in extreme heat and in climate conditions that foster the growth and spread of pathogens. Improving stressed public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.	NCA4[2]
	California has more than 1 million people that are especially vulnerable to extreme heat. Summers are getting muggier as the dewpoint temperature rises. Currently, California averages 35 dangerous heat days a year. By 2050, the state is projected to see almost 50 such days a year.	States at Risk (California)[3]
Sea Level Rise	Projected sea level rise, coastal erosion, and increasing storm surges may cause fragile sea cliffs to collapse, shrink beaches, and destroy coastal property.	NCA3[4]
	Homes, beaches, fish, and other coastal resources in the Southwest have experienced sea level rise, ocean heating, ocean acidification, and reduced oxygen, all manifestations of human-caused climate change. Coastal infrastructure, marine plants and wildlife, and people who depend on fishing confront increased risks under continued climate change.	NCA4[5]
	California currently has 170,000 people at risk of coastal flooding. By 2050, an additional 204,000 people are projected to be at risk due to sea level rise. California currently has more than 200 square miles in the 100-year coastal floodplain. This area is projected to double to more than 550 square miles by 2050 due to sea level rise.	States at Risk (California)
	By 2035 the San Diego County Water Authority projects an increase in total normal water demand of 20 percent. Currently 85 to 90 percent of the City of San Diego's water supply is met by imported water.	City of San Diego CAP[6]
Drought and Water Supply	Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems. The southwest produces more than half of the nation's high value crops, reduced yields from increasing competition for scarce water supplies will displace jobs.	NCA3[7]
	Renewable hydropower in the Southwest has shown declines during drought, due in part to climate change. Continued temperature increases, energy use from a growing population, and water competition with farms and cities reduce the future reliability of fossil fuels and hydropower. Renewable solar and wind energy are increasing and offer future options to cut carbon emissions and reduce water use. Water supplies for people and nature in the Southwest decreasing during droughts due in part to human-caused climate change. Intensifying droughts, increasingly heavy downpours, and reduced snowpack are combining with increasing water demands from a growing population, aging infrastructure, and groundwater depletion to reduce the future reliability of water supplies. Availability of food and viability of rural livelihoods are vulnerable to water shortages in the Southwest. Increased drought and reduction of winter chill can harm crops and livestock, exacerbate competition for water among food production, energy generation, and residential uses, and increase future vulnerabilities of food security and rural livelihoods. Traditional foods, livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are affected by drought, wildfire, and ocean warming. Because future changes could disrupt the ecosystems on which Indigenous peoples depend, tribes are developing adaptation measures and emissions reduction actions.	NCA4[8]
	By 2050, the severity of widespread summer drought is projected to almost triple in California.	States at Risk (California)[9]

Wildfires	Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems. Fire models project more wildfire and increased risks to communities across extensive areas.	NCA3[10]
	The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change. Carbon emissions reductions, fire management, and other actions can help address future vulnerabilities of ecosystems and human well-being.	NCA4[11]
	More than 11.2 million people in California, or 30 percent of the state's population, are at an elevated risk of wildfire. By 2050, California projected to see more than 140 days a year with high wildfire potential, the greatest number of days among the lower 48 states.	States at Risk (California)[12]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[3] Climate Central, 2018: *States at Risk – California*. Website: http://statesatrisk.org/california/all

[4] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[5] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[6] United States, City of San Diego. (2015, December). *Climate Action Plan*. Retrieved from https://www.sandiego.gov/sites/default/files/final_july_2016_cap.pdf

[7] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United* States*: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[8] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[9] Climate Central, 2018: *States at Risk – California*. Website: http://statesatrisk.org/california/all

[10] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[11] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[12] Climate *Central*, 2018: *States at Risk – California*. Website: http://statesatrisk.org/california/all

Cadmus identified the following assessments, policies, and/or plans related to climate change and San Diego Public Utilities and useful for this project.

Resource Name	Description	Date
County of San Diego, Climate Action Plan – Chapter 4: Climate Vulnerability, Resiliency, and Adaptation	This report outlines the County's CAP as it relates to climate mitigation and adaptation. Chapter 4: Climate Vulnerability, Resiliency, and Adaptation outlines the climate risk and vulnerabilities the County faces now and into the future as well as the adaptation and resilience measures they're taking to address these risks.	2018
Safeguarding California Plan, 2018 Update	This 2018 Update to the Safeguarding California Plan, developed by 38 agencies across state government, is a catalogue of ongoing actions and recommendations that protect infrastructure, communities, services, and the natural environment from climate change.	2018
2017 Annual Report, Climate Action Plan, City of San Diego	This annual report highlights the progress made towards achieving the goals set out in the 2015 CAP.	2017
City of San Diego, Climate Action Plan	This CAP highlights climate resiliency as one of five actions the City will take to enhance the City's future prosperity and quality of life by: building communities that are resilient to climate change through the identification of vulnerabilities and the corresponding implementation of adaptation measures. These measures are intended to protect public health and safety; secure and maintain water supplies and services; protect and maintain urban infrastructure and community services; protect environmental quality; maintain open space, parks, and recreation; support coastal management and protection; promote urban forest management and local food production; improve building and occupant readiness; and enhance community education, knowledge and collaboration.	2015
Port of San Diego, Climate Action Plan	The San Diego Unified Port District (the Port) developed a comprehensive CAP to protect and enhance its future success as a thriving, working port. This Plan primarily speaks to climate mitigation.	2013
2012 Long-Range Water Resources Plan	This long-range plan includes sections and content on climate change, and water resources.	2012

Common Water Utility Business Functions

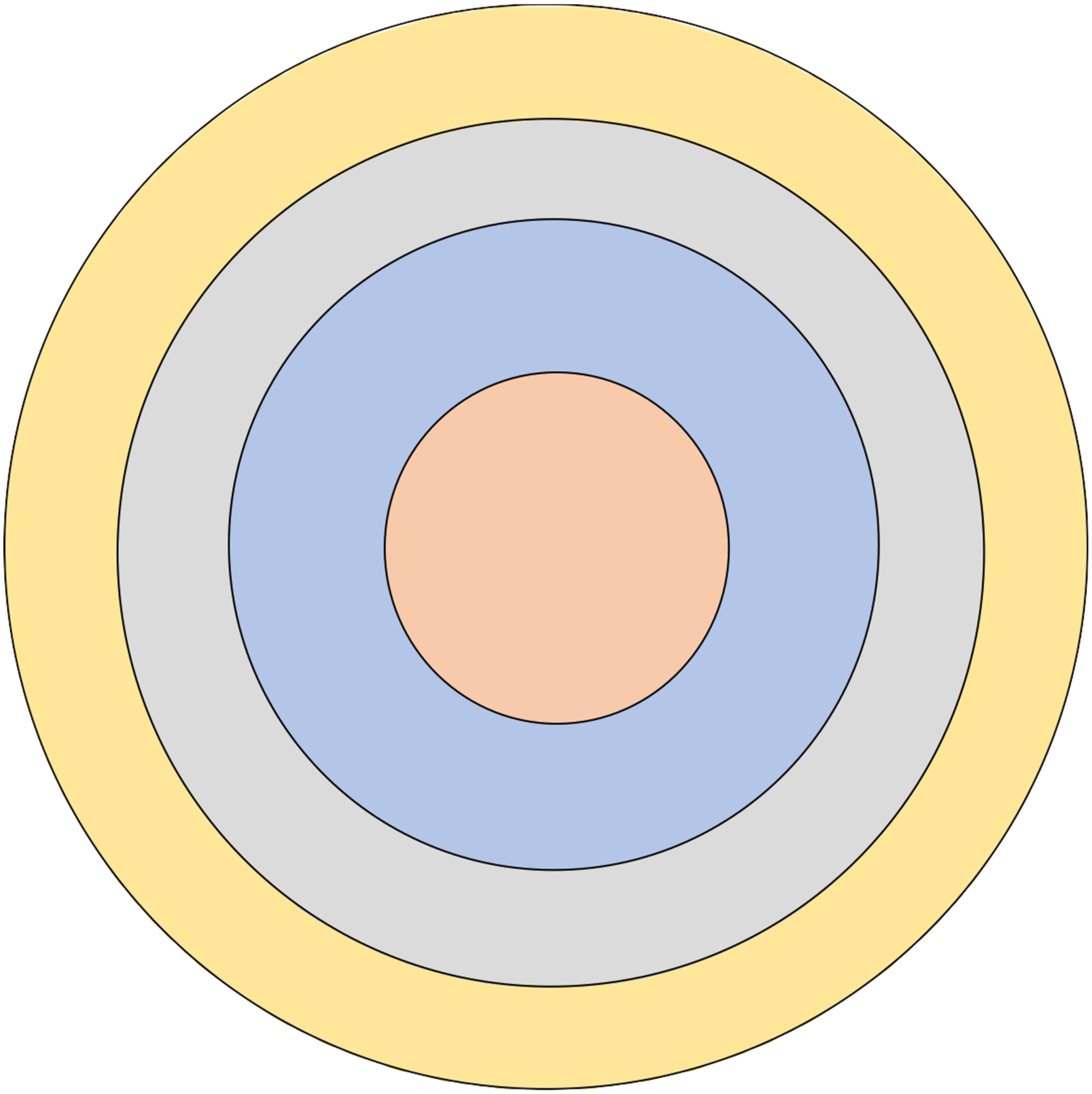
Based on background research and discussions with the WUPG, a list of common business functions for water utilities has been compiled.

Water-Specific Business Functions	Other Business Functions
Drinking Water **Water Supply** • Planning, modeling, forecasting and analysis • Conservation • Drought planning/water shortage stage management • Raw water/untreated irrigation water management • Seawater desalination • Recycled water management • Reservoir and surface water management • Groundwater management **Wastewater** • Wastewater collection • Wastewater treatment • Biosolids management • Effluent management **Environmental Monitoring and Management** • Groundwater and surface water quality and treatment • Watershed management • Stream rehabilitation • Ocean monitoring • Cross agency water quality management **Stormwater management** • Flood control • Drainage basins and infrastructure • Stormwater quality	**Accounting and Human Resources** • Contracts, business services, recordkeeping, and billing • Finance and insurance • Human resources, employment, and staff training • Asset management • Business case evaluations **Procurement** **External Affairs** • Customer service (residential, commercial) • Public education and outreach • Community relations and advocacy • Legal and regulatory affairs • Environmental compliance • Cross-agency coordination • Communications **Operations** • Infrastructure maintenance • Engineering design and construction • Field operations • Security (physical, computer, and data) • Information technology • Emergency management/hazard mitigation

Interview Prep Exercise*: Core Business Functions You Regularly Engage With

*This prep exercise is associated with question 8 of the interview questions below

1. In advance of our interview, each person should fill out this diagram.
2. In the center (pink circle), write your business function/unit.
3. In the next ring out (blue ring), write the business functions with whom you directly interact on a frequent basis.
4. On the next ring out (purple ring), indicate which business functions those identified in step 3 regularly interact.
5. On the next right out (orange ring), indicate which business functions those identified in step 4 regularly interact.
6. Please bring your completed sheet to your interview with the Cadmus Research Team.
7. After the interview, please scan your sheet and yours peers and email them to your Cadmus point of contact.



Interview Materials

Interview Purpose

A. Understand core business functions for each utility and existing perceptions of climate risks and opportunities.
B. Develop an understanding of actions taken to date to address these issues and associated resources (e.g., planning, policy, action).
C. Lay the foundation for future work to identify and analyze climate risks and data/tools/approaches for managing those risks and for building a transferrable framework.

Interview Objectives

A. Understand the relevant and core business functions for each utility.
B. Understand the existing and potential range of efforts to assess climate risks and opportunities.
C. Understand potential cascading impacts across business units.

Terminology

To make sure the terminology we're using is consistent across the board, here is how we've defined the following terms:

Term	Research Team Definition
Core Business Function	A category of processes or operations that are performed routinely to carry out a part of the utility's mission.
Climate Risk	The combination of the likelihood (probability of occurrence) and the consequences of an adverse climate event. Climate risks include both of the following: • **Acute Climate Risk:** An extreme weather event which is affected (not necessarily caused by) climate change; its intensity, duration or frequency (or any combination) is expected to change over time and may cause injury, illness, or death to people, or damage to physical or environmental assets. Examples include hurricanes, floods, heatwaves, wildfires, and drought. • **Chronic Climate Risk**: A longer-term condition or trends related to longer-term climate variability and change. Examples include higher temperatures, sea level rise, and changes in precipitation patterns.
Climate Opportunity	The potential to derive positive outcomes from understanding and preparing for climate-related challenges, including resource efficiency and cost savings, development of new products and services, access to new markets, and building resilience across the utility and along its supply chain.
Climate Adaptation	Actions taken to help limit risk and maximize opportunities associated with changing climate conditions.
Climate Resilience	The capacity to anticipate, plan, adapt, and thrive in a changing climate.

Terminology

To make sure the terminology we're using is consistent across the board, here is how we've defined the following terms:

Background

1. Can you each please state your name, title, and role within your utility?
2. How long have each of you worked for the Southern Nevada Water Authority?
3. Has your utility provided any guidance to staff about language to use relative to climate change?

Develop a Suite of Water Utility Business Functions

4. In preparation for this interview, we did some background research on the various business functions performed by utilities across the nation, including your own [see the business function list above]. When you think about your utility, are any major categories of business functions missing that we should include?
    a. If yes, can you tell me a bit about what business functions are missing, what their responsibilities are, and why/how your utility works in this area?
    b. Do you have an internal organizational chart that you can share with us that illustrates the organization of business functions across your utility? (If so, please share via email).
5. During this background research, we also identified some subcategories within each of the core business functions we found across the nation. Did we miss any major subcategories?
6. Has your utility identified any regulatory or structural barriers to climate adaptation and/or other risk management innovations that you had hoped to implement?
7. At your utility (or unit within the utility), what key decisions are made? More specifically:
    a. Can you describe how decisions are made on a day to day basis?
    b. Is there a different process for long-term or policy decisions? If yes, can you please describe?

8. In advance of this call, we asked you to fill out a document highlighting the core business functions you as an individual regularly engage/work with. If you completed those sheets, can you bring them out now?
    a. Can you each briefly share your results?

Compile an Array of Available Information to Understand and Evaluate Climate Risks and Opportunities by Business Function

9. During our background research, we identified the following assessments, policies, and/or plans that your utility has undertaken to begin understanding and/or planning for climate risks and opportunities [see the assessments, policies, and/or plans table above]. Are there other efforts your utility has undertaken to integrate climate change into your planning, policies, risk assessment or management process, or decision-making?
10. What sources or data did you use to compile your utility-specific climate information?
    a. Do you currently have information or tools to assist in identifying and assessing the likelihood and consequences of low probability/high impact events?
11. Do you have ongoing relationships with partners or consultants who assist you in finding or generating climate information?
12. What other processes does your utility have in place to identify, assess, and manage any type of risk or hazard (e.g., earthquakes, disease outbreaks, strong storms, cyber security, economic downturns)?
    a. Which business function conducts these assessments and manages the risks or opportunities?
    b. Does any business function specifically conduct assessments and work on managing climate risks or opportunities? If yes, how?
13. Have you engaged with other partners (e.g., utilities, community organizations, hazard mitigation planners, or government staff) on climate risk or opportunity assessments or plans related to the risks your utility is facing? If yes, please describe the engagement and resulting output and/or outcome.
14. Has your jurisdiction/state taken any steps to adopt or promote policies and regulations to incorporate climate change into planning, policies, or decision-making, and if so, has that driven actions within the utility? If yes, which business functions were involved?

Identify Individual, Interrelated, and Cascading Climate Risks and Opportunities by Business Function (Understanding Exposure, Sensitivity, and Adaptive Capacity)

15. Based on our research, it appears that you've been faced with a major drought, rising seas, and extreme heat events over the past few years. Using the diagram on page 5 that you've filled out, can you indicate on that sheet how the drought, rising seas, and extreme heat events have impacted your business function and then note how these changes have impacted other business functions you regularly interact with?
16. What other major extreme weather and climate events (including heat waves, flooding, drought, etc.) has your utility faced over the past 5 years? Please describe the impacts that you faced and any linked or cascading effects to the various business functions.
17. What, if anything, do you think your utility/business function could have done differently to better prepare for these impacts?
18. What climate risks and opportunities are your utility planning for, if any?
    a. Are there specific investments or plans in place now to manage the risks and leverage the opportunities associated with climate change?
    b. If so, are they focused on managing the impacts of individual climate risks like drought, flooding, or heat waves or opportunities like diversifying business activities, employee retainment, or resource efficiency?

19. When you think about projected changes in climate, where do you think your utility is the most sensitive now (e.g., what are you the most worried about)? How about in the future?
20. To the extent relevant, what projects, if any, have you implemented to address climate risks and opportunities?
21. What information, tools or support do you think your utility needs to help it to identify, assess, adapt to or manage the risks and opportunities associated with projected changes in the climate?
22. What opportunities, if any, do you think your utility should embrace to help increase climate resilience?
23. Is there anything that I forgot to ask you that you would like to share with me?
24. If I have any further questions, is it okay to follow-up with you directly?

Research Team Interview Point of Contact

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APPENDIX B

Climate Risks and Resources by Region and Utility Location

Great Plains Region and Austin

According to data and information gathered from scientifically reputable sources (e.g., the Third National Climate Assessment [NCA3; USGCRP 2014], draft Fourth NCA [NCA4; USGCRP 2017], and Climate Central) and the Austin Water website, the Great Plains (and Southern Great Plains) region and Austin is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.	NCA3[1]
	Mean annual temperature has increased by approximately 1°F since the first half of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century, with associated increases in extreme heat events.	State Summaries[2]
	Climate change will increase exposure to certain health threats, including extreme heat and diseases transmitted through food, water, and insects. These health threats may occur over longer periods of time, or at times of the year where these threats are not normally experienced. Given the widespread changes expected in the Southern Great Plains, health threats will be both varied and widespread. Higher temperatures, extreme precipitation, and rising sea levels associated with climate change make the built environment in the Southern Plains increasingly vulnerable to disruption, particularly as infrastructure ages and populations shift to urban centers. Tribal nations and indigenous communities in the Southern Great Plains are particularly vulnerable to the effects of climate change, including water resource impacts, extreme weather events, higher temperatures, and other public health issues. Efforts to adapt and build community resilience may be hindered by economic, political, and infrastructure limitations. Traditional knowledge and intertribal organizations provide opportunities to respond to the challenges of climate change.	NCA4[3]
	Texas is home to 9 of the hottest cities in the U.S. Summers are getting muggier as the dewpoint temperature rises. Texas currently averages more than 60 dangerous heat days a year. By 2050, the state is projected to see 115 such days a year, second only to Florida. Nearly 840,000 people living in Texas are especially vulnerable to extreme heat.	States at Risk (Texas)[4]
Drought and Water Supply	Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.	NCA3[1]
	Although projected changes in annual precipitation are uncertain, increases in extreme precipitation events are projected. Higher temperatures will increase soil moisture loss during dry spells, increasing the intensity of naturally occurring droughts.	State Summaries[2]
	Texas currently faces the worst threat from widespread summer drought among the lower 48 states. By 2050, the state is projected to see an increase in severity of approximately 75 percent.	States at Risk (Texas)[4]

Key Risk	Key Finding	Source
Wildfires	More than 18 million people living in Texas, or 72 percent of the state's population, are currently living in areas at elevated risk of wildfire. By 2050, Texas is projected to top the nation with the worst overall wildfire threat.	States at Risk (Texas)[4]
Ecosystems	Climate change affects terrestrial and aquatic ecosystems, influencing extreme droughts, unprecedented floods, and wildfires that directly and indirectly alter ecosystems and impact species. Some species adapt to changing climates, while others cannot, resulting in significant impacts to both services and people living in these ecosystems.	NCA4[3]
Energy- Water-Food Nexus	The region's growing population, the migration of individuals from rural to urban locations, and climate change will increase and redistribute demand and result in resource contention at the intersection of food consumption, energy production, and water resources. This "nexus" is inextricably linked to quality of life, particularly in rural areas as well as across both national and transnational borders.	NCA4[3]
	Superimposed on the existing complexities at the food, energy, and water nexus is the specter of climate change. During 2012–2015, the multiyear regional drought resulted in no irrigation water for the Texas Rice Belt farmers on the Texas coastal plains. The reduced quantity of available water along the Colorado River basin had to be rationed among multiple stakeholders and uses, including the municipal and recreational needs for the City of Austin; the coastal plain rice farmers requiring it for irrigation to support their livelihoods; the need to replenish cooling reservoirs for the South Texas Project's two nuclear reactors that supply power to two million households in Austin, Dallas and San Antonio; and the Fayette Power Project coal plant that supplies power to 320,000 homes in the Austin area. In one year, planted acres of rice in Matagorda County, Texas, dropped from 22,000 acres to 2,100 acres. The ripple effect on the local economy was severe, with a 70% decline in sales of farm implements and machinery. Some family-owned establishments that had survived for decades closed permanently. Irrigation strategies shifted from river-based to pumping water from the Gulf Coast Aquifer, and dozens of new wells were drilled. Drilling water wells then resulted in declining groundwater levels, adding stress to water levels that had historically been falling in the region. Some farmers were forced to make the difficult transition to other crops such as corn. When flooding rains inundated the region in 2016, 15% of the corn crop in the region was swept away in flood waters.	NCA4[3] - Case Study

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] Runkle, J., K. Kunkel, J. Nielsen-Gammon, R. Frankson, S. Champion, B. Stewart, L. Romolo, and W. Sweet, 2017: *Texas State Summary*. NOAA Technical Report NESDIS 149-TX, 4 pp. Website: https://statesummaries.ncics.org/tx#

[3] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[4] Climate Central, 2018: *States at Risk – Texas*. Website: http://statesatrisk.org/texas/all

Cadmus identified the following assessments, policies, and/or plans related to climate change and Austin Water and useful for this project.

