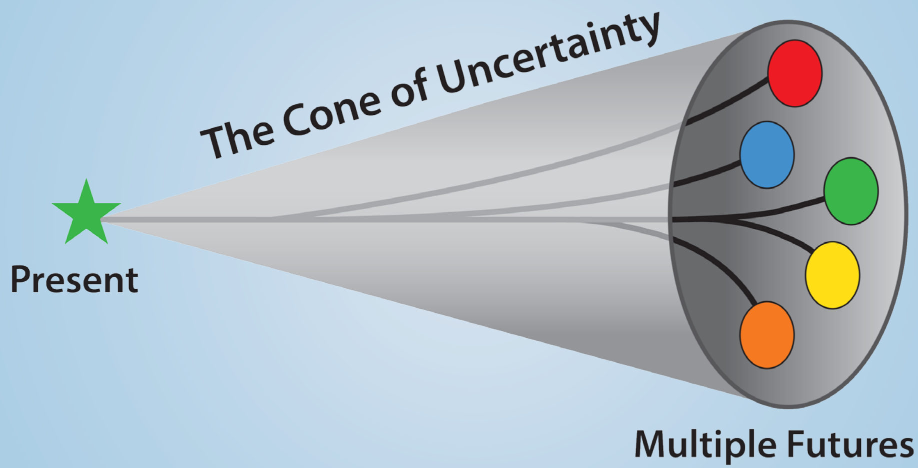
EMBRACING UNCERTAINTY

A Case Study Examination of How Climate Change is Shifting Water Utility Planning



Prepared for:

Water Utility Climate Alliance (WUCA)
American Water Works Association (AWWA)
Water Research Foundation (WRF)
Association of Metropolitan Water Agencies (AMWA)

Project Manager: Laurna Kaatz, Denver Water

WUCA Water Utility Climate Alliance
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Executive Summary

Climate change has emerged as one of the greatest challenges facing water utilities as they plan for the future, adding a new source and level of complexity that is forcing many agencies to reexamine their decision-making processes, especially in long-term planning. This case study white paper, written for water utility professionals, shares insights into how and why water agencies are modifying their planning and decision-making processes to prepare for climate change.

A fundamental goal of this white paper is to provide water professionals with practical and relevant examples, with insights from their peers. As the 13 case studies (shown below) shared in this paper illustrate, water agencies are incorporating climate change information into all types of planning processes, from immediate-term operational decisions to asset management to long-term supply planning.

Although this interview-based white paper does not attempt to provide an inclusive representation of how the water agencies interviewed are changing all of their planning practices to handle an uncertain future, nor to represent actions taken by all water agencies, the following five general themes emerged from the case studies:

- ***The utilities interviewed are bringing climate considerations into a variety of their decision processes.*** Although we expected to find that agencies are incorporating climate information into their long-term water supply planning decisions, we also found that even agencies not currently engaged in a long-term planning process are incorporating climate into many aspects of their decision-making processes. These utilities have found that the time for climate adaptation is now.

- ***Climate change projections are not predictions of the future.*** Climate projections are based on information that is highly uncertain, including how greenhouse gas concentrations will change over time, the ways these emissions affect the global climate system, and how these global changes may manifest locally. As such, climate projections provide a broad range of potential climate futures. Many interviewees found that the degree of uncertainty surrounding climate projections – both the range of projections and the inability to determine their predictive capabilities – is so large that applying probabilities, or accepting a likelihood that one future is more likely to occur than another, is not helpful in their decision-making. Instead, many utilities are now developing and incorporating plausible ranges of possible change into their decision-making.

Case Study List

- Water Corporation of Western Australia: *Planning for Significant Climate Change with "Security through Diversity"*
- Denver Water: *Moving to Scenario Planning*
- Bureau of Reclamation: *Using Robust Decision-Making in the Colorado River Supply and Demand Study*
- California Department of Water Resources: Two short stories: (1) *Adding Robust Decision-Making to a Scenario Planning Process;* and (2) *Forming a Climate Change Technical Advisory Group*
- Metropolitan Water District of Southern California: *Using Robust Decision-Making to Identify Adaptive Management Triggers*
- Inland Empire Utilities Agency: *A Comparison of Robust Decision-Making and Scenario Planning*
- United Utilities (United Kingdom): Three short stories: (1) *Planning beyond the Median Climate Projection;* (2) *Working with Regulators to Develop Flexibility;* and (3) *Upsizing Stormwater Infrastructure*
- Tampa Bay Water: *Climate Information in Operational and Seasonal Decision-Making*
- Seattle Public Utilities: *Climate Change and Asset Management*
- International Upper Great Lakes: *Decision Scaling – A New Planning Tool*
- Sydney Catchment Authority (Australia): Two short stories: (1) *Developing and Using Plausible Ranges of Future Climate Conditions;* and (2) *A Need for More Sophisticated Modeling and Assessments*
- Sonoma County Water Agency: *Using an Independent Science Review Panel in Planning*
- Southern Nevada Water Authority: *Testing the Climate Resilience Evaluation and Awareness (CREAT) Tool*

- ***The relationship between the change in climate and the change in water availability is not linear. Therefore, climate projections alone do not provide adequate information for good decision-making.*** This is because small changes in precipitation can turn into big changes in flows available for capture, and warmer temperatures will have different impacts depending on the hydrologic situation. Many of the utilities interviewed for this project found that a hydrologic model is vital for translating and understanding the broader implications of climate change for their agencies, in terms of key aspects such as changes in flows and demand.

- ***Planning methods and tools need to allow utilities to plan for more than one future.*** As water agencies began considering climate change in their planning, many found that planning for multiple futures is the key to preparing for the decades ahead. Agencies have begun using planning methods that identify a set of management actions to meet the needs presented by a range of plausible futures (i.e., are robust across plausible futures). Methods used in the case studies examined include scenario planning and robust decision-making, and tools include the Climate Resilience Evaluation and Awareness Tool and decision-scaling.

- ***Public involvement is now a top priority.*** Many agencies interviewed noted the importance of bringing their various internal agency departments, governing board members, and/or customers along for the whole decision-making process rather than just informing these stakeholders of the recommended plan at the end of the planning process. Benefits of stakeholder involvement range from early support for a planning approach to a better understanding of customer values.

To access the products developed as part of this white paper, please click on the links below:

- Introduction
- Case studies
- Appendix A: A Decision Support Planning Methodology Fact Sheet
- Appendix B: Project Objectives, Background, and Methodology

Introduction

Climate change is proving to be one of the greatest challenges facing water utilities as they plan for the future, adding a new source and level of complexity to their decision-making. Many water utilities are now familiar with the wide range of climate projections for their regions. Some have conducted assessments of their own vulnerabilities and discussed the importance of adaptation strategies such as flexibility and diversity. However, a significant barrier for many agencies is determining how to incorporate highly uncertain climate information into decision-making. Specifically the challenge is how to move away from the deterministic thinking found in traditional planning methods in order to make climate-informed decisions.

Climate Change and Planning

Climate change challenges the fundamental principle of traditional planning, which assumes that *if your plan performs well under historical climate conditions, it will perform sufficiently in the future*. Traditional planning methods often rely on historical, recorded data to represent the breadth of conditions a water system will experience in the future, presuming that a region's climate and watershed conditions do not change over time. Planning using only historical hydrology is not a bad or wrong way to plan. With the expectation that climate change impacts will ramp up over time, the use of long-term, up-to-date historical hydrology will continue to play a vital role in water utility planning, particularly in the near-term (about 20 years or less).

In the long-term, however, planning with only historical hydrology data has certain limitations that should be recognized. For instance, using the historical record to represent future conditions assumes the range and pattern of weather and hydrologic variability will be the same in the future as it was over the period of record. Even with a long historical record, only part of the full range of natural variability is represented. Traditional planning also assumes that the average climate conditions do not change over time. Climate change fundamentally challenges these assumptions and pushes water planners to look for different ways to approach long-term planning.

Incorporating climate projections into planning is part three of the four-part process the Water Utility Climate Alliance (WUCA) identified as a common aspect in the pursuit of climate adaptation. Described in detail below, these are not meant to define the only or exact steps of climate adaptation, but rather to help utilities understand the part of the process in which they are engaged and what else can be pursued to adapt to climate change. Each aspect of this process is in itself a climate adaptation action:

- ***Understanding*****:** Utilities develop an understanding of climate science, climate change projections, techniques for downscaling projections to regional scales, and the capabilities and limitations of the science for applied uses. Understanding is also a fundamental outcome for each step in the adaptation framework, as it continuously evolves and expands as utilities progress through or revisit these steps.

- ***Assessing***: Utilities use the understanding gained in the first step to perform analyses aimed at identifying potential impacts on their water systems from climate change and to better appreciate vulnerabilities to future climate changes.

- ***Planning***: In light of the looming challenges of climate change, utilities begin incorporating climate science and assessments into water utility planning and identifying adaptation strategies. This step leads utilities to examine the robustness of their planning methods, models, data, and fundamental system assumptions, and often requires additional assessments and research to support planning needs.

- ***Implementing***: Utilities make decisions and implement actions aimed at adapting to climate change and reducing system vulnerabilities. Actions depend on the planning outcomes and can range from pursuing new research to setting new policy to investing in new infrastructure.

This white paper, based on interviews with 13 water agencies worldwide (Figure I.1), shares insights into how and why water agencies are modifying their planning and decision-making processes as they begin the process of incorporating climate information.

Figure I.1. Location of interviews.

A Collaborative Project

WUCA and the American Water Works Association (AWWA), in coordination with the Water Research Foundation (WRF) and the Association of Metropolitan Water Agencies (AMWA) are working together, on this project and others, to solve the issues that are challenging water agencies today and in the future. These professional organizations teamed up to ensure that this white paper engages a wide range of professional groups in thinking about how to make climate-informed decisions, has a high level of peer review, and is both applicable and available to a wide audience. Funding for this white paper was provided by WUCA and the Water Industry Technical Action Fund managed by AWWA.

All four organizations have resources that support water agency climate-related actions.

WUCA is a coalition of 10 of the largest water providers in the United States (see Figure I.2).[1] Together, they supply drinking water for more than 43 million people in the United States. It was formed in 2007 to better understand the effects of climate change on water-related infrastructure and water resource supplies. WUCA provides leadership in assessing and adapting to the potential effects of climate change through collaborative action. The coalition seeks to enhance the usefulness of climate science for the adaptation community and to improve water management decision-making in the face of climate uncertainty.

