Climate Risks to Water Utility Built Assets and Infrastructure

A synthesis of interviews with national and international water utilities

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FROM FOREST TO FAUCET

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The authors would like to thank Jeff Leighton, PWB's Asset Manager, for his guidance and review during the survey and report-writing process.

****Cover photo by Paul Fesko, City of Calgary – Calgary flood, June 2013**

I. Background

Traditionally, water utility engineers and planners have assumed a certain level of climate 'stationarity' to design infrastructure and quantify risks to assets: that is, the climate[1] fluctuates within an unchanging envelope of variability. While this approach still incorporates the probability of occurrence of extreme events over some historical time period, it does not take into account the changing distribution and probability of future extremes with climate change. Because climate change is expected to increase both the variability and uncertainty of future conditions, traditional engineering practices may need to be rethought to address a new range of plausible climate futures.

In recognition of this challenge, the American Society for Civil Engineers (ASCE) released a white paper report in June 2015 titled *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. This report states that "engineers should develop a new paradigm for engineering practice in a world in which climate is changing" (Olson, 2015), and advocates for shifting the current practice away from relying on historical data. The ASCE paper adds to the growing body of knowledge about climate and extreme weather impacts to the nation's infrastructure, and how engineers can manage these risks in the future.

II. Purpose

The Portland Water Bureau (PWB) has been studying the potential impacts of climate change to its primary water supply, the Bull Run Watershed, for over fifteen years. PWB is also a member of the Water Utility Climate Alliance (WUCA) whose mission is to provide leadership in assessing and adapting to the potential effects of climate change through collaborative action. Through this work PWB is already actively involved in assessing projected climate impacts to Portland's water supply. PWB also has a mature asset management program and has used asset management practices since 2005 to improve the way it cares for infrastructure. This program provides the direction and reference points for asset information for the foreseeable future.

The purpose of this survey was for PWB to broaden its knowledge of an emerging field of understanding in climate change vulnerability assessments for the water sector: **how climate risks and extreme weather events are likely to affect built assets and infrastructure, and how utilities are responding by building new infrastructure, replacing or repairing assets, and changing operations.**

Because of PWB's involvement in asset management and the broadening influence of this infrastructure assessment, maintenance and management framework within the utility industry, the focus of the survey was originally structured to review asset management principles within utilities as related to climate change. The interview process revealed, however, that climate change as an issue is provoking a wide array of insightful utility questions and management needs that go beyond traditional asset management categories including financial planning, communications, and natural resources. This report therefore includes shared information and topics covering the gambit of utility climate-related planning and management activities.

[1] Climate is the average of weather at a location over at least a 30-year period (NOAA Climate Prediction Center)

The primary aim at the beginning of the survey process was to share information obtained through the survey with PWB staff. This synthesis report is therefore mostly focused on findings from the interviewed utilities and not on PWB's system, although background on PWB is provided. PWB hopes that this survey will also be of interest to the utilities that participated, and possibly to a broader water utility audience.

The survey information that was collected has been very informative in helping PWB consider the range of potential climate risks to its assets, and the tools and processes that could be used to incorporate these risks into PWB's asset management and infrastructure planning. **The authors deeply appreciate the willingness of our utility peers around the world to collaborate on these issues and to share the valuable information included here.**

III. Methodology

In order to solicit information on this topic from peer national and international water utilities and industry experts, PWB developed a set of survey questions (see Appendix). These questions include whether utilities have experienced extreme climatic events that affected their built systems, how they have responded, and whether potential future impacts and climate risks are included in asset management plans and utility management approaches.

PWB interviewed a geographically diverse group of retail and wholesale national and international utilities, most of which are drinking water providers, although several are also wastewater or stormwater/drainage utilities. For the purposes of learning, PWB deliberately chose to interview utilities that are already planning for climate change or extreme events, several of which are at the forefront of water utility climate adaptation. The survey results are therefore more likely to be representative of leading edge approaches to climate change by water and wastewater utilities.

PWB staff, including Jeff Leighton (PWB's Asset Manager and chair of the American Water Works Association Asset Management National Committee) identified a list of U.S., Canadian, British and Australian municipal utility contacts to include in the survey. PWB invited 28 water/wastewater utilities to participate and was able to organize 18 interviews. In addition, PWB spoke to two non-utility entities (Engineers Canada and Climate Risk) which have developed processes and tools to incorporate climate risks into asset management and infrastructure planning. In total PWB conducted 20 phone interviews between February and June 2015.

The survey questions were sent in advance to help utilities prepare for the phone conversation. Survey participants from each utility included either the asset manager or climate/sustainability lead, and sometimes several staff. PWB documented the surveys and subsequently shared these notes with each participant after the interview to enable them to provide comments and edits.

Instead of reporting on each utility's specific situation on a case-by-case basis, PWB has synthesized information from the interviews around common findings and utility examples. **While the information in this paper does not provide a comprehensive summary of everything that the surveyed utilities are doing related to climate change and extreme events, it highlights how these utilities are thinking about and acting on these challenges.** PWB has also included a brief summary of anticipated climate issues for Portland's water system.

IV. Survey Participants

Figure 1 illustrates the location of all survey participants and Figure 2 lists and summarizes information on the utilities interviewed, including services provided, water sources, and customers served. The 18 surveyed utilities serve a total population of more than 53 million people internationally.