Resource Name	Description	Date
Water Forward – Resources	Recently, Central Texas experienced a historic drought that eclipsed the 1950's drought. Considering such droughts, increasing population and a changing climate, the Water Forward plan will recommend water management strategies for our community's future.	Ongoing

Southwest Region and Fort Collins

According to data and information gathered from scientifically reputable sources including the Third National Climate Assessment (NCA3; USGCRP 2014), draft Fourth NCA (NCA4; USGCRP 2017), and the Western Water Assessment, Fort Collins is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Projected regional temperature increases, combined with the way cities amplify heat will pose increased threats and costs to public health, and disruptions to water supplies will exacerbate those health problems.	NCA3[1]
	Heat-associated deaths and illnesses, vulnerabilities to disease, and other health risks to people in the Southwest increase in extreme heat and in climate conditions that foster the growth and spread of pathogens. Improving stressed public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.	NCA4[2]
	Statewide average temperatures are projected to increase by 1.5 to 4.5 degrees F by 2050 under a low emissions scenario. The highest summertime temperatures are projected to increase even more than average temperatures.	Climate Change in Colorado[3]
Wildfire	Increased warming, drought, and insect outbreaks, have increased wildfires and impacts to people and ecosystems. Fire models project more wildfire and increased risks to communities across extensive areas.	NCA3[1]
	The frequency and extent of wildfires are projected to increase, and that increase would likely lead to more destructive flooding as burned areas are more susceptible to flooding and runoff of sedimentation and debris.	NCA3[1]
Drought and Water Supply	Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems. The southwest produces more than half of the nation's high value crops, reduced yields from increasing competition for scarce water supplies will displace jobs.	NCA3[1]
	Projections for future total annual precipitation vary and because warmer air can hold more moisture, models project that extreme precipitation events will increase even in areas where total precipitation may decrease. Most published studies suggest that annual streamflows in all of Colorado's river basins could be decreased and peak streamflows are projects to come earlier in the year.	Climate Change in Colorado[3]
	Renewable hydropower in the Southwest has shown declines during drought, due in part to climate change. Continued temperature increases, energy use from a growing population, and water competition with farms and cities reduce the future reliability of fossil fuels and hydropower.	NCA4[2]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*.
Website: https://www.globalchange.gov/content/nca4-planning

[3] Lukas, Jeff., 2014: *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* Western Water Assessment.

Cadmus identified the following assessments, policies, and/or plans related to climate change and Fort Collins Utilities.

Resource Name	Description	Date
Fort Collins Climate Action Plan	An update on the city's progress toward its greenhouse gas and waste reduction goals. The document includes information on energy reduction, utility bill savings, recycling accomplishments, and transportation goal achievements.	2016
Case Study: Water and Wastewater Utilities Planning for Climate Change	A case study on the climate threats, the planning process, and adaptation efforts of Fort Collins Utilities. The case study highlights FCU's concern about water quality issues caused by flash flooding following wildfires.	2017
Fort Collins Community Resilience Assessment	An assessment and implementation document of Fort Collins' community resilience efforts. The document includes a six-step guide to planning for community resilience, a list of the planning team, and an indication of objectives and implementation activities.	2016
Climate Wise Report on Fort Collins	A video documenting the proactive approach Fort Collins took following extreme weather events in 2012 and 2013 to plan for climate change impacts.	2014
Joint Front Range Climate Change Vulnerability Study	A report on the assessed changes in the timing and volume of hydrologic runoff that might be expected from several climate change scenarios for years 2040 and 2070 for the Front Range of the United States.	2012

Northeast Region and New York City

According to data and information gathered from scientifically reputable sources including the Third National Climate Assessment (NCA3; USGCRP 2014), Climate Central, and the New York City Climate Change Integrated Modeling Project, New York City is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Milder winters and earlier spring conditions are already changing habitats, affecting species, and creating irreversible changes to hydrology and wildlife.	NCA4[2]
	If emissions continue to increase, 4.5° to 10° F warming is projected by the 2080s, and if global emissions were reduced substantially, projected warming ranges from 3° to 6° F by the 2080s.	NCA3[1]
Flooding	New York has 431,000 people at risk of coastal flooding. By 2050, an additional 228,000 people are projected to be at risk due to sea level rise.	States at Risk[3]
	Storm surges and heavy rains can impair or damage critical equipment and result in overflows of untreated sewage into the city's waterways.	NCA3[1]
	New York currently has 100 square miles in the 100-year coastal floodplain. By 2050, this is projected to increase to 150 square miles due to sea level rise.	States at Risk[3]
	New York City is served by a combined sewer system that collects and treats both stormwater and municipal wastewater. During heavy rain events, combined systems can be overwhelmed, and untreated water may be release into local water bodies.	NCA3[1]
Drought and Water Supply	The timing of the spring snowmelt is predicted to shift from a distinct peak in late March and April to being more evenly distributed throughout the winter and fall due to increased temperatures causing less precipitation to fall as snow, decreased snow accumulation, and earlier snowmelt.	Climate Change Integrated Modeling[4]
	Changes in temperature and precipitation can have dramatic impacts on urban water supply available for municipal and industrial uses.	NCA4[2]
	The shifting seasonal pattern in streamflow similarly affects the turbidity loads into Schoharie Reservoir and impacts Schoharie withdrawals, with increased turbidity in the fall and winter and decreased turbidity in the spring.	Climate Change Integrated Modeling[4]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*.
Website: https://www.globalchange.gov/content/nca4-planning

[3] Climate Central. n.d. *Top New York Risks.* States at Risk. Retrieved from http://statesatrisk.org/new-york/coastal-flooding

[4] United States, New York City Department of Environmental Protection, Bureau of Water Supply. (2013, October). Climate Change Integrated Modeling Project: Phase I Assessment of Impacts on the New York City Water Supply. Retrieved from http://www.nyc.gov/html/dep/pdf/climate/climate-change-integrated-modeling.pdf.

Cadmus identified the following assessments, policies, and/or plans related to climate change and New York City DEP.

Resource Name	Description	Date
NYC Wastewater Resiliency Plan	A climate risks assessment and adaptation study with strategies to reduce flooding damage to wastewater infrastructure and safeguard public health and the environment.	October 2013
One New York City: One Water	This plan highlights the history of DEP, strategies to reduce DEP's carbon footprint, and climate adaptation needs and plans for water management in New York City.	2015
Climate Change Integrated Modeling Project	Presents an assessment of climate change impacts on the New York City water supply.	October 2013
Special Initiative for Rebuilding and Resiliency	A report in the aftermath of Hurricane Sandy that includes recommendations for rebuilding communities and increasing the resilience of infrastructure throughout the city.	June 2013
Climate Change Assessment and Action Plan	Outlines climate change science, potential climate change impacts on DEP, and adaptation strategies.	2008

Southwest Region and Salt Lake City

According to data and information gathered from scientifically reputable sources including the Third National Climate Assessment (NCA3), draft Fourth NCA (NCA4), and NOAA's Utah State Climate Summary (NOAA 2017), Salt Lake City is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Projected regional temperature increases, combined with the way cities amplify heat will pose increase threats and costs to public health, and disruptions to water supplies will exacerbate those health problems.	NCA3[1]
	Heat-associated deaths and illnesses, vulnerabilities to disease, and other health risks to people in the Southwest increase in extreme heat and in climate conditions that foster the growth and spread of pathogens. Improving stressed public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.	NCA4[2]
	Average annual temperature has increased about 2°F since the early 20th century. Warming is particularly evident as an increase in very warm nights and a below average occurrence of extremely cold nights over the past two decades. Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century.	Utah State Climate Summary[3]
Wildfire	Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems. Fire models project more wildfire and increased risks to communities across extensive areas.	NCA3[1]
	The frequency and extent of wildfires are projected to increase, and that increase would likely lead to more destructive flooding as burned areas are more susceptible to flooding and runoff of sedimentation and debris.	NCA3[1]
Drought and Water Supply	Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems. The southwest produces more than half of the nation's high value crops, reduced yields from increasing competition for scarce water supplies will displace jobs.	NCA3[1]
	Droughts are a serious threat in this water-scarce state. The intensity of naturally occurring future droughts and the frequency of wildfire occurrence and severity are projected to increase in Utah.	Utah State Climate Summary[3]
	Renewable hydropower in the Southwest has shown declines during drought, due in part to climate change. Continued temperature increases, energy use from a growing population, and water competition with farms and cities reduce the future reliability of fossil fuels and hydropower	NCA4[2]
	Projected changes in winter precipitation include an increase in the fraction falling as rain rather than snow, potentially decreasing snowpack water storage. The number and magnitude of heavy precipitation events are projected to increase, which could increase the risk of flooding.	Utah State Climate Summary[3]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[3] Frankson, R., K. Kunkel, L. Stevens and D. Easterling, 2017: Utah State Climate Summary. NOAA Technical Report NESDIS 149-UT, 4 pp.

Cadmus identified the following assessments, policies, and/or plans related to climate change and Salt Lake City Public Utilities.

Resource Name	Description	Date
Planning for an Uncertain Future: Climate Change Sensitivity Assessment toward Adaptation Planning for Public Water Supply	A study of the potential impacts of future climate-driven hydrologic changes on factors important to planning at the Salt Lake City Department of Public Utilities.	2013
Incorporating Potential Severity into Vulnerability Assessment of Water Supply Systems under Climate Change Conditions	A vulnerability assessment using an integrated modeling framework driven by temperature and precipitation data for a 30-year historical (1981–2010) period. The analysis includes a sensitivity analysis to show the impact and importance of various factors on the vulnerability of the system under different climate conditions.	2016

Southwest Region and San Diego

According to data and information gathered from scientifically reputable sources (e.g., the Third National Climate Assessment [NCA3], draft Fourth NCA [NCA4], and Climate Central) and the San Diego Public Utility website, the Southwest region of California and San Diego is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Projected regional temperature increases, combined with the way cities amplify heat will pose increase threats and costs to public health, and disruptions to water supplies will exacerbate those health problems.	NCA3[1]
	Heat-associated deaths and illnesses, vulnerabilities to disease, and other health risks to people in the Southwest increase in extreme heat and in climate conditions that foster the growth and spread of pathogens. Improving stressed public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.	NCA4[2]
	California has more than 1 million people that are especially vulnerable to extreme heat. Summers are getting muggier as the dewpoint temperature rises. Currently, California averages 35 dangerous heat days a year. By 2050, the state is projected to see almost 50 such days a year.	States at Risk (California)[3]
Sea Level Rise	Projected sea level rise, coastal erosion, and increasing storm surges may cause fragile sea cliffs to collapse, shrink beaches, and destroy coastal property.	NCA3[1]
	Homes, beaches, fish, and other coastal resources in the Southwest have experienced sea level rise, ocean heating, ocean acidification, and reduced oxygen, all manifestations of human-caused climate change. Coastal infrastructure, marine plants and wildlife, and people who depend on fishing confront increased risks under continued climate change.	NCA4[2]
	California currently has 170,000 people at risk of coastal flooding. By 2050, an additional 204,000 people are projected to be at risk due to sea level rise. California currently has more than 200 square miles in the 100-year coastal floodplain. This area is projected to double to more than 550 square miles by 2050 due to sea level rise.	States at Risk (California)[3]
	By 2035 the San Diego County Water Authority projects an increase in total normal water demand of 20 percent. Currently 85 to 90 percent of the City of San Diego's water supply is met by imported water.	City of San Diego CAP[4]
Drought and Water Supply	Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems. The southwest produces more than half of the nation's high value crops, reduced yields from increasing competition for scarce water supplies will displace jobs.	NCA3[1]

Key Risk	Key Finding	Source
	Renewable hydropower in the Southwest has shown declines during drought, due in part to climate change. Continued temperature increases, energy use from a growing population, and water competition with farms and cities reduce the future reliability of fossil fuels and hydropower. Renewable solar and wind energy are increasing and offer future options to cut carbon emissions and reduce water use. Water supplies for people and nature in the Southwest are decreasing during droughts due in part to human-caused climate change. Intensifying droughts, increasingly heavy downpours, and reduced snowpack are combining with increasing water demands from a growing population, aging infrastructure, and groundwater depletion to reduce the future reliability of water supplies. Availability of food and viability of rural livelihoods are vulnerable to water shortages in the Southwest. Increased drought and reduction of winter chill can harm crops and livestock, exacerbate competition for water among food production, energy generation, and residential uses, and increase future vulnerabilities of food security and rural livelihoods. Traditional foods, livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are affected by drought, wildfire, and ocean warming. Because future changes could disrupt the ecosystems on which Indigenous peoples depend, tribes are developing adaptation measures and emissions reduction actions.	NCA4[2]
	By 2050, the severity of widespread summer drought is projected to almost triple in California.	States at Risk (California)[3]
Wildfires	Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems. Fire models project more wildfire and increased risks to communities across extensive areas	NCA3[1]
	The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change. Carbon emissions reductions, fire management, and other actions can help address future vulnerabilities of ecosystems and human well-being.	NCA4[2]
	More than 11.2 million people in California, or 30 percent of the state's population, are at an elevated risk of wildfire. By 2050, California projected to see more than 140 days a year with high wildfire potential, the greatest number of days among the lower 48 states.	States at Risk (California)[3]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[3] Climate Central, 2018: *States at Risk – California*. Website: http://statesatrisk.org/california/all

[4] United States, City of San Diego. (2015, December). *Climate Action Plan*. Retrieved from https://www.sandiego.gov/sites/default/files/final_july_2016_cap.pdf

Cadmus identified the following assessments, policies, and/or plans related to climate change and San Diego Public Utilities and useful for this project.

Resource Name	Description	Date
County of San Diego, Climate Action Plan – Chapter 4: Climate Vulnerability, Resiliency, and Adaptation	This report outlines the County's CAP as it relates to climate mitigation and adaptation. Chapter 4: Climate Vulnerability, Resiliency, and Adaptation outlines the climate risk and vulnerabilities the County faces now and into the future as well as the adaptation and resilience measures they are taking to address these risks.	2018
Safeguarding California Plan, 2018 Update	This 2018 Update to the Safeguarding California Plan, developed by 38 agencies across state government, is a catalogue of ongoing actions and recommendations that protect infrastructure, communities, services, and the natural environment from climate change.	2018
2017 Annual Report, Climate Action Plan, City of San Diego	This annual report highlights the progress made towards achieving the goals set out in the 2015 CAP.	2017
City of San Diego, Climate Action Plan	This CAP highlights climate resiliency as one of five actions the City will take to enhance the City's future prosperity and quality of life by: building communities that are resilient to climate change through the identification of vulnerabilities and the corresponding implementation of adaptation measures. These measures are intended to protect public health and safety; secure and maintain water supplies and services; protect and maintain urban infrastructure and community services; protect environmental quality; maintain open space, parks, and recreation; support coastal management and protection; promote urban forest management and local food production; improve building and occupant readiness; and enhance community education, knowledge and collaboration.	2015
Port of San Diego, Climate Action Plan	The San Diego Unified Port District (the Port) developed a comprehensive CAP to protect and enhance its future success as a thriving, working port. This Plan primarily speaks to climate mitigation.	2013

Southwest Region and Southern Nevada

According to data and information gathered from scientifically reputable sources (e.g., the Third National Climate Assessment [NCA3], draft Fourth NCA [NCA4], and Climate Central) and your utilities public-facing website, the Southwest region and Southern Nevada is likely to experience the following impacts:

Key Risk	Key Finding	Source
Temperature	Projected regional temperature increases, combined with the way cities amplify heat will pose increase threats and costs to public health, and disruptions to water supplies will exacerbate those health problems.	NCA3[1]
	Heat-associated deaths and illnesses, vulnerabilities to disease, and other health risks to people in the Southwest increase in extreme heat and in climate conditions that foster the growth and spread of pathogens. Improving stressed public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.	NCA4[2]
	More than 70,000 people living in Nevada are especially vulnerable to extreme heat. Currently, Nevada averages 20 days a year classified as dangerous. By 2050, Nevada is projected to see nearly 30 such days a year. By 2050, the typical number of heat wave days in Nevada is projected to increase from 15 to nearly 55 days a year.	States at Risk (Nevada)[3]
Drought and Water Supply	Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems. The southwest produces more than half of the nation's high value crops, reduced yields from increasing competition for scarce water supplies will displace jobs. The Colorado River is projected to experience a median imbalance of 3.2 million acre-feet per year between supply and demand by the year 2060. In the near term, hydrologic modeling indicates a high probability that Lake Mead water levels will continue to decline.	NCA3[1]
	Renewable hydropower in the Southwest has shown declines during drought, due in part to climate change. Continued temperature increases, energy use from a growing population, and water competition with farms and cities reduce the future reliability of fossil fuels and hydropower. Renewable solar and wind energy are increasing and offer future options to cut carbon emissions and reduce water use. Water supplies for people and nature in the Southwest are decreasing during droughts due in part to human-caused climate change. Intensifying droughts, increasingly heavy downpours, and reduced snowpack are combining with increasing water demands from a growing population, aging infrastructure, and groundwater depletion to reduce the future reliability of water supplies. Availability of food and viability of rural livelihoods are vulnerable to water shortages in the Southwest. Increased drought and reduction of winter chill can harm crops and livestock, exacerbate competition for water among food production, energy generation, and residential uses, and increase future vulnerabilities of food security and rural livelihoods. Traditional foods, livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are affected by drought, wildfire, and ocean warming. Because future changes could disrupt the ecosystems on which Indigenous peoples depend, tribes are developing adaptation measures and emissions reduction actions.	NCA4[2]
	If upstream states continue to be unable to make up the shortage, Lake Mead, whose surface is now about 1,085 feet above sea level, will drop to 1,000 feet by 2020. Under present conditions, that would cut off most of Las Vegas's water supply.	States at Risk (Nevada)[3]

Wildfires	Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems. Fire models project more wildfire and increased risks to communities across extensive areas.	NCA3[1]
	The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change. Carbon emissions reductions, fire management, and other actions can help address future vulnerabilities of ecosystems and human well-being.	NCA4[2]
	The number of large fires on Forest Service land is increasing dramatically. More than 1.2 million people living in Nevada, or 46 percent of the state's population, are living in areas at elevated risk of wildfire.	States at Risk (Nevada)[3]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter*. Website: https://www.globalchange.gov/content/nca4-planning

[3] Climate Central, 2018: *States at Risk – Nevada*. Website: http://statesatrisk.org/nevada/all

Cadmus identified the following climate-related SNWA resources useful for this project.

Resource Name	Description	Date
SNWA Water Resource Plan	The plan fulfills the requirement of the SNWA Cooperative Agreement and provides a comprehensive overview of projected water demands in Southern Nevada and of the resources available to meet demands over time.	2017
Climate Resilience Evaluation and Awareness Tool 2.0 Exercise with SNWA	SNWA participated in an exercise with the U.S. Environmental Protection Agency (EPA) to demonstrate use of the recently released Climate Resilience Evaluation and Awareness Tool (CREAT) version 2.0 by beginning an assessment of overall risks to its system and identifying opportunities for adaptation.	2014
Colorado River Basin Water Supply and Demand Study	A joint study conducted by the seven Colorado River Basin States and the U.S. Bureau of Reclamation outlines several options to reduce the potential impacts of water shortages on the river system.	2012

Southeast Region and Tampa Bay

According to data and information gathered from scientifically reputable sources including the Third National Climate Assessment (NCA3), draft Fourth National Climate Assessment (NCA4), and the Florida Climate Institute, Tampa Bay is likely to experience the following impacts:

Key Risk	Key Finding	Source
Water Quality and Supply	Infrastructure related to drinking water treatment and wastewater treatment may be compromised by climate-related events.	NCA4[2]
	Potential increases in temperature, and the variations in precipitation patterns, may degrade water quality, exacerbate algae problems, and cause eutrophication of important water bodies.	Florida Climate Institute[3]
	Heavy precipitation events can cause massive overflows of untreated sewage into streams, rivers, bays, canals, and homes. More than 150 gallons of sewage has spilled in St. Petersburg due to heavy rain events.	States at Risk[4]
	Rising temperatures will likely increase the intensity of naturally-occurring droughts in this area because of increases in rate of loss of soil moisture.	State Summary[5]
Sea Level Rise	The combined effects of changing extreme rainfall events and sea level rise are increasing flood frequencies, making the Southeast highly vulnerable to climate change impacts. Without significant adaptation measures many coastal cities will experience daily tidal high tide flooding by the end of the century.	NCA4[2]
	Sea level rise increases pressure on utilities by contaminating potential freshwater supplies with saltwater. Such problems are amplified during extreme dry periods with little runoff. Porous aquifers in some areas make them particularly vulnerable to saltwater intrusion.	NCA3[1]
Temperature Increase	Temperatures across the Southeast are expected to increase during this century, with projected increases in the range of 4° F to 8° F.	NCA3[1]
	Climate model simulations of future conditions project increases in temperature and extreme precipitation for both lower and higher scenarios.	NCA4[2]

[1] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 148 pp.