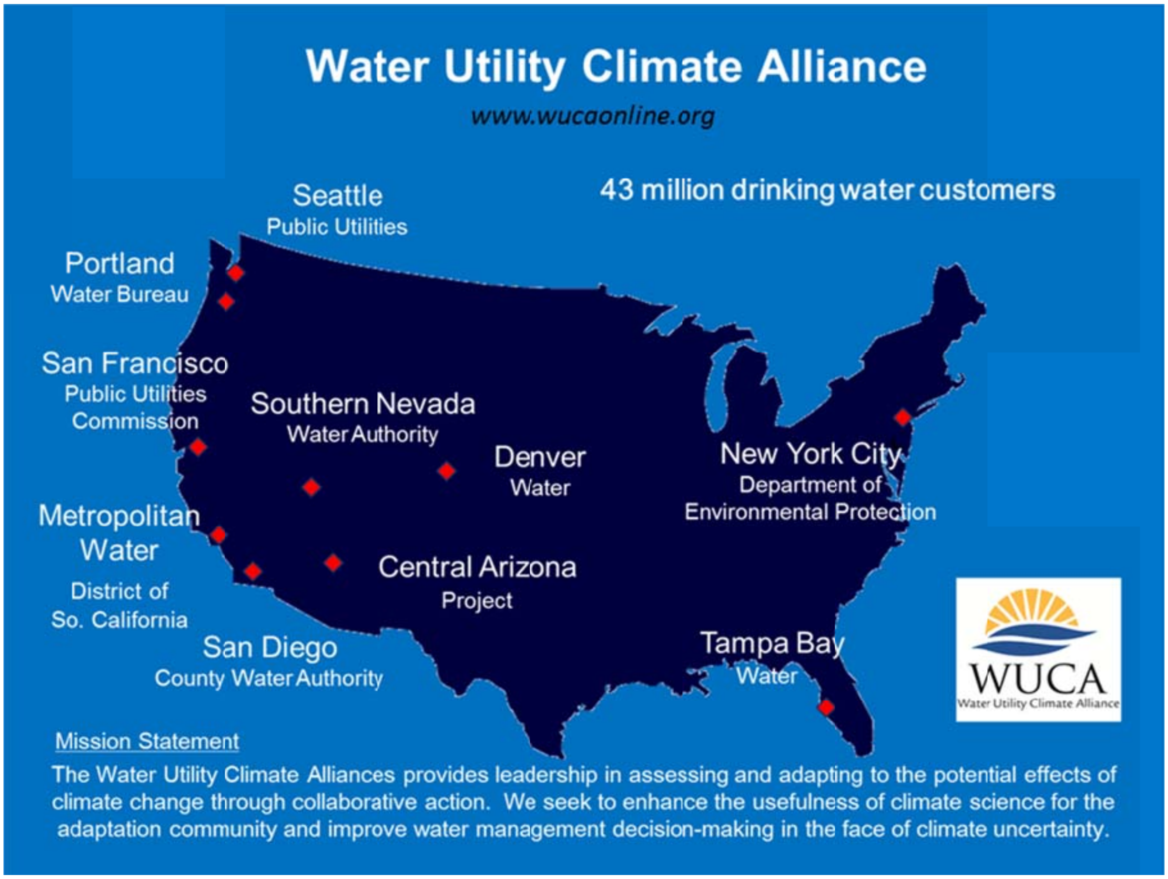

Figure I.2. WUCA member utilities and locations.

1. WUCA member utilities include the Central Arizona Project, Denver Water, the Metropolitan Water District of Southern California, the New York City Department of Environmental Protection, the Portland Water Bureau, the San Diego County Water Authority, the San Francisco Public Utilities Commission, Seattle Public Utilities, the Southern Nevada Water Authority, and Tampa Bay Water.

In addition to examining how utilities are changing decision-making practices due to large future uncertainties, the coalition has published two white papers: *Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning*, and *Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change*. Along with the release of this white paper, WUCA is also releasing another white paper, *Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments*. This companion white paper documents the experience of four utilities as they worked collaboratively with climate scientists to co-produce actionable science. All three white papers are available at http://www.wucaonline.org.

AWWA, established in 1881, is the largest nonprofit, scientific and educational association dedicated to managing and treating water, the world's most important resource. With approximately 50,000 members, AWWA provides solutions to improve public health, protect the environment, strengthen the economy, and enhance our quality of life. AWWA's *Resource Communities* is intended to keep the water industry *in the know* about tools, issues, and developments related to climate change. Visit http://www.awwa.org and select "Resource Communities" for more information.

WRF is an internationally recognized leader in water research dedicated to advancing the science of water by sponsoring cutting-edge research and promoting collaboration. WRF research provides industry insights and practical solutions to the most complex challenges facing the water community today and into the future. WRF has developed a number of publications on potential climate change impacts on water utilities, including an Executive Toolkit, a Media Library, Fact Sheets, Vulnerability Assessments, Adaptation, Mitigation, and Communication. This information can be accessed at http://www.waterrf.org/knowledge/climatechange/Pages/default.aspx.

AMWA is an organization of the largest publicly owned drinking water systems in the United States. AMWA's membership serves more than 130 million Americans – from Alaska to Puerto Rico – with safe drinking water. Adapting to climate change is a particularly important issue for maintaining water system resilience, and AMWA has consistently raised awareness in Washington, DC, about water utility challenges in the face of a changing climate. AMWA also advocates for actionable information and science to support utility decision-making. AMWA regularly communicates with members about climate-related policies, initiatives, and adaptation strategies to support resilient, sustainability utilities. To access information about AMWA climate-related activities, please access http://www.amwa.net/resilience-climate-adaptation.

About this White Paper

This work was originally designed to identify the modifications needed to ensure Decision Support Planning Methodologies (DSPMs), the analytical methods used to support decision-making, address future uncertainty of all kinds. However, as part of the interview process, we found that agencies are changing more than just their long-term planning methods; they are also changing how they work collaboratively with their communities, how they handle probabilities in planning, and how climate information is being incorporated into operational and capital planning decisions. Because of this new information, the project shifted from focusing exclusively on how utilities were changing their long-term planning processes and expanded to illuminate how agencies are changing all aspects of their decision-making processes to ensure they produce climate-informed decisions at all levels.

White Paper Organization

Thirteen illustrative case study stories are shared here to provide pragmatic information on what has and has not worked for others as they incorporate climate change and climate data into their decision-making efforts. Each case study story focuses on a single aspect of how that agency is incorporating climate change into their planning process. It is not meant to detail all climate adaptation activities happening at the organization. Some of the case studies are short and provide a brief snapshot of a climate adaptation story, while others provide an in-depth examination of an important modification to or a completely new decision-making method. Each case study starts with a brief description of the decision examined and is followed with background information that provides context for that decision. The case studies conclude with an overview of lessons learned.

Two appendices are also included. **Appendix A** provides a simple overview of the planning methods and tools (Decision Support Planning Methodology Fact Sheets) discussed in the case studies, including those commonly used in the past as well as emerging methods. A fact sheet frame is utilized to make the review easy. **Appendix B** provides an overview of the project methodology, including a summary of a survey conducted by WUCA, AWWA, AMWA, and WRF that preceded this project.

Water Corporation of Western Australia: Planning for Significant Climate Change with "Security through Diversity"

Decision Examined: Climate-Independent Water Supply Planning

The Water Corporation of Western Australia (Water Corporation) is known both nationally and internationally as a leader in planning for climate change; it is often considered the "canary in the coal mine" for others in the water-supply industry because of the significant climate impacts Western Australia is already experiencing.

> *Western Australia has seen climate change happen faster and earlier than almost anywhere else on the planet. In the last 15 years, the water from rain into our dams has dropped to one-sixth of what it used to be.*
>
> Ms. Sue Murphy,
> Chief Executive Officer of the Water Corporation

In this case study, we share the lessons learned from the Water Corporation, one of the first water agencies to plan for a climate-independent water supply – a supply that is dependable in the face of climate variability. This case study examines the Water Corporation's decision to:

- Plan for larger climate variability, while scientists are debating whether the climate is changing
- Proactively design a system that incorporates communities' values, as identified through more than 10 years of stakeholder engagement, which included changing individual water-use patterns and values statewide
- Develop a climate-independent water supply for a broad, complex water supply system centered on Perth, the capital city of Western Australia, which serves 1.7 million people.

The Decision Background

The Water Corporation is the principal supplier of water, wastewater, and drainage services to hundreds of thousands of homes, businesses, and farms in Western Australia (see Figure 1.1). The utility is also the primary provider of bulk water to farms for irrigation in some areas. The utility currently manages assets with a replacement value of $34 billion (Australian dollars) to

Figure 1.1. The Water Corporation serves most of Western Australia.

Source: http://educonsultancyservices.com/newedu/wp-content/uploads/2014/09/mapa-australia1.gif.

deliver water services across the entire 2.6 million square-kilometer (1 million square miles) expanse of the State of Western Australia. The private sector handles about 90% of the Water Corporation's capital expenditure program while alliances are used to good effect for major construction projects and operational and maintenance programs.

The Water Corporation is one of the State's largest state-owned businesses, accountable to one shareholder, the State Minister for Water. The majority of any financial surplus created as part of the utility's operations is returned to the government as a dividend to contribute to the development of Western Australia, with the remainder reinvested in capital works.

In 1995, following the prolonged worst drought on record, the Water Corporation asked, "Is this a drought period or is our climate changing?; and, Will the climate return to how it was during the wetter 1950–1970 period?" These questions spawned a large internal agency and community-wide debate centered on understanding whether Western Australia's climate was in fact changing, or if this was an increase in variability within the region's historical climate conditions.

While the scientific community researched these questions, the utility decided to plan and prepare for a much wider range of climate variability than experienced in the past. This resulted in an acceleration of planned investment in traditional water sources such as dams and groundwater.

Then 2001 saw the onset of a sudden, devastating drought that kicked off Perth's driest period on record. There was a real risk of needing to apply severe watering restrictions that would have been devastating in Perth where long hot and dry summers are the norm. Recent big investments in water supply infrastructure had increased the city's supply; however, this was now severely limited by the lack of rainfall and still in a precarious balance. The Water Corporation launched into a major planning effort that eventually transformed the approach to water supply while demand-side planning initiatives such as water use and public awareness were advanced in parallel. This work changed the way the community valued water, no longer taking it for granted. A quick and highly successful measure was to bring in two-days-per-week rostering of home garden watering to reduce demand. It is believed this measure avoided more severe restrictions later. With a significant reduction in surface runoff, the Water Corporation increased its groundwater extraction. However, Perth's shallow aquifers were already overdrawn and were not a long-term solution. At this time recycled water and desalination rose to the top of the list for new water supply opportunities to address long-term needs.