Figure 1: Map of surveyed utilities & PWB

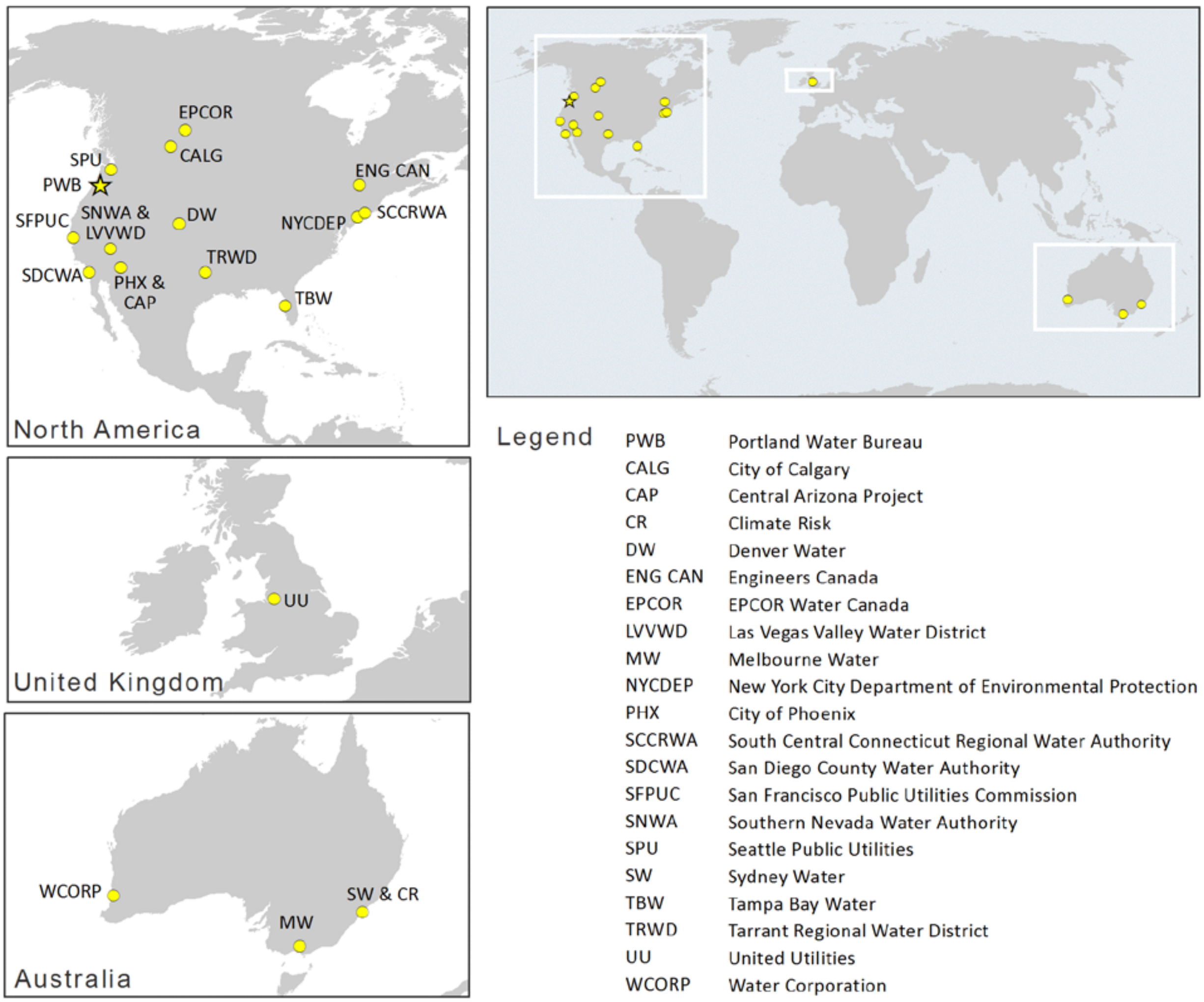


Figure 2: Summary information on surveyed utilities & PWB

Utility	Acronym	Area(s) served	Services provided*					Population served (millions)	Supply sources**				Entity***	
			DW	WW	SW	G/R	P		SUR	GRO	REC	DES	RTL	WSL
Calgary (City)	**Calgary**	**Calgary, Canada**	**x**	**x**	**x**	**x**		**1.2**	**x**				**x**	
Central Arizona Project	CAP	Pima, Pinal and Maricopa Counties, Arizona	x					5.3	x					x
Denver Water	**DW**	**Denver, Colorado**	**x**					**1.3**	**x**				**x**	
EPCOR Water Canada	EPCOR	Based in Edmonton, Canada with services in British Columbia, Alberta and Saskatchewan	x	x				1.6	x	x			x	x
Las Vegas Valley Water District	LVVWD	Las Vegas, Nevada	x					1	x	x			x	
Melbourne Water	MW	Melbourne, Australia	x	x	x			4	x			x		x
New York City Department of Environmental Protection	**NYCDEP**	**New York, New York**	**x**	**x**	**x**		**x**	**9.4**	**x**				**x**	**x**
Phoenix (City)	Phoenix	Phoenix, Arizona	x	x				1.5	x	x			x	
Portland Water Bureau	**PWB**	**Portland, Oregon**	**x**					**0.95**	**x**	**x**			**x**	**x**
San Diego County Water Authority	SDCWA	San Diego, California	x					3.1	x			x		x
San Francisco Public Utilities Commission	**SFPUC**	**San Francisco, California**	**x**	**x**	**x**		**x**	**2.4**	**x**		**x**		**x**	**x**
Seattle Public Utilites	SPU	Seattle, Washington	x	x	x	x		1.4	x				x	x
South Central Connecticut Regional Water Authority	SCCRWA	New Haven, Connecticut	x					0.4	x	x			x	x
Southern Nevada Water Authority	SNWA	Southern Nevada & Las Vegas	x					2	x					x
Sydney Water	SW	Sydney, Australia	x	x	x			4.6	x		x	x	x	
Tampa Bay Water	TBW	Tampa Bay, Florida	x					2.3	x	x		x		x
Tarrant Regional Water District	TRWD	Fort Worth & Tarrant County, Texas	x					1.8	x					x
United Utilities	UU	North West England	x	x	x			6.9	x	x			x	x
Water Corporation	WCORP	Perth, Australia	x	x	x			2	x	x	x	x	x	x
TOTAL			**18**	**10**	**7**	**2**	**1**	**53.15**	**17**	**8**	**1**	**5**	**12**	**10**

***Services provided: DW (Drinking water), WW (Wastewater), SW (Stormwater), G/R (Garbage/Recycling), P (Power)**
****Supply sources: SUR (Surface water), GRO (Groundwater), REC (Recycled water), DES (Desalination plant)**
*****Entity: RTL (Retail), WSL (Wholesale)**
Utilities interviewed are government or publicly-owned, except for EPCOR Water Canada and United Utilities, which are privately-owned.

V. Portland Water System & Anticipated Climate Issues

Bull Run Lake (Credit: Portland Water Bureau)

PWB is a public drinking water utility within the City of Portland, Oregon which serves drinking water to over 950,000 retail and wholesale customers. The drinking water system has two sources of supply. The primary surface water supply is the Bull Run Watershed on the Mount Hood National Forest. Water from the Bull Run Watershed is not filtered, but is treated through chloramination. Water distribution to town is reliant on gravity, although water must be pumped to customers at higher elevations.

Portland's secondary water supply is the groundwater system at the Columbia South Shore Well Field. These aquifers are capable of producing a sustainable yield of 80 million gallons per day of high quality drinking water. Groundwater is used in some years to supplement supply during the summer high demand season, and as an emergency backup if high turbidity leads to a shutdown of Bull Run. Groundwater must be pumped to be supplied.

Future climate in the Northwest region of the U.S. is expected to include both hotter, drier summers and more intense wet season rainfall (Dalton *et al*., 2013). PWB does not anticipate that climate change will lead to supply-related challenges because the Bull Run reservoirs are mostly rain-fed and therefore less vulnerable to the effect of warming temperatures on snow, unlike snow-dependent water systems across the western U.S. In addition, the groundwater supply - which currently provides ample peak season supplemental supply and can be substantially expanded if necessary - increases the system's resilience and provides a buffer in the face of changing conditions. Additionally, total and per capita water demand has decreased over the past couple of decades providing additional buffer capacity. For these reasons, PWB expects to be able to continue meeting customer water supply needs for the foreseeable future.

However, climate change may mean that PWB will have to rethink how it operates and manages its drinking water system. Because the Bull Run supply is unfiltered, it has to be shut off in the event of currently infrequent turbidity events. If extreme rainfall becomes more frequent or intense in the future as expected, this could lead to more turbidity events, and PWB would have to rely more often on its groundwater supply. Increasing variability and uncertainty around future rainfall patterns could also shift operational assumptions around the timing and length of drawdown for the Bull Run reservoirs, which are reliant on spring and fall rainfall to fill and refill. It's possible that an increased risk of flooding in the future may also impact some of PWB's assets.

Warmer air temperatures are also a major concern for PWB because these conditions, accompanied by lower seasonal snowpacks and earlier snowmelt, can lead to warmer stream and reservoir temperatures. Warmer stream temperatures will make it even more challenging for PWB to meet its stream temperature targets for threatened salmon in the lower Bull Run River, and could lead to future nitrification, taste and odor, or lead and copper corrosion challenges in the drinking water distribution system. Furthermore, the risk of dry season wildfires is a regular concern for the unfiltered Bull Run supply, and this risk could be amplified in the future as a result of less snow, hotter summer temperatures, lower soil moisture, and increased evapotranspiration. Finally, the increased chance of wildfire in and around Portland's urban-wildland interface might also influence pipe sizing decisions for fire flow.

VI. Climate & Extreme Weather Risks to Utilities

Warming temperatures and an intensified hydrologic cycle are expected to cause a shift in the distribution of hydrologic and climatologic conditions, leading to new averages and extremes. There are several types of climate risks that the surveyed utilities are concerned about which are grouped together below: extreme rainfall, storms and flooding; drought, temperature and extreme heat; wildfire and bushfire; and sea level rise and storm surge. **The survey findings are organized below according to the type of climate or extreme weather risk, and then by providing examples of utility responses through planning, capital infrastructure, managing asset risks, and operations and maintenance.**

1. Extreme Rainfall, Storms & Flooding

While the utilities interviewed have experienced extreme rainfall, storms and flooding historically, most recognize that climate change could lead to a greater risk of these types of events in the future due to changes in the timing (frequency), amount (intensity) and duration of rainfall. For some regions this may include heavier downpours. In the western U.S., warmer air temperatures will mean that more precipitation is likely to fall as rain rather than snow during winter months. Twelve of the surveyed utilities cited storms (including hurricanes) and flooding as threats to their systems now and in the future. Utilities are having to rethink how to address the increased risk of extreme storms and flooding to their assets and infrastructure.

Water utility dam during storm (Credit: anonymous)

a. Planning

Several utilities noted they are addressing flooding risks through planning efforts. For example, in 2013, the City of Calgary in Canada experienced a catastrophic flood event in the Bow and Elbow Rivers due to a rain-on-snow event. But because the city was already tracking real-time river flows, it had 17 hours to prepare before the floods hit town. The flood still resulted in damage to property and infrastructure. The flood event directly influenced Calgary's emergency planning as it led to the creation of an internal emergency response unit. The city is now focused on delivering an extensive list of projects as part of its Flood Recovery Framework, and is trying to determine how the city will build resilience for the future. The city is working through a program to strengthen flood related policy by connecting with Provincial counterparts on alignment of work plans. In addition Calgary is engaging both flood impacted and non-impacted communities to provide input on flood mitigation options.

The 2013 flood followed other notable extreme events: another flood event in 2006, and a severe drought in 2002 which prompted the creation of a Drought Management Plan. These events seem to have acted as catalysts to create drought and flood management planning responses and have brought funding to the table. As a result, Calgary is considering how it can prepare for two different sets of extremes and whether there are opportunities in employing the same strategies to respond to both – for example, by increasing water storage capacity to act as flood control and boost supply during drought.

b. Capital Infrastructure Projects

Utilities have experienced damage to infrastructure and are building new infrastructure due to current and future flooding risks. In 2013 the Denver/Boulder area of Colorado experienced a large flood event that led to significant property and infrastructure damage. The flood was a 500-year event in most parts of Denver Water's (DW) system, and a 1,000-year event in other parts. The utility reported $5 million of damage on watershed roads due to landslides. Parts of its reservoirs' emergency spillways were also damaged (although that is intended use of those systems). In New England, the South Central Connecticut Regional Water Authority (SCCRWA) is planning a capital project (scheduled to begin in the next five years) to reinforce a 150-year old dam to be prepared for predicted increases in the frequency and severity of high intensity storm events.

c. Managing Asset Risks

Utilities that have experienced recent flooding, extreme rainfall, or hurricanes have had to repair or consider replacing water system assets. Utilities are also preparing for increased risk to their assets in the future. New York City's Department of Environmental Protection (NYCDEP) has both water and wastewater assets. For example, concerning water supply, NYCDEP wants to ensure the spillway capacity of its drinking water reservoirs will be able to withstand the larger future storm events it expects. These older reservoirs have served well for a long time but standards are now more stringent and the agency is looking to make its existing reservoirs able to pass full Probable Maximum Flood (PMF). New York State currently requires that dams pass half the PMF.

NYCDEP's Bureau of Water Supply already looks at the cyclical inspection and repair of assets like aqueducts as part of a State of Good Repair Program, and believes this same approach could be used when responding to future extreme storms or hurricanes. The agency plans to use its existing asset management process to deal with certain future asset risks and may not complete a project immediately or prioritize an asset which could be impacted by future extreme weather. However, the agency will move these climate-related projects along as it begins to see effects. Existing NYCDEP facility plans, for both water and wastewater facilities, detail the work that needs to be done within the next 100 years, but projects outlined for the next 20-30 years are based on the existing asset management process. NYCDEP's system, like many of the utilities interviewed, is specifically designed with redundancy in mind so when it comes to extreme events, this redundancy is tremendously helpful to system security.