[2] U.S. Global Change Research Program, 2017: DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter.
Website: https://www.globalchange.gov/content/nca4-planning

[3] Obeysekera, J., W. Graham, M. C. Sukop, T. Asefa, D. Wang, K. Ghebremichael, and B. Mwashote. Implications of Climate Change on Florida's Water Resources. Florida Climate Institute, Chapter 3.

[4] Climate Central, 2018. States at Risk – Florida. Website: http://statesatrisk.org/florida/drought

[5] Runkle, J., K. Kunkel, S. Champion, R. Frankson, B. Stewart, and W. Sweet, 2017: Florida State Summary. NOAA Technical Report NESDIS 149-FL, 4 pp. Website: https://statesummaries.ncics.org/fl

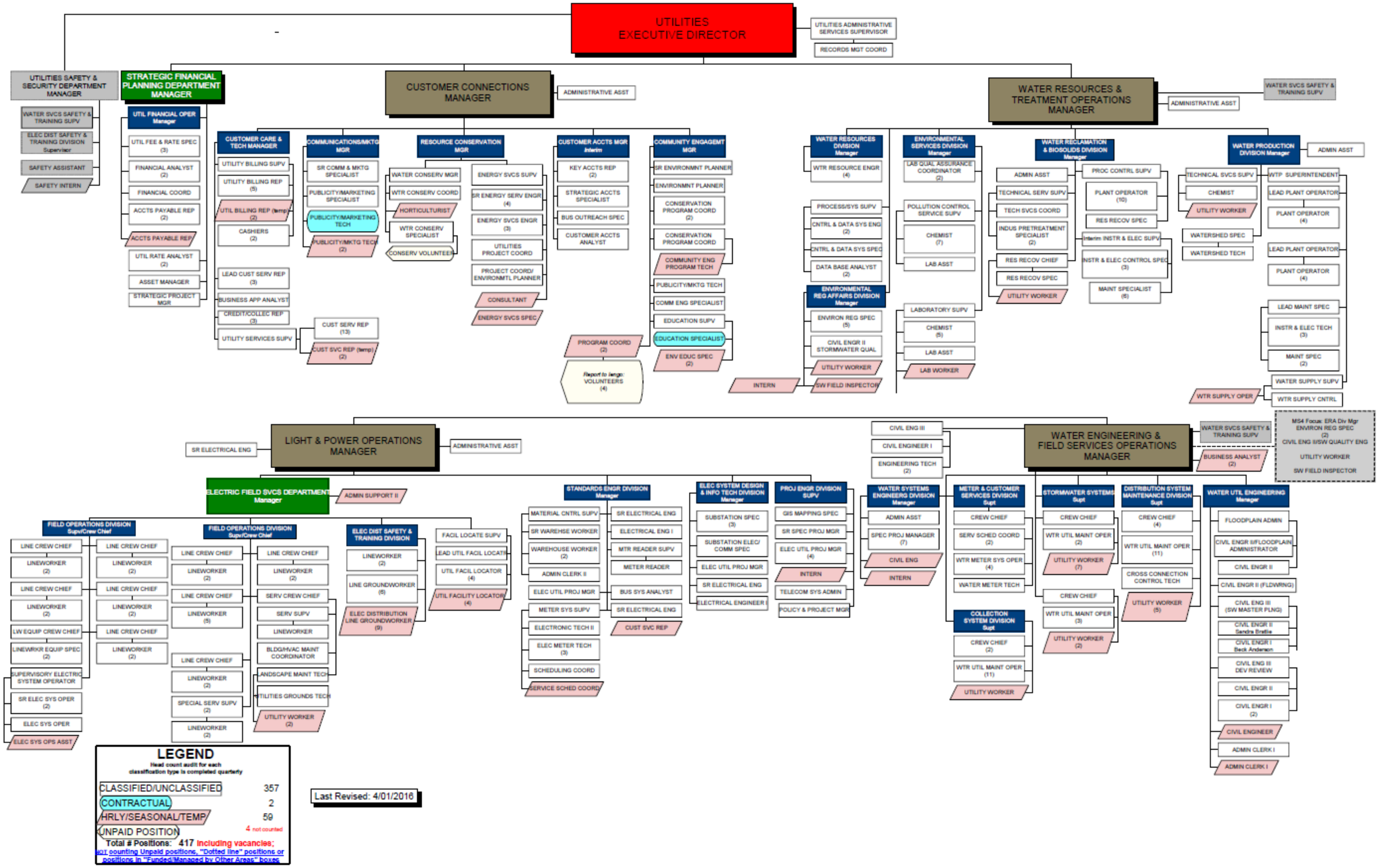
Cadmus identified the following assessments, policies, and/or plans related to climate change and Tampa Bay Water.

Resource Name	Description	Date
2017 Supply & Demand Recap: Weathering Extremes	A review of water supply and demand for the fiscal year ending September 30, 2017 including impacts associated with Hurricane Irma and a record dry spring.	2017
Climate Change and its Effect on Future Water Supply Planning	An article on the ways in which Tampa Bay Water is involved in research to understand climate variability and climate change.	2015
Predicting the Impacts of Climate Variability on Florida	A review of Tampa Bay Water's research including hydrologic modeling and downscaling efforts to employ climate information in water supply planning activities.	2013
Tampa Bay Climate Science Advisory Panel	An assessment of future impacts to the Tampa Bay Region from climate change impacts including sea level rise and subsequent flooding.	2015

APPENDIX C

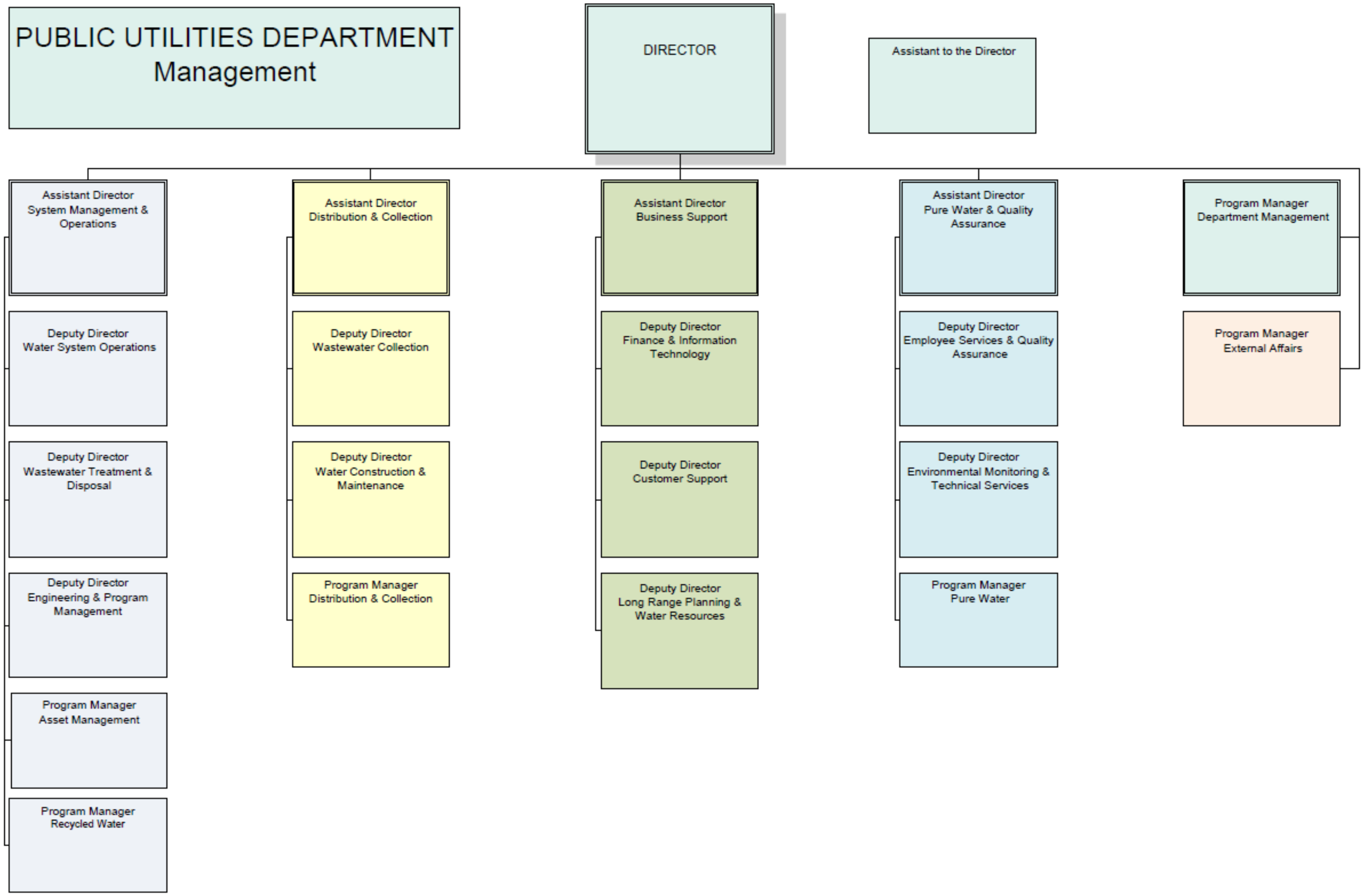
Example Organizational Charts

Fort Collins Utilities: Fort Collins, Colorado



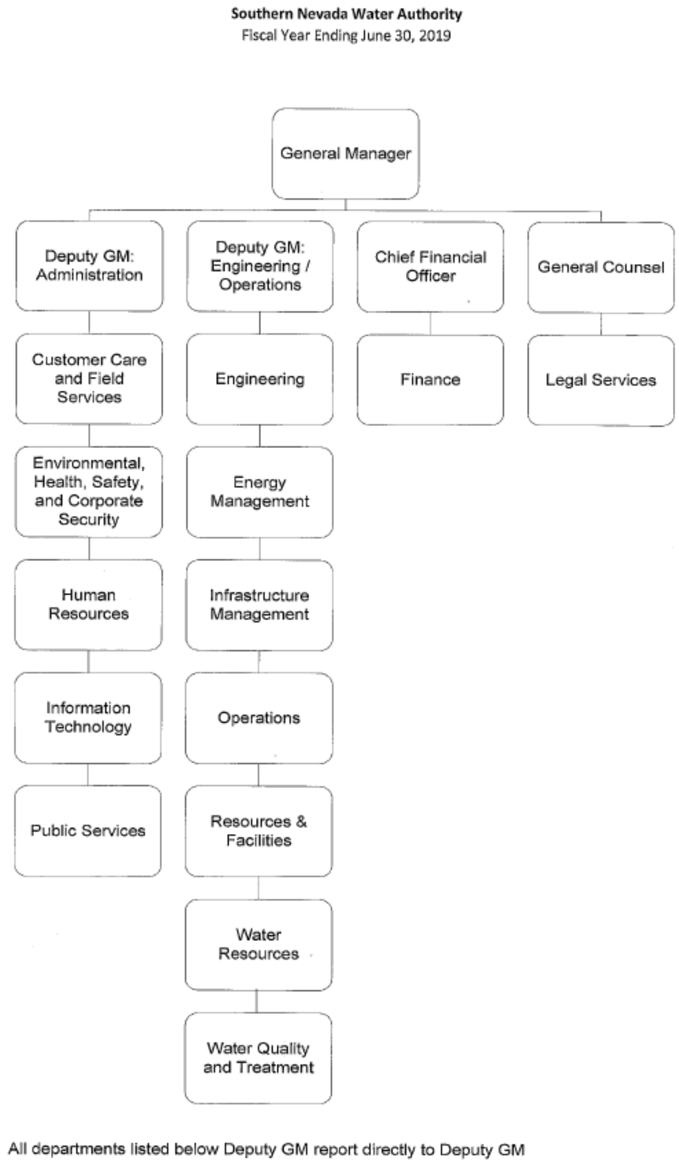
Source: Courtesy of Fort Collins Utilities.

San Diego Public Utilities Department: San Diego, California



Source: Courtesy of San Diego Public Utilities Department.

Southern Nevada Water Authority: Las Vegas, Nevada

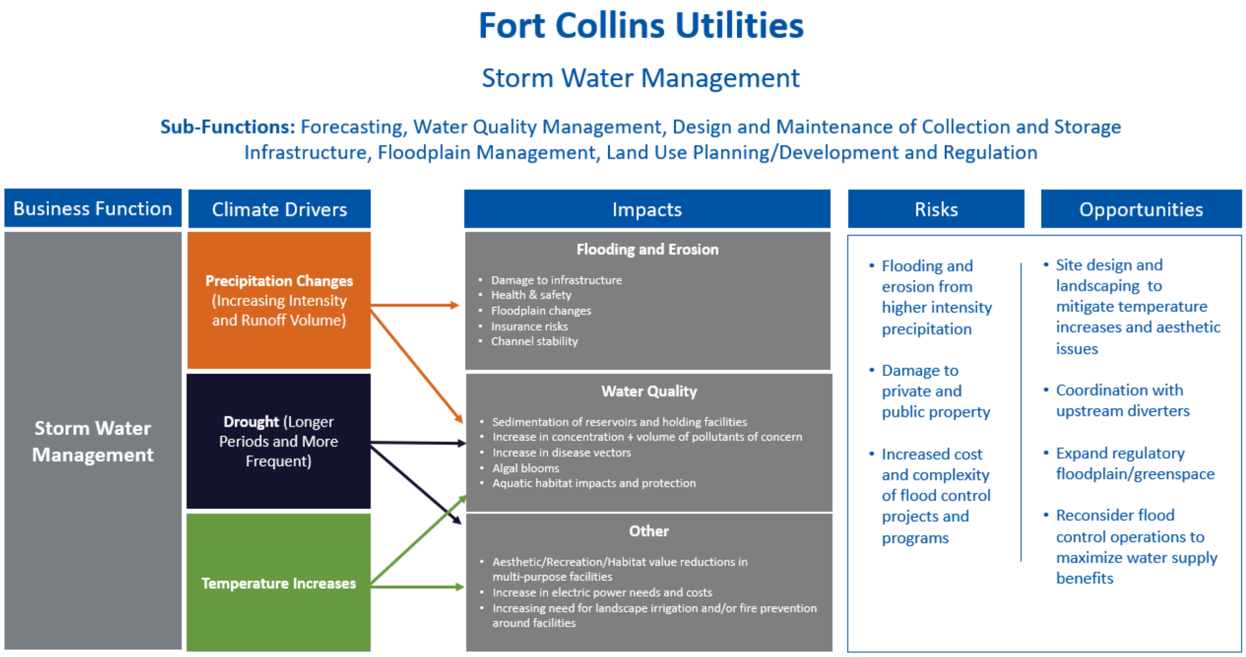


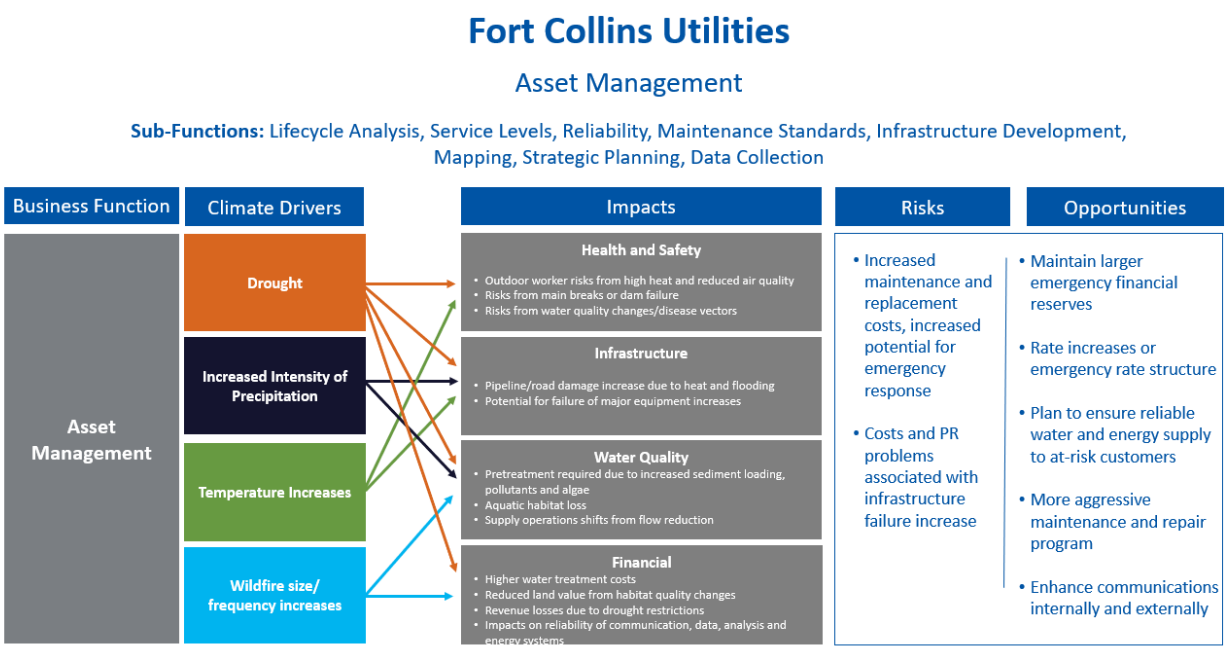
Source: Courtesy of Southern Nevada Water Authority.

APPENDIX D

Case Study Example Risk and Opportunity Maps

Fort Collins Utilities: Fort Collins, Colorado

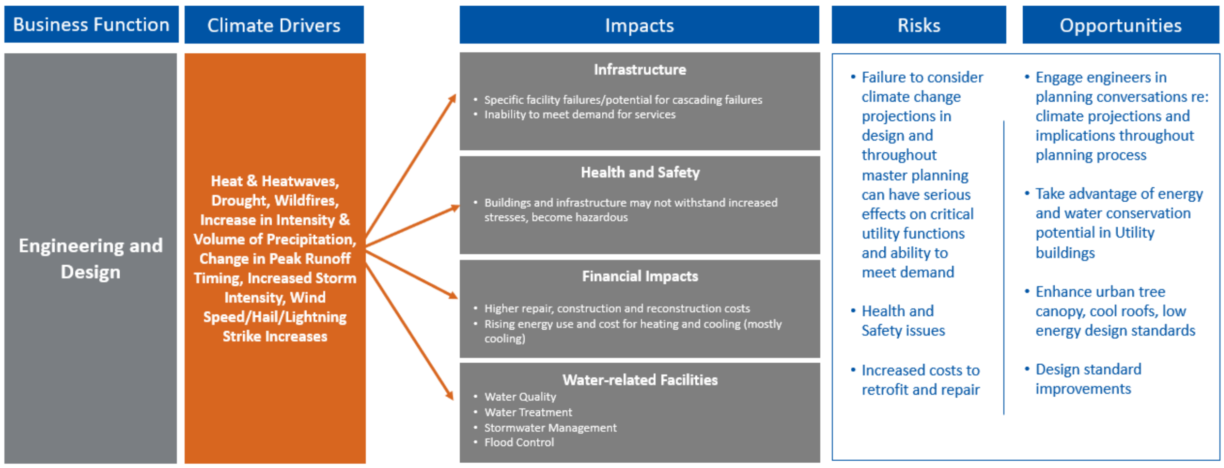




Fort Collins Utilities

Engineering and Design

Sub-Functions: Surveying, Sizing, Layout, Design Standards

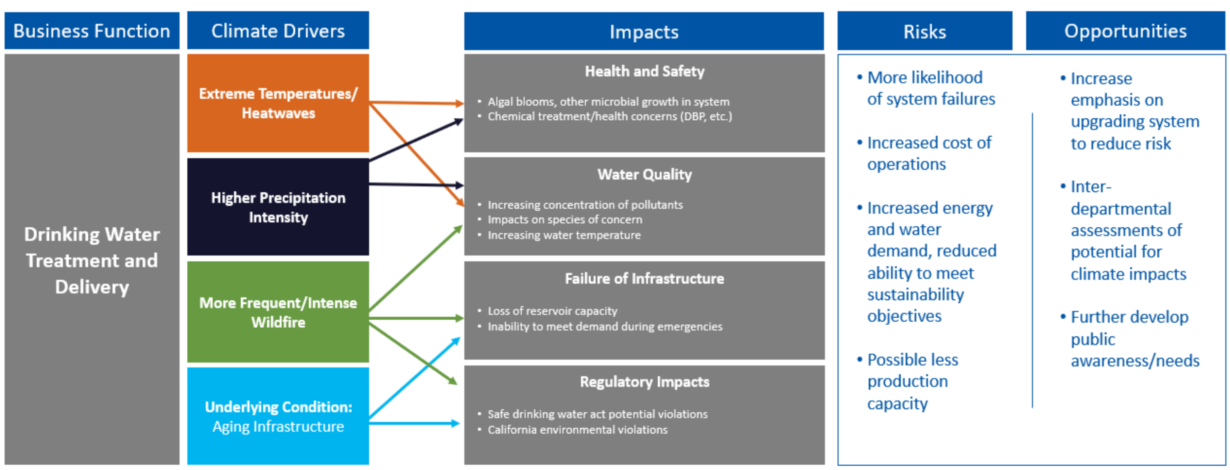


San Diego Public Utilities Department: San Diego, California

San Diego PUD

Drinking Water Treatment and Delivery

Sub-Functions: Treatment Facilities, Facility Maintenance, Pipelines, Physical & Chemical Treatment of Raw Water, Remedial Treatment for Impaired Water, Reuse of Municipal Effluent, Storm Water Runoff Quality, Upstream Watershed Conditions