In order to incorporate climate uncertainty into their planning decisions, the Water Corporation adopted Scenario Planning. For example, one scenario examined what would happen if in-flows to reservoirs were to stop completely, while another scenario examined how water supplies would fair if groundwater allocations required significant curtailment. As part of the Scenario Planning process, the Water Corporation adopted a "Security through Diversity" objective. This produced a change of direction toward more diversified, climate-resilient water sources, preparing a number of large source options for development in parallel, boosting water use efficiency across all communities and sectors, and pursuing much greater recycling of water.

Starting in 2002, the Water Corporation also engaged the community as never before. A series of workshops across the state and a final government-led symposium in the Parliament House, Perth, culminated in the State's first water strategy, released in early 2003. The strategy called for strong community, government, and industry partnerships to ensure a sustainable water future. Its initiatives included rebates to increase purchases of water-efficient products, higher prices for higher domestic water consumption, and help for the industry to identify and implement opportunities to save water.

As a result of Scenario Planning, the Water Corporation decided to proceed with building the State's, and Australia's, first major seawater desalination plant. The Water Corporation also reached out to Orange County, California, to learn how this county had worked with its community to build support for indirect potable reuse in groundwater replenishment programs, recognizing that reuse might need to be added to the "Security through Diversity" plan sometime in the future.

Building a desalination plant was a high-risk choice for both the Water Corporation and the government. There were perceptions elsewhere in Australia that desalination was too expensive and the climate was not really changing.

In late 2006 the Perth Seawater Desalination Plant, constructed just south of Perth, began producing 45 billion liters (11.89 billion gallons) of fresh drinking water a year, approximately 17% of Perth's water supply. Five years later a second plant was completed about 95 miles south of the first plant. With a doubling of its initial capacity, it produces up to 100 billion liters (26.42 billion gallons) per year so that both plants combined are supplying almost half of Perth's drinking water needs. Both plants were fast tracked and sourced their energy from wind generation, and now provide base-load supply to 1.7 million people every day.

The Water Corporation then moved on to its next major sustainable water source – groundwater replenishment. Following a successful three-year trial, a major scheme is now under construction. It will highly treat already-treated wastewater and inject it into a deep aquifer for storage and eventual abstraction of an equivalent volume. By late 2016 it will be producing 14 billion liters (3.70 billion gallons) of potable water per year to take the Perth-based supply system closer to a target of becoming fully drought-proof by 2022. It is anticipated that this process, when expanded, will provide 20% of the city's drinking water needs by 2060. This project, as well as the two seawater desalination plants, achieved fast tracking through comprehensive, innovative stakeholder engagement programs that are a study in themselves.

Meanwhile, the Water Corporation rolled out programs across the state to improve water-use efficiency and drive down demand. These included retrofitting low water-use fittings in thousands of homes, large-scale installation of "smart" meters, and pressure reduction for supply schemes. These helped to reduce average per capita consumption in Perth alone by about 31% in 13 years. A parallel program to reduce water use by businesses and industries has saved about 46 billion liters (12.15 billion gallons) of water since it began in 2007.

By 2009, the Water Corporation had developed a new comprehensive water plan, Water Forever: Towards Climate Resilience (Water Corporation, 2009). The overall planning goal was to develop a portfolio of options to manage the utility's demand-supply balance through to 2060. The strategy calls for further reducing water use by 25%, increasing wastewater recycling to 60%, and developing new sources of supply.

Another key planning assumption in the Water Corporation's plan (2009) is that Perth's population will be 3.1 million by 2060. Because population growth presents another large future uncertainty, the Water Corporation decided to apply a 15% variation to the projected growth rates to create a plausible range of high and low supply-demand forecasts. The utility also selected three potential levels of water savings and demand reduction levels by 2030. The Water Corporation used these data in combination with climate projections to create three planning scenarios:

- A best-case scenario, with higher rainfall, lower population growth, and lower per-person water demand
- A middle-case scenario that includes water-efficiency initiatives, mid-range efficiencies, and the adapted climate change projection based on a 20% decline in rainfall by 2030
- A worst-case scenario, with lower rainfall, higher population, and higher per-person demand.

The most significant lever for change across the three scenarios is the degree of implementation of additional water-efficiency initiatives (i.e., small changes in water-efficiency measures can have a significant effect on the need for new sources). However, once efficiency measures have been invested in, they are not available as a tool to reduce demand further.

Scenarios that looked at the best-case, middle case, and worst case, similar to the one used for the 50-year plan, were also used for planning purposes to update a 10-year investment plan. Major components of the Water Corporation's 10-year plan include:

- Relying on deeper groundwater aquifers and reducing reliability on superficial aquifers to reduce impacts on wetlands and lakes
- Replenishing deep aquifers in Perth using highly treated recycled wastewater (advanced treatment plant under construction)
- Doubling the capacity of the Southern Seawater Desalination Plant to offset the declining inflow to dams (completed)
- Continuing to conserve water while preserving outdoor lifestyles and continued growth

- Increasing the use of wastewater recycling for industry, public open spaces, and agriculture
- Preserving existing dams to store water from new sources in years of low inflow.

Today, as a result of making bold decisions that reflect a focus on supply diversity, Western Australia's water supplies are becoming more climate-independent under the "Security through Diversity" banner.

Lessons Learned

The Water Corporation shared the following insights into their experiences in planning for an uncertain future:

- Today, everyone has an opinion on water. It is crucial to a water plan's success to bring together the utility, government, and community – no water supply plan will succeed without doing this.
- Now that people in Western Australia pay more for higher water use, they value it more, and use less of it.
- Aligning the political process with a clear vision for water supply is critical to success. The Water Corporation benefited greatly by having the leader of state government as a champion.
- Take advantage of a crisis. The dry years helped bring the community together to discuss water and its social values.
- When the Water Corporation spoke about climate change and current and future scenarios, they did not say, "This is it, this is the future hydrology we need to plan for." Instead they said, "This is a possible representation of what future hydrology could be, and this is how we think we should prepare our water supply, in case it is." This approach kept the Water Corporation from fighting over what is or is not known with certainty and from having to agree on what the future will be. Instead, the Water Corporation could focus on preparation.
- It took 10 years of community engagement to build a water supply plan that the community supported. The Water Corporation worked hard during this time to maintain and increase community trust in the organization to deliver the right water supply outcomes.

- The media has an important role to play in enhancing the community engagement process through constructive and informed debate.
- The Water Corporation brought the community along through education, so if the community did not support their choices, at least they understood them.
- Be prepared to listen. This is actually much more important than preparing what you want to say, and much harder.
- Remember, you are not alone. Most water agencies are facing similar problems. Look to them for ideas.

Learn More

We encourage readers to learn more about the Water Corporation and their path to water independence. Please find these resources to download online at http://www.watercorporation.com.au/about-us/planning-for-the-future.

Additional resources include:

Bureau of Meteorology and CSIRO. 2007. New Projections for Australia's Changing Climate. October 2. Sydney Australia. Available: http://www.csiro.au/Organisation-Structure/Divisions/Marine--Atmospheric-Research/ClimateChangeInAustraliaReport.aspx.

CSIRO. 2007. Climate Change in Australia: Technical Report 2007. CSIRO, Australian Bureau of Meteorology. October 14. Available: http://www.csiro.au/Organisation-Structure/Divisions/Marine--Atmospheric-Research/Climate-Change-Technical-Report-2007.aspx.

Mercer, P. 2014. How Australia's Perth is Battling a Water Crisis. BBC News. June 16. Available: http://www.bbc.com/news/world-asia-27225396.

Water Corporation. 2009. Water Forever: Towards Climate Resilience. Summary. October.

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About Our Interviewee

Mr. Mark Leathersich is General Manager Acquisition for the Water Corporation. During development of the planning process described above, he was the Manager of Infrastructure Planning at the Water Corporation.

Denver Water: Moving to Scenario Planning

Decision Examined: Moving from Traditional to Scenario Planning

Denver Water has historically relied on traditional planning methods to make decisions regarding future water supply and conservation programs. Under this traditional framework, Denver Water developed one scenario of how the future would look based on historical climate data and expected population growth. They then projected the future demand for water and developed a set of management actions that could be used to meet these demands. In 2002, Denver Water experienced both the driest year and the worst Colorado wildfire on record. These two events, as well as Denver Water's increased understanding of potential climate impacts, led them to conclude they needed to start planning for more changes and simultaneous crises in the future.

In this case study, we examine Denver Water's change from using traditional planning to scenario planning for long-term water supply planning.

The Decision Background

When Denver Water began to explore alternative decision frameworks, they considered using both robust decision-making (RDM)[1] and scenario planning. The utility ultimately decided to go with scenario planning because it was a more subtle change from traditional planning and could be easily understood at the utility governance level.

The modeling and data requirements associated with RDM were also a deciding factor. Scenario planning allowed Denver Water to take a smaller first step while maintaining transparency and the ability to plan for multiple futures. The process also received support and buy-in at the board level. As a result of Denver Water's success, the State of Colorado also used scenario planning as its foundation for its state planning process. Denver Water is in the process of incorporating RDM methods into their planning process to examine climate change more comprehensively.

1. Additional information on the RDM process is in the Bureau of Reclamation case study on page 18.

The Scenario Planning Framework

To keep things simple, Denver Water identified five future planning scenarios, each representing one primary driver of change (i.e., they have not evaluated combinations of drivers). Maintaining a small number of scenarios has made it easier for Denver Water to integrate scenario planning into their existing integrated resource planning (IRP) process and provides a framework that is easy to explain and understand. Denver Water's five long-term planning scenarios include:

- ***Traditional Future:*** The future is extrapolated from past trends, with limited unanticipated major changes. Population is the biggest driver of change, and environmental and social factors remain stationary.

- ***Water Quality Rules:*** The public demands the highest practical quality of drinking water.

- ***Hot Water:*** A warmer climate is accompanied by more frequent and more severe droughts. Average temperatures increase by 5°F. System yield decreases by 20% and demand increases by 7%.

- ***Economic Woes:*** We experience a long period of economic downturns and slow recovery. Demand does not grow as quickly due to reduced growth.

- ***Green Revolution:*** Environmental values and sustainable living become dominant social norms. Conservation and urban infill increase within the City and County of Denver.