In the southeastern U.S., Tampa Bay Water (TBW) noted that it can handle short-term power outages associated with Category 1 or 2 hurricanes, tropical storms or extreme weather events. The quality of its raw water supplies is generally not threatened by hurricanes but the utility acknowledges that climate change could increase the risk of extreme storms in the future with operational impacts. TBW's surface water treatment plant is located in a low-lying floodplain and is required to shut down in a Category 1 or higher hurricane event. The utility's desalination plant, located along Tampa Bay, is required to shut down under tropical storm conditions.

CAP canal (Credit: U.S. Bureau of Reclamation)

Across the country in the desert southwest, episodic storms and flash floods can be a risk to assets. Central Arizona Project's (CAP) canal crosses many of the drainages across the state of Arizona. The embankments protecting the canal have been largely effective even in the face of historical extremes (including a recent 200-yr flood in the Phoenix area). So while there is no plan to relocate facilities outside of the floodplain of some of the river crossings, CAP is addressing some issues with canals and canal embankments. CAP's pipelines cross riverbeds that fluctuate annually between dry beds and fast flowing rivers during storms and the agency has had problems with inverted siphons that were constructed at major river crossings. Four of the crossings were constructed with cast-in-place concrete and six siphons of prestressed concrete pipe. Three of the 21-foot diameter prestressed concrete pipelines have now been replaced. Two of the replaced siphons were constructed with steel pipe and one of them with cast-in-place concrete.

In North West England, flooding in 2009 led to short-term local interruptions in service for United Utilities (UU), and in one case a landslide flowed into one of the utility's key reservoirs. This led to treatment challenges which could have impacted a significant area; however supplies were re-routed from elsewhere so that most customers were not affected. Flooding is not expected to significantly affect UU's assets or infrastructure in the future because most facilities are already well outside of the 100-year flood plain, and the utility considers the rate of change to be sufficiently slow so that it will be able to reassess the risk and react as climate projections change. UU's most critical sites are protected against a 1-in-1,000 year flood. The system includes one of the largest Integrated Resource Zones in the United Kingdom, with interconnections between distant water supply sources, so the loss of any one facility to flooding is rarely a high risk in terms of impact to customer service. The utility noted that this resource zone increases the reliability of water supply to current droughts and floods, and is a form of redundancy that will enable UU to be more resilient to future flooding and storm events with climate change.

In Australia, Sydney Water (SW) is a leader in quantifying the risk of climate change hazards (including riverine flooding) to its extensive system and assets. SW sees significant value in quantifying the business case, risk cost, and net present value of climate change impacts and associated adaptation options. The agency worked with the Water Service Association of Australia, the Australian Government, and Climate Risk (a consulting firm) to develop an innovative tool, AdaptWater™, which can be used to prioritize assets based on risk cost or service level impacts (see Tools section).

SW is also interested in assessing cascading impacts from floods and storms to assets (via interdependencies), and is using these interdependencies to reduce cost barriers to adaptation. For example, SW was involved in a study with the Australian government that looked at supply chain interdependencies and learned that one electric utility sub-station supplied electricity to nine SW assets, making it a critical asset even though it is not owned or operated by SW. SW has more than one electricity supplier and needs to understand the contingency plans of these supply-chain partners in order to better inform its own adaptation planning. The issue of how best to address system interdependencies remains challenging with supply chain providers at different stages of addressing climate change risk. However it is envisaged that greater collaboration and integration of adaptation planning will develop over time. The New South Wales State government is working to streamline this process by promoting more consistency in the adaptation planning approaches adopted by agencies that operate government infrastructure and services.

d. Operations & Maintenance

Utilities which are concerned about flooding or storm impacts to their operations have adjusted operations in response. For example, the SCCRWA altered the operation of one of its reservoirs by maintaining lower reservoir levels to create additional storage capacity for heavy rains. SCCRWA has access to continuous real time data of reservoir levels and precipitation events, and the agency mentioned that this system is helpful both for flood emergency preparedness and drought planning purposes.

SCCRWA was fortunately able to maintain full service during tropical storms over the last few years because of backup generators, which are part of the water authority's long-standing effort to increase storm resiliency. The SCCRWA headquarters is in a coastal area and is vulnerable to storm surge and sea-level rise, and a decision was made to evacuate the building during hurricane/tropical storm Sandy. Through its business continuity planning process, SCCRWA had already put a system in place to run operations at an offsite facility in the event that its headquarters becomes inaccessible or not usable. The storms also changed the way SCCRWA hosts customer data – data are now stored remotely in the event of an emergency and backup servers were relocated from the first floor of the headquarters to another location.

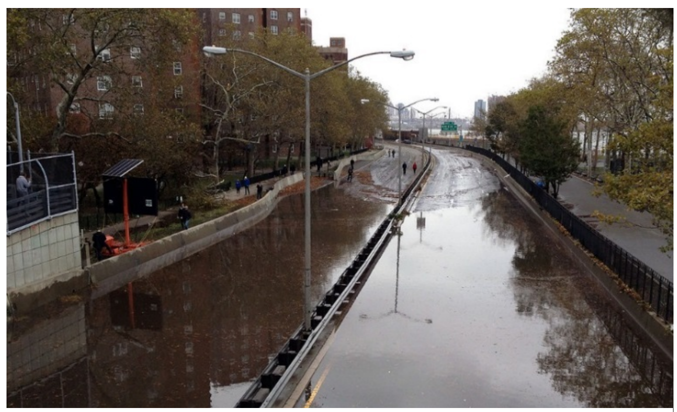
In addition to impacts to built systems, increased storm events due to climate change could lead to future turbidity and water quality impacts. In Alberta both water color and nutrient loading increase during seasonal spring runoff events so EPCOR Water Canada (EPCOR) has concerns over impacts on taste and odor now and during future events. Both EPCOR and SCCRWA specifically mentioned that they may experience more frequent water quality issues like turbidity spikes due to climate change before they would expect to face water quantity issues. Water Corporation (WCORP) in Western Australia is also aware of the potential for future water quality challenges because the growing intensity of rainfall events (contrasted with ambient dry conditions) is a large risk to the agency's system.

The City of Phoenix noted that unpredictable and intense rain events on the Salt/Verde Watershed have increased the turbidity of canal water to levels that can be difficult for the city's surface water treatment plants to manage. Increasing intense storms in the future could lead to more turbidity events for the city, potentially causing a plant to shut off if there is too much debris loading the system. It is not clear if other plants would be able to replace the lost capacity, so Phoenix is already thinking and acting on treatment issues to prepare for future turbidity events.

In contrast, two of the utilities interviewed noted that their drinking water systems are able to deal with increased turbidity events in the future. NYCDEP's Catskills system already experiences turbidity events due to geology and spring flooding which melts snowpack and can increase turbidity. However, NYCDEP does not think the increased likelihood of turbidity events brought on by climate change will be a major concern because it is able to make operational adjustments and rely on system redundancies. For example, NYCDEP can minimize Catskills water diversions by drawing from the less turbid Delaware system or directing Catskills water out of the system via a release channel. Or, if Catskills water supply is necessary at certain times, but is experiencing turbidity, the water is treated with alum in order to meet regulatory standards (this had to be done during both Hurricanes Lee and Irene). Furthermore, NYCDEP is building an interconnection between the Delaware and Catskills aqueducts which will further manage turbid Catskills water by allowing reduction in flow from the Catskill System and replacing it with water from the Delaware System. The agency also recently brought its new Croton water treatment plant online.

Calgary is also not concerned about increasing turbidity risks to its drinking water system because the city has already invested $1.5 billion to increase pre-treatment processes at its filtration treatment plant due to population growth in its services area. The plant now handles turbidity events of any size, thus making it more resilient to future flooding. Incidentally, because these upgrades happened in 2012, the system was able to maintain chlorine residuals following the 2013 flood, and drinking water remained potable.

e. Wastewater & Stormwater Systems



New York flooding following Hurricane Sandy (Credit: Beth Carey, Creative Commons)

Storms and flooding events have also shifted infrastructure planning, design and operational processes in wastewater and stormwater systems. When a small, isolated wastewater plant was knocked out of service for several days during Hurricane Sandy, NYCDEP used the opportunity to determine the feasibility of decommissioning the plant and sending flows elsewhere as a viable alternative to retrofitting the plant to withstand future extreme events. NYCDEP also opted to redesign certain pump stations that failed during the storms because they had electrical components buried underground. New designs recommend moving these components above ground to be able to withstand future storms. In the future, if one of NYCDEP wastewater treatment plants experiences overflowing, or a pump station goes out of service, NYCDEP can bypass these systems and avoid service failure.

The city of San Francisco is heavily developed and lacks natural systems to absorb and retain water. The San Francisco Public Utilities Commission (SFPUC) SFPUC is building and expanding infrastructure as part of a $6.9 billion Sewer System Improvement Program (SSIP), including a proposed large diameter tunnel to convey combined flows to the wastewater treatment plant and to add extra storage. Additionally, SFPUC is working to install green and grey infrastructure to manage stormwater and to reduce combined sewer discharge (CSD) events. The utility has invested $57 million dollars in near-term green infrastructure projects. Of similar note, Portland's Bureau of Environmental Services (BES) has made substantial investments in an improved stormwater system and green infrastructure over the past decade. While climate change was not the driver for BES investments, the projects may help with future climate resilience.

SFPUC also mentioned that it is preparing its wastewater/stormwater system for climate change because staff are seeing events that are very different from the past, including longer droughts and unpredictable weather patterns and storms. Intense rainfall can exceed the SFPUC's stormwater storage capacity, despite having 200 million gallons of transport/storage boxes that allow Total Suspended Solids and sediment to settle in place. SFPUC will be using models and real-time controls (like an advanced predictive rainfall system) to evaluate impacts, and help inform modifications to deal with future CSDs and salt water intrusion. Because different parts of the city experience different weather, certain areas might require higher levels of preparedness. SFPUC is also is measuring and confirming intensity, duration and frequency (IDF) curves.