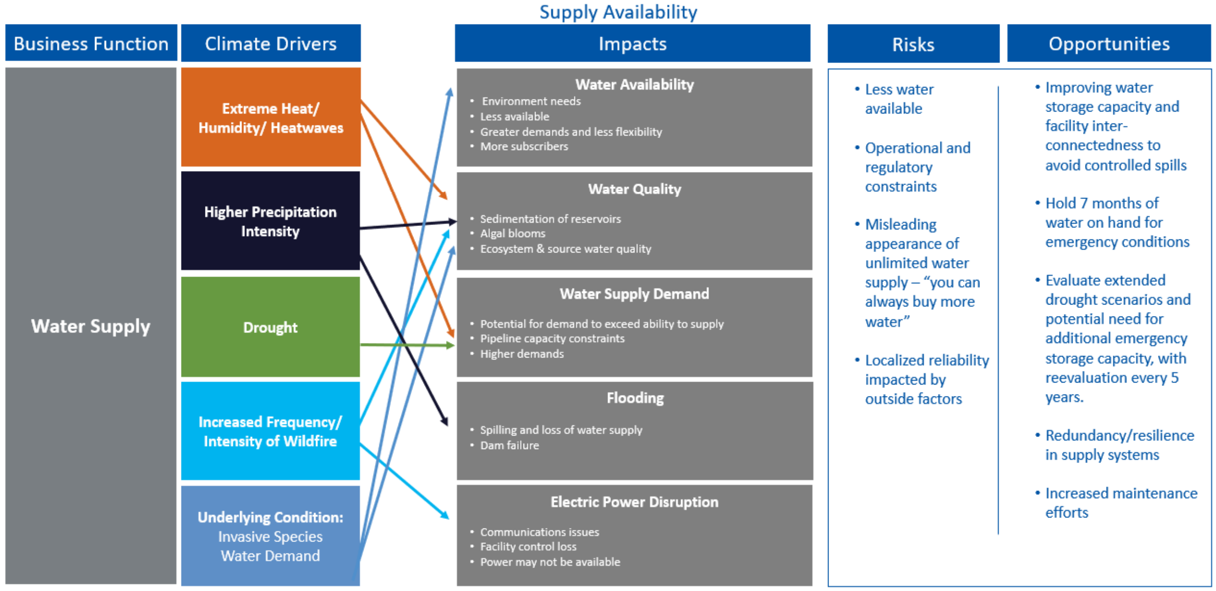


San Diego PUD

Water Supply

Key Function: Operational considerations within San Diego's local storage/reservoir system

Sub-Functions: San Diego County Water Authority Supplies, Groundwater Rights, Reservoir Water Supply and Storage Agreements w/ County, Water Rights Agreements with Colorado River Water, Prioritization Process for Water Purchases, Native Water, Imported Water Prices, Water Supply Availability

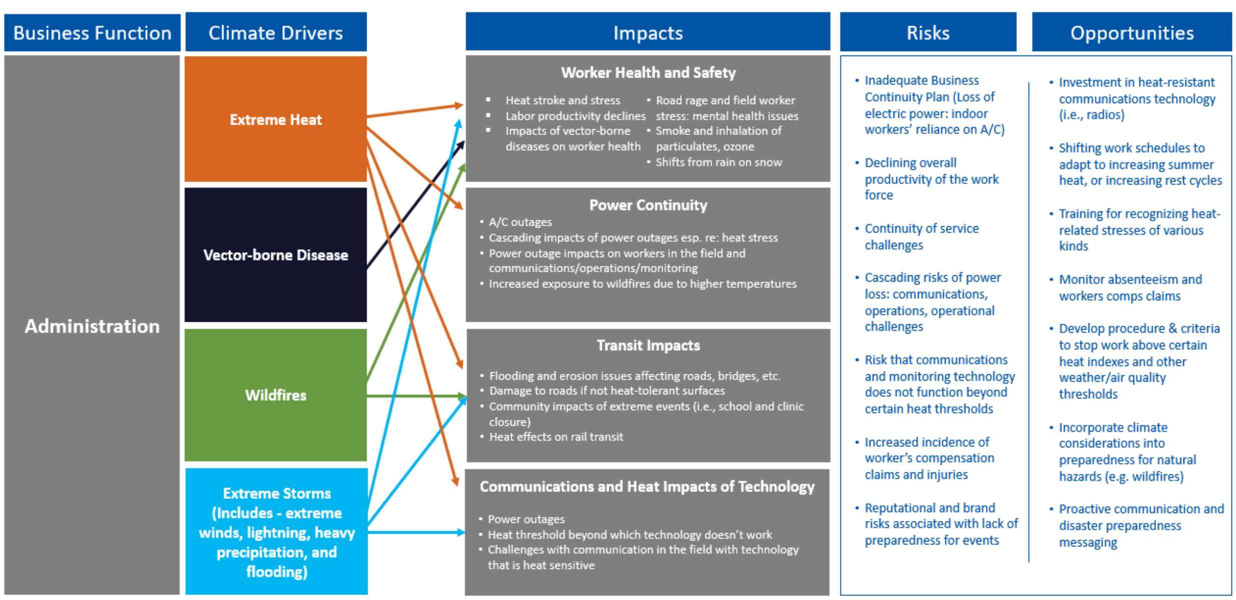


Southern Nevada Water Authority: Las Vegas, Nevada

Southern Nevada Water Authority

Administration

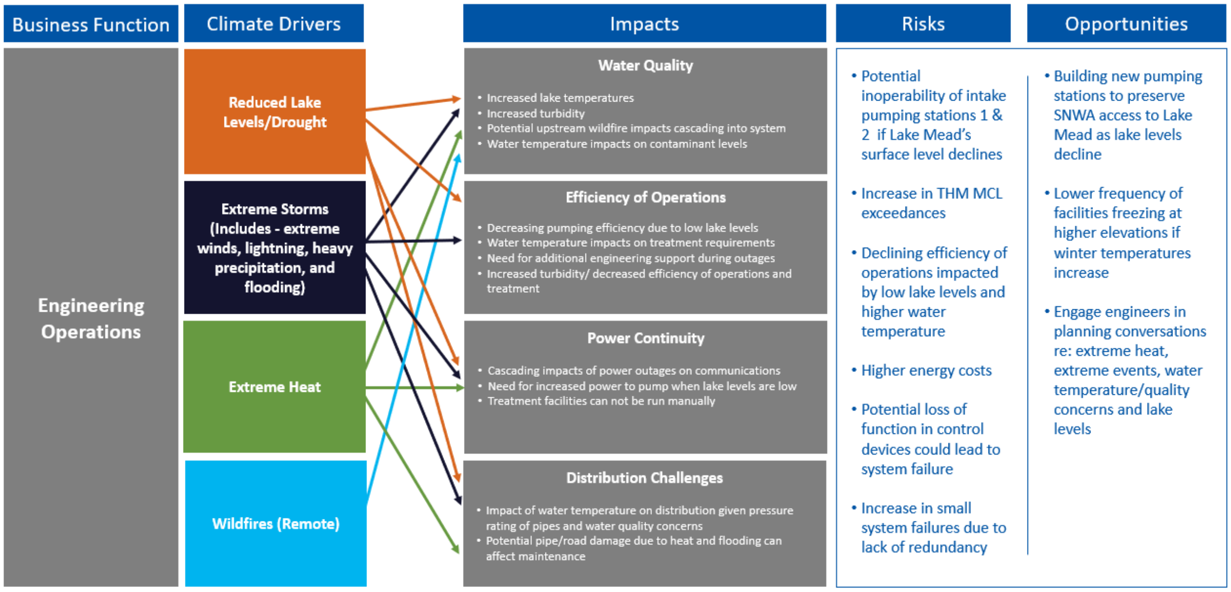
Sub-Functions: Customer Care & Field Services, EHS & Security, Human Resources, Information Technology, Public Services



Southern Nevada Water Authority

Engineering Operations

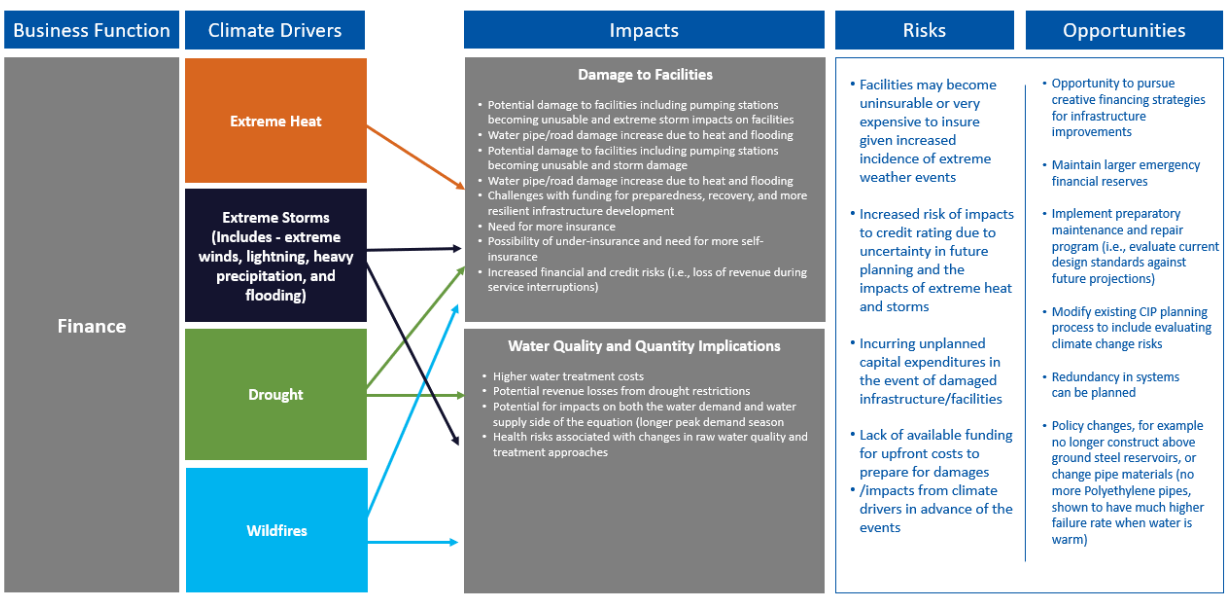
Sub-Functions: Energy Management, Engineering, Infrastructure Management, Operations, Resources & Facilities, Water Quality & Treatment



Southern Nevada Water Authority

Finance

Sub-Functions: Accounting, Financial Services, Purchasing
(e.g. *long-term rate structure, purchasing equipment, chemicals, paper, etc., long-term planning alignment)*

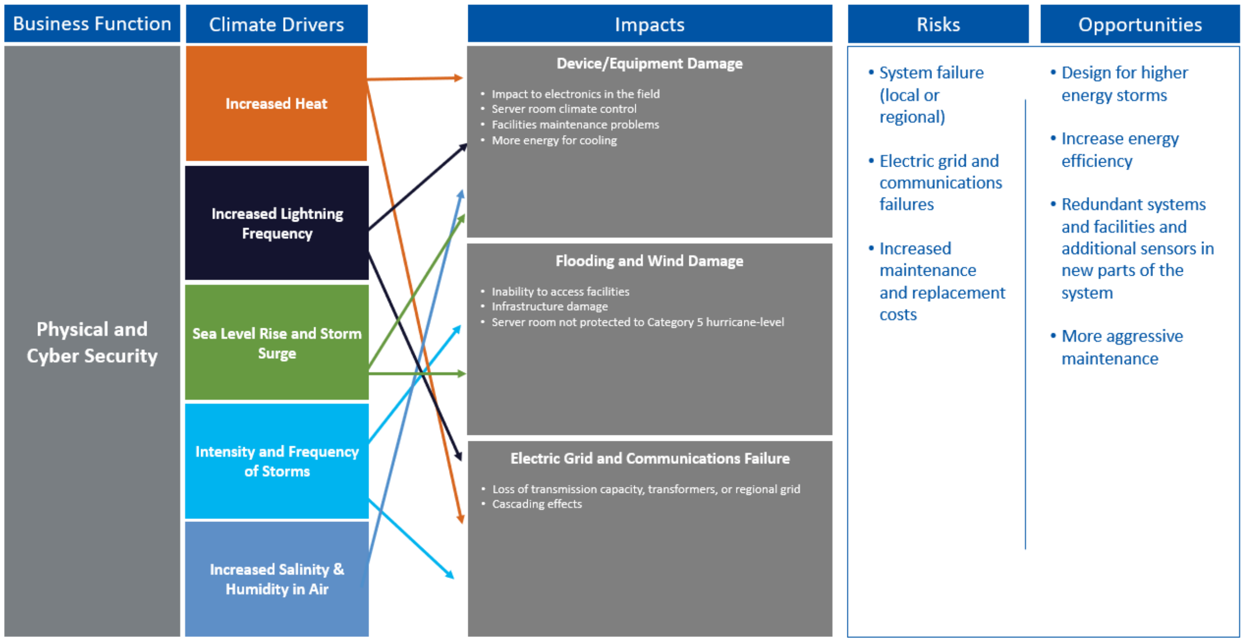


Tampa Bay Water: Clearwater, Florida

Tampa Bay Water

Physical and Cyber Security

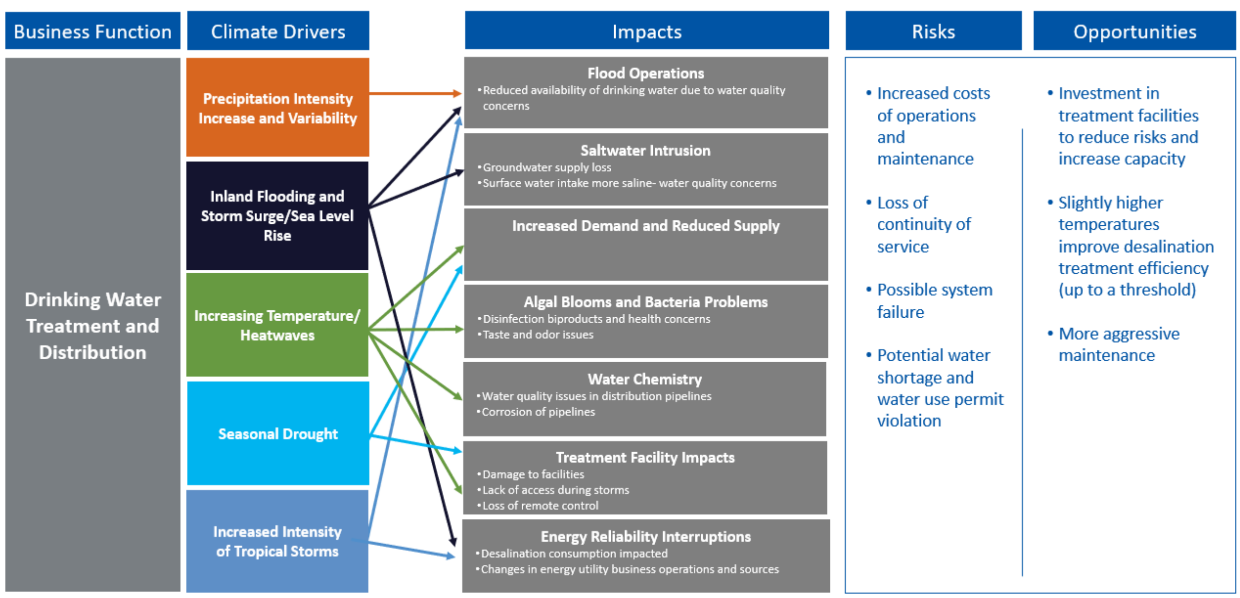
Sub-Functions: Communications, Physical Plant, Information Technology, Detection, Sensors, SCADA



Tampa Bay Water

Drinking Water Treatment and Distribution

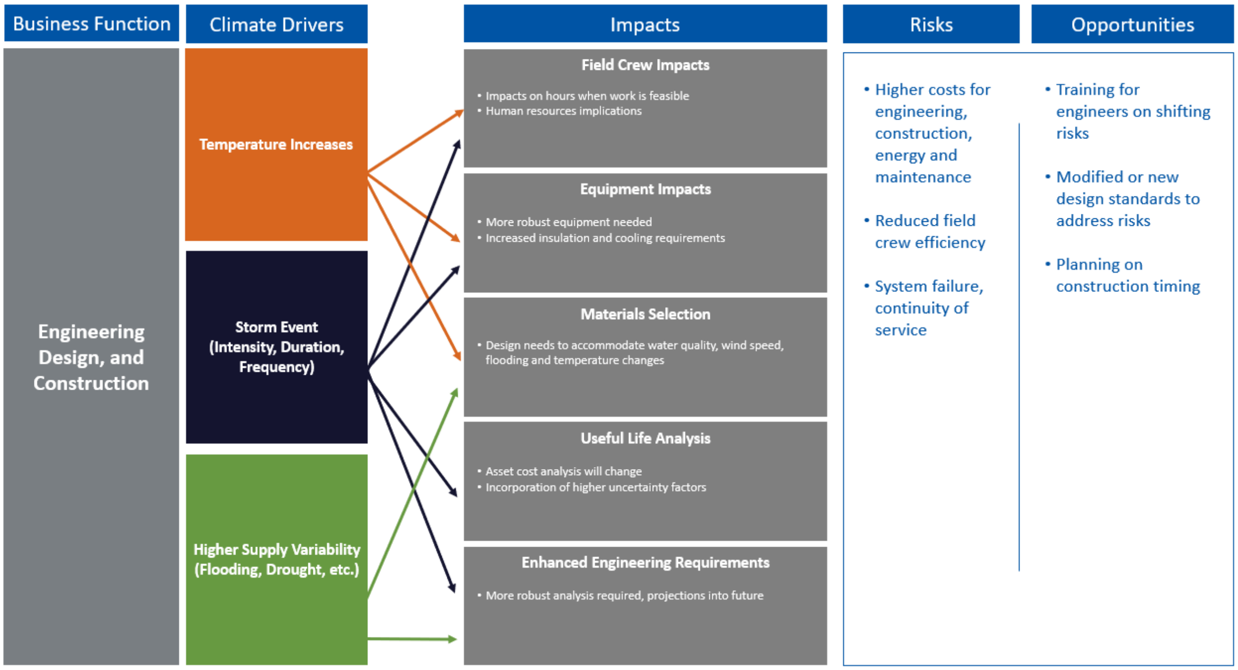
Sub-Functions: Incoming Water Quality, Treatment Facility Capacity, Treatment Technology, Distribution System, Storage, Treatment Type (physical & chemical), Monitoring, Desalination



Tampa Bay Water

Engineering, Design, and Construction

Sub-Functions: Construction Standards, Construction Specifications, Constructability of Assets, Site Selection, Design Standards, Material Selection, Useful Life Analysis, Physical Construction



APPENDIX E

Water Utility Business Risk and Opportunity Profiles

For each of the water utility partners, Water Utility Business Risk and Opportunity Profiles were generated. For the four case study utilities, City of Fort Collings, San Diego Public Utilities, Southern Nevada Water Authority, and Tampa Bay Water, more in-depth profiles were generated that can be used to inform their planning decisions. Less detailed profiles were developed for the three remaining utilities.

CLIMATE RISK AND OPPORTUNITY PROFILE

Austin Water

CLIMATE PROJECTIONS

Drought
From 2008 to 2016, the Austin region experienced a historic drought. Higher temperatures will increase naturally occurring droughts.[5]

Heatwaves
Long periods of extreme heat have increased, causing stress to community health and power availability.[1]

Flooding
Extreme flooding events have damaged infrastructure that provides facility access.[3]

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Planning, Modeling, Forecasting, and Analysis
Austin Water has used four planning horizons to assess precipitation, temperature, and evaporation projections.

Business Affairs
The extended drought from 2008 to 2016 reduced water demand and impacted revenue, which resulted in rate structure adjustments.

Treatment
Austin Water's major water and wastewater plants have experienced limited functionality and access during recent large flooding events.

UTILITY OVERVIEW

For more than 100 years, Austin Water has been committed to providing safe, reliable, high-quality, sustainable, and affordable water services. Over the last several years, Austin Water has faced major climate and extreme weather events including drought, extreme and prolonged heat waves, more severe flooding events, shifts in precipitation patterns, and wildfires. Extreme flooding events have impeded treatment plant operations and damaged infrastructure that provides access to key utility facilities.

Austin Water is currently developing plans to expand water supply storage capacity and improve access to facilities, so each facility is more resilient to climate change risks including flooding and drought. Austin Water has also identified funding and strategies to repair and bring systems back more quickly after extreme events, including using FEMA funding sources to repair damaged facilities.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends include the following:

- Mean annual temperature has increased by approximately 1°F since the first half of the 20th century.[2]
- More than 18 million people living in Texas, or 72% of the state's population, are currently living in areas at elevated risk of wildfire.[4]

FUTURE CLIMATE

Projected changes include the following:

- By 2050, the state is projected to see 115 dangerous heat days a year, second only to Florida.[4]
- Higher temperatures will increase soil moisture loss during dry spells, intensifying naturally occurring droughts.[2]
- Texas currently faces the worst threat from widespread summer drought among the lower 48 states. [4]

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

PLANNING, MODELING, FORECASTING, AND ANALYSIS

- **Summary:** Austin Water worked with Dr. Katharine Hayhoe to develop climate change adjusted streamflow projections over the 100-year planning horizon, using 20 Global Climate Models on an 8.5 Representative Concentration Pathway.
- **Current risk:** Austin Water's planning horizons vary depending upon department needs. Financial planning typically considers 1-, 5-, and 10-year horizons, while infrastructure and water supply planning prioritize near and mid-terms needs and consider 100-year and lifespan planning horizons.
- **Climate impacts include:** All climate change impacts (drought, flooding, heatwaves, etc.), even remote to the region, will affect planning, modeling, forecasting, and analysis.
- **Opportunities:** The Water Forward Integrated Water Resource Plan includes strategies for the 2020, 2040, 2070, and 2115 planning horizons, with more detailed implementation plans for the time period between now and 2040.