The scenarios provide a straightforward way for Denver Water to examine the wide range of plausible supply needs they may face in the future. A key focus for Denver Water was identifying low-regret strategies that, in the near term, would prepare them for all five long-term scenarios. Some futures could be quite challenging, leaving very few viable no-regrets options. As a result, Denver Water is exploring several new, innovative supply and conservation opportunities and identifying low-cost ways to preserve them. For example, Denver Water could buy properties for potential reservoir sites and obtain right-of-way easements for possible pipelines.

Denver Water is also building additional flexibility into their water supply arrangements with other utilities and service areas. For example, an agreement detailing the amount of water Denver Water will provide a partner in a water reuse project would include clauses allowing changes if climatic or hydrological conditions exceed specific thresholds.

One no-regret option Denver Water identified was teaming up with water providers and legislators to create state legislation to phase out the sale of less efficient bathroom fixtures. The bill was signed into law in 2014.

Lessons Learned

- Planning for multiple plausible futures has been a paradigm shift for Denver Water and is now considered fundamental to developing a robust, flexible and adaptive plan.

- Climate is only one of many drivers of future uncertainty, though it rivals population growth as the biggest future challenge facing the water utility. Population growth, land use planning, regulatory challenges, watershed changes, the economy and more are also considerations in water resources planning.

- Scenario planning is a relatively simple way to consider a wide range of uncertainties (demographic, social, economic, etc.) along with climate change, which allows an organization to focus on planning rather than debating a single vision for the future. Scenario planning is also a familiar idea, making it easy to involve a board and upper management, build organization-wide buy-in, and facilitate group engagement.

- Scenario development led Denver Water to call out assumptions that had become so ingrained in staff members' thinking that they were no longer being recognized. Denver Water shifted away absolutes such as "firm" yield and "build-out" demand. Denver Water used to think that once all the vacant land within the fixed boundaries of its water service area was developed or built out, water use would reach an upper limit. The Green Revolution future encouraged Denver Water to consider the potential for big increases in density, which could dramatically increase both city and county water use in the service area.

- The expanded thinking and analysis brought on by going through the process of developing and planning with scenarios was equally, if not more, valuable to Denver Water than the actual outcomes.

- Scenario planning outcomes take many different forms, from the agreed-upon scenarios themselves to the options identified as needing more research. The process is extremely fruitful because it increases knowledge of system vulnerabilities, underlying assumptions, and what it takes to build organization-wide understanding of long-term planning.

- The most important outcome of the scenario planning process was to identify the potential for a much bigger water portfolio than had been planned for in the past.

- This lead to the investigation of new and innovative supply, conservation, and reuse options that could be used to meet more challenging future conditions than has been planned for in the past.

- A key strategy being used is to preserve options. Scenario planning helped Denver Water recognize how they can invest in new supply or conservation opportunities without fully developing them by preserving options, allowing them to react appropriately in the future rather than fully invest right away. It also allows them to scale and time the development of options. An example is buying land for a potential off-stream reservoir site, preserving this option for future storage without immediately facing the high costs of permitting and construction or the potential of developing unnecessary storage.

Learn More

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Interviewee

Marc Waage leads the water resources planning section of Denver Water, which is responsible for long-range water planning, watershed planning, and planning for climate change adaptation. Mr. Waage also works on technical and policy issues through the Front Range Water Council, the Colorado Interbasin Compact Committee, the Colorado Water and Growth Dialogue, the South Platte Basin Study and the Colorado River Basin Study. Prior to working in water resources planning, Marc directed the operation of Denver Water's extensive water collection system for 20 years. Denver Water is the oldest and largest water utility in Colorado, serving 1.3 million customers.

Bureau of Reclamation: Using Robust Decision-Making in the Colorado River Supply and Demand Study

Decision Examined: Adding Robust Decision-making to the Colorado River Basin Supply and Demand Study

The Colorado River is the single most important source of water in the southwestern United States, providing water and power to nearly 40 million people. However, in recent decades, federal managers and Colorado River water users have become increasingly concerned about the future availability of the river's water supply due to increasing demands, lower-than-expected stream flows, and future climate uncertainties.

In response to these concerns, the U.S. Department of the Interior Bureau of Reclamation (Reclamation) and water management agencies from the seven Colorado River Basin states, the Study Team, initiated the Colorado River Basin Water Supply and Demand Study (Basin Study) to evaluate the resiliency of the Colorado River system over the next 50 years (2012–2060) given a range of potential futures. As part of the Basin Study, robust decision-making (RDM) was selected to augment Scenario Planning as the primary analytic frame.

In this case study we examine why the Basin Study Team decided to use RDM to (1) incorporate uncertain climate assessment data, (2) identify key future vulnerabilities in managing the Colorado River System, and (3) evaluate different options for reducing these vulnerabilities.

The Decision Background

The Study Team initiated the Basin Study due to increased concerns about the future reliability of the river's supply. As part of this study, the Basin Study Team applied a RDM framework to:

- Incorporate climate assessment information
- Identify specific future conditions that make the Colorado River System vulnerable to reductions in water supply and unable to meet regional water delivery objectives
- Develop portfolios of management options reflecting different strategies for reducing imbalances identified in the Basin Study

- Evaluate the ability of management action portfolios across a range of simulated future climate scenarios to reduce vulnerabilities in the Colorado River System
- Identify key tradeoffs across portfolios of management actions.

Initially, the Basin Study Team used Scenario Planning as their primary planning framework. However, they chose to add RDM to the primary planning framework because of the:

- Large number of planning elements that have large uncertainty, including: future temperatures, precipitation, drought frequency and severity, changes in demands, other supplies, technology, land use planning, energy availability and costs, water law issues, and regulations.
- Complexity of data and systems models used in the study. The Study Team used a wide range of data sources and complex simulation models to assess changes.
- Number of stakeholders involved and the requirement to address all of their individual issues.
- Desire to address different questions, i.e., *what are the conditions that are most likely to trigger vulnerabilities?* This was a particularly important consideration. Scenario Planning is able to only evaluate the performance of the system across a small number of futures. RDM, in contrast, by evaluating a large set of futures can credibly address the question, *what management actions are robust across all potential futures?* For this study the Basin Study Team was also interested in identifying the conditions that are most likely to trigger vulnerabilities. For example, is the system more vulnerable to changes in hydrology or changes in demand or a combination of both? The Study Team was also interested in identifying the sign points that indicate that changes are occurring that will require modifications or additional investments to ensure successful management. For example, if reductions in precipitation by 10% trigger vulnerabilities, then they can monitor rates of changes in precipitation and if trend analysis indicates that precipitation rates are getting close to a 10% overall reduction than the Study Team could take actions to change management actions.

The RDM Framework

The RDM decision support planning methodology was developed by the RAND Corporation (Groves and Bloom, 2013). Its application to the Basin Study was novel in the complexity of the analysis and level of stakeholder interaction. Reclamation purposely modified many of the technical terms used in the actual Basin Study report because they found it was confusing to their stakeholders.

RDM is not intended to provide decision-makers with specific decision actions. Rather, the Basin Study Team utilized the RDM framework to:

- Identify specific circumstances that present vulnerabilities to the system's ability to meet supply need objectives, and
- Bring stakeholders together to explore a new decision-making process that will allow Basin Study managers to effectively make decisions across multiple interests and objectives, in the face of an uncertain future.

The RDM frame uses a framework called "XLRM." As detailed in Figure 3.1, the XLRM framework requires decision-makers to develop four model components: information pertaining to uncertainties (X); decisions, options, or levers for managing the system (L); a model that can represent system relationships and responses to changes in temperatures and precipitation (R); and a series of performance metrics (M).

Uncertainties (X)	**Decisions, options, or levers (L)**
▸ Colorado River water demand ▸ Future stream flow or water supply climate drivers ▸ Reservoir operations post-2026	▸ Current management ▸ Four portfolios comprised of individual demand reduction and supply augmentation options
Relationships or models (R)	**Performance metrics (M)**
▸ Colorado River Simulation System (CRSS)	▸ Water deliveries (9 metrics) ▸ Electric power resources (2 metrics in 3 locations) ▸ Water quality (1 metric in 20 locations), ▸ Flood control (3 metrics in 10 locations) ▸ Recreational resources (2 metrics in 13 locations) ▸ Ecological resources (5 metrics in 34 locations)

Figure 3.1. XLRM framework with a summary of uncertainties, policy levers, relationships, and metrics.

Source: Groves and Bloom, 2013.

Four ***supply scenarios*** (X in Figure 3.1) were developed each using a different source of information for projecting future streamflow. Each supply scenario included a set of individual time series of stream flows *traces* for the 2012–2060 time period. The historical scenario had 103 traces, the Paleo record had 1,244, the Paleo/Historical Blend had 500, and the Future Climate Downscaled general circulation model (GCM) projection had 112 for a total of 1,959 traces. The first supply scenario is based on data from the recent historical record and included 103 traces. Each trace within the historical scenario is a repeat of the historical record (from 1906 to 2007) with a different starting year. The second and third scenarios, containing 1,244 and 500 traces, are based on stream flow estimates derived from paleo-climatological proxies, such as tree-ring data. The fourth scenario, containing 112 traces, is derived from the projections of future climate conditions from 16 GCMs (CMIP3) and three global carbon emissions projections translated into streamflow by the VIC hydrology model.

Six ***demand scenarios*** (X) were also developed. Each demand scenario reflects a single projection of future demand. Collectively, the demand scenarios span a wide range of future demands for water from the Basin Study, including (1) current projected growth, (2) slow growth with an emphasis on economic efficiency, (3) rapid growth because of economic resurgence, (4) rapid growth with current attitudes toward human and environmental values, (5) enhanced environment because of expanded environmental awareness, and (6) enhanced environment because of increased stewardship with a growing economy.

Two ***reservoir operations scenarios*** (X) were developed, reflecting different assumptions about how the system would be operated beyond 2026, when the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lakes Powell and Mead are set to expire. In one scenario, the guidelines are extended; in the other, they revert to the “No Action” Alternative as stipulated in the 2007 Interim Guidelines Environmental Impact Statement. Continuation of the Interim Guidelines means that the continuation of mandatory, agreed-upon Lower Basin shortages will help maintain storage in Lake Mead if the lake elevation drops below 1,075 feet and Lakes Powell and Mead would continue coordinated operations.

When evaluating the performance of the system, the Basin Study Team combined the individual traces from the supply scenarios, with the six demand scenarios and two reservoir operations scenarios, creating 23,508 individual futures. Each future represents a different combination of projected stream flow, potential demand, and reservoir operation management.