Over the past five years Seattle Public Utilities (SPU) has observed a change from long-duration storms with moderate precipitation to high intensity, short-duration storms. These storms have overwhelmed SPU's system which was designed for long-duration 24 hour storms. SPU has made changes to its storm modeling process by running multiple model storms through the system taking into account 158 years of historical weather information. Comparable to SFPUC, SPU has an enhanced weather/rainfall forecasting system and in-house meteorological forecasting services. Also similar to SFPUC and BES, SPU has expanded green infrastructure investments which should help with climate resilience. While SPU recognizes the uncertainty in future precipitation projections due to increased climate variability, it does incorporate a "factor of safety" for precipitation which is then used to inform project designs. Because overbuilding infrastructure comes at a cost, SPU develops the business case for a project to understand what additional costs would be incurred by using higher precipitation numbers. SPU typically assesses both "best case" and "worse case" scenarios when it develops a business case.

WCORP mentioned that its wastewater pump stations in low-lying areas have previously flooded temporarily, increasing the risk of wastewater pump station failure. The utility thinks that local stormwater drainage capacities currently in place will be stretched by the anticipated higher intensity storm events due to climate change, and flow rate capacity will decrease.

2. Drought, Temperature & Extreme Heat

Climatic factors are a significant driver of drought for water utilities in the U.S. and internationally. While in many cases drought has led to water supply shortages, it has also resulted in other impacts for utilities. Warmer or hotter temperatures can increase evapotranspiration rates, as well as reduce mountain snowpacks which are the main source of streamflows and water supply in snow-dominant watersheds throughout the western U.S. National and international utilities have also observed declining surface water reservoir levels due to decreasing precipitation. Of the utilities interviewed, thirteen are already experiencing drought or anticipate more severe drought conditions in the future.

a. Planning

In Arizona, CAP is beginning to prepare for a 75% probability that there will be a water shortage in 2017 because of lower reservoir levels in the Colorado River Basin from declining snowpack due to warmer temperatures. Short-term projections from the Bureau of Reclamation indicate that water elevations in Lake Mead, the primary water source for the Southern Nevada Water Authority (SNWA) and its member agencies, including the Las Vegas Valley Water District (LVVWD), could reach levels that lead to Nevada taking less than its total annual allocation - a condition never experienced in the 100-year history of federal management of the Colorado River Basin. Beginning in the late 1980's and continuing today, SNWA stores unused Colorado River water to supplement long- and short-term supplies during drought and to provide interim supplies while additional permanent supplies are brought online.

Two of the Tarrant Regional Water District's (TRWD) northern reservoirs in Texas are lower than average due to several years of dry and warm conditions, so the water district has become more reliant on its southern reservoirs and associated transmission systems. TRWD is conducting supply planning out to 2070 (in accordance with the Texas State Water Plan) primarily because of growing demand and population growth rather than drought. However, drought is built into the demand projections in the State Water Plan. Nonetheless, planning out five decades appears to be unusual amongst the drinking water utilities surveyed. TRWD is also reconstructing paleoclimate records to understand historic drought extremes to inform its future planning (similar efforts have taken place in the Colorado River Basin).

Seasonal drought makes supply-demand planning more challenging for UU because it has to manage its water supply while at the same time providing higher river flows below its reservoirs in order to meet government regulations for ecological protection. UU noted that these regulatory-driven reductions in water availability currently provide the greatest planning challenge to meeting potable water demands during seasonal drought or dry conditions.

UU is also incorporating both drought and climate change into its long-term planning. UU measures drought events against a historic record worst drought (1995-96 for most of its water sources). This measure provides a baseline for how low reservoirs can be allowed to drop before emergency measures are necessary. This historic drought led to methodology changes in UU's Water Resources Management Plan and the utility now plans for future uncertainty due to climate change. The planning methodology incorporates "headroom" between supply and demand forecasts to act as a buffer for uncertainty in the face of changing conditions.

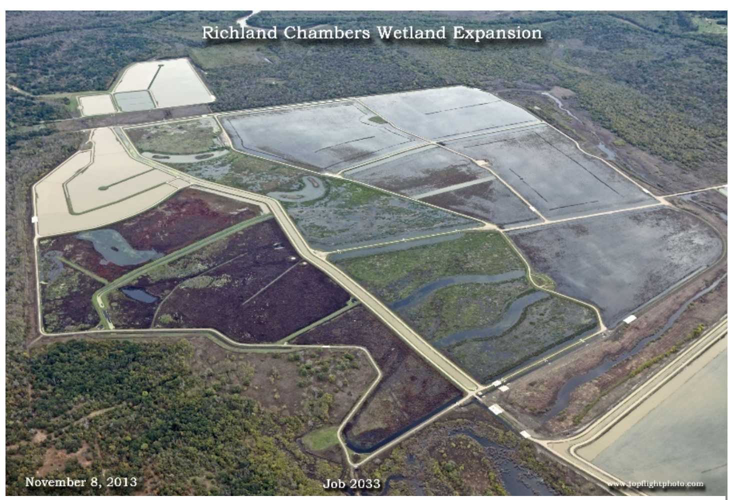
SCCRWA's drought planning is also based on a drought of record in the 1960s. The SCCRWA currently has a large margin of safety to withstand a similar drought, especially given that water demand is currently in a long-term decline. But if climate change alters safety margins by creating previously unseen drought conditions, the water authority acknowledges that circumstances and planning could change. SCCRWA is also planning to meet new streamflow regulations in Connecticut that will be implemented in ten years. The water authority will have to increase releases from reservoir storage to maintain downstream flow requirements, creating more potential challenges for the SCCRWA to balance customer and environmental needs for water. Climate change could amplify this challenge.

b. Capital Infrastructure Projects

Several utilities have already invested in large capital infrastructure projects to respond to drought and warmer temperatures. Due to declining elevations in Lake Mead and persistent drought, SNWA has experienced a number of water quality and operational impacts (withdrawal of reduced quality raw water, increased energy requirements to pump water a greater vertical lift to treatment facilities, and warmer finished water in the distribution system). Accordingly, SNWA has invested a total of $1.5 billion in large capital projects to address these impacts, including: modifying existing intakes; constructing a third intake and accompanying low lake level pump station to withdraw deeper and cooler raw water in Lake Mead; restaging pumping stations at lower elevations to address pumping inefficiencies; and adding aerators and blending water to reduce warm water in the distribution system.

Low-level intake structure in Lake Mead (Credit: Southern Nevada Water Authority)

In addition to planning for drought, TRWD is also investing in large capital projects. To augment water supply, the water district has added transmission pipelines and new booster pump stations to move water in-between sources, utilizing urban lakes as terminal storage, and investing in an artificial wetlands facility which filters diverted water from the Trinity River and adds potable water back into existing reservoirs. TRWD accrued $29 million in energy costs for pumping in 2014 alone, but as a result the drought-stricken northern reservoirs were able to be augmented and preserve water supply that otherwise would not have been available due to extreme drought conditions. While these projects are costly, TRWD has also developed the business case to connect and expand its regional water transmission system with the City of Dallas.



Richard Chambers Wetland Expansion (Credit: Tarrant Regional Water District)

Some of the utilities in the U.S. and Australia have built desalination plants to supplement supply during drought. In southern California, SDCWA has partnered with a private investor-owned company on development of a $1 billion desalination plant which will come online in late 2015 to supplement up to ten percent of SDCWA's supply. In Florida, TBW also has a desalination plant that provides nine percent of its supply.

Melbourne Water (MW) and SW both rely significantly on surface water catchments which were affected by Australia's Millennium Drought in the 2000s. According to MW, this severe drought was more extreme than a 1-in-500 year drought event and exceeded the high climate change scenarios modeled for the year 2030. Both MW and SW built their desalination plants towards the end of the drought. These plants cost approximately $3.5 billion and $2 billion, for MW and SW respectively, and are examples of large capital investments made in response to an extreme event. The plants have not been used since the drought, but are in stand-by to supply drinking water in times of critical need. SW views its desalination plant as one of the ways the utility is securing its water supply against the effects of climate change, a growing population and drought. And, while MW noted that the natural watersheds/catchments it relies on were able to mostly recover after the drought, staff anticipate that future droughts could have more severe and irrecoverable impacts.

In Perth, WCORP experienced a severe, system-wide drought in the 1970s. Over the past 40 years, the agency has recognized a permanent change in surface water levels and expects future conditions to be hotter and drier for Western Australia based on information from climate models. Over the decades, Perth's water supply has shifted from primarily surface water to primarily groundwater and ocean desalination (which required $1 billion in investment), although surface water is still used in combination with these sources. WCORP also has a sustainable water restriction program that meets customer needs, including seasonal sprinkler rosters and sprinkler bans. WCORP's current "Climate Resilience" strategy is committed to meeting water demands in the future, despite the long-term shift in climatic conditions for the region.

c. Managing Asset Risks

Many of the surveyed utilities are concerned about how current drought conditions and warmer air temperatures are affecting asset conditions, and some are preparing for an increased risk of impacts due to climate change. WCORP mentioned that, while its pipes do not experience a lot of movement or breakage (because of predominantly dry and loose sandy soils in the service area), staff have noticed that the water table is dropping due to drought. These conditions have exposed acid-sulfate soils to the sun which leads to oxidization and pipe corrosion. Despite the slow and small-scale nature of this process, WCORP has already observed impacts to pipes. Additionally, the agency is also witnessing tree roots growing into sewers as trees search for water in drought conditions. Existing monitoring systems and preventative maintenance are being used to address the impact of this "root ingress" to sewer pipes.