Climate Stressors and Risks **PLANNING, MODELING, FORECASTING, AND ANALYSIS**	
Stressors	**Risks**
• Increased average temperatures • Increased frequency and intensity in heat waves • Increased incidence of drought • Increased flooding • Increased intensity and frequency of heavy rainfall events	• Much wider range of possible future conditions • Changes in availability of local and regional water supplies • Changes in demand for outdoor irrigation and other water uses

BUSINESS AFFAIRS

- **Summary:** Austin Water has had several severe flooding events that have damaged utility infrastructure, but its catastrophic insurance has provided some reimbursement for damage. The extended drought from 2008 to 2016 impacted Austin Water significantly.
- **Current risks:** Reduced water demand has impacted revenue, which resulted in rate structure adjustments intended to stabilize revenues. Finances were strained to the point that bond rating agencies put the utility on a negative watch, although that has now been removed and finances have stabilized.
- **Climate impacts include:** Extreme events including increases in heat waves, storm intensity, and precipitation linked to droughts and flooding.
- **Opportunities:** Austin Water completed a joint committee process where commissioners from three different city council-appointed commissions convened when drought conditions and accompanying decreased water use led to significant losses in revenue. Austin Water looked at various options for financial planning, such as rate changes, increasing fixed charges, drought rates, and increased reserves, to help the utility absorb some of the financial impacts.

Climate Stressors and Risks **BUSINESS AFFAIRS**	
Stressors	**Risks**
• Increased frequency in heat waves • Increased incidence of drought • Flooding • Increased acres burned and severity of wildfire	• Increase in flood frequency and magnitude • Impeded drinking water production • Flooding of stormwater outfalls • Flood damage to infrastructure

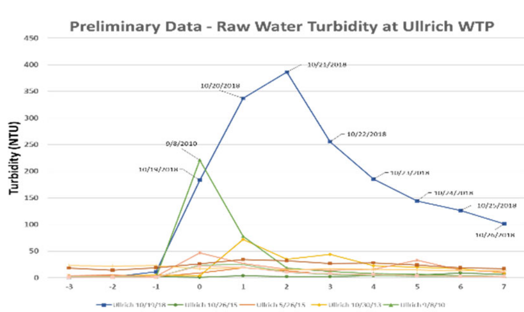
WASTEWATER TREATMENT

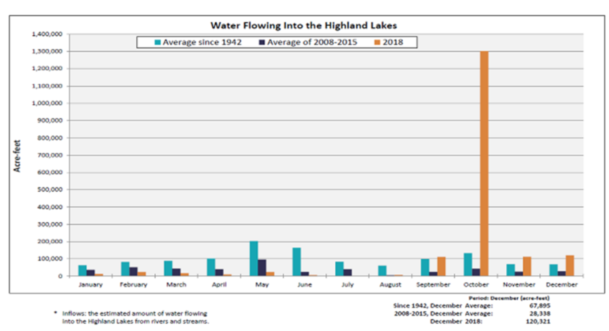
- **Summary:** Several City of Austin departments convened and noted that both of Austin's wastewater treatment plants are near floodplain areas, and one requires bridge access that is maintained by a different entity.
- **Current risks:** One of Austin Water's major wastewater treatment plants have experienced limited access during recent large flooding events.
- **Climate impacts:** Impacts include flooding, shifting precipitation patterns, increased intensity, and frequency of heavy rainfall.
- **Opportunities:** The process of intradepartmental coordination showed that while the bridge for wastewater treatment access may not be a priority for the traffic-related transportation team, it is a priority for Austin Water. Austin Water found it very useful to think about how to prioritize actions across departments and business functions.

DRINKING WATER TREATMENT AND STORAGE CAPACITY

Climate Stressors and Risks **WASTEWATER TREATMENT**	
Stressors	**Risks**
• Increased flooding • Increased intensity and frequency of heavy rainfall • Land use changes • Increased incidence of drought	• Increased challenge accessing wastewater treatment facilities • Flood impacts on wastewater treatment capacity and infrastructure • Stormwater intrusion into wastewater systems • Regulatory issues due to water quality concerns

- **Summary:** A catastrophic upstream flood in October 2018 resulted in dramatic increases in the turbidity of Austin's raw water supply. This reduced drinking water treatment plant production and resulted in emergency conservation measures and a city-wide boil water notice that lasted for seven days.
- **Current risks:** Future flood events could result in a recurrence of this scenario.
- **Climate impacts:** Impacts include flooding, shifting precipitation patterns, increased intensity, and frequency of heavy rainfall.
- **Opportunities:** Austin Water is developing turbidity triggers for issuing future emergency conservation measures. Expanding Austin's drinking water storage capacity has become a higher priority.





Source: Courtesy of Austin Water.

Climate Stressors and Risks **DRINKING WATER TREATMENT AND STORAGE CAPACITY**	
Stressors	**Risks**
• Increased flooding • Increased intensity and frequency of heavy rainfall • Land use changes • Increased incidence of drought	• Increased challenge managing turbidity in raw water supplies • Impacts on drinking water plant production and pressure within the distribution system • Impacts on drinking water storage capacity

Utility Strategies, Plans, and Reports

- Water Forward – (Adopted Nov 2018)
- Climate Change Projections for the City of Austin (2014)
- City of Austin Climate Resilience Action Plan (2018)
- Understanding the Drought (2015)

Sources

[1] Melillo, J. M., T.C. Richmond, and G.W. Yohe, Eds. *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* Prepared for the U.S. Global Change Research Program, p. 148. 2014. Website: https://nca2014.globalchange.gov/highlights

[2] Runkle, J., and K. E. Kunkel. *Texas State Summary*. Prepared for NOAA Technical Report NESDIS 149-TX, p. 4. 2017. Website: https://statesummaries.ncics.org/tx#

[3] U.S. Global Change Research Program. *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter.* 2017. Website: https://www.globalchange.gov/content/nca4-planning

[4] Climate Central. *States at Risk – Texas*. 2018. Website: http://statesatrisk.org/texas/all

[5] Austin Water. *Understanding the Drought*. 2015. Website: http://www.austintexas.gov/sites/default/files/files/Water/Drought/Understanding_the_Drought_Feb2015.pdf.

CLIMATE RISK AND OPPORTUNITY PROFILE

Fort Collins Utilities

CLIMATE PROJECTIONS

Extreme Temperature
Statewide average temperatures are projected to increase by 2.5°F to 5°F by 2050 under an RCP 4.5 scenario.[3]

Wildfires
Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems.[1]

Seasonality of Precipitation
Annual streamflows in all of Colorado's river basins could decrease and peak streamflows are projected to come earlier in the year.[3]

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Stormwater Management
Intensity of precipitation and the occurrence of drought put the utility's stormwater management systems at risk.

Asset Management
Increased frequency of extreme climate-related events may increase asset maintenance and replacement costs.

Engineering and Design
Failure to consider climate change projections in design and throughout master planning could have serious impacts on critical utility functions and ability to meet demand.

UTILITY OVERVIEW

Fort Collin's first city sewer system was built in 1888, with five sewer districts formed by ordinance in 1891. The city established a public works department in the early 1900s and then obtained senior water rights and built the Poudre Canyon Treatment Plant.

Today, Fort Collins has not experienced many significant climate-related incidents, which has made it difficult to act on the topic. Fort Collins Utilities has primarily promoted climate change mitigation and has not facilitated much community conversation about adaptation and resilience. However, the utility is in the planning, design, and construction stage of infrastructure development, which is the right time to discuss future risks and opportunities.

Fort Collins Utilities is not using downscaled modeling for its *Water Supply Vulnerability Study;* instead, it is completing the modeling with a range of precipitation and temperature changes. It will map these results against the range of climate model predictions rather than assessing plans against a single climate model.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends include the following:

- Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems.[1]
- Renewable hydropower in the Southwest has declined during drought, due in part to climate change.[2]

FUTURE CLIMATE

Projected changes include the following:

- Statewide average temperatures are projected to increase by 2.5° F to 5° F by 2050 under a medium-low (RCP 4.5) emissions scenario.
- The frequency and extent of wildfires are projected to increase, and that increase will likely lead to more destructive flooding.[1]

The following pages of this risk and opportunity profile outline the relevant climate drivers, both risks and opportunities, mapped to Fort Collins Utilities' key business functions as identified by Fort Collins Utilities in August 2018.

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

Fort Collins Utilities participated in this research project to investigate how the utility's core business functions anticipate climate risks and opportunities. Fort Collins Utilities identified stormwater management, asset management, and engineering and design as the three business functions of highest interest in relation to climate change.

STORMWATER MANAGEMENT

- **Summary:** Fort Collins Utilities' stormwater management includes forecasting, water quality management, design and maintenance of collection and storage infrastructure, floodplain management, land use, and planning, development, and regulation.
- **Current risk:** The utility's water quality management and maintenance of infrastructure are at risk due to precipitation intensity, extreme temperatures, and drought.
- **Barriers to action:** Fort Collins Utilities requires quality climate data to update stormwater management design standards.
- **Opportunities:** For Fort Collins Utilities' Water Supply Vulnerability Study, the utility is completing the modeling with a range of precipitation and temperature changes. This modeling can also inform scenario analysis for stormwater management.

Case Study

Water and Wastewater Utilities Planning for Climate Change

A case study on the climate threats, the planning process, and adaptation efforts by Fort Collins Utilities to mitigate water quality issues caused by flash flooding following wildfires.

Impacts of Climate Drivers and Underlying Conditions

Flooding and Erosion

Climate Drivers	Impacts
Runoff Volume Higher Precipitation Intensity	• Damage to infrastructure and increased insurance risk • Floodplain changes, channel stability, and debris management • Health and safety concerns connected to rain or snow events

Water Quality

Climate Drivers	Impacts
Extreme Temperatures Higher Precipitation Intensity Drought	• Sedimentation of reservoirs and holding facilities • Increase in concentration and volume of pollutants of concern • Increase in disease vectors, growth of algal blooms, and changes to aquatic habitat

Other Impacts

Climate Drivers	Impacts
Drought Extreme Temperatures	• Aesthetic and habitat value reductions in multipurpose facilities • Increase in electric power needs and the need for landscape irrigation and fire prevention around facilities

STORMWATER MANAGEMENT	
Risks	**Opportunities**
• Flooding and erosion from higher intensity precipitation • Damage to private and public property • Increased cost and complexity of flood control projects and programs	• Site design and landscaping to mitigate temperature increases and aesthetic issues • Coordinate with upstream diverters • Expand regulatory floodplain/greenspace • Reconsider flood control operations to maximize water supply benefits

ASSET MANAGMENT

- **Summary:** Fort Collins Utilities asset management includes lifecycle analysis, service levels, reliability, maintenance standards, infrastructure development, mapping, strategic planning, and data collection.
- **Current risk:** Thus far, Fort Collins has not experienced many significant climate-related incidents, so has not yet acted in a major way to adapt assets to climate risks; however, Fort Collins Utilities understands the potential future risks and is approaching this topic with great interest at present.
- **Opportunities:** Fort Collins Utilities has opportunities to maintain larger emergency financial reserves and to enhance communications internally and externally.

Impacts of Climate Drivers and Underlying Conditions

Health and Safety

Drought Temperature Increases Higher Precipitation Intensity	• Outdoor workers are at risk from high heat and reduced air quality • Increased risks of main breaks or dam failure due to drought and increased intensity of precipitation • Increased temperatures lead to increased risks from water quality changes and disease vectors

Infrastructure

Drought Temperature Increases Higher Precipitation Intensity	• Increases in pipeline and road damage due to heat and flooding • Increased potential for failure of major equipment • Decreased reliability of communication, data, analysis, and energy systems

Water Quality

Higher Precipitation Intensity Drought Increased Size and Frequency of Wildfire	• Pretreatment required due to increased sediment loading, pollutants and algae • Aquatic habitat loss • Supply operations shifts from flow reduction

Financial Impact

Drought Increased Size and Frequency of Wildfire	• Higher water treatment costs • Reduced land value from habitat quality changes • Revenue losses due to drought restrictions

ASSET MANAGEMENT	
Risks	**Opportunities**
• Increased maintenance and replacement costs and increased potential for emergency response • Increased costs and public relation problems associated with infrastructure failure	• Maintain larger emergency financial reserves • Increase rate or emergency rate structure • Ensure reliable water and energy supply to at-risk customers • Implement a more aggressive maintenance and repair program • Enhance communications internally and externally

ENGINEERING AND DESIGN

- **Summary:** Fort Collins Utilities' engineering and design work includes surveying, sizing, layout, and design standard development.
- **Current risk:** Engineers at the utility want clear data indicating a specific trend for the Front Range based on the last 50 years of data to inform design standards. Much of the utility's policy guidance is around specific design criteria (i.e., planning for 100-year flood event). As an institution, Fort Collins Utilities has been unable to quantify the impacts of climate change to systems and fully understand how to prepare for it. The utility is challenged with incorporating climate change into policy documents where there is limited climate information.
- **Opportunities:** There is an opportunity to engage more engineers more frequently in conversations about climate projections and its implications throughout planning process. There is also the opportunity to increase the use of scenario-based planning to determine what could happen rather than trying to predict a specific outcome. Scenario planning will assist the utility with flexible long-term planning for a number of uncertain factors related to climate change.

Impacts of Climate Drivers and Underlying Conditions

Infrastructure

Climate Drivers	Impacts
Heat and Heatwaves Drought Increased Wind Speed	• Specific facility failures and potential for cascading failures due to increased wind speed, heat waves, and drought • Inability to meet demand for services in the instance of extreme drought or a heat wave

Health and Safety

Climate Drivers	Impacts
Increased Extreme Heat Increased Storm Intensity Drought	• Buildings and infrastructure may not withstand increased stresses and may become hazardous • Increased incidence of extreme heat threatens the health of works in the field who are exposed to outdoor conditions for extended periods

Financial Impacts

Climate Drivers	Impacts
Change in Runoff Timing Drought	• Higher repair, construction, and reconstruction costs • Rising energy use and cost for heating and cooling • Potential rate structure shifts to account for seasonality changes

Heat and Heatwaves Drought Change in Runoff Timing	• Increased stress to water quality, water treatment, and stormwater management • Flood control and reservoir storage challenges due to drought and precipitation intensity increases • Strained diversions and delivery facility capacity

ENGINEERING AND DESIGN	
Risks	**Opportunities**
• Failure to consider climate change projections in design and throughout master planning can have serious effects on critical utility functions and ability to meet demand • Health and safety issues • Increased costs to retrofit and repair	• Take advantage of energy and water conservation potential in utility buildings • Enhance urban tree canopy, cool roofs, and low energy design standards • Design standard improvements

*In August 2018, staff from Fort Collins Utilities collaborated with the research team to map three example water utility business functions, **stormwater management, asset management, and engineering and design**, to five different climate stressors and impacts. Stressors and impacts related to precipitation, temperature, and wildfire were common to both drinking water treatment and delivery and water supply. Each checkmark in Table 1 indicates that the climate stressor and impact has an effect on the relevant business function.*

Table 1. Climate Stressors and Impacts

Business Functions	Climate Stressors and Impacts					
	Drought	Precipitation	Runoff	Storms	Temperature	Wildfire
Asset Management	✓	✓			✓	✓
Engineering and Design	✓	✓	✓	✓	✓	✓
Stormwater Management	✓	✓	✓	✓	✓	

SUMMARY OF CLIMATE INFORMATION SOURCES AND TYPES

Below is a summary of climate information sources and types that were identified to help evaluate risks and opportunities for similar water utilities, organized by the five different climate stressors and impacts identified in Table 1. The sources and types represent a sampled and pragmatic, rather than an exhaustive, list of climate information for these examples as the actual number of potential sources and types is large and continues to expand. The following tables can be used as starting points from which a utility can remove or add climate information sources and types that aid in evaluating climate-related risks and opportunities.

Table Key (Tables 2 – 13)

Climate Stressors and Impacts were classified by the following:

- **Derivative:** sources that provide static or interactive content through predetermined analyses or syntheses in graph, map, or text formats.
- **Data:** sources that require end users to download, analyze, or visualize data to generate climate information

(F) = fine-scale information, higher resolution

(B) = broad-scale information, county level or lower resolution

DROUGHT

Table 2. Drought Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Change in Colorado (B)	✓			✓
Colorado State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA NCEI Weekly Divisional Products (B)		✓		
U.S. Drought Monitor (B,F)	✓	✓		
U.S. Drought Portal (B,F)		✓		
U.S. Monthly Drought Outlook (B)			✓	
U.S. Seasonal Drought Outlook (B)			✓	
West Wide Drought Tracker (B,F)	✓	✓		
Western Water Assessment Climate Extremes (B,F)	✓			

Table 3. Drought Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Colorado State Climate Summary (B)	✓			✓
NOAA NCEI Drought Variability[a] (B)	✓			
U.S. Drought Monitor (B,F)	✓	✓		
West Wide Drought Tracker (B,F)	✓	✓		

[a] Tree-ring reconstructions of two drought indices, see the Precipitation section for more related data sources

PRECIPITATION

Table 4. Precipitation Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Climate Change in Colorado (B,F)	✓			✓
Climate Explorer (B,F)	✓			✓
Colorado State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA CPC ENSO Diagnostic Discussion (B)		✓	✓	
NOAA CPC Precipitation (B)		✓		
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS AHPS Precipitation (F)		✓		
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS National Operational Hydrologic Remote Sensing Center (B)	✓	✓		
NOAA NWS Storm Prediction Center (B)			✓	
NOAA NWS WPC Quantitative Precipitation Forecasts (B)			✓	
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)		✓		
U.S. Climate Atlas (B)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

Table 5. Precipitation Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	✓			✓
Colorado State Climate Summary (B)	✓			✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
NOAA NWS AHPS Precipitation (F)		✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

RUNOFF

Table 6. Runoff Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Change in Colorado (B,F)	√			√
Fourth National Climate Assessment (B)	√			√
Joint Front Range Climate Change Vulnerability Study (B,F)				√
NOAA NWS AHPS Experimental Long-Range River Flood Risk (F)			√	
NOAA NWS AHPS River Forecasts (F)			√	
NOAA NWS AHPS River Observations (F)		√		
TreeFlow (F)	√			
USGS National Water Information System (F)	√	√		
Western Water Assessment Climate Extremes (B,F)	√			

Table 7. Runoff Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
TreeFlow (F)	√			
USGS National Water Information System (F)	√	√		

STORMS

Table 8. Storms Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	√			√
NOAA NWS (B,F)		√	√	
NOAA NWS CPC U.S. Hazards Outlook (B)			√	
NOAA NWS Storm Prediction Center (B)			√	
Western Water Assessment Climate Extremes (B,F)	√			

Table 9. Storms Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Change in Colorado (B,F)	√			√
NOAA Severe Weather Data Inventory (B,F)	√			

TEMPERATURE

Table 10. Temperature Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		√		
Climate Change in Colorado (B,F)	√			√
Climate Explorer (B,F)	√			√
Colorado State Climate Summary (B)	√			√
Fourth National Climate Assessment (B)	√			√
NOAA NCEI Climate at a Glance (B,F)	√			
NOAA NCEI Daily Summaries Map (F)	√	√		
NOAA NCEI Weekly Divisional Products (B)		√		
NOAA NWS (B,F)		√	√	
NOAA NWS CPC (B)			√	
NOAA NWS CPC U.S. Hazards Outlook (B)			√	
NOAA NWS Storm Prediction Center (B)			√	
PRISM (B,F)	√	√		
U.S. Climate Atlas (B)	√			
West Wide Drought Tracker (B,F)	√	√		
Western Water Assessment Climate Extremes (B,F)	√			

Table 11. Temperature Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	√			√
Colorado State Climate Summary (B)	√			√
LOCA (F)				√
NOAA NCEI Climate at a Glance (B,F)	√			
NOAA NCEI Climate Data Online (F)	√	√		
The North American CORDEX Program (F)				√
PRISM (B,F)	√	√		
West Wide Drought Tracker (B,F)	√	√		

WILDFIRE

Table 12. Wildfire Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
Geospatial Multi-Agency Coordination (F)	✓	✓		
Hazard Mapping System Fire and Smoke Product (B)		✓		
InciWeb: Incident Information System (F)		✓		
National Significant Wildland Fire Potential Outlooks (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	
Western Water Assessment Climate Extremes (B,F)	✓			

Table 13. Wildfire Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA NCEI Fire History (F)	✓			

Utility Strategies and Plans

- Fort Collins Climate Action Plan (2016)
- Case Study: Water and Wastewater Utilities Planning for Climate Change (2017)
- Fort Collins Community Resilience Assessment (2016)
- Climate Wise Report on Fort Collins (2014)
- Joint Front Range Climate Change Vulnerability Study (2012)

Sources

[1] Melillo, J. M., T.C. Richmond, and G.W. Yohe, Eds. *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* Prepared for the U.S. Global Change Research Program, p. 148. 2014. Website: https://nca2014.globalchange.gov/highlights

[2] U.S. Global Change Research Program. *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter.* 2017. Website: https://www.globalchange.gov/content/nca4-planning

[3] Lukas, J. *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* Prepared for Colorado Water Conservation Board. 2014. Website: https://wwa.colorado.edu/climate/co2014report/Climate_Change_CO_Report_2014_FINAL.pdf

Acronyms

AHPS = Advanced Hydrologic Prediction Service
CORDEX = Coordinated Regional Downscaling Experiment
CPC = Climate Prediction Center
ENSO = El Niño-Southern Oscillation
LOCA = Localized Constructed Analogs
NCEI = National Centers for Environmental Information
NOAA = National Oceanic and Atmospheric Administration
NWS = National Weather Service
PRISM = Parameter-elevation Regressions on Independent Slopes Model
SNOTEL = Snow Telemetry
USGS = United States Geological Survey
WPC = Weather Prediction Center

Environmental Protection

CLIMATE RISK AND OPPORTUNITY PROFILE

New York City Department of Environmental Protection

CLIMATE PROJECTIONS

Temperature
If emissions continue to increase (A2 scenario), 4.5°F to 10° F warming is projected by the 2080s[1]

Coastal Flooding
New York has 431,000 people at risk from coastal flooding[3]

Drought & Water Supply
Shifting seasonal patterns in streamflow affect the turbidity loads into the Catskill System[4]

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Environmental Monitoring and Management
Increased difficulty balancing Clean Water Act compliance and adaptation measures.