For each of the futures described above, the Basin Study used the CRSS model (R) to evaluate the vulnerability in the Colorado River system under the “current management baseline (L) and four additional portfolios comprised of individual demand reduction and supply augmentation options (L).” This analysis was used to address several key questions: (1) Under which futures does the Basin Study not meet water delivery objectives?; (2) Which future conditions lead to these vulnerabilities?; (3) How do different portfolios of options reduce these vulnerabilities; and (4) What are the cost and performance tradeoffs among different portfolios?

The Basin Study Team defined vulnerabilities based on the performance metrics (M) described in Figure 3.1. For example, the Basin Study Team evaluated the reliability of the Upper and Lower Basins based on two key water delivery metrics: Lee Ferry deficits and Lake Mead pool elevation. These metrics were evaluated across all 23,508 traces, representing future uncertainty in two ways: (1) the percentage of traces in which management objectives are not met at least once during the time period, and (2) the percentage of all years in the simulation in which outcomes did not meet objectives. This analysis shows how vulnerable the Current Management approach (L) is over time with respect to the various performance metrics.

To identify the external conditions that lead to the projected vulnerabilities, the Basin Study Team looked for a set of future conditions that best represents the vulnerable traces, with respect to each performance metric. For example, using RDM vulnerability analysis techniques and statistical summaries of stream flow at Lee Ferry, the Basin Study Team found that the Upper Basin is susceptible to a Lee Ferry deficit when two future conditions occur simultaneously: (1) long-term average stream flow declines beyond what has been observed over the past century (more than 8%), and (2) the flow for the driest eight-year period of consecutive drought is less than about 11 million acre-feet (MAF). Traces that meet both of these conditions – called *Declining Supply* vulnerable conditions – lead to a Lee Ferry deficit 87% of the time.

Using the same approach, the Basin Study Team found that Lake Mead pool elevation is vulnerable to conditions in which supplies are simply below the long-term historical average. Specifically, when long-term average stream flow at Lees Ferry falls below 15 MAF, and the flow during the driest eight-year period of consecutive drought is below 13 MAF occurs. These conditions, deemed *Low Historical Supply* vulnerable conditions, describe 86% of all traces that lead to unacceptable results with respect to Lake Mead elevations.

Next, the Basin Study Team evaluated a wide array of different supply-augmentation and demand-reduction options that could improve system performance and reduce vulnerabilities. Based on this evaluation, the Basin Study Team developed four prioritized portfolios made up of individual supply-augmentation and demand-reduction options (L).

The Basin Study Team used CRSS to evaluate how each portfolio performed across the wide range of futures identified, as well as under particularly vulnerable conditions. CRSS estimated the future performance of the system under the different portfolios with respect to the performance metrics presented in Figure 3.1 above.

This CRSS assessment included the development of rules within the model that trigger the implementation of options under each portfolio only when conditions indicate a need for them. The Basin Study Team based these rules on a series of “signposts” developed for six different water delivery metrics. Signposts specify a set of observable system conditions – both for the hydrologic and managed systems – and thresholds that indicate that vulnerabilities are developing. During a simulation, the model monitors the signpost conditions. If any thresholds are crossed, then it implements options from the top of the portfolio option list. In this way, the dynamic portfolios seek to more realistically mimic how the various options would be implemented over time in response to system needs.

In addition to evaluating the effectiveness of the portfolios in reducing vulnerabilities, the Basin Study Team assessed implementation costs within the model. Results show a wide range in costs across the traces. One of the advantages of the RDM approach is that it allowed Reclamation to combine the cost and vulnerability results together to draw out the distinctions and tradeoffs among the four portfolios.

Reclamation and other agencies are already collecting key information (e.g., streamflow, climate conditions, and reservoir status) that they can use to help assess options and strategies that may be implemented in the future. Building this information into systematic and recurring system assessments will enable managers to better understand how conditions are evolving, and plan additional management options accordingly.

Lessons Learned

One of the most useful elements of the RDM methodology is its ability to evaluate how alternative water management strategies would perform across a wide-range of plausible future conditions and identify those strategies most robust to these futures. To do this, RDM evaluates the performance of water management strategies across thousands of futures and generates large quantities of data. RDM then includes the tools to analyze the large amounts of data and identify the key information to inform decision-makers. This reduces the need for decision-makers to make choices about the specific futures they must plan for. It also avoids the requirement that all future conditions be assigned a probability – which can be difficult and contentious. Lastly, RDM supports an iterative planning process in which increasingly refined management strategies can be developed and tested. While RDM provides a useful framework for planning, it requires sophisticated computer simulation and analysis.

Reclamation feels that the RDM decision-support planning methodology has been successful. The RDM framework has achieved buy-in from the seven Basin states, and has identified elements that threaten long-term water availability given future uncertainties in the Basin. However, because of the highly political nature associated with decisions regarding Colorado River water supply, additional outreach and support need to be developed before RDM is accepted as the primary model for decision-making. Accordingly, Reclamation and the seven Basin states are considering further exploration of this framework.

As part of moving forward with using RDM, Reclamation would propose to serve as the primary administrator of the framework, underlying simulation model, and analysis. This fits well with the overall role of Reclamation during the Basin Study – to provide coordination, guidance, and technical expertise to the Basin States. In addition, Reclamation has the technical expertise and computing capabilities necessary to maintain and update the framework and associated analyses.

As part of the RDM process, Reclamation and the Basin States would need to coordinate monitoring efforts so that the conditions that lead to vulnerabilities (as determined through the RDM process) can be identified on the ground. Once identified, these conditions could ultimately trigger the implementation of various management options.

Learn More

For more information on the RDM framework and analysis, visit: http://www.rand.org/jie/projects/colorado-river-basin.html.

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Interviewee

James Prairie is a Hydrologic Engineer with Reclamation’s Upper Colorado Region. His present work activities include research and development of mid-term operational and long-term planning models for the Colorado River, hydrologic and salinity analysis, and maintaining datasets of historical and projected natural flow, salt concentration, Upper Basin consumptive use, and projected demands within the Colorado River System.

California Department of Water Resources: Two Short Stories

1. Adding robust decision-making (RDM) to a scenario planning process
2. Forming a Climate Change Technical Advisory Group (CCTAG)

Decision 1: Adding RDM to Scenario Planning for the California Water Plan

The California Department of Water Resources (DWR) decided to add RDM to their traditional scenario planning process as part of updating the California Water Plan. DWR determined that the use of scenarios without the additional analytic capability of RDM would leave them with unanswered questions about the importance of climate change relative to other planning risks. As part of this particular decision process, DWR wants to answer: "*Is climate change the uncertainty we need to worry about or is it something else?*"

In this case study, we examine DWR's decision to add RDM to their most complex and highest priority planning process – the California Water Plan.

Decision 2: Forming a CCTAG

DWR decided they needed to develop a standard approach for integrating climate information into their planning processes. As a first step toward developing this approach, DWR reviewed past planning documents to determine how climate projections have traditionally been characterized and planned for. Based on the review, DWR decided it was necessary to seek external scientific expertise to assist them in developing a new approach. As a result, DWR formed the CCTAG as an outside expert panel for advice on climate model and climate change scenario selection.

The Decision Background

DWR's major responsibilities include overseeing the statewide process of developing and updating the California Water Plan; protecting and restoring the Sacramento-San Joaquin Delta; regulating dams, providing flood protection, and assisting in emergency management; educating the public about the importance of water and its proper use; providing technical assistance to service local needs; and planning, designing, constructing, operating, and maintaining California's State Water Project.

DWR undertakes analyses to meet these responsibilities through a combination of two rather different types of analysis: general planning studies, which describe future conditions, and project-specific studies, which provide more specific information related to implementation. This case study examines changes DWR has made to their largest general planning study – the California Water Plan. The distinction between these two types of analyses is made to acknowledge that significant differences exist between studies that focus on specific projects versus studies that consider more general, comprehensive future conditions.

As part of the California Water Plan, DWR decided that the department needed an additional analytic tool to support their planning process that would identify the set of uncertainties that are most likely to threaten the plan's performance. The RDM approach solves for robustness[2] by identifying the set of management actions that perform under a wide range of future conditions. The process also identifies the specific condition and combinations of conditions (scenarios) that can cause the plan to fail. DWR was able to test multiple combinations of low, medium, and high change for both land use and population growth, together with 21 plausible climate change scenarios, to identify threats. The department found that climate change was the most important factor. Even in the scenario that combined high population growth with high land-use change, climate change was the factor that was important regardless of the plausible future climate conditions. This was crucial information for DWR as they now know that their critical question of concern is, "*How will climate conditions change?*"

As part of determining if they need a CCTAG, DWR concluded that there was some consistency in past planning studies, but that there was much variability driven by the specific project manager and consultant choices that were not necessarily based on scientific reasoning. DWR found that in the past, they considered future climate and hydrology change using four approaches: (1) a scenario approach based on the selection of a limited number of general circulation model simulations, (2) an ensemble-informed approach based on 112 available downscaled simulations from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007), (3) relative change approaches that apply perturbations to historical data to simulate the potential impacts of climate change, and (4) qualitative approaches.

DWR is developing a "toolbox" and guidance of assessment approaches. The toolbox includes a range of analytic approaches, as different planning settings may require different tools. Some people at DWR were hoping for a cookbook on how to incorporate climate projections step by

2. Decisions that outperform other courses of action regardless of the future climate probability assumptions.

step, at least for some planning settings. However, the climate change development team found that they need to think about the resources available to them when selecting approaches. The review of past studies analyzed how DWR characterized future climate and how to carry that through into the future. DWR did not focus on the decision-making side in this study.

DWR found that consistency in the basic data used for assessments and decision-making is important to ensure that decision-makers are getting information across projects that is comparable, consistent, and meets a high level of scientific rigor and quality. DWR did not redo any of the project-specific assessments to determine if a different approach would have changed the decision, primarily because in this study they focused on how to select climate variables, not on the decision-making process itself. However, they do believe that it is important for future decisions to all use a similar assessment approach. Based on their review, DWR determined that they needed to seek external scientific expertise.