While inspecting and cleaning pipelines TRWD has noticed more damage and corrosion due to surrounding dry and cracking soils in its region of Texas. TRWD can only replace ten segments of a given pipe in a year. At this rate, replacing all the district's pipes will take 3200 years, so TRWD is invested in finding a more efficient system. Demand and drought affects the ability to replace pipes because the pipes are almost always running. Maintenance on these pipes usually only occurs during periods of cold temperatures when seasonal water demand decreases so the water district has experienced catastrophic failures on its transmission line. Furthermore, TRWD's original pump room cooling systems were inadequate for higher temperatures in the region, so the district has redesigned and reconstructed large-scale pump station cooling systems to increase the range of operating temperatures.

Even without considering climate change, LVVWD's polyethylene service laterals can leak and fail as they age in the intense desert heat. LVVWD experiences approximately 2,000 polyethylene service lateral failures each year, with most of the failures occur during the hottest time of the year between May to September. Failed service lines are replaced with copper service lines, which experience a lower rate of failure in Las Vegas' extreme heat conditions.

Looking to the future, both SNWA and LVVWD are considering climate change temperature projections in new facility designs: for instance whether to rely on evaporative cooling as opposed to air conditioning to cool critical electrical infrastructure, or whether to place important electronics on the ground versus hanging them from the ceiling. SNWA also considered a range of future climate scenarios as part of an internal working group's risk assessment of impacts to key utility infrastructure. Instead of evaluating the utility's thousands of assets (pipes, valves, etc.), the group focused on a subset of critical assets, and how climate change could affect those assets. Assets included water intakes, treatment facilities, the distribution system as a whole, and other natural resources.

The effect of extreme temperatures on assets is, however, a relative concept for some utilities. While both Calgary and EPCOR are located in Alberta, Calgary mentioned that the existing water system ventilation systems are not enough to withstand rising temperatures long term, so the city is examining these vulnerabilities. On the other hand, EPCOR staff noted that Alberta's climate is one of the most variable climates on the planet so the agency already operates equipment within a wide range of temperature extremes. Likewise, CAP and SDCWA stated that their facilities are used to dealing with higher temperatures as regional norms, and are therefore already able to withstand extreme heat.

d. Operations & Maintenance

In addition to impacts to assets, utilities are also having to rethink operations, water treatment processes, and emergency back-ups system in response to drought and warmer temperatures.

Tampa Bay Water treatment plant (Credit: Tampa Bay Water)

At both SDCWA and TBW, the combination of reduced water levels in the system (during periods of drought) and lowered customer demand have forced pumps and other water treatment facilities to be left idle for long periods of time, thereby changing utility operations. According to staff, TBW's system is diverse and integrated, but is not all needed, so the utility may potentially transition its system to smaller, year-round pumps if rainfall projections change or if some of its pumps do not operate as intended. As a wholesale water provider, TBW delivers large quantities of water over substantial distances to its members. Travel time of treated water is on the order of days in some cases. Current summer time temperatures and low demands can lead to water quality problems. Increasing temperatures due to climate change will challenge TBW to maintain delivered water quality.

DW is also aware of the operational impacts of idling pumps due to reductions in both demand and supply, and prioritizes keeping the system fluid and moving to avoid the risk of turning systems off. CAP anticipates it may have to decrease running operations due to water shortages brought on by drought in the future.

Maintenance of an aqueduct (Credit: United Utilities)

In response to seasonal summer drought, UU has built a large regionally interconnected system including a recent two-way pipeline that also enables the utility to maintain levels of service when it needs to shut down aqueducts for maintenance. The utility recently took an aqueduct offline to assess condition and undertake maintenance, and was able to do so because of the interconnections. According to UU staff the pipeline also provides the added benefit of climate adaptation.

Higher temperatures and lower water levels due to drought and heat have resulted in operational water quality challenges for SNWA and SDCWA. SNWA has observed warmer water temperatures for both raw and finished water. This has reduced the residence time of treated water in the distribution system before higher levels of trihalomethanes (THMs), a disinfection by-product, are observed. SNWA is mitigating this impact by changing distribution operations and in certain locations utilizing aeration systems to ventilate these volatile compounds from the water, and/or blending local groundwater with treated Colorado River water to reduce THMs in the system. SDCWA's member agencies have similarly had to reduce water residence times in response to warm water and nitrification issues in their distribution system.

While warmer water temperature is not a current concern for DW, the utility does foresee potential challenges with water quality due to climate warming. For example, water going to Denver Airport has to travel long distances, and because the airport's demand is relatively low the water moves slowly or stagnates. Warmer conditions due to climate change could result in additional water quality problems in DW's system.

Heat events can lead to electrical outages, and several utilities already plan to operate with back-up generator power if such events occur. For example, NYCDEP's drinking water pumping stations have back-up power and generators and securing backup power for all of SCCRWA's stations is a high priority for the water authority. WCORP noted the risk regarding the electricity network within the wastewater system, and it has discussed grid interdependencies with electricity providers, identified critical electricity stations, and installed back- up generators. TBW has a large number of electrical storms annually and uses backup generators if commercial power is shut down. However, the utility is aware that its generators may not be able to maintain the high pressure system required to move water long distances.

3. Wildfire & Bushfire

Hot temperatures, high evapotranspiration rates, lack of precipitation, and low snowpacks are climatic and hydrologic drivers of wildfire. Climate change is expected to exacerbate the risk of wildfire in the future for many parts of the western U.S. and other dry regions globally. Wildfire and bushfire (in Australia) are a concern for utilities because of the potential damage to infrastructure and assets and associated operational and water quality challenges.

Following the 2002 Hayman wildfire which burned a large section of DW's Working Horse watershed, a large rain event then washed sediment and debris into one of the main reservoirs. DW had to spend millions of dollars in dredging to remove the sediment, and even so the reservoir continues to experience water quality issues from sludge. Following the fire, water stored in the reservoir also had high levels of ash resulting in an acidic pH and had to be released downstream.


Hayman Fire near Denver (Credit: Michael Rieger, FEMA)

For Phoenix, forests within the Salt/Verde River Watershed have become prone to extreme wildfire events as a result of past forest management practices. Numerous efforts (e.g. forest thinning programs) are underway to reduce the intensity of future wildfires. However, major wildfires can have a tremendous impact on the city's water quality through increased erosion and the introduction of fire residuals entering surface waters. The city's Water Services Department has had to use different techniques for water treatment to handle turbidity events that can measure up to 3,000 NTU. Additionally, Phoenix has had to change backwash procedures. The entire process has altered operational practices such as cleaning and running the system. To combat water quality impacts following future wildfires, Phoenix installed granular activated carbon in its water treatment plant to filter out the increase of organic matter. Following this upgrade, existing filters had to be retrofitted to accept the new carbon system. These upgrades, while necessary, are costly and illustrate how utilities may have to invest in new systems to reduce future climate risks.

In Australia, bushfires have posed tremendous threats to MW's surface water catchments and to SW's treatment plants, pumping stations, and electrical components through sedimentation, debris and treatment problems. SW includes bushfire as a climate change hazard in the AdaptWater™ tool so it can identify risks to assets and prioritize investments. MW incorporates bushfire risk in its asset management planning and Climate Change Risk Register (see Processes section). Bushfires also pose threats to WCORP's surface water catchments.

4. Sea-Level Rise & Storm Surge

Sea-level rise is caused by global warming due to the thermal expansion of water and melting of glaciers and ice sheets. Several coastal utilities identified sea-level rise and storm surge as a threat to assets, infrastructure and treatment processes. SFPUC is analyzing how its combined wastewater and stormwater system will function after 2100 because the system depends heavily on gravity: water is gravity-fed to treatment plants then gravity-fed out. Storm surge and sea-level rise could cause inundation and backflows into the system so SFPUC may need to rely more on pumping in the future. Also, while the number of CSD events depends on the year, sea-level rise could lead to additional salt water backflow into the system.

Sea-level rise is a significant threat to TBW because its desalination and associated power plant are five feet above sea level and current projections anticipate 2100 sea-level to rise between 4 and 6.8 feet. Additionally, one of TBW's surface water rivers has no salt water barrier in place at the drinking water intake (which is the lowest point of the river) so the intake could be affected by rising sea-level.

SPU has climate adaptation in mind when designing stormwater drainage system projects in low-lying or tidal areas. The utility considers different sea-level rise projections out into the future based on the expected life of a project, and then reacts accordingly. For example, SPU looked at sea-level rise projections at its tidally-influenced Duwamish pump station. SPU also recently analyzed the costs of raising a pump station an additional two feet which only added an estimated 1% to the overall project cost. SPU is furthermore studying the combined effects of sea-level rise and extreme precipitation on its drainage network so it can understand if and how impacts on the drainage network are amplified by those events happening in tandem.

WCORP also mentioned that it has identified wastewater pump stations that are at risk of future sea-level rise. Moving these stations would be a $10 million project, quite small in scale to the agency's entire capital budget. WCROP therefore has the ability to address these issues and respond to climatically-driven events as they occur, and so does not need to act beforehand.