Stormwater Management
Storm surge and sea level rise impact flood mitigation measures and NYC DEP's stormwater portfolio.

External Affairs
Increased need to develop cost benefit analyses and apply for hazard mitigation and resiliency funding.

UTILITY OVERVIEW

New York City Department of Environmental Protection (NYC DEP) manages the city's water supply and provides more than 1.1 billion U.S. gallons of water each day to more than 9 million residents. Hurricane Sandy was a driver in transforming NYC DEP's strategy surrounding climate risks, while Hurricane Irene and Tropical Storm Lee in the upstate area disrupted the city's water supply system by requiring additional water treatment. New York City is sensitive to storm surge, sea level rise, and chronic and extreme rain in combination with sewer overflows.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends over the last two decades include the following:

- Milder winters and earlier spring conditions are already changing habitats, affecting species, and creating irreversible changes to hydrology and wildlife.[2]
- The shifting seasonal pattern in streamflow affects the turbidity loads into the Schoharie Reservoir and impacts Schoharie withdrawals, with increased turbidity in the fall and winter, and decreased turbidity in the spring.[4]

FUTURE CLIMATE

Projected changes include the following:

- If emissions continue to increase, 4.5°F to 10°F warming is projected by the 2080s; however, if global emissions are reduced substantially, projected warming ranges from 3°F to 6°F by the 2080s.[1]
- New York State currently has 100 square miles in the 100-year coastal floodplain. By 2050, this is projected to increase to 150 square miles due to sea level rise.[3]

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

ENVIRONMENTAL MONITORING AND MANAGEMENT

- **Summary:** Most planning and activities undertaken by NYC DEP are guided by environmental regulatory compliance standards, and significant resources go to ensuring that water quality in New York's harbor complies with the Clean Water Act.
- **Current risk:** Hurricane Irene and Tropical Storm Lee in upstate New York had a devastating effect on parts of NYC DEP's water supply system, particularly upstate watershed communities. Both events caused turbidity events that lasted for months and involved major treatment to avoid violating clean water standards.

- **Climate impacts include:** Sea-level rise, salt-water intrusion into freshwater aquifers, higher storm surges, inland flooding, and coastal flooding.
- **Opportunities:** NYC DEP continues to identify synergies where water quality investments can help alleviate flooding.

Climate Stressors and Risks **ENVIRONMENTAL MONITORING AND MANAGEMENT**	
Stressors	**Risks**
• Increased average temperatures • Increased frequency in heat waves • Increased flooding • Increased intensity and frequency of heavy rainfall events • Saline Intrusion	• Monitoring and management of ocean, lake, and stream water quality • Impacts on habitat and endangered species • Environmental compliance implications for the Safe Drinking Water Act, the Endangered Species Act, the Clean Water Act, and the National Environmental Policy Act • Increased costs for watershed management and stream rehabilitation

STORMWATER MANAGEMENT

- **Summary:** Stormwater has been a historic driver for NYC DEP's climate and natural preparedness work. More specifically, compliance with combined sewer overflows and the Clean Water Act have been a focus for stormwater management. Meanwhile, compliance with drinking water regulations and turbidity drive water supply management.
- **Current risks:** Extreme rain events are particularly risky in the Catskills in terms of water planning and quality (turbidity).
- **Climate impacts:** Impacts include inland flooding, coastal flooding, sea-level rise, salt-water intrusion into freshwater aquifers, higher storm surges, inland flooding, and coastal flooding.
- **Opportunities:** NYC DEP has undertaken planning to respond to sea-level rise, storm surge, and flooding events. The utility has begun a contract to prepare its 14 wastewater treatment plants for increased flooding and storm surge. NYC DEP's Wastewater Resilience Plan will be responsible for leading and implementing a wastewater resiliency plan.

Climate Stressors and Risks **STORMWATER MANAGEMENT**	
Stressors	**Risks**
• Inland flooding • Coastal flooding • Sea-level rise • Salt-water intrusion into freshwater aquifer • Higher storm surges	• Increase in flood frequency and magnitude • Combined inland and coastal flooding events • Flooding of stormwater outfalls • Flood damage to infrastructure

EXTERNAL AFFAIRS

- **Summary:** The utility has its own Bureau of Sustainability, which focuses on how to make the utility more sustainable and resilient. Through the bureau's efforts, NYC DEP works with other city agencies to meet the goals and objectives outlined in the OneNYC plan and other citywide sustainability plans.
- **Current risks:** NYC DEP is expected to demonstrate investment in resiliency to system investigators and regulators. Failure to invest would put investor, consumer, and regulator confidence at risk.
- **Climate impacts:** All climate change impacts (i.e., drought, flooding, snowpack, sea-level rise, and air quality), even remote to the region, will affect external affairs.
- **Opportunities:** The utility has identified a need for communication support with regulators to better advocate for revisions to consent orders and regulations that focus on the Clean Water Act and other climate-related risks. This includes working with regulators to synergistically improve water quality and alleviate flooding.

Climate Stressors and Risks **EXTERNAL AFFAIRS**	
Stressors	**Risks**
• Increased temperatures • Increased flooding • Increased intensity and frequency of heavy rainfall • Changes in snowpack • Decline in air quality	• Increased potential for emergency events and disruption of service • Increased need for customer service, public education, and communication • Additional potential for legislative actions that need to be monitored • Increased need for intra- and interagency coordination

Utility Strategies and Plans

- NYC Wastewater Resiliency Plan (2013)
- One New York City: One Water (2015)
- Climate Change Integrated Modeling Project (2013)
- Special Initiative for Rebuilding and Resiliency (2013)
- Climate Change Assessment and Action (2008)

Sources

[1] Melillo, J. M., T.C. Richmond, and G.W. Yohe, Eds. *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* Prepared for the U.S. Global Change Research Program, p. 148. 2014. Website: https://nca2014.globalchange.gov/highlights

[2] U.S. Global Change Research Program. *DRAFT Fourth National Climate Assessment – Southwest Public Review Chapter.* 2017. Website: https://www.globalchange.gov/content/nca4-planning

[3] Climate Central. "Top New York Risks. States at Risk." Accessed October 25, 2018. Website: http://statesatrisk.org/new-york/coastal-flooding

[4] NYC DEP, Bureau of Water Supply. *Climate Change Integrated Modeling Project: Phase I Assessment of Impacts on the New York City Water Supply*. October 2013. Website: http://www.nyc.gov/html/dep/pdf/climate/climate-change-integrated-modeling.pdf

CLIMATE RISK AND OPPORTUNITY PROFILE

San Diego Public Utilities

CLIMATE PROJECTIONS

Extreme Temperature
Heat wave intensity and frequency will increase 20% to 50% with a 6°F temperature increase by 2100.[7]

Precipitation Intensity
Short heavy rain events overwhelm conventional water storage systems and post-drought rain can lead to mudslides.[8]

Drought
Drought conditions will increase in intensity and frequency due to lower precipitation and higher temperatures.[9]

Wildfires
Higher temperatures and more intense drought seasons can result in wildfires that will be exacerbated by Santa Ana winds.

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Drinking Water Treatment and Delivery
San Diego PUD identified sea level rise as a threat to water quality and existing delivery structures.

Water Supply
Water imports from California and Colorado are increasingly exposed to pollutants from wildfires and high temperatures.

Employee Education
Climate uncertainty impairs San Diego PUD's ability to implement large-scale climate risk planning.

UTILITY OVERVIEW

San Diego Water Company's first well was dug in 1873 to serve roughly 2,000 inhabitants.[1] Today, San Diego Public Utilities Department (PUD) serves 1.4 million inhabitants.[2] Due to its semi-arid desert climate, San Diego is dependent upon water imports from Northern California and the Colorado River for 80-90% of its water. San Diego PUD has over 3,300 miles of water lines, nearly 50 water pumping plants, and potable water storage capacity of 200 million gallons. Despite its current water management and hazard mitigation planning, San Diego PUD faces major climate and extreme weather events including higher temperatures, increased precipitation intensity, increased wildfires, and exacerbated drought years. San Diego's 70 miles of coastline is vulnerable to sea level rise, which threatens San Diego's tourism, real estate prices, and public infrastructure.[3]

San Diego PUD collaborates with local research institutions, including UC San Diego's Scripps Institution of Oceanography, to model and monitor imported water projections and climate-related risks and opportunities. San Diego PUD's hazard mitigation plan includes water shortage contingency plans and the utility now coordinates with the City's new Department of Sustainability and is compliant with the City's Climate Action Plan.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends include the following:

- From 1961 to 1990, California's annual mean temperature was 74.2°F.[4]
- Each year of the 1970s, roughly 133,000 acres of U.S. Forest Service land was burned by wildfire.[5]

FUTURE CLIMATE

Projected changes include the following:

- California's annual mean temperature is projected to be 79.8°F by 2070.[4]
- By 2050, California is projected to experience more than 140 days a year with high wildfire potential—a 14% increase in days with high wildfire potential from 2000.[5]
- By 2050, San Diego's 100-year flood events are 100 times more likely, which will result in the current 100-year flood event occurring every year.[6]

The following pages of this risk and opportunity profile outline the relevant climate drivers, both risks and opportunities, mapped to San Diego PUD's key business functions as identified in consultation with San Diego PUD in August 2018.

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

San Diego PUD staff were interviewed in this research project to investigate how the utility's core business functions anticipate climate risks and opportunities. San Diego PUD identified drinking water treatment and delivery, water supply, and employee education as the three business functions of highest interest in relation to climate change.

DRINKING WATER TREATMENT AND DELIVERY

- **Summary:** San Diego PUD works with local and national research institutions and consultants to model supply and demand in the face of climate change and explore imported water projections and county growth.
- **Current risk:** Operational costs and demand for potable water are expected to increase as the availability of water resources decrease. Water delivery is interrupted by reduced flows and imported water supply shortages.
- **Opportunities:** The San Diego PUD has made important strides in implementing long-range and climate focused projects with Capital Improvement Plans (CIPs). San Diego PUD's Water Sustainability Report will include water supply forecasting for its portfolio risks; when published, it will be incorporated into the Water Demand Forecast and inform the 2020 Long-Range Water Resources Plan.

Collaborative Partners

- U.S. Bureau of Reclamation
- UC San Diego's Scripps Institution of Oceanography
- The Association of Metropolitan Water Agencies
- San Diego County Water Authority
- Integrated Regional Water Management
- U.S. Geological Survey

Impacts of Climate Drivers and Underlying Conditions

Health and Safety

Drivers	Impacts
Extreme Temperatures/Heatwaves Higher Precipitation Intensity	• Rising temperatures increase algal blooms, microbes, and waterborne agents, leading to water quality issues [9] • Water polluted by flooded sewers requires chemical treatment

Water Quality

Drivers	Impacts
Extreme Temperatures/Heatwaves Higher Precipitation Intensity More Frequent/Intense Wildfires	• The concentration of pollutants in water increases with extreme heat because water evaporates faster • Coastal species are impaired by erosion and sedimentation • Rising temperatures increase algal blooms, microbes, and waterborne agents, leading to water quality issues[9]

Infrastructure Impacts

Drivers	Impacts
More Frequent/Intense Wildfires Underlying: Aging Infrastructure	• Existing reservoir and delivery infrastructure have fixed capacities, possibly causing problems in emergencies

Regulatory Impacts

Drivers	Impacts
More Frequent/Intense Wildfires Underlying: Aging Infrastructures	• Potential violations of the Safe Drinking Water Act from fire debris and sedimentation • Potential violations of California's numerous environmental laws

EFFECTS OF CLIMATE CHANGE ON DRINKING WATER TREATMENT AND DELIVERY	
Risks	**Opportunities**
• Potentially less production capacity • Increased energy and water demand and reduced ability to meet sustainability objectives • Increased cost of operations • Increased likelihood of system failures	• Increased emphasis on upgrading mitigation systems to reduce risk • Interdepartmental assessments of potential for climate impacts • Potential for research development and educational resources for the public

WATER SUPPLY

- **Summary:** San Diego PUD is dependent upon imported water for up to 80-90% of its water supply.[17] Imported water is at risk due to water delivery contracts, ecological harm to Northern California delta habitats from over-pumping, water quality, and distance (hundreds of miles away).
- **Current risk:** Increasing mean annual temperatures threaten San Diego PUD's water imported sources, including the Colorado River and Northern California, jeopardizing existing water rights, prioritization processes, and imported water prices.
- **Opportunities:** 1) Pure Water, 2) San Diego PUD is investigating and potentially expanding groundwater basins within the San Diego River Valley Groundwater Basin.

San Diego PUD Water Sources

- The Colorado River
- Northern California, origins at the Sacramento-San Joaquin River Delta (Delta)
- Nine local reservoirs
- San Diego recycled water
- Groundwater

Impacts of Climate Drivers and Underlying Conditions

Water Availability

Underlying: Invasive Species & Demand

- To protect fisheries, courts restricted Delta water exports[10]
- Invasive species (giant reed and Quagga mussel) reduce availability[10]
- Greater demands from population growth and land development result in less flexibility across water sources

Water Quality

Extreme Heat/Humidity/Heatwaves

Higher Precipitation Intensity

More Frequent/Intense Wildfires

Underlying: Invasive Species & Demand

- The concentration of pollutants in water increases with extreme heat because water evaporates faster
- Rising temperatures increase algal blooms, microbes, and waterborne agents, leading to water quality issues[12]
- Storm surges cause flooding, which may result in sewer spills that could corrupt San Diego PUD's water quality[14]

Water Demand

Extreme Heat/Humidity/Heatwaves

Drought

Underlying: Invasive Species & Demand

- San Diego County's population is projected to reach 4 million by 2050[13]
- High heat and low precipitation will extend drought seasons requiring greater quantities of water
- Existing abilities to transport water to treatment plants are limited by pipeline capacity

Flooding

Higher Precipitation Intensity

Underlying: Invasive Species & Demand

- Storm surges cause flooding and may result in sewer spills that could corrupt the quality of San Diego PUD's water supply[14]
- Flash floods can overwhelm dam structures and may cause dam failure if flood management is not appropriately incorporated

Electric Power Disruption

More Frequent/Intense Wildfires

Underlying: Invasive Species & Demand

- Climate events disrupting power lines may inhibit San Diego PUD's ability to pump imported water into San Diego[15]
- Service continuity lost when power outages halt water treatment

EFFECTS OF CLIMATE CHANGE ON WATER SUPPLY	
Risks	**Opportunities**
• Less water available • Additional operational and regulatory constraints • Misleading appearance of unlimited water supply due to wholesale water purchasing model • Local reliable sources impacted by physical climate	• Improve water storage and reservoir capacity and facility interconnectedness • Evaluate extended drought scenarios and potential for additional emergency storage capacity, with reevaluation every five years • The Pure Water program will source local water[16]

Climate Data and Information

*In August 2018, staff from San Diego PUD collaborated with the research team to map two example water utility business functions, **drinking water treatment and delivery and water supply**, to five different climate stressors and impacts. Climate stressors and impacts related to temperature, precipitation, and wildfire were common to both drinking water treatment and delivery and water supply. Each checkmark in Table 1 indicates that the climate stressor and impact influence the relevant business function.*

Table 1. Climate Stressors and Impacts

Water Utility Business Functions	Climate Stressors and Impacts				
	Drought	Humidity	Precipitation	Temperature	Wildfire
Drinking water treatment and delivery			✓	✓	✓
Water supply	✓	✓	✓	✓	✓

SUMMARY OF CLIMATE INFORMATION SOURCES AND TYPES

Below is a summary of climate information sources and types that were identified to help evaluate risks and opportunities for similar water utilities, organized by the five different climate stressors and impacts identified Table 1. The sources and types represent a sampled and pragmatic, rather than an exhaustive, list of climate information for these examples, as the actual number of potential sources and types is large and continues to expand. The following tables can be used as starting points from which a utility can remove or add climate information sources and types that aid in evaluating climate-related risks and opportunities.

Table Key (Tables 2 – 11)

Climate Stressors and Impacts were classified by the following

- **Derivative:** sources that provide static or interactive content through predetermined analyses or syntheses in graph, map, or text formats.
- **Data:** sources that require end users to download, analyze, or visualize data to generate climate information

(F) = fine-scale information, higher resolution

(B) = broad-scale information, county level or lower resolution

DROUGHT

Table 2. Drought Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Cal-Adapt Extended Drought Scenarios (F)				✓
California State Climate Summary (B)	✓			✓
California's Fourth Climate Change Assessment (B,F)				✓
CNAP Drought Tracker (B,F)		✓	✓	
Fourth National Climate Assessment (B)	✓			✓
NOAA NCEI Weekly Divisional Products (B)		✓		
U.S. Drought Monitor (B,F)	✓	✓		
U.S. Drought Portal (B,F)		✓		
U.S. Monthly Drought Outlook (B)			✓	
U.S. Seasonal Drought Outlook (B)			✓	
West Wide Drought Tracker (B,F)	✓	✓		

Table 3. Drought Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
California State Climate Summary (B)	✓			✓
NOAA NCEI Drought Variability[a] (B)	✓			
U.S. Drought Monitor (B,F)	✓	✓		
West Wide Drought Tracker (B,F)	✓	✓		

[a] Tree-ring reconstructions of two drought indices, see PRECIPITATION below for more related data sources

HUMIDITY

Table 4. Humidity Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA NWS (B,F)		✓	✓	

Table 5. Humidity Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Cal-Adapt Additional VIC Variables (F)				✓
NOAA NCEI Climate Data Online (F)	✓	✓		

PRECIPITATION

Table 6. Precipitation Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Cal-Adapt (F)				✓
California State Climate Summary (B)				✓
California's Fourth Climate Change Assessment (B,F)				✓
Climate Explorer (B,F)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA CPC Precipitation (B)		✓		
NOAA CPC ENSO Diagnostic Discussion (B)		✓	✓	
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS AHPS Precipitation (F)		✓		
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS National Operational Hydrologic Remote Sensing Center (B)	✓	✓		
NOAA NWS Storm Prediction Center (B)			✓	
NOAA NWS WPC Quantitative Precipitation Forecasts (B)			✓	
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)		✓		
TreeFlow (F)	✓			
U.S. Climate Atlas (B)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

Table 7. Precipitation Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Cal-Adapt (F)				✓
California State Climate Summary (B)	✓			✓
Climate Explorer (B,F)	✓			✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
NOAA NWS AHPS Precipitation (F)		✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)	✓			
TreeFlow (F)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

TEMPERATURE

Table 8. Temperature Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Cal-Adapt (F)				✓
California State Climate Summary (B)	✓			✓
California's Fourth Climate Change Assessment (B,F)				✓
Climate Explorer (B,F)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	
PRISM (B,F)	✓	✓		
U.S. Climate Atlas (B)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

Table 9. Temperature Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Cal-Adapt (F)				✓
California Heat Assessment Tool (B,F)				✓
California State Climate Summary (B)	✓			✓
Climate Explorer (B,F)				✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		
West Wide Drought Tracker (B,F)	✓	✓		

WILDFIRE

Table 10. Wildfire Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
CAL FIRE Incident Information (F)		✓		
Cal-Adapt Wildfire (F)				✓
California's Fourth Climate Change Assessment (B,F)				✓
Fourth National Climate Assessment (B)	✓			✓
Geospatial Multi-Agency Coordination (F)	✓	✓		
Hazard Mapping System Fire and Smoke Product (B)		✓		
InciWeb: Incident Information System (F)		✓		
National Significant Wildland Fire Potential Outlooks (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	

Table 11. Wildfire Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Cal-Adapt Wildfire (F)				✓
NOAA NCEI Fire History (F)	✓			

Utility Strategies and Plans

- City of San Diego Urban Water Management Plan (2016)
- City of San Diego Public Utility Department: 2012 Long-Range Water Resources Plan (2013)
- Pure Water San Diego (Ongoing)
- Customer Outreach (Ongoing)

Sources

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[16] City of San Diego Public Utilities Department: *Water Purification Demonstration Project*. Website: https://www.sandiego.gov/sites/default/files/legacy/water/pdf/wpdpspeakers.pdf

[17] San Diego Public Utilities Department. "Water Supply." Accessed October 10, 2018. Website: https://www.sandiego.gov/public-utilities/sustainability/water-supply

Acronyms

AHPS = Advanced Hydrologic Prediction Service
CNAP = California-Nevada Climate Applications Program
CORDEX = Coordinated Regional Downscaling Experiment
CPC = Climate Prediction Center
ENSO = El Niño-Southern Oscillation
LOCA = Localized Constructed Analogs
NCEI = National Centers for Environmental Information
NOAA = National Oceanic and Atmospheric Administration
NWS = National Weather Service
PRISM = Parameter-elevation Regressions on Independent Slopes Model
SNOTEL = Snow Telemetry
VIC = Variable Infiltration Capacity
WPC = Weather Prediction Center

CLIMATE RISK AND OPPORTUNITY PROFILE

Salt Lake City Department of Public Utilities

CLIMATE PROJECTIONS

Temperature
Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs.[1]

Wildfire and Flooding
The frequency and extent of wildfires are projected to increase, which will likely lead to more destructive flooding.[1]

Drought & Water Supply
The intensity of naturally occurring future droughts are projected to increase in Utah.[3]

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Operations
Cascading impacts from flooding and algal blooms have affected operations as infrastructure has required extensive repairs.