Lessons Learned: Adding RDM

- RDM does take more technical resources. It uses a sophisticated model so that the development of scenarios can be automated, which means users need more time to set it up and more knowledge of analytical methods to make it work.
- RDM also requires more thought regarding study design because there is more information to consider. Would-be users have to decide which data they want to explore and which key points they want to understand. Scenario planning did not identify the factors that are most likely to prevent the selected management actions from meeting the planning objectives. RDM, however, directly identifies those factors.
- RDM requires extensive technical and financial resources; it takes longer to set up and run.
- DWR will release their new water plan in 2015, but RDM’s complexity means that the department must already begin thinking about what to do for 2018 and how to improve the 2015 iteration.
- RDM allows a much wider range of uncertainty to be explored. Uncertainty can be explored along multiple dimensions (e.g., climate, population, land use, others). And the visualization tools developed for analyzing modeling output allow a greater understanding of system vulnerabilities and the key drivers of vulnerability.

Lessons Learned: Creating a Climate Advisory Team

- DWR found that consistency in the basic data used for assessments and decision-making is important to ensure that decision-makers are getting information across projects that is comparable, consistent, and meets a high level of scientific rigor.
- Based on their review, DWR determined that they need to seek external scientific expertise to help determine a consistent assessment approach and to build confidence in their climate assessments in order to use them to make decisions.
- DWR hopes that using an expert panel increases confidence in climate assessments, and will increase the ability of decision-makers to actually make decisions.

Learn More

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Interviewee

Andrew Schwarz is a Senior Engineer in the Climate Adaptation Section at the California Department of Water Recourses. Mr. Schwarz has led climate change planning activities at DWR since January 2013. His efforts include developing regional collaborations and incorporating a wide range of long-term climate change projections as a part of water supply management.

Metropolitan Water District of Southern California: Using Robust Decision-Making to Identify Adaptive Management Triggers

Decision Examined: Using Robust Decision-Making to Identify Triggers for Adaptive Management Decisions

In 2010, the Metropolitan Water District of Southern California (Metropolitan or the district) adopted a 2010 Integrated Resources Plan (IRP) that is based on an adaptive management framework. In order to provide decision support information for making investments within that framework, the district needed an analytical approach that would identify key future trends that the district could monitor to ensure that the plan performs under a large range of future climate conditions as well as other areas of uncertainty. The adaptive management framework needs to identify when additional investments on top of the IRP preferred resource mix would be needed to meet projected demand and most expected increases and changes in demands through 2035.

To address this need, Metropolitan incorporated robust decision-making (RDM) into their planning framework, which included the addition of a quantitative RDM model to their resource planning simulation model. Metropolitan used the RDM approach to identify their system vulnerabilities to changes in climate, demographics, state water plan reliability, and potential changes in production levels. Metropolitan used the outputs from the coupled models to iteratively assess strategies for the adaptive management plan. The information from the models provides Metropolitan with a set of signposts and monitoring requirements that identify when certain conditions are being met that can reduce the IRP's ability to meet stated objectives, thus triggering the need for Metropolitan to consider alternative or additional investments.

In this case study, we examine Metropolitan's decision to bring RDM into their 2010 IRP to support the development of adaptive management in their long-term planning.

The Decision Background

Metropolitan is a large wholesale supplier of water to Southern California and has 26 member agencies that receive all or part of their total water supplies from Metropolitan. As part of development of their long-term IRP, Metropolitan recognized the uncertainty regarding the future concerning climate; demographic shifts, such as whether growth will occur in the cooler coastal regions or in the hotter and drier inland areas; the amount of water that will be reliably available from the State Water Project (SWP); and the region's ability to increase production from groundwater, recycled water, and other locally developed supplies. Because of the complexity of their system and the high degree of future unpredictability, Metropolitan determined that they needed additional planning support to ensure that their resource plan would perform adequately for a number of plausible futures.

Metropolitan uses a resource simulation model, known as IRPSIM, as their primary IRP planning tool. Metropolitan developed and used IRPSIM, a hydrologic system response model, over the last 25 years to evaluate and plan for changes in supply and demand.

Building on a collaborative planning process that originated in the early 1990s, Metropolitan initiated a participatory process in 2008 that involved all of its member agencies, elected officials, and community groups to collectively discuss strategic directions for the future of water supply in Southern California. As part of this process, the group examined current constraints on the Southern California water supply and a wide number of water management options, including water conservation, recycling, desalination, and the construction of a new infrastructure that would make the Northern California water conveyance system (both the SWP and the Central Valley Project) more reliable (MWD, 2010). As part of this process, Metropolitan assembled three different bundles of water management options into the following strategies: *Current Approach*, *Imported Focus*, and *Enhanced Regional Focus*. In the *Current Approach* strategy, Metropolitan and their member agencies would develop future water resources in a manner similar to the path taken following the 1996 IRP and 2004 IRP update. Under the *Imported Focus* strategy, Metropolitan would take a limited and reduced role in developing regional reliability. Metropolitan would focus on implementing an interim and long-term California Bay-Delta solution to improve the reliability of the SWP while also improving the reliability of the Colorado River Aqueduct (CRA). Metropolitan would maintain their existing water management assets and storage but would not seek to develop new assets. Under the *Enhanced Regional Focus* strategy, Metropolitan would take steps to increase their current role in developing regional reliability in anticipation of guarding against an indefinite delay in achieving a long-term California Bay-Delta solution. Metropolitan would take the lead in developing projects and programs to improve the reliability of the SWP and the CRA while maintaining their existing water management assets and storage and developing new assets if needed.

Ultimately, Metropolitan adopted a 2010 IRP strategy that included targeted investments in conservation, local resources, and imported supplies. The 2010 IRP strategy also included a framework for developing alternative or additional supply programs. In order to identify if the IRP strategy would best meet the district's needs, the district needed to evaluate how the IRP strategy would perform under a wide range of future conditions. Metropolitan determined that coupling a quantitative frame that evaluates the robustness of each action to their resource simulation model would provide them with the information they needed to develop a flexible and adaptive plan. RDM was selected, in part, because it incorporates a wide range of possible climate change scenarios without requiring each scenario to be weighted probabilistically. Because their existing modeling with IRPSIM already allowed a great deal of flexibility in adjusting inputs, assumptions, and generating key outputs, Metropolitan was able to incorporate the RDM framework fairly easily into their planning process (Means et al., 2010).

Metropolitan's objective of incorporating the RDM tool was to develop more robust strategies based on identified key vulnerabilities, and to evaluate management actions against a large ensemble of uncertainty-based scenarios to identify key performance tradeoffs. The uncertainties examined include future hydrologic conditions driven by multiple downscaled general circulation model outputs (CMIP3), demographic and economic growth patterns, new regulations and restrictions on supplies, customer responses to various agency conservation programs, and local resource development.

The quantitative modeling framework, coupled with the district's system models, creates an enhanced version of Metropolitan's primary planning model. The model was run over many thousands of cases, representing different combinations of assumptions about future demand, conditions in the California Bay-Delta, climate conditions, local resource yields, and implementation challenges. A statistical cluster analysis[3] was applied to the resulting database of model runs to identify specific scenarios and combinations of scenarios that summarize the types of future conditions under which the IRP core resources strategy would not meet its supply reliability goals. The common characteristics of these scenarios provide Metropolitan with early warning indicators that guide the adaptive management component of the IRP (Groves et al., 2014). For example, one plausible future scenario that would require Metropolitan to modify their IRP resource plan is if retail demand increases disproportionately in hot and dry areas in combination with specific changes in temperature and precipitation in Southern California.

3. Cluster analysis is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters).

Lessons Learned

> *We are fortunate to have had the foresight to develop the system response models over the past decades; if we had to start from scratch it would have taken a great deal of money and been incredibly labor intensive to use RDM.*
>
> Brandon Goshi,
> Manager of Water Policy and Strategy

- Metropolitan had reservations about the technically intensive nature of the RDM approach. Some decision-makers were concerned that the approach was too complex for useful decision-making. Ultimately, RDM proved to be a great value in identifying practical signposts (decision triggers) and monitoring needs that fit well with the adaptive management approach of Metropolitan's IRP.

- Metropolitan's implementation of the RDM framework with the coupled models can be used again in 2015, as part of the five-year IRP update. This is useful to see if the signposts have changed over time.

- RDM model findings indicate that:

  - The range of climate changes identified as part of the climate assessment does not create vulnerabilities to the resource plan in and of themselves; however, climate change coupled with other uncertainties, such as higher than expected demand growth or challenges in maintaining or implementing other supplies, hinders reliability without changes to the IRP strategy

  - Significant loss of local water supply is the single largest threat to the resource plan.

Learn More

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Interviewee

Brandon Goshi has been with Metropolitan since 1994. He is a Manager in the Planning and Development section of the Water Resource Management Group. He and his staff are primarily responsible for the analysis of the integrated water supply and demand planning for Metropolitan's 5,200 square-mile service area. This responsibility includes developing regional water supply and demand projections, defining approaches and strategies for managing uncertainty, and recommending resource implementation and operational strategies.

Inland Empire Utilities Agency: A Comparison of Robust Decision-Making and Scenario Planning

Decision Examined: Comparison of Traditional Scenario Analysis, Probabilistic Weighted Scenario Analysis, and Robust Decision-Making

> *It is not the analytic tool (method) used in decision-making that matters; it is the process.*
>
> Richard Atwater, former IEUA General Manager

In 2006, the Inland Empire Utilities Agency (IEUA) was invited to participate in a National Science Foundation (NSF) study to examine how outputs from a robust decision-making (RDM) analysis compared with outputs from either a traditional scenario planning or probabilistic-weighted scenario planning analysis within the context of water resources planning under future climate uncertainty. These three decision support methodologies were applied to IEUA's 2005 Regional Urban Water Management Plan (RUWMP) to identify if information from the three approaches would result in different decisions.

In this case study, we share insights gathered from IEUA decision-makers as they compared information developed from each of three planning methodologies – traditional scenario planning, probabilistic weighted scenario planning, and RDM – to select a portfolio of long-term water supply management and investment options.

The Decision Background

IEUA develops a RUWMP that is updated every five years. It is the process used by IEUA to decide how to manage water supplies to meet water demands 25 years into the future. Decision-makers at the utility and in the region use the RUWMP to select management actions that will ensure adequate, reliable, and economical long-term water supply. To accommodate anticipated rapid population growth in the coming decades, the 2005 RUWMP planned to increase supplies through an expanded groundwater-replenishment program and a significant increase in the use of recycled urban wastewater. The 2005 plan envisioned increasing groundwater use by 75%, facilitated largely by recharge from reusing about 70,000 acre-feet of recycled water (a more than six-fold increase) by 2025. While IEUA was confident that their plans would perform well under historical climate conditions for any of the nine future scenarios, they had not yet considered (included in the scenarios) potential vulnerabilities from future climate change.