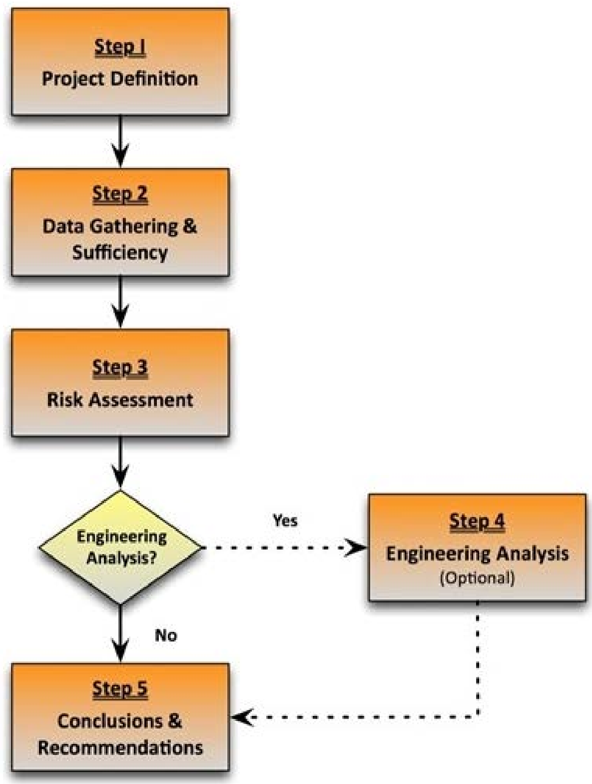
VII. Climate Risk Assessment

While the traditional asset management planning approaches that many of the utilities use do not incorporate climate risks directly, several utilities and non-utility entities are changing how they quantify risks in asset management planning by using climate change projections. Specific risk assessment processes and tools are at the forefront of an emerging area of practice to incorporate climate change into water utility supply planning, capital planning or asset management programs. Some of these are highlighted below.

1. Processes

a. PIEVC (Engineers Canada)

The PIEVC (Public Infrastructure Engineering Vulnerability Committee) Engineering Protocol is a process-oriented approach to assessing the engineering vulnerability of individual or system-wide infrastructure to current and future climate conditions. PWB found out about the process through the interview with Paul Fesko at the City of Calgary which has used PIEVC to assess climatic vulnerabilities to its water supply system. The process was developed by Engineers Canada (the national body for engineers which coordinates engineering standards and practices) out of a need to develop adaptation-based tools to help engineers understand climate impacts to infrastructure. PWB interviewed David Lapp, FEC, P.Eng., Practice Lead, Engineering and Public Policy (david.lapp@engineerscanada.ca) with Engineers Canada to find out about PIEVC.



PIEVC Engineering Protocol (Credit: Engineers Canada)

The PIEVC Protocol is a five-step structured, documented process that can be used to ascertain climate risks to any type of infrastructure. The level of granularity is user-defined which means the process can look at a set of assets (e.g. all pump stations in a system) or can break down assets into individual components (individual pump stations, or even parts of pump stations). PIEVC has been applied to assessing vulnerability and risk to buildings, roads, electrical systems, airport and water, wastewater and stormwater systems in over 45 projects in Canada and two internationally, but not in the U.S. to date. Engineers Canada is interested in having government entities in the U.S. that own and operate public infrastructure to the use PIEVC Protocol.

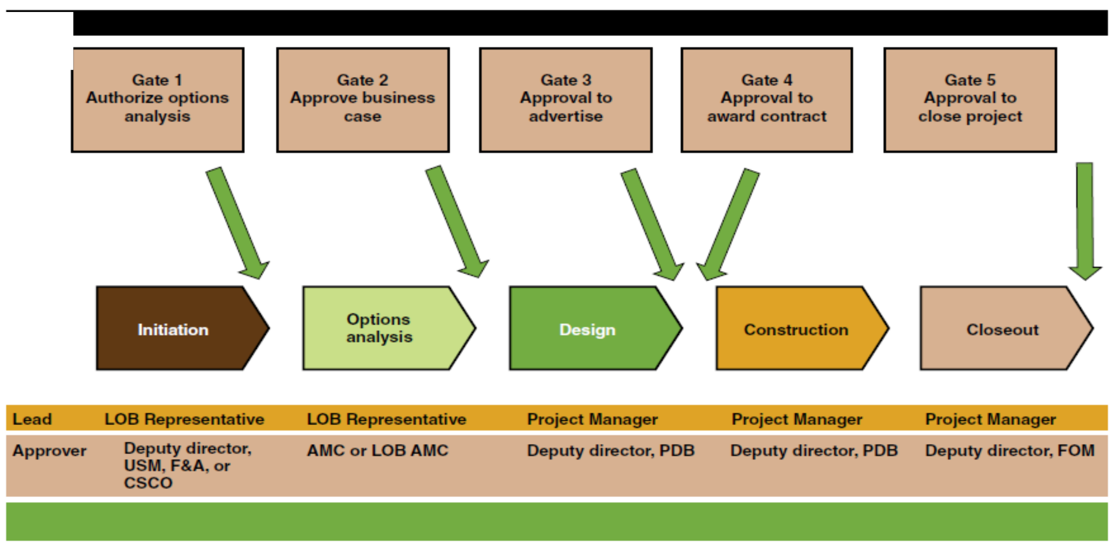
The process is a multi-disciplinary team-based approach to determine climate risks to infrastructure. The team often consists of asset managers and engineers (who plan and design infrastructure), climate science experts (who understand climate projections and modeling), and O&M operators (who are familiar with the individual assets operations and local weather conditions). The team uses data and knowledge from the above fields to collectively develop professional judgments about how infrastructure risk may increase with climate change, using a typical risk matrix (likelihood x consequence). Key considerations include the expected lifetime of the assets being evaluated, and interdependencies between assets which could lead to failure. David Lapp recommends the user conduct this process for the most critical assets and infrastructure, rather than for all assets.

In order to use the PIEVC Protocol, the user obtains a free license, and then works with Engineers Canada to act as a coordinator of the process. Engineers Canada brings external volunteer advisors who have used the process and can provide guidance and advice. To learn more, Engineers Canada can conduct a webinar to describe PIEVC or can conduct an on-site training or an on-line training course. There is more information about the Protocol and many case studies at the recently updated www.pievc.ca. The case studies of infrastructures across Canada demonstrate how the Protocol has been applied, and the recommendations that support infrastructure resilience planning and implementation.

b. Stage Gates (Seattle Public Utilities)

SPU uses a "governance system" and project approval process called Stage Gates. Before approving a project, SPU considers options and risks for a project. Because all projects are allocated a certain budget, if a project needs more (or less) funding, the Stage Gates process requires justification before the project can proceed. The Stage Gates template covers all key components of making a decision and a project team is brought together to make a project recommendation and provide this information to the utility's Asset Management Committee and other decision-makers.

FIGURE 2 Seattle Public Utilities' Stage-Gate process for standard infrastructure projects



Source: Seattle Public Utilities

AMC—Asset Management Committee, CSCO—Corporate Strategies and Communications Office, F&A—Finance and Administration, FOM—Field Operations and Maintenance, LOB—line of business, PDB—Project Delivery Branch, USM—Utility Systems Management

Stage Gates process (Credit: Seattle Public Utilities)

Climate change is incorporated into the Stage Gates checklist and project managers and the team are asked if climate change is going to be a factor in the project. Sea-level rise projections have been applied to assess risks to drainage projects in tidally-influenced areas. If projects are going to be sited in a tidal area, staff are required to look at a sea-level rise viewer via a GIS platform to assess potential risks.

Option analysis currently does not incorporate quantitative precipitation or flooding projections because of the coarseness in available future precipitation data. However, SPU does use a qualitative consideration of the sensitivity of the project to changes in precipitation intensity. The utility is planning on updating IDF curves, and intends to incorporate climate considerations into them so they can be utilized by project designers. SPU also noted that common types of projects like retrofitting a pump station or installing new mechanics are not sensitive to climate change and do not incorporate climate information during the Stage Gates process.

c. Sea-Level Rise in Levels of Service (San Francisco Public Utilities Commission)

SFPUC has developed levels of service with the overall goal to "Modify the System to Adapt to Climate Change". One level of service requires new infrastructure to accommodate expected sea-level rise within the service life of the asset (specifically: 16 inches by 2050, 25 inches by 2070 and 55 inches by 2100), and another level of service is that existing infrastructure will be modified based on actual sea-level rise. SFPUC runs simulations for current and future performance of assets with storm surge and sea-level rise built in, and projections are then used to inform design guidelines for wastewater treatment plants and pump stations. SFPUC's risk-based approach looks at a wide range of potential asset failures, then focuses in on the most likely scenarios with climate change. Based on sea-level rise projections, SFPUC plans to raise electrical equipment because these assets are currently vulnerable at a low elevation.

d. Prioritizing Current & Emerging Climate Risks (United Utilities)

UU ran 10,000 future global climate model simulations and identified 20 representative scenarios to use in planning for future uncertainty in the utility's most recent Water Resources Management Plan. After identifying over 200 climate change risks to its business, UU spent the last couple of years applying a service delivery approach to prioritize identified risks. UU separated risks into 'current' risks (i.e. risks now that will get worse as the climate changes) and 'emerging' risks (i.e. areas which will become risks as the climate changes).

e. Climate Change Risk Register (Melbourne Water)

Until recently, climate change had been considered in MW's asset planning on a case by case basis. For example, MW has factored rising sea-level into adaptive management plans for a coastal sewage treatment plant and to construct new tidal gates. However, given the unprecedented severity of the Millennium Drought and its impact on water resources management, MW wants to expand its asset management program to consider the full range of risks that climate change poses across the whole business. It has developed a "Climate Change Risk Register" which includes impacts on river health and biodiversity, flood management, bushfire risk, asset lifecycle, and health and safety. MW has spent the last couple of years using a service delivery (instead of a hazard-based) assessment to prioritize risks so that actions align with the core business mission. The utility has identified the critical assets and systems needed to deliver core services, studied climate change information, looked at different time scales and ranges, and then determined which assets and systems (and therefore services) are most at risk of climate change impacts. So, while climate change is not yet built into MW's strategic asset management plans, MW does intend to update the plans to include future service levels and climate change using a core services list of priorities.

2. Tools

a. AdaptWater™ (Sydney Water & Climate Risk)

Sydney Water (SW) developed AdaptWater™ in collaboration with the Water Services Association of Australia (WSAA), other Australian water utility partners, Climate Risk, and the Australian

Government to meet the need for a tool that assesses climate impacts and risks to water utility infrastructure, and quantifies adaptation options, costs and investment decisions.