Procurement
Major events spur a rush to procure disaster clean up services to respond to infrastructure challenges.

External Affairs
Following major events, external affairs is called upon communicate to the public including state, Federal, and municipal decision-makers.

UTILITY OVERVIEW

Established in 1876, the Salt Lake City Department of Public Utilities (Public Utilities) is the oldest retail water provider in the western United States. Public Utilities provides drinking water to more than 350,000 people in Salt Lake City and portions of Salt Lake County, conducts flood control and stormwater management, collects and treats wastewater, and maintains public street lighting. It also protects source waters in the Central Wasatch Mountain watersheds and promotes conservation through efficient water use.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends over the last two decades include the following:

- Average annual temperature has increased about 2°F since the early 20th century. Warming is particularly evident as an increase in very warm nights and a below average occurrence of extremely cold nights over the past two decades.[3]
- Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems.[1]

FUTURE CLIMATE

Projected changes include the following:

- The frequency and extent of wildfires are projected to increase, and that increase will likely lead to more destructive flooding as burned areas are more susceptible to flooding and runoff of sedimentation and debris.[1]
- Snowpack and streamflow amounts are projected to decline in parts of the U.S. Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems.[1]
- Projected changes in winter precipitation include an increase in the fraction falling as rain rather than snow, potentially decreasing snowpack water storage.[3]

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

OPERATIONS

- **Summary:** Public Utilities' operations include source protection, water treatment and distribution, and infrastructure operations and maintenance. Major climate events impacted operations in 2016 and 2017.
- **Current risk:** Major flooding events, drought, and algal blooms impacted the utility's operations. Cascading impacts from a 2017 200-year storm event led to the need for infrastructure repair and assessment. Following a 2016 algal bloom, the operations team temporarily replaced irrigation secondary water with culinary sources as needed.
- **Climate impacts:** Impacts include drought, inland flooding, shifts in snowpack, wildfires, and algal blooms.
- **Opportunities:** Multi-hazard training for all operations staff can lead to potential co-benefits and better emergency preparedness, improved health and safety records, and better employee morale.

Climate Stressors and Risks **OPERATIONS**	
Stressors	**Risks**
• Utility infrastructure size, complexity, and condition • Increased frequency in heat waves • Increased flooding • Increased intensity and frequency of heavy rainfall events	• Direct exposure of operations staff to climate risks in the field • Heatwaves, storms, floods, and wildfires may be life threatening • Increased costs for infrastructure repairs and water resource/source management

PROCUREMENT

- **Summary:** Increased incidence of disasters can lead to a need to procure disaster clean-up, engineering design, and construction services quickly.
- **Current risks:** Extreme rain events and algal blooms posed risks to the utility's procurement functions in 2016 and 2017.
- **Climate impacts:** Impacts include heat waves, increased intensity of winter storms, intense or prolonged freezing periods, droughts, and flooding, and local and distant climate events impacting supply chains.
- **Opportunities:** Actions to mitigate risks include intra- and interagency hazard and emergency preparedness training, on-site storage of infrastructure repair supplies, and facilitated contracting procedures for emergency response conditions.

Climate Stressors and Risks **PROCUREMENT**	
Stressors	**Risks**
• Inland flooding • Increased algal blooms • Severity of wildfire and post-fire flooding • Land cover change • Intensity of winter storms	• Increased energy costs • Additional emergency procurement and contracting issues to recover from extreme events • Challenges with global, national, and regional supply chains/transportation of products • Need for emergency procurement of disaster clean-up, engineering, and construction services

EXTERNAL AFFAIRS

- **Summary:** Increased incidence of extreme events will cause the utility to communicate more frequently with the public and with external stakeholders.
- **Current risks:** Following a 200-year storm event, the utility's communications team was engaged, and the utility did 14 interviews to communicate to the public. The external affairs team also ran weekly situational phone calls with 62 parties from the state, federal, and municipal levels following a 2016 algal bloom.
- **Climate impacts:** Impacts include all climate change impacts (i.e., drought, flooding, snowpack, and air quality), even remote to the region, will affect external affairs.
- **Opportunities:** Well-structured and targeted communications, external affairs plans, and programs can have co-benefits across all aspects of utility management such as higher customer satisfaction, reduced potential for lawsuits, more ability to affect policy and legislation, community-level standing agreements, mutual assistance efforts, and hazard mitigation command structures.

Climate Stressors and Risks **EXTERNAL AFFAIRS**	
Stressors	**Risks**
• Increased temperatures • Increased flooding • Increased intensity and frequency of heavy rainfall • Decline in water quality • Decline in air quality	• Increased potential for emergency events and disruption of service • Increased need for customer service, public education, and communication • Additional potential for legislative actions that need to be monitored • Increased need for intra- and interagency coordination

Utility Strategies and Plans

- Planning for an Uncertain Future: Climate Change Sensitivity Assessment toward Adaptation Planning for Public Water Supply (2013)
- Incorporating Potential Severity into Vulnerability Assessment of Water Supply Systems under Climate Change Conditions (2016)

Sources

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SOUTHERN NEVADA WATER AUTHORITY

CLIMATE RISK AND OPPORTUNITY PROFILE
Southern Nevada Water Authority

CLIMATE PROJECTIONS

Extreme Heat
Heat waves above 110 °F will become 5 times more frequent, while average annual temperatures will increase between 5°F and 10 °F by 2100.[5]

Drought
Streamflow in the Colorado River is expected to decline by about 20% by midcentury from warming temperatures alone.[8]

Storm Intensity
Extreme rainfall events and storm intensity may increase in the future.[5]

Wildfires
Increased warming, drought, and insect outbreaks have increased wildfires and impacts to people and ecosystems.

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Administration
Intensity of heat and flood events from extreme storms put SNWA's employees and communication systems at risk.

Engineering Operations
Wildfires, extreme heat, and drought require more energy and costs to pump and treat water before distribution to customers.

Finance
Increased conservation and lower water demand in response to drought, along with financial downturns and increasing costs of living, have the potential to disrupt SNWA's current funding streams.

UTILITY OVERVIEW

Southern Nevada Water Authority (SNWA) was founded in 1991 as the regional wholesale water provider to seven member agencies in one of the driest states of the country. SNWA treats, delivers, and manages water resources, for more than 2.1 million residents - 90% of which is pumped from Lake Mead and the Colorado River.[1] To achieve its mission of providing "sustainable, adaptable and responsible" water services, SNWA uses an integrated resource planning approach to ensure demands are met today and into the future.[2] To ensure continued reliability in the face of climate change and extreme events, a large workforce - one half of whom work outside - must maintain Lake Mead water intakes, two water treatment facilities, nearly 7,000 miles of waterlines, reservoirs, pumping stations, and production wells.

To prepare for declining Lake Mead reservoir elevations, SNWA's steps for adaptive management include conservation, water banking, and integrated resource and infrastructure planning. SNWA is now beginning to explore potential impacts and solutions to personnel and infrastructure.

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends include the following:

- From 1980 to 2015, the average dew point temperature in Las Vegas increased from 44°F to 50°F, thereby making it more challenging for the body to cool itself.[3]
- Between 1970 and 2016, Clark County, Nevada has warmed 2.6°F.[4]

FUTURE CLIMATE

Projected changes include the following:

- By 2100, average annual temperatures in Clark County will warm between 5 °F and 10 °F.[5]
- Under present conditions, Lake Mead is projected to decline below 1,075 feet above sea level by 2020, triggering a reduction in water deliveries to NV and AZ.[6]
- Las Vegas may experience 106 days per year with a Heat Index above 105°F by 2050.[7]

The following pages of this risk and opportunity profile outline the relevant climate drivers, both risks and opportunities, mapped to SNWA's key business functions as identified by SNWA in August 2018.

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

SNWA participated in this research project to investigate how the utility's core business functions anticipate climate risks and opportunities. SNWA identified administration, engineering operations, and finance as the three business functions of highest interest in relation to climate change.

ADMINISTRATION

- **Summary:** SNWA personnel live and work in one of the hottest and driest states in the country. Climate change and extreme weather events could increase risks to personnel.
- **Current risk:** SNWA employees are exposed to public health and water quality stressors, such as extreme temperature, wildfires, and storm events, that will likely increase in intensity and frequency as a result of climate change.
- **Barriers to action:** State and local politicians within Southern Nevada are hesitant to include the concepts of climate-related events in assessments. Evaluating impacts to personnel is a new area of study and there is limited information in the water sector to draw on to develop solutions.
- **Opportunities:** SNWA is currently conducting an enterprise risk management assessment to include climate conditions grounded in historical hydrological variability and climate events. To take on a global perspective on risk, SNWA's assessment interviewed 183 individuals to discuss risk.

Impacts of Climate Drivers and Underlying Conditions

Worker Health and Safety

Extreme Heat Vector-borne Disease Wildfires Storm Intensity	• Increased health impacts on outdoor workers including heat stroke, heat stress, storm exposure, and mental health disorders • Warmer climates are exposed to increased vector-bone diseases that threaten worker health and contaminate water sources • Wildfires increase toxic particulate matter in the air • Wildfires increase the amount of ozone in the atmosphere close to the earth's surface, which is harmful to crops and humans

Power Continuity

Extreme Heat	• Power outages from extreme heat have cascading effects that cause AC outages, heat stress, and water monitoring disruptions

Transit Impacts

Wildfires Storm Intensity	• Roads, bridges, and railways are damaged from heat due to heat-intolerant materials • Intense flooding and erosion inhibit employee access to facilities

Communication and Technology Impacts

Extreme Heat Wildfires	• Technology cannot operate beyond a certain heat threshold • Field technology and communication systems are sensitive to heat and may not function during extreme heat events

ADMINISTRATION	
Risks	**Opportunities**
• Inadequate Business Continuity Plan (loss of electric power—indoor workers' reliance on AC) • Declining overall productivity of the work force • Cascading risks of power loss: communications, operations, and operational challenges • Risk communications and monitoring technology does not function beyond certain heat thresholds • Increased incidence of worker's compensation claims and injuries • Impacts to reputation and brand associated with lack of preparedness for events	• Investment in heat-resistant communications technology (i.e., radios) • Shifting work schedules to adapt to increasing summer heat or increasing rest cycles • Training for recognizing various heat-related stresses • Monitor absenteeism and worker comp claims • Develop procedures and criteria halting work above certain heat indexes and other air-quality thresholds • Incorporate climate considerations into preparedness for natural hazards (e.g., wildfires) • Ensure proactive communication and disaster preparedness messaging

ENGINEERING/OPERATIONS

- **Summary:** Due to extreme climate risks that currently take place in Southern Nevada, SNWA's safety engineers have participated in training courses about climate change impacts on engineering.
- **Current risk:** Increasing mean annual temperatures and changing source water conditions threaten critical infrastructure used in water treatment and distribution
  Opportunities: SNWA is already facing climate impacts due to its extreme environment; as a result, SNWA has an opportunity to be a leader in the water utility industry for sustainable water use and resilience planning.

SNWA Water Sources

- Colorado River via Lake Mead
- Local Groundwater
- Recycled Water

Impacts of Climate Drivers and Underlying Conditions

Water Quality

Climate Drivers	Impacts
Drought Storm Intensity Extreme Heat Wildfires	• Drought reduces freshwater inputs to surface reservoirs, groundwater recharge, and ability to meet water demand • Higher water temperatures in Lake Mead increase contaminant levels • Turbidity impairs water quality during storm events and floods • Wildfires introduce pollutants to exposed water resources

Efficiency of Operations

Climate Drivers	Impacts
Drought Storm Intensity Extreme Heat	• Low lake levels require increased pumping efficiency to meet demand • Warmer water requires more extensive and costly treatment • Generator and energy storage is needed during power outages

Power Continuity

Climate Drivers	Impacts
Extreme Heat Storm Intensity Drought	• Power outages cause cascading effects including the inability to treat and transport water • Without power, SNWA is unable to effectively communicate to its staff to recover systems or to its customers to indicate when water will be restored

Distribution Challenges

Climate Drivers	Impacts
Drought Extreme Heat	• Warm water limits distribution by pressure rated pipes • Maintenance demand would increase with pipe and road damage from extreme heat and flood events

ENGINEERING/OPERATIONS	
Risks	**Opportunities**
• Potential inoperability of intake pumping stations 1 and 2 if Lake Mead's surface level declines • Increase in THM MCL exceedances • Declining efficiency of operations impacted by low lake levels and higher water temperature • Higher energy costs • Potential loss of function in control devices could lead to system failure • Increase in small system failures due to lack of redundancy	• Building new pumping stations to preserve SNWA access to Lake Mead as lake levels decline • Lower frequency of facilities freezing at higher elevations if winter temperatures increase • Engage engineers in planning conversations about extreme heat, extreme events, water temperature and quality concerns, and lake levels

FINANCE

- **Summary:** Since the financial downturn in 2008, SNWA has brought in financial experts, completed stress tests, and made a concerted effort to realign revenue streams to make the utility more resilient to change and external impacts.
- **Current risk:** Facility and/or personnel impacts from climate change and extreme events could result in unbudgeted financial expenditures. Increased conservation and lower water demand in response to drought and climate change has the potential to reduce SNWA's current funding streams.
  Opportunities: SNWA has established internal and external citizen-based advisory committees to guide long-term investment decisions when current economic and environmental futures are uncertain.

Impacts of Climate Drivers and Underlying Conditions

Damage to Facilities

Climate Drivers	Impacts
Extreme Heat Storm Intensity Wildfires Drought	• Extreme storms make pumping stations and exposed facilities unusable if damaged • Exposed facilities endure more wear and tear from climate events • Heat and flooding damage pipe infrastructure and roads • HVAC units experience frequent outages during storms • Costs increase due to demands for comprehensive insurance • Increased financial and credit risks due to loss of revenue from more frequent climate-related service interruptions

Water Quality and Quantity Implications

Climate Drivers	Impacts
Wildfires Storm Intensity	• Higher water treatment costs • Potential revenue losses from drought restrictions • Potential for impacts on both the water demand and water supply side of the equation (longer peak demand season) • Health risks associated with changes in raw water quality and treatment approaches

FINANCE	
Risks	**Opportunities**
• Facilities may become uninsurable or very expensive to insure given increased incidence of extreme weather events • Increased risk of impacts to credit rating due to uncertainty in future planning and the impacts of extreme heat and storms • Incurring unplanned capital expenditures in the event of damaged infrastructure and facilities • Lack of available funding for upfront costs to prepare for damages or impacts from climate drivers in advance of the events • Drought restrictions potentially result in revenue loss	• Opportunity to pursue creative financing strategies for infrastructure improvements • Maintain larger emergency financial reserves • Implement preparatory maintenance and repair program (evaluate current design standards against future projections) • Modify existing capital improvement planning process to include evaluating climate change risks • Redundancy in systems can be planned • Policy changes such no longer constructing above-ground steel reservoirs or changing pipe materials (no more polyethylene pipes as they are shown to have much higher failure rate when water is warm)

In September 2018, staff from Southern Nevada Water Authority's representatives mapped three example water utility business functions, ***administration, engineering/operations, and finance****, to four different climate stressors and impacts. Stressors and impacts related to storms (including extreme winds, lightning, heavy precipitation, and flooding), temperature, and wildfire were common to all three business functions. A checkmark in Table 1 indicates which climate stressors and impacts affect individual business functions.*

Table 1. Climate Stressors and Impacts

Business Functions	Climate Stressors and Impacts			
	Drought	Storms	Temperature	Wildfires
Administration		✓	✓	✓
Engineering / Operations	✓	✓	✓	✓
Finance	✓	✓	✓	✓

SUMMARY OF CLIMATE INFORMATION SOURCES AND TYPES

Below is a summary of climate information sources and types that were identified to help evaluate risks and opportunities for similar water utilities, organized by the different climate stressors and impacts identified Table 1. The sources and types represent a pragmatic, rather than an exhaustive, list of climate information for these examples, because the actual number of potential sources and types is large and continues to increase. The following tables can be used as starting points from which a utility can remove or add climate information sources and types that aid in evaluating climate-related risks and opportunities.

Table Key (Tables 2 – 13)

Climate Stressors and Impacts were classified by the following:

- **Derivative:** sources that provide static or interactive content through predetermined analyses or syntheses in graph, map, or text formats.
- **Data:** sources that require end users to download, analyze, or visualize data to generate climate information

(F) = fine-scale information, higher resolution

(B) = broad-scale information, county level or lower resolution

DROUGHT

Table 2. Drought Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
CNAP Drought Tracker (B,F)		✓	✓	
Colorado River System 5-Year Projected Future Conditions (F)		✓	✓	
Fourth National Climate Assessment (B)	✓			✓
Nevada State Climate Summary (B)	✓			✓
NOAA NCEI Weekly Divisional Products (B)		✓		
U.S. Bureau of Reclamation (F)	✓	✓		
U.S. Drought Monitor (B,F)	✓	✓		
U.S. Drought Portal (B,F)		✓		
U.S. Monthly Drought Outlook (B)			✓	
U.S. Seasonal Drought Outlook (B)			✓	
West Wide Drought Tracker (B,F)	✓	✓		

Table 3. Drought Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Nevada State Climate Summary (B)	✓			✓
NOAA NCEI Drought Variability[a] (B)	✓			
U.S. Bureau of Reclamation (F)	✓	✓		
U.S. Drought Monitor (B,F)	✓	✓		
West Wide Drought Tracker (B,F)	✓	✓		
Nevada State Climate Summary (B)	✓	✓		

[a] Tree-ring reconstructions of two drought indices, see the Precipitation section for more related data sources

FLOODING

Table 4. Flooding Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS AHPS Experimental Long-Range River Flood Risk (F)			✓	
NOAA NWS AHPS River Forecasts (F)			✓	
NOAA NWS AHPS River Observations (F)		✓		
USGS National Water Information System (F)	✓	✓		

Table 5. Flooding Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short-Term	Long-Term
USGS National Water Information System (F)	✓	✓		

PRECIPITATION

Table 6. Precipitation Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Climate Conditions in Clark County, NV (B,F)	✓			✓
Climate Explorer (B,F)	✓			✓
Nevada State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA CPC ENSO Diagnostic Discussion (B)		✓	✓	
NOAA CPC Precipitation (B)		✓		
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS AHPS Precipitation (F)		✓		
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS National Operational Hydrologic Remote Sensing Center (B)	✓	✓		
NOAA NWS Storm Prediction Center (B)			✓	
NOAA NWS WPC Quantitative Precipitation Forecasts (B)			✓	
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)		✓		
U.S. Climate Atlas (B)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

Table 7. Precipitation Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	✓			✓
Nevada State Climate Summary (B)	✓			✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
NOAA NWS AHPS Precipitation (F)		✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		
SNOTEL and Snow Course (F)	✓			
West Wide Drought Tracker (B,F)	✓	✓		

STORMS (INCLUDING EXTREME WIND AND LIGHTNING)

Table 8. Storm Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS (B,F)		✓	✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	

Table 9. Storm Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA Severe Weather Data Inventory (B,F)	✓			

TEMPERATURE

Table 10. Temperature Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Climate Conditions in Clark County, NV (B,F)	✓			✓
Climate Explorer (B,F)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
Nevada State Climate Summary (B)	✓			✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	
PRISM (B,F)	✓	✓		
U.S. Climate Atlas (B)	✓			
West Wide Drought Tracker (B,F)	✓	✓		
Western Water Assessment Climate Extremes (B,F)	✓			

Table 11. Temperature Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	✓			✓
LOCA (F)				✓
Nevada State Climate Summary (B)	✓			✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		
West Wide Drought Tracker (B,F)	✓	✓		

WILDFIRE

Table 12. Wildfire Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
Geospatial Multi-Agency Coordination (F)	✓	✓		
Hazard Mapping System Fire and Smoke Product (B)		✓		
InciWeb: Incident Information System (F)		✓		
National Significant Wildland Fire Potential Outlooks (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	

Table 13. Wildfire Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA NCEI Fire History (F)	✓			

Utility Strategies and Plans

- 2017 Water Resource Plan (2017)
- SNWA Sustainability in Action
- SNWA Water Conservation Plan 2014-2018 (2014)

Sources

[1] Southern Nevada Water Authority. "Mission and history." Accessed October 17, 2016. Website: https://www.snwa.com/about/mission/index.html

[2] Southern Nevada Water Authority: *Water Resource Plan 2017*. 2018. Website: https://www.snwa.com/assets/pdf/water-resource-plan.pdf

[3] Climate Central: *Summers Getting Muggier As Dewpoint Temp Rises*. July 6, 2016. Website: http://www.climatecentral.org/gallery/graphics/summers-getting-muggier-as-dewpoint-temp-rises

[4] NOAA National Centers for Environmental information, Climate at a Glance: County Time Series, published November 2018. Website: https://www.ncdc.noaa.gov/cag/

[5] Kalansky, J, Sheffield, A., Cayan, D., Pierce, D. 2018, Climate Conditions in Clark County, NV: An Evaluation of Historic and Projected Future Climate using Global Climate Models, a report developed for Southern Nevada Water Authority. Website: https://www.wucaonline.org/assets/pdf/pubs-clark-county-climate-report.pdf

[6] Bureau of Reclamation, Colorado River System 5- year Projected future conditions as of August 2018. November 13, 2018. Website: https://www.usbr.gov/lc/region/g4000/riverops/crss-5year-projections.html

[7] Climate Central: *U.S. Faces Dramatic Rise in Extreme Heat, Humidity.* July 13, 2016. Website: http://www.climatecentral.org/news/sizzling-summers-20515#dangerdays

[8] Udall, B., and J. Overpeck (2017), The twenty-first century Colorado River hot drought and implications for the future, Water Resour. Res., 53, doi:10.1002/2016WR019638.