In 2006, IEUA received an NSF grant to study the effect of adding climate change data to the 2005 RUWMP. Two of the primary objectives of the NSF research, which the RAND Corporation conducted, were to (1) evaluate options for reducing vulnerability to supply shortfalls under a range of plausible future conditions, and (2) identify the usefulness of outputs from a variety of Decision Support Planning Methods (DSPMs) for decision-makers (RAND, 2008). The study explored three analytic methodologies: scenario planning, probabilistic-based scenario planning, and RDM.

The RAND study found for their first objective, evaluating options to reduce vulnerabilities from future climate changes, that:

1. The traditional scenario planning method demonstrated that the IEUA RUWMPs would perform well if climate conditions are wetter than current conditions, even with incomplete implementation of the recycling and replenishment goals. If the future climate were drier and warmer, IEUA would not only need to meet its recycling and replenishment goals, but also invest in more efficiency, and possibly allow more recycled-groundwater replenishment to ensure sufficient supply to meet demand.

2. The probability-weighted scenario method suggested that if one believes the probabilities associated with climate assessment data and the IEUA region can meet the utility's recycling and replenishment goals, the current IEUA RUWMP would be sufficient to ensure only a 7% chance of a shortage. This DSPM was rejected by the group very early in the process as they did not believe the underlying probabilistic information.

3. The RDM method was used in two ways: first, as a way to identify the specific elements that create a risk to the plan's success for any of the nine futures (scenarios) developed as part of the traditional planning method and second, as a way to identify elements that pose a risk to success when a wider range of elements is included in examining the future (this technique is described in more detail below). RDM identified declining precipitation, strong effects of climate change on water imports, and greater-than-anticipated declines in percolation as the largest threats to the plan's success for the original nine scenarios developed as part of the 2005 RUWMP. However, when RDM was expanded in order to identify threats for a wider range of over 2000 possible sets of futures (scenarios), the model could not identify a small set of key threats.

At the end of the study, a survey of decision-makers was conducted to identify the usefulness of the different planning analytical methods, the second study objective, in making long-term decisions under high levels of uncertainty resulting from a range of climate projections and various combinations of recycled and replenishment water program sizes. Based on this survey, RDM was identified as providing slightly more useful information than either of the two other approaches because it analyzed strategy options along with climate projections. The probabilistic approach was discarded as the decision-makers had little confidence in the ability of the probabilities to predictably assign likelihoods to different futures. The scenario approach was identified as the easiest for decision-makers to understand.

Based on RDM outputs, decision-makers opted to expand and accelerate their investments in reuse water and groundwater desalination beyond the levels originally selected as part of the 2005 RUWMP. Water planners also indicated that the information derived from the RDM analysis increased their beliefs that they can mitigate and/or manage potential threats. It was unclear to Richard Atwater, General Manager at IEUA during this analysis, if it was actually the process of having an esteemed facilitator (i.e., the RAND Corporation) lead the group through the process, or the outputs, that increased support for the RUWMP.

In addition, IEUA identified two primary drawbacks to using RDM. First, one of the key benefits of using RDM is its ability to identify common elements across future scenarios that will cause the plan to fail. It is important to IEUA to be able to identify a small set of primary threats so that they can identify signposts for future actions (i.e., if these conditions occur, we need to change our plan). However, the expanded RDM identified many threats and IEUA found that identifying a large number of threats to the plan is not particularly useful to them. The second drawback to RDM was that decision-makers found RDM histograms and scatter plots difficult to interpret and needed a consultant to explain their meaning. RDM also requires significant computing power, which is typically beyond the capabilities of most water utilities to perform in-house. At the end of the study period, IEUA chose to use scenario planning for future water planning and not RDM, primarily because it was more difficult and expensive to use and in the end the additional analysis did not affect their final decision.

The RDM Tool

RDM is a powerful mathematical analytic tool. The two primary objectives of RDM are to identify (1) the robust set of actions that allows a plan to succeed regardless of future climate conditions, and (2) the specific set of conditions that will cause a plan to fail. When utilities are unsure what the future will look like it is helpful to identify the set of management actions that are effective across potential futures (i.e., which plans are robust). In addition, knowing what conditions will cause the plan to fail is invaluable as this information establishes signposts and thresholds an agency can use to monitor when conditions are occurring that will cause their plan to fail.

RDM allows the decision community to test many planning inputs and identify the set of management actions that are robust across inputs. Inputs can include any number of demand forecasts, supply enhancement management actions, and potential future climate conditions. Due to the large computational capability of RDM, any number of other planning factors can also be added. For example, changes in economic conditions and land-use regulations were included in the RDM process used as part of the planning process in the Colorado River Plan.

An agency begins the RDM process by identifying the set of inputs that will be tested. A mathematical relationship is then developed that connects each input with the agency's water models. A water model of some kind is necessary to run RDM as the relationship between inputs and changes in water supplies and demands are not linear. Each unique set of inputs defines a specific scenario. For example, demands in year 2025 of 2,000 mgd, with an increase in supply from groundwater of 100 mgd, temperatures increases of 2 degrees, and decreases in precipitation of 5%, represents one simple scenario. Changing any one input, for example, changing demand from 2,000 mgd to 2,500 mgd, creates an entirely new scenario that can be tested in RDM. IEUA used RDM to test over 2,000 different sets (scenarios) of supply, demand, climate, and management actions.

Next, decision-makers identify the objective or performance metrics; the RDM method has the computer capability to solve for more than one objective. For example, cost-effectiveness is almost always one performance metric. Other metrics may include supply reliability, supply adequacy, water quality, and flood control. Once the inputs and the performance objectives have been identified, and the agency is confident that the relationship expressed in the water model is accurate, then RDM tests each set of future elements (scenarios) to identify if the plan can meet the objective(s) under those future conditions.

The RDM process at IEUA evaluated potential threats using two performance metrics: the cost of providing supply to customers (i.e., how much it costs to provide customers with a reliable supply using different management actions, including demand reductions and supply enhancements for the specified demand) and the cost of incurring shortages. The cost of incurring shortages included a number of factors, including costs to customers (e.g., curtailment costs to residential and commercial customers) and costs to the utility (e.g., reductions in income due to a reduction in sales). Based on these metrics, IEUA identified the largest threats in the original scenarios developed for the 2005 RUWMP as declining precipitation, strong effects of climate change on water imports, and greater-than-anticipated declines in percolation. Unfortunately, RDM could not identify common threats when the plan was expanded beyond the original set of scenarios.

The ability of RDM to identify common elements that threaten the success of the plan is one of its key selling points – but IEUA's experience indicates that even RDM cannot always identify common threats. However, when common threats are identified, RDM can be very helpful when looking at futures with large uncertainties. The threats identified can also be used as signposts or trigger points. For example, when percolation rates decline below those anticipated, or reach an identified threshold, the plan may need to be modified. For example, RDM found that IEUA changes in groundwater percolation rates were a serious threat to plan performance under the original 2005 RUWMP scenarios. This information allows IEUA to closely monitor percolation rates and note when they change in ways that will affect the plan. In this case groundwater percolation rates are used as a signpost for identifying when the plan may fail and needs to be revisited.

Lessons Learned

- One of the strengths of RDM is its ability to identify threats to a plan's performance. Threats to the success of the RUWMP are defined as common sets of inputs that significantly increase the risk of plan failure. For example, RDM identified that for the nine original RUWMP scenarios, if future climate conditions are drier, have more frequent and severe extreme precipitation events, and recycling is not available to provide additional supplies, the plan is likely to fail.

- RDM is expensive and computationally intensive and often requires a consultant to run and interpret the results. Utilities can follow the basic principles from the RDM process without using extensive modeling.

- Meeting routinely with all the major stakeholders was the most useful part of the process at IEUA.

- Decision-makers at IEUA found RDM to be a useful methodology to (1) identify elements that threaten the success of the RUWMP, and (2) present climate-related risks in a way that increased decision-makers' understanding and concerns about the likelihood and severity of significant climate effects.

Learn More

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A Framework for Assessing Climate Change Vulnerability and Defining Robust Risk Management Strategies for Water Utilities (Forthcoming, Water Research Foundation).

Richard Atwater can be reached at atwater.richard@gmail.com.

Interviewee

Richard Atwater is the Executive Director of the Southern California Water Committee and former General Manager of the IEUA. Mr. Atwater has worked to increase the region's ability to take effective actions today to meet an uncertain future. His efforts include developing regional collaborations and incorporating a wide range of long-term climate change projections as a part of water supply management.

United Utilities: Three Short Stories

1. Planning beyond the median climate projection
2. Working with regulators to develop flexibility
3. Upsizing storm water infrastructure

In this case study we share three decisions United Utilities has made regarding the use of climate assessment data in their planning processes.

The Decision Background

United Utilities is the United Kingdom's (UK's) largest private water supply and wastewater management company. United Utilities is located in northwest England and has a vast array of inter-connected water supply resources available across their large service area. As a private business entity in the UK, United Utilities is regulated by an economic regulator, as well as by an array of environmental and public health agencies, including the Department for Environment, Food & Rural Affairs,[4] and the Environment Agency.[5] As such, the utility's decisions are subject to considerable scrutiny and regulatory approval. In addition, as part of national climate policies in the UK, United Utilities is given a suite of climate scenarios by the UK's National Climate Impacts Program. The government directives require that United Utilities use these climate scenarios in their Water Resources Management Plans (WRMPs) and specify how they need to be used. In addition, water agencies in the UK are required to ensure that the WRMPs are adaptable and consider future uncertainty; the WRMPs must conduct scenario testing focused on the government's currently identified primary drivers of uncertainty – climate change, and environmental requirements for water.

One of the relatively large climate-related risks faced by United Utilities, identified by United Utilities in their most recent WRMP, is the potential for more frequent and/or severe droughts. Drought periods will limit the agency's surface supplies and, coupled with an anticipated increase in water demands due to warmer temperatures, could result in shortages. Simultaneously, concerns will be heightened over maintaining environmental flows to protect aquatic habitat for several special status species. Climate change projections also indicate that

4. The UK government department responsible for policy and regulations on environmental, food, and rural issues.

5. The Environment Agency is an executive, non-departmental public body, sponsored by the Department for Environment, Food & Rural Affairs (https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs).

extreme precipitation events may increase in intensity and/or frequency in the decades ahead. The UK and United Utilities are concerned that an increase in extreme precipitation events will present a corresponding increase in flooding events.