The system was tested in five cities, and SW has now imported approximately 1.5 million assets worth $30 billion (from sections of pipes to full treatment plants) into the system. SW has conducted a 'State of Asset Resilience' Report to assess the climate change risks to all major assets and is using the system in management planning to optimize any new assets for climate change.

AdaptWater™ is a secure cloud-based tool that uses algorithms and statistical risk-based calculations to quantify annual risk costs. It can be used to prioritize assets based on risk, cost or service level impacts. The tool is able to estimate the probability of damage and failure of assets from current and future climate hazards. The tool has a list of climate change hazards (riverine flooding, extreme wind, coastal inundation, heatwave, and saltwater ingress) that can currently be used; two new hazards (salt corrosion and soil compaction) are being added in the near future (Mallon, 2015).

PWB found out about AdaptWater™ during the interview with Nicola Nelson from SW. PWB staff were given on-line access and tested the tool (with Karl Mallon of Climate Risk on Skype), and were able to conduct an example analysis of a series of assets to determine risk cost, implement adaptation options to reduce risk cost, and visualize the location of priority assets and investments.

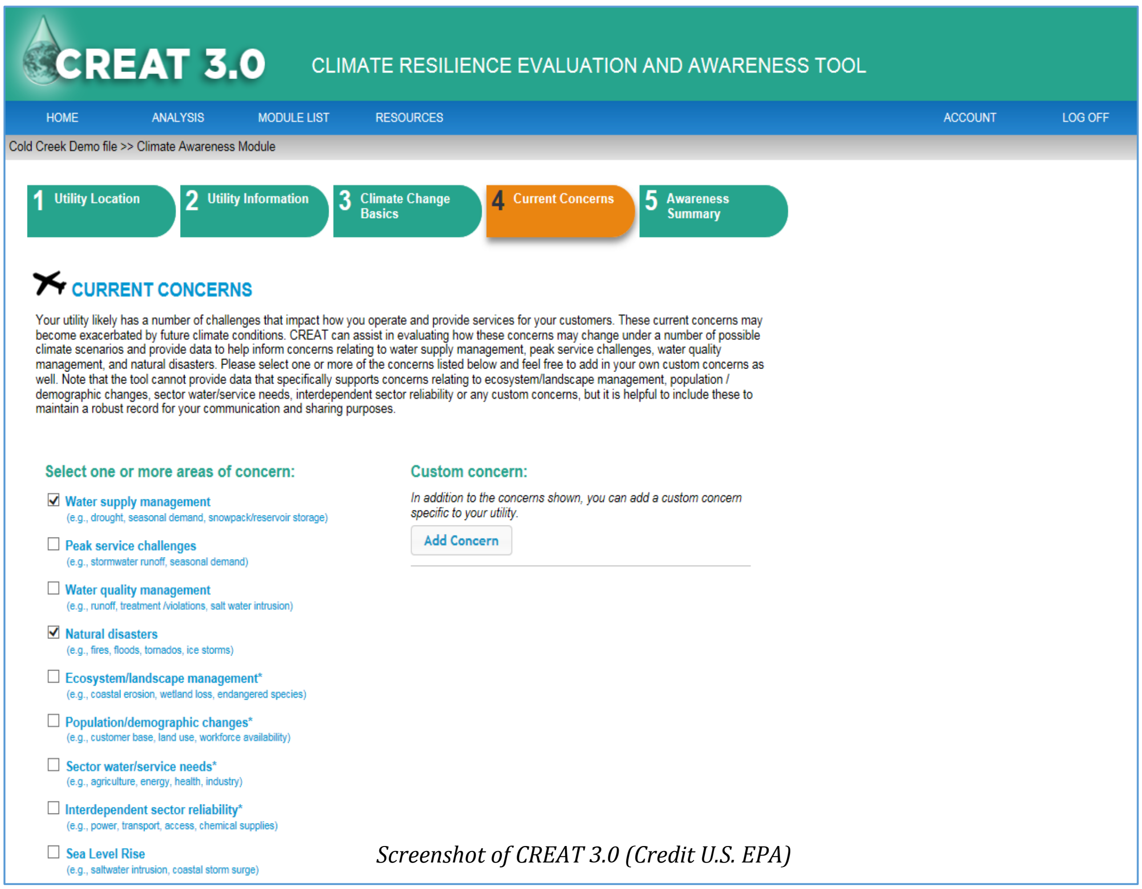
To set up the tool, a utility uploads a data-set of assets (normally exported directly from their own database), and any GIS data related to hazards and asset exposure (the AdaptWater team can assist in sourcing government data too). Once operational any staff member can set up an account and select assets or regions they want to assess. The user can also choose climate scenarios, financial settings and asset management protocols, and then assess the vulnerability of one or more asset (and its mechanical, electrical and civil components), to their selected climate hazards. The tool applies a Monte Carlo analysis to simulate the range of exposure, uncertainty and vulnerability out to an identified future year.

AdaptWater™ then estimates the average annual risk and cost associated with the probability of asset failure. The user has the ability to compare the costs and Net Present Values of a series of adaptation options to reduce risks and costs. These options include a wide range of changes to the assets such as relocation, changes in materials and design specification. Finally the user can view and prioritize assets or adaptation options based on risk, cost or service level and generate a 'business-case' ready report. The system is geographically agnostic and can be used in the U.S. Annual licenses can be obtained via SW.

b. CREAT (U.S. Environmental Protection Agency)

The Climate Resilience Evaluation and Awareness Tool (CREAT) version 3.0 was developed by the U.S. EPA Office of Water to help water and wastewater utilities understand climate change concerns and threats and identify potential adaptation options. While PWB did not interview the EPA for this survey, PWB staff attended a Portland workshop on June 23rd and 24th, 2015 to train on the new version of the tool. Staff spoke to the EPA and other utilities about the new CREAT format.

To use CREAT, utilities must first enter information about their utility into one of five modules in the tool. Based on location, the tool then provides historical and projected climate data (temperature and precipitation) at 32 kilometer resolution. The climate data are used to generate climate scenarios and climate threats (e.g. flooding, drought, number of hot days) in another module. Utilities then specify their main concerns related to climate change or extreme weather (e.g. water quality, reservoir storage, saltwater intrusion) in subsequent modules. In order to quantify the risk to assets and infrastructure, the tool then has a module that uses benchmarking data and industry surveys provided by the EPA and the American Water Works Association to determine consequence and risk to assets from climate threats. Each asset has to be manually entered into the tool in order to quantify the risk (a database of assets cannot be uploaded). These data are then used to monetize risks to assets before and after adaptation. In addition to the default climate projections and data on asset replacement values, the tool is completely customizable, so utilities who have downscaled climate data or specific asset data they want to apply can use these instead to quantify risk costs. CREAT is free and data are stored offsite.



Screenshot of CREAT 3.0 (Credit U.S. EPA)

c. CIMPACT-DST (Cascadia Consulting)

PWB did not interview Cascadia Consulting as part of this survey, but became aware of the CIMPACT-DST tool when Cascadia reached out to the City of Portland. The tool has been used to identify potential climate change impacts on infrastructure and land use projects in Seattle and Vietnam. CIMPACT-DST is Excel-based and analyzes project or asset risks to climate change using information on site location, lifespan and timeframe, and climate hazard zones. The tool outputs bullet-point summaries of potential temperature, precipitation, and flooding impacts. It is mostly designed for entities to compile information about climate change impacts in one place that can then be assessed at a project level. The tool does not use its own algorithms or statistics to prioritize or quantify climate impacts, and adaptation options have to be pre-defined by the user. Also, assets are analyzed from a very broad perspective, and are not broken down into specific electrical or mechanical components within an asset.

VIII. Rate & Financial Impacts

The water and wastewater utilities interviewed emphasized the challenges of managing inevitable rate increases brought on by the changes to asset management, operations and capital projects due to extreme weather events and climate change preparation. For many utilities, including DW, the financial costs of meeting service levels are already perceived to be expensive, and preparing for extreme events will only increase costs. CAP is bracing for increases in rates despite a projected decrease in supply due to the drought. CAP would be selling less water but would still have a fixed cost to operate and maintain the same infrastructure.

A few providers are spending more money to meet certain levels of service. TRWD customers require as close to 100% reliability of the TRWD transmission system as is possible to achieve, and TRWD internal leadership work closely with customers to ensure that capital improvement and O&M spending realizes this goal.

When beginning to plan and construct its desalination plant in the early 2000s, WCORP obtained support from the Western Australian State Government. Water restrictions are historically a sensitive issue for the region, so the State Government hired an economist to assess if there was an economically-efficient way to impose restrictions, or if WCORP should instead develop more water supply to meet customer needs. The study suggested water restrictions would have a tremendous economic and social impact and this gave the government confidence to invest in water supply infrastructure. A desalination plant now provides around 40% of Perth's water supply. WCORP also has a large scale system, responsible for serving water to one-third of Australia's land mass (~10% of the population) and does not have a larger budget available to address operational and service issues brought on by climate change. The utility will therefore respond to events as they occur.

SNWA is also investing more to ensure customer needs and service levels are met even if hydrologic conditions do not improve. SNWA's Integrated Resources Advisory Committee, made up of citizens representing diverse areas of the community, recommended that SNWA should develop the low lake level pump station at Lake Mead after the committee determined that the risk associated with losing access to Southern Nevada's primary water supply due to declining lake levels was too great for the community to bear. Furthermore, the committee identified that water ratepayers were willing to fund the capital costs associated with the critical facility. After considering different ways these costs could be distributed across the customer base, a fixed rate charge was adopted (approximately $5 per residential customer per month), based on the assumption that losing access to the main water supply would be an equal risk for all community members.