Acronyms

AHPS = Advanced Hydrologic Prediction Service
CNAP = California-Nevada Climate Applications Program
CORDEX = Coordinated Regional Downscaling Experiment
CPC = Climate Prediction Center
ENSO = El Niño-Southern Oscillation
LOCA = Localized Constructed Analogs
NCEI = National Centers for Environmental Information
NOAA = National Oceanic and Atmospheric Administration
NWS = National Weather Service
PRISM = Parameter-elevation Regressions on Independent Slopes Model
SNOTEL = Snow Telemetry
USGS = United States Geological Survey
WPC = Weather Prediction Center

CLIMATE RISK AND OPPORTUNITY PROFILE

Tampa Bay Water

CLIMATE PROJECTIONS

Extreme Temperature
Temperatures across the Southeast are expected to increase during this century, with projected increases in the range of 4°F to 8°F.[15]

Precipitation Intensity
Extreme rainfall events and storm intensity are increasing flood frequencies, making the Southeast highly vulnerable.[16]

Sea Level Rise
Rising sea levels will cause daily coastal floods during high tides if adaptation measures are not implemented.[16]

Storm Intensity
Warming oceans from increasing atmospheric temperatures can increase hurricane wind intensity and cause more damage.[17]

KEY BUSINESS FUNCTIONS IMPACTED BY CLIMATE CHANGE

Drinking Water Treatment and Distribution
Water quality and delivery is increasingly risk-prone as temperatures and storms become more intense.

Physical & Cyber Security
Tampa Bay Water's field electronics and servers are sensitive to increased heat, humidity, and precipitation.

Engineering, Design, and Construction
Cost-effective management of Tampa Bay Water's equipment requires robust material analyses as climate-related uncertainties persist.

UTILITY OVERVIEW

Tampa Bay Water was created in 1998 as an alliance between six west-central Florida governments. Tampa Bay Water supplies wholesale drinking water to more than 2.5 million Floridians, is a national leader in reliable water supply and best practices, and is an advocate for local public water resources.[1] To diversify water supply sources, Tampa Bay Water has invested in surface water from the Tampa Bypass Canal and Seawater Desalination. Additionally, Tampa Bay Water's Seawater Desalination facility is capable of processing 25 million gallons of water per day.

Updated in 2016, the first goal of Tampa Bay Water's Strategic Plan is to "maintain water supply and delivery system reliability and sustainability." Through partnerships with Florida State University, the University of Florida, and local Water Utility Climate Alliance (WUCA) members, Tampa Bay Water works to incorporate climate into its risk management framework.

The City of Tampa, Florida and the Bay[14]

CLIMATE SUMMARY

HISTORICAL CLIMATE

Climate trends include the following:

- Over the past 40 years the Gulf of Mexico has warmed 1°F to 2°F, and the Atlantic Ocean has warmed up to 4°F.[2]
- Florida has experienced one severe drought every decade since 1900.[3]
- Since 1970, Miami has experienced an average of 72.5 more days per year above 90°F.[4]

FUTURE CLIMATE

Projected changes include the following:

- Miami is projected to experience an average of 126 days per year with a heat index above 105°F by 2030 and 151 days per year by 2050.[4]
- By 2100, sea level is projected to rise one to four feet, threatening 20% of Tampa Bay's population.[5]

The following pages of this risk and opportunity profile outline the relevant climate drivers, both risks and opportunities, mapped to Tampa Bay Water's key business functions as identified by Tampa Bay Water in August 2018.

BUSINESS FUNCTION RISKS AND OPPORTUNITIES

Tampa Bay Water participated in this research project to investigate how the utility's core business functions anticipate climate risks and opportunities. Tampa Bay Water identified drinking water treatment and distribution, physical and cyber security, and engineering, design, and construction as the three business functions of highest interest in relation to climate change.

DRINKING WATER TREATMENT AND DISTRIBUTION

- **Summary:** Tampa Bay Water has partnered with local universities and other WUCA members to investigate climate impacts on water supply, demand, and the infrastructure in place to ensure reliable water delivery. Looking forward, Tampa Bay Water aims to develop new design standards for its outdoor assets to increase resilience against extreme temperatures and humidity.
- **Current risk:** Tampa Bay is exposed to variable and intense precipitation, temperatures, and storm events as a result of climate change threatening water quality and distribution infrastructure.
- **Barriers to action:** Community members and customers are hesitant to embrace climate change, which ultimately inhibits political support for climate-related policy and planning.
- **Opportunities:** Tampa Bay Water recognizes climate change as an opportunity to develop innovative solutions to water treatment and distribution issues.

Impacts of Climate Drivers and Underlying Conditions

Climate Drivers	Impacts
Precipitation Intensity Extreme Temperature Storm Intensity Sea Level Rise	• Heavy rains cause inland flooding and sewer overflows that contaminate surface water sources[6] • Water taste and color are tainted by algal blooms and bacterial growths from excess nutrient runoff and warming waters[7] • Tampa Bay Water's Seawater Desalination facility is at sea level; as sea levels rise the facility's ability to continue operating is in question
Saltwater Intrusion	
Sea Level Rise	• Saltwater will increasingly affect coastal rivers and aquifers as sea levels rise[8]
Increased Demand and Reduced Supply	
Extreme Temperature Drought	• Water pollutant concentrations increase with extreme heat • From 2012 to 2013, severe drought in Florida required water providers to diversify water sources to meet consumer demands
Facility Infrastructure	
Extreme Temperature Drought	• Increased heat and humidity damage outdoor equipment and inhibits water distribution • Droughts reduce water storage and increase demand
Energy Reliability	
Sea Level Rise Storm Intensity	• Water treatment and desalination facilities go offline in Category 3 hurricanes, reducing Tampa's supply of clean water to distribute • Employees cannot repair or access damaged assets during storms

DRINKING WATER TREATMENT AND DISTRIBUTION	
Risks	**Opportunities**
• Increased costs of operations and maintenance • Loss of continuity of service • Possible system failure • Potential water shortage and water use permit violation	• Investment in treatment facilities to reduce risks and increase capacity • Slightly higher temperatures improve desalination treatment efficiency (up to a threshold) • More aggressive maintenance may reduce risks

PHYSICAL AND CYBER SECURITY

- **Summary:** Tampa Bay Water's treatment and distribution network is dependent upon physical and cyber infrastructure, including a water treatment plant, desalination plant, a 15.5-billion-gallon reservoir, and an extensive groundwater well network.
- **Current risk:** Extreme temperatures, precipitation, and sea level rise threaten Tampa Bay Water's physical and cyber security as electronic grid communications and infrastructure may fail during climate events. In Tallahassee, Florida's capital, 96% of customers lost power during Hurricane Michael.[10]
- **Opportunities:** Tampa Bay Water is working to increase its physical and cyber resilience, which will result in increased energy efficiency, innovative design, and reliable water delivery.

Hurricane-driven Grid Outages[11]

- Hurricane Hermine = 323,505 accounts
- Hurricane Matthew = 1.13 million accounts
- Hurricane Irma = 6.52 million accounts
- Hurricane Nate = 13,539 accounts
- Hurricane Michael = 400,000 accounts[9]

Impacts of Climate Drivers and Underlying Conditions

Device/Equipment Damage

Climate Drivers	Impacts
Extreme Temperature Precipitation Intensity Sea Level Rise Air: Humidity and Salinity	• Costs to maintain facilities, indoors and outdoors, will increase as temperatures rise, requiring more intensive cooling systems • Sea level rise and intense storm debris hinder access to assets • Tampa Bay Water's server rooms are not protected against Category 5 hurricanes • Humidity and salinity damage electronics by disrupting circuitry

Flooding and Wind Damage

Climate Drivers	Impacts
Sea Level Rise Storm Intensity	• Physical damage to Tampa Bay Water's treatment plants, groundwater wells, and water pumps increase with storm intensity (electrical circuits are corrupted if exposed to water)

Grid and Communication Failure

Climate Drivers	Impacts
Extreme Temperature Storm Intensity	• Internal and external communications are disrupted by storms • Blackouts due to excessive electric demand during high-temperature days threatens water purification and delivery systems

CLIMATE AND CYBER SECURITY

Computer systems and backup systems are likely to be affected by grid outages caused by more frequent and more intense climate events, ultimately halting continuity of service.

PHYSICAL AND CYBER SECURITY	
Risks	**Opportunities**
• System failure (local or regional) • Electric grid and communications failures • Increased maintenance and replacement costs	• Design facilities for higher energy storms • Increase energy efficiency initiatives • Include redundant systems and facilities and additional sensors in new parts of the system • Implement more aggressive maintenance

ENGINEERING, DESIGN, AND CONSTRUCTION

- **Summary:** Tampa Bay Water has prioritized the health and safety of its water as well as the health and safety of its employees. According to Tampa Bay Water's 2016 Strategic Plan, over $1 billion was invested in distribution infrastructure. The agency will also formalize its employee Health and Safety Program.
- **Current risk:** Tampa Bay Water's ability to provide clean and reliable water to its customers depends on the integrity of its infrastructure and productivity of its employees. Aging infrastructure is increasingly vulnerable to climate events and new engineering solutions are required so that new infrastructure can meet the demands of a variable climate.
- **Opportunities:** Tampa Bay Water has diversified its water portfolio to increase resilience against climate variability. Looking forward, Tampa Bay Water plans to include climate in its engineering risk assessments and modify existing standards to meet climate-related standards.

Tampa Bay Water's Sources[13]

- Floridan Aquifer
- Alafia River, Hillsborough River, and the Tampa Bypass Canal
- Seawater desalination

Impacts of Climate Drivers and Underlying Conditions

Employee Well-Being

Climate Drivers	Impacts
Extreme Temperature Storm Intensity	• Extreme heat is unsafe for outdoor workers and altering working hours may not be acceptable to all employees[9,12] • Intense storms events uproot homes and cars and threaten lives

Equipment and Materials

Climate Drivers	Impacts
Extreme Temperature Storm Intensity Water Supply Variability	• Increasing temperatures require more insulation and energy for cooling Tampa Bay Water's facilities • Investment in more robust equipment that can withstand additional water and heat may be required • Future water supplies may be more costly

Enhanced Engineering Requirements

Climate Drivers	Impacts
Storm Intensity Water Supply Variability	• If Tampa's water demand increases, further engineering may be required to bolster existing infrastructure and develop new delivery methods that can withstand supply variability and intense storms

Tampa Bay Water Map and Resources[14]

ENGINEERING, DESIGN, AND CONSTRUCTION	
Risks	**Opportunities**
• Higher costs for engineering, construction, energy and maintenance • Reduced field crew efficiency • System failure and continuity of service problems	• Training for engineers on changing risks • Modified or new design standards to address risks • Changes in planning assumptions and construction timing

Climate Data and Information

In August 2018, staff from Tampa Bay Water collaborated with the research team to map three example water utility business functions, ***drinking water treatment and distribution, engineering, design, and construction, and physical and cyber security****, to eight different climate stressors and impacts. Stressors and impacts related to drought, flooding, sea-level rise, storms, and temperature were common for at least two of the three business functions identified. Each checkmark in Table 1 indicates that the climate stressor and impact influence the relevant business function.*

Table 1. Climate Stressors and Impacts

Water Utility Business Functions	Climate Stressors and Impacts							
	Air Humidity and Salinity	Drought	Flooding	Precipitation	Sea Level Rise/ Storm Surge	Storm Intensity	Extreme Temper-ature	Tropical Cyclones
Drinking water treatment and distribution		✓	✓	✓	✓		✓	✓
Engineering, design, and construction		✓	✓			✓	✓	
Physical and cyber security	✓				✓	✓	✓	

SUMMARY OF CLIMATE INFORMATION SOURCES AND TYPES

Below is a summary of climate information sources and types that were identified to help evaluate risks and opportunities for similar water utilities, organized by the eight different Climate Stressors and Impacts identified Table 1. The sources and types represent a pragmatic, rather than an exhaustive, list of climate information for *these examples. The actual number of potential sources and types is large and continues to expand. The following tables can be used as starting points from which a utility can remove or add climate information sources and types that aid in evaluating climate-related risks and opportunities.*

Table Key (Tables 2 – 17)

Climate Stressors and Impacts were classified by the following:

Derivative: sources that provide static or interactive content through predetermined analyses or syntheses in graph, map, or text formats.

- **Data:** sources that require end users to download, analyze, or visualize data to generate climate information

(F) = fine-scale information, higher resolution

(B) = broad-scale information, county level or lower resolution

AIR (INCLUDING HUMIDITY AND SALINITY)

Table 2. Air Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA NWS (B,F)		✓	✓	
NOAA National Data Buoy Center (F)	✓	✓		
NOAA Tides & Currents (F)		✓	✓	

Table 3. Air Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA National Data Buoy Center (F)	✓	✓		
NOAA NCEI Climate Data Online (F)	✓	✓		

DROUGHT

Table 4. Drought Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Florida State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			
NOAA NCEI Weekly Divisional Products (B)		✓		
U.S. Drought Monitor (B,F)	✓	✓		
U.S. Drought Portal (B,F)		✓		
U.S. Monthly Drought Outlook (B)			✓	
U.S. Seasonal Drought Outlook (B)			✓	

Table 5. Drought Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA NCEI Drought Variability[a] (B)	✓			
U.S. Drought Monitor (B,F)	✓	✓		

[a] Tree-ring reconstructions of two drought indices, see the Precipitation section for more related data sources

FLOODING

Table 6. Flooding Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS AHPS Experimental Long-Range River Flood Risk (F)			✓	
NOAA NWS AHPS River Forecasts (F)			✓	
NOAA NWS AHPS River Observations (F)		✓		
USGS National Water Information System (F)	✓	✓		

Table 7. Flooding Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
USGS National Water Information System (F)	✓	✓		

PRECIPITATION

Table 8. Precipitation Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Climate Explorer (B,F)	✓			✓
Florida State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
Implications of Climate Change on Florida's Water Resources (B)				✓
NOAA CPC ENSO Diagnostic Discussion (B)		✓	✓	
NOAA CPC Precipitation (B)		✓		
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS AHPS Precipitation (F)		✓		
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	
NOAA NWS WPC Quantitative Precipitation Forecasts (B)			✓	
PRISM (B,F)	✓	✓		
U.S. Climate Atlas (B)	✓			

Table 9. Precipitation Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	✓			✓
Florida State Climate Summary (B)	✓			✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
NOAA NWS AHPS Precipitation (F)		✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		

SEA-LEVEL RISE/STORM SURGE

Table 10. Sea Level Rise/Storm Surge Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Florida State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS National Hurricane Center (B)		✓	✓	
NOAA OCM Digital Coast Historical Hurricane Tracks (B)	✓			
NOAA Sea Level Rise Viewer (B,F)			✓	✓
NOAA Tides & Currents (F)		✓	✓	
Scenarios for the National Climate Assessment (B)				✓

Table 11. Sea Level Rise/Storm Surge Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA OCM Digital Coast Historical Hurricane Tracks (B)	✓			✓
NOAA Sea Level Rise Viewer (B,F)			✓	✓
NOAA Severe Weather Data Inventory (B,F)	✓			

STORM INTENSITY

Table 12. Sea Level Rise/Storm Surge Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS (B,F)		✓	✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	

Table 13. Sea Level Rise/Storm Surge Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
NOAA Severe Weather Data Inventory (B,F)	✓			

TEMPERATURE

Table 14. Temperature Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Applied Climate Information System Maps (B,F)		✓		
Climate Explorer (B,F)	✓			✓
Florida State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
Implications of Climate Change on Florida's Water Resources (B)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Daily Summaries Map (F)	✓	✓		
NOAA NCEI Weekly Divisional Products (B)		✓		
NOAA NWS (B,F)		✓	✓	
NOAA NWS CPC (B)			✓	
NOAA NWS CPC U.S. Hazards Outlook (B)			✓	
NOAA NWS Storm Prediction Center (B)			✓	
PRISM (B,F)	✓	✓		
U.S. Climate Atlas (B)	✓			

Table 15. Temperature Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Climate Explorer (B,F)	✓			✓
Florida State Climate Summary (B)	✓			✓
LOCA (F)				✓
NOAA NCEI Climate at a Glance (B,F)	✓			
NOAA NCEI Climate Data Online (F)	✓	✓		
The North American CORDEX Program (F)				✓
PRISM (B,F)	✓	✓		

TROPICAL CYCLONES

Table 16. Sea Level Rise/Storm Surge Derivative

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
Florida State Climate Summary (B)	✓			✓
Fourth National Climate Assessment (B)	✓			✓
NOAA NWS CPC Atlantic Hurricane Season Outlook (B)			✓	
NOAA NWS National Hurricane Center (B)		✓	✓	

Table 17. Sea Level Rise/Storm Surge Data

Source (spatial scale)	Timeframes			
	Historical	Recent	Short Term	Long Term
IBTrACS (B)	✓			
NOAA Severe Weather Data Inventory (B,F)	✓			

Utility Strategies and Plans

- Tampa Bay Water Strategic Plan (2016)
- Tampa Bay Water Regulatory Plan (2018- 2019)
- Tampa Bay Water Special District Public Facilities Report (2018)

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Acronyms

AHPS = Advanced Hydrologic Prediction Service
CORDEX = Coordinated Regional Downscaling Experiment
CPC = Climate Prediction Center
ENSO = El Niño-Southern Oscillation
IBTrACS = International Best Track Archive for Climate Stewardship
LOCA = Localized Constructed Analogs
NCEI = National Centers for Environmental Information
NOAA = National Oceanic and Atmospheric Administration
NWS = National Weather Service
OCM = Office for Coastal Management
PRISM = Parameter-elevation Regressions on Independent Slopes Model
USGS = United States Geological Survey
WPC = Weather Prediction Center

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Glossary

Business Function A category of processes or operations that are performed routinely to carry out a part of the utility's mission.

Cascading Impacts Cascading Impacts occur as a direct or indirect result of an initial event, which, due to linkages between systems, results in major disruptions across an organization, supply chain, community, or region. The following two examples illustrate this concept:

- Flash flood -> disrupts electricity -> electrical grid failure -> traffic accidents -> hazardous materials spills -> local stream contamination -> neighborhoods evacuated.
- Higher temperatures -> more intense drought -> forest stress -> more severe wildfires -> poorer air quality -> increase in human respiratory issues (e.g., the Bay Area in fall 2018).

Climate Adaptation Actions taken to help limit risk and maximize opportunities associated with changing climate conditions.

Climate Drivers The combination of the likelihood (the probability of occurrence) and the consequences of an adverse climate event. Climate drivers include both of the following:

- *Acute:* An extreme weather event that is affected (not necessarily caused) by climate change; its intensity, duration or frequency (or any combination) is expected to change over time and may cause injury, illness, or death to people, or damage to built, natural, or social infrastructure or assets. Examples include hurricanes, floods, heatwaves, blizzards, wildfires, and drought.
- *Chronic:* Longer-term conditions or trends related to longer-term climate variability and change. Examples include higher temperatures, sea level rise, and changes in precipitation patterns.

Climate Resilience The capacity to anticipate, plan, adapt, and thrive in a changing climate.

Critical Pathway A critical path includes processes, knowledge and, equipment essential for successfully conducting a business function.

Impacts The impacts associated with the acute and chronic climate drivers (as noted above), such as snowpack declines, water shortages, increases in storm surge, infrastructure damages, biodiversity losses, ocean acidification, disease outbreaks, and land loss.

Opportunity The potential to derive positive outcomes from understanding and preparing for climate-related challenges, including resource efficiency and cost savings, development of new products and services, access to new markets, and building resilience across the utility and along its supply chain.

Risk Risk is the likelihood of a hazard's occurrence, multiplied by the consequences

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