Decision 1: Using More than the Median Projection

> *One of the key challenges related to uncertainty is knowing when you have reached a tipping point – when the time has come to make an investment in an adaptive response.*
>
> Steve Whipp, retired Head of Innovation at United Utilities

Under the UK regulatory system, United Utilities is required to develop a 25-year water supply plan. A climate change vulnerability assessment was conducted as part of this planning process, using a probability distribution based on the subset of climate scenarios provided by the UK's National Climate Impacts Program. Although their primary risk – more frequent and/or severe droughts – do not compel them to make changes at the median value (i.e., 50th percentile of the distribution), it struck them that due to the extreme uncertainty in the models, there might not be that much of a difference between the validity of the 50th percentile and, for example, the 75th percentile.

In this case study, we examine how United Utilities came to the conclusion that using only the median values from a climate assessment may not be prudent, and that considering other plausible ranges of the distribution was important.

The vulnerability assessment context

United Utilities is required to update their WRMP every five years. As part of the WRMP process, United Utilities is mandated to identify any emerging changes in projected supply and demand, and to facilitate timely adjustments. Regulators in the UK provide water agencies with information they need to include in their WRMPs, including a specified climate assessment process as well as in-stream flow requirements for environmental needs. The climate assessment process uses a probability distribution driven by 20 selected climate change "samples" drawn from a larger suite of 1,000 samples provided by the UK Climate Impacts Program.

The current WRMP indicates that the utility has sufficient water to meet water demands over the 25-year planning horizon, based on the 50th percentile result from the scenario-driven probability distribution (the utility has opted to lean toward the drier scenarios in their WRMP as their primary concern is related to a drier future – not a wetter one). The resiliency of the projected supply is due to their vast array of water supply sources coupled with anticipated reductions in demand as water-use efficiencies improve through their customer base. Therefore, United Utilities has not yet had to propose any additional water supply investments to accommodate future climate uncertainty through 2040.

However, as part of the WRMP process, the utility has pondered whether the 50th percentile is the appropriate value to use in their planning with regulators. For example, United Utilities has noted that some supply enhancements by 2020 would be called for at the 75th percentile of their current WRMP projections. Given the large uncertainty surrounding climate change projections, United Utilities is moving to using a plausible range of projections rather than median values in their WRMP process.

In addition, United Utilities found during the WRMP process that they need to identify thresholds/tipping points (i.e., specific changes or trends which indicate that an adaptation action needs to be implemented). As part of the next WRMP process, United Utilities will be establishing tipping points.

For further discussion of *how and why utilities are using ranges* of climate assessment data instead of the median values, see the Sydney Catchment Authority case study.

Lessons learned

- United Utilities vulnerability assessment indicates that the agency's water supplies are not currently vulnerable to the median climate change projection at a level that requires additional flexibility in their extraction permit.
- The utility pondered whether using the median value, the 50th percentile, is the appropriate value to use in their planning for climate change. For example, the utility has noted that some supply enhancements by 2020 would be called for at the 75th percentile of their current WRMP projections.
- The utility needs to define critical thresholds (tipping points) that indicate when a regulatory change may be warranted, and establish monitoring systems to indicate (with sufficient advance notice) when those critical tipping points are being hit.
- United Utilities remains concerned that it will be very challenging to communicate effectively with the public and regulators if the time arises when climate-related supply and demand projections indicate that additional water supply investments need to be made and, hence, that rates need to be increased to facilitate adaptation.

Decision 2: Working with Regulators to Develop Flexibility

- United Utilities operates under an abstraction license, issued by the UK's Environment Agency, which defines how much water the utility can obtain from their surface and groundwater supplies. A critical component of climate change adaptation planning entails the ability to work quickly and effectively to modify supply choices in the face of potentially large changes in climate, including increases in droughts. United Utilities is working with regulators to ensure they have the flexibility to respond quickly (i.e., adapt) when the need arises by working toward a tiered abstraction permit under proposed revisions to national rules.

The regulatory context

A critical component of adaptation planning for climate change entails the ability to work quickly and effectively to modify regulated extraction levels during drought events. This reflects a need for an "adaptive management" approach that addresses climate uncertainties by enabling regulatory flexibility. This is particularly important when monitoring indicates that a threshold/tipping point is being reached in terms of potential shortages. As a private business entity, United Utilities is subject to economic regulation. As part of United Utilities approach to enhancing flexibility in the face of climate uncertainty, the utility is working with the Environment Agency to develop a tiered series of abstraction options to facilitate relatively prompt modifications to extraction limits when future climate circumstances warrant the adjustment. This change is consistent with the direction of national policy in the UK.

United Utilities is currently engaging in the process of requesting a tiered extraction permit.

Lessons learned

- Adaptive management is a sound strategy that provides flexibility for timely adaptation to an unpredictable and changing climate. Regulatory constraints are a potentially critical barrier to that flexibility. The tiered abstraction permit approach is intended to provide a greater ability to accommodate flexibility in a relatively timely manner.

- United Utilities continues to work with the Environment Agency to develop tiered abstraction options so that relatively prompt modifications can be made if and when future climate circumstances warrant the adjustment. This change is consistent with the direction of national policy in the UK.

Decision 3: Upsizing Storm Water Infrastructure

In this portion of the case study, we examine how the recognition of climate uncertainties has been applied to developing approved strategies with environmental and economic regulators to expand storm water infrastructure to reduce the potential flooding issues linked to climate change.

The storm water management context

In recent years, parts of United Utilities service area have experienced unprecedented extreme precipitation events and severe flooding. These events are often local and impose significant economic loss and personal hardship to small areas. The utility has been investing in improving their capacity to handle major rainfall events and reduce the risks to local communities associated with flooding.

The climate change projections provided by the government, and described in more detail above, indicate extreme precipitation events may increase in intensity and/or frequency in the decades ahead. The analysis, which uses median projections in hydraulic system models, indicates that flooding appears to be primarily responsive to increases in the frequency of precipitation events. In contrast, higher-intensity events are mostly associated with a higher number of sewer overflows. Also, the responses are nonlinear, with a 10% increase in frequency and intensity over historical levels resulting in a 3% increase in flood volumes. Given uncertainty regarding future climate, United Utilities is asking, “How much should United Utilities invest in upsizing its capacity to manage more storm water?”

Lessons learned

- Upsizing storm water holding tanks is a “low regrets”[6] adaptation strategy, as there is a relatively low marginal cost to upsize the facility once the decision has been made to install a new (or replace an old) holding tank (i.e., with high fixed costs for any excavation and construction activity related to storm water infrastructure, upsizing adds a relatively modest additional cost).

- It is reasonably easy to gain approval for investing a relatively modest increment to an already very large capital program, especially when there has been recent experience with highly adverse consequences of flooding.

- The capital program is not specifically targeted to address climate change. Rather, the utility is factoring climate change uncertainty into their design considerations, and doing so in accordance with guidance from the UK Environment Agency.

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6. Low regrets are actions that are likely to provide benefits under most conditions. No regrets are those actions that provide benefits under all conditions.

Learn More

In December 2011, the British Government published Water White Paper *Water for Life: Market Reform Proposals*, a policy paper with resilience as the key theme. It examines how the industry can become better equipped to respond to climate change, while simultaneously ensuring that customers come first and water remains affordable for all.

United Utilities has been developing a new draft WRMP, which will cover the years 2015–2040. This draft plan, along with an overview document, executive summary, and other supporting documents, can be found here at the United Utilities website: http://www.unitedutilities.com/.

The Water Resources Management Plan Direction 2012 (Defra, 2012) sets out specific requirements for the preparation and publication of a WRMP.

Abstraction permit reform information can be found at https://consult.defra.gov.uk/water/abstraction-reform/.

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Interviewees

Special thanks to Richard Blackwell (Supply Demand Manager) at Strategic Asset Planning, as well as Simon Boyland (Wastewater Supply Demand Manager), and Steve Whipp (Head of Innovation, retired) at United Utilities.

Richard Blackwell

Steve Whipp

Tampa Bay Water: Climate Information in Operational and Seasonal Decision-Making

Decision Examined: Incorporating Climate Information into Operational, Seasonal, and Long-Term Planning Extraction Decisions

Climate variability has a huge impact on weekly, seasonal, and yearly extraction decisions at Tampa Bay Water. In order to maximize use of low-cost precipitation driven sources, as well as to plan for long-term climate changes, Tampa Bay Water has developed a Decision Support System (DSS). The DSS models the relationship between precipitation and temperature and system storage and extraction sites, allowing the utility to better plan for future climate risks and helping to ensure that they will continue to maximize operational efficiencies to meet multiple objectives.

In this case study, we examine how Tampa Bay Water decision-makers use a DSS composed of hydrologic models to make weekly, seasonal, yearly, and long-term (5-, 10-, and 25-year) source-water allocation planning decisions as part of their long-term supply and demand planning processes. The Tampa Bay Water DSS uses probabilistic and deterministic data for weather and climate forecasts, surface-water flows, and current groundwater-level conditions to determine how to rotate production among available supplies to meet demand. The DSS is also used to forecast demands. This case study provides insights into the importance of understanding how climate affects your system before you examine how to incorporate climate projections in long-range planning.

The Decision Background

With water from two river sources, reservoir storage, desalinated seawater, and groundwater, TBW has a complex supply system. Maintaining operational flexibility across multiple sources to meet demands, protect the environment, adhere to regulatory requirements, ensure reliability, and minimize costs can be challenging, and weather and climate uncertainty exacerbate this challenge. On a weekly basis, Tampa Bay Water uses deterministic weather forecasts from the National Oceanic and Atmospheric Administration (NOAA) to allocate extractions between water sources. Although groundwater is the cheapest source, the quantity available is regulated based on a 12-month running average. Surface water has the second-lowest costs, but regulated minimum flows need to be maintained and flows are highly seasonal. Surface water is generally only available during the summer rainy season. Desalinating water is always an available option, but it is the most expensive source; minimum usage is required, and it cannot be easily turned on and off. All three sources require different treatment regimens, which requires maintaining adequate supplies of chemicals and treatment flows. Identifying how to manage available water sources to meet cost, regulatory, and operational requirements is difficult.

Tampa Bay Water is highly influenced by Southern Oscillation patterns. On a seasonal basis, Tampa Bay Water uses probabilistic NOAA El Niño Southern Oscillation (ENSO) forecasts to decide how to set up operations for the next year. Using data available in the late summer or early fall, NOAA forecasts how global circulation patterns are setting up for the next year. NOAA bases these forecasts on ocean surface temperatures in the eastern tropical Pacific and convection patterns in the western Pacific. If global circulation patterns are