Some utility customers are willing to spend less for improvements to levels of service. UU surveyed customers in 2007 and 2013 to gage how highly they valued a reliable water supply compared to other investment priorities, and if they were willing to pay higher bills if the future frequency of water restrictions were reduced. A second stage of this survey in 2013 measured customer value of the environmental, recreational and economic impacts of drought permits and use bans. UU learned customers were generally happy with the current level of service provided and were most interested in keeping their rates low.

IX. Communicating Climate Change

Utilities have different approaches to communicating climate change impacts to their systems, both with customers and among internal staff. For example, MW and CAP have internally discussed whether local extreme weather (severe drought and sudden onset flooding, respectively) were simply instances of natural variability, or if these shifts were a more permanent sign of future conditions. For EPCOR, historical natural variability has made it more difficult to identify long-term trends or a clear climate signal. This can make it challenging to engage stakeholders about climate change, increased variability in seasonal patterns, and potential impacts on water resources. However, EPCOR mentioned there is a growing acknowledgement of an observed significant change in the climate these last ten years that suggests the climate regime has shifted.

TBW and WCORP staff have found it challenging to persuade peers to think long-term about risk assessment and climate change, especially with demand on the decline and current adequate supply levels. A majority of the water and wastewater providers interviewed are already experiencing extremes, so convincing employees to prepare for a wider range or change in those extremes is difficult for a few of the utilities. Furthermore, there may be small, growing changes that accrue before substantial impacts take place, and these are hard to garner attention around.

At SNWA, communications are framed within the context of the drought and consumers are reminded that "it's a desert out there, be Water-Smart". During Hurricane Sandy, SCCRWA did not start conversations on service shortages with customers, as other utilities had done, because the water authority was confident in its ability to maintain service during these events.

SPU's Strategic Business Plan (which involved an external customer review panel and several community focus groups) includes climate change at the beginning of the plan, and SPU's first Action Plan is focused on adaptation. In addition, SPU has used Consumer Confidence Reports/Water Quality Annual reports and its climate change website and blog to show Seattle's citizens and elected officials how foundational climate change is to the utility's strategy.

DW mentioned that PWB's survey has sparked more conversation within the utility regarding the role of climate change in asset management planning.

Gardening in Perth (Credit: Water Corp)

Utilities are also observing customer behavior changes due to climatic events. All of the Australian utilities interviewed (SW, MW, WCORP) have observed changes in customer behavior due to drought or water restrictions. In the early 2000s, WCORP did not want to implement water restrictions but did want to manage water use, so the agency required customers to follow a permanent, daytime water sprinkler ban, a permanent sprinkler 2-day roster, and a no-watering rule during winter. As a result, consumers sought out less water sensitive plants which incidentally are also more climate resilient.

At SW, the Millennium Drought brought forth government-implemented water restrictions as well as a variety of water conservation initiatives, and the utility notes that these initiatives led to long-term changes in customer behavior, even post-restrictions. However, above average rainfall that occurred during a La Niña period at the end of the Millennium Drought resulted in declining public interest in climate change and drought in MW's service area.

Changing customer behavior is also one of the major drivers of reduced demand across many U.S. water utilities including PWB, due to new plumbing codes, more efficient appliances, and changes in land use.

X. Common Themes

The interviews highlighted several common themes in how water and wastewater utilities are addressing the risk of climate change and extreme weather to assets and infrastructure, despite the differences in geography, supply sources and weather.

1. Utilities are planning for extreme weather events and climate change

Most of the utilities interviewed are seriously considering future extreme weather events and climate change in terms of impacts to their water supplies, assets and infrastructure. Many utilities integrate drought, flooding, and sea-level rise and storm surge risks into their long-term water supply and systems planning. In most cases this is because those utilities have already experienced, or are currently experiencing, vulnerabilities due to specific events. In fact, 17 of the 18 utilities identified one or more extreme or climatic events as having significantly impacted their system already at some point in the past. *All* utilities identified climate change as a future threat to some part of their system, and several acknowledged a range of plausible future conditions.

In response, most utilities are either building new infrastructure, increasing supply resilience, building system redundancy, replacing assets, changing operational processes, or incorporating climate change projections into planning. Some utilities are implementing all of the above strategies. Notably, several utilities have experienced dual extreme events with different outcomes – for example drought and flooding. These events can result in different impacts to assets and infrastructure and certainly make it more challenging for utilities to plan for the future. However, utilities are looking for strategies with co-benefits to address both sets of extremes. As climate change increases the variability and range of uncertainty in future extreme events, these multiple-purpose strategies will undoubtedly be valuable.

2. Extreme events catalyze action

Several utilities had experienced extreme events that were essentially 'game-changers' that brought about systematic changes to utility planning. Historic drought, storms and flooding generated more public attention and financial resources. These events seem to be an important catalyst for efforts underway to plan for future extreme events and climate change. Utilities have responded by developing new supply plans and diversification strategies, emergency response plans, new infrastructure, and water conservation programs.

3. Existing assets and asset management processes might be sufficient

Utilities who have relatively "new" systems, or who are invested in assets that are still fairly new in their replacement cycles, plan to first rely on existing assets before replacing them with entirely new components. Managers are hopeful, and in some cases confident, that they can continue replacing and repairing assets as part of existing asset management plans without needing to change how they determine asset risks. These utilities plan to monitor how conditions change due to new extreme events or climate change before redesigning or upgrading assets.

4. New assets and infrastructure are being built

On the other hand, most of the utilities said that they are already building new infrastructure through capital projects, or replacing damaged or old assets that are unable to cope with certain weather or long-term climate conditions. In direct response to drought, flooding, and sea-level rise and storm surge, utilities have spent or are spending millions to billions of dollars to bring new infrastructure online to ensure sufficient clean water supply and management of wastewater and stormwater. These large infrastructure projects, while often triggered by recent events or regulatory drivers, have the ancillary benefit of increasing resilience to future climate impacts.

5. System redundancy helps with climate resilience

Many of the utilities interviewed noted how system redundancies help make their drinking water or wastewater systems more resilient to extreme events and climate change. Examples of such redundancy are far-ranging and include: adding new sources of supply, integrating resource zones, building interconnections between pipelines and sources of supply, adding or redesigning treatment plants, installing back-up generators, and incorporating "safety margins" or "headroom" into infrastructure designs and supply plans. Where there is vulnerability in a system, utilities are looking at the interdependencies among assets and are identifying which critical assets need back-up power, redundancies or replacements.

6. New asset management processes and tools are being used

A few utilities and non-utility entities are at the forefront of integrating climate risks into asset management and infrastructure planning. These entities have already developed new processes and tools to update traditional approaches to asset management, and have applied these tools either internally, or more widely through the water, wastewater and other infrastructure sectors. As mentioned previously, climate change is expected to increase both the variability and uncertainty of future conditions, so traditional engineering practices may need rethinking as utilities design for and assess the risk of future climate variability and uncertainty. The tools and processes identified in this report offer new insights on how water and wastewater utilities can identify asset risks and vulnerabilities, and develop adaptation actions and investments in response.

7. Opportunities exists for asset managers and climate staff to work together

The utility staff interviewed for this survey were either asset managers or climate staff at the utilities, and sometimes both. Some utilities are already integrating climate risks and staff resources into asset management and infrastructure planning processes, while for others this survey provided an opportunity to have internal conversations about climate risks to assets. Utilities are communicating climate change differently depending on their regions and customer bases, and some see the need to build more internal support for climate work.

XI. Appendix : Survey Questions

Brief overview of your water system and/or your mission

1. Are you a public agency or a private company?
2. What is/are your current water source(s) and how many customers do you serve?
3. If you are not a water provider, what is your mission?

Managing climate change and extreme weather risks to assets and built infrastructure

4. Have you observed any climate or extreme weather impacts to your built infrastructure in recent years? *(E.g. drought, wildfires/bushfires, hurricanes, storm events, landslides).* If so, what are you experiencing, and how are you responding?
5. What do you think are the most significant climate or extreme weather threats to your built infrastructure and assets in the future? (*E.g. impacts of flooding on pipe crossings, siting of facilities in floodplains, increasing landslide risk for facilities on steep slopes, extreme heat events affecting pumps, carbonization of concrete leading to faster decay*)
6. Do your asset management plans or risk matrices consider low likelihood/high consequence events? *(E.g. 100 year floods, earthquakes, mega-droughts, landslides)*. How might climate change or an increased frequency and intensity of extreme weather change your planning approach? (e.g*. if the 500 year flood becomes the 100 year flood)*
7. How do you incorporate climatic uncertainty into your risk management strategies? (*E.g. there is less confidence about future precipitation changes in some regions, and the extremes or 'tails' of the distribution from climate models are more variable than averages*)
8. Do you consider the business case for managing climate or weather risks to your infrastructure? (*E.g. the avoided costs or cost savings of relocating your facilities*)
9. What large capital investment projects are planned over the next 20 years? Do these projects consider climate change, or the increased frequency and intensity of extreme weather events? (*E.g. building new supply sources, replacing or repairing old infrastructure).* What are your other infrastructure priorities, and why?
10. Are you doing any projects solely because of climate change and/or extreme weather events? If so, do they have significant financial impacts to your utility budget? If yes, what is the impact? (*E.g. rate impact, reallocation of money from other projects, increased debt*)
11. Do you use certain asset management/planning tools or approaches that you think could be useful in evaluating climate change risks? What others lessons about managing climate change or extreme weather can you share with other water utilities?

Communicating with your customers

12. Are you communicating with your ratepayers about how climate change or extreme weather could impact your system and services? How are you doing this? (*E.g. brochures, websites, community meetings, etc.*)
13. Is climate relevant to any performance metrics or service levels that you track? *(E.g. carbon emissions, outage service levels)*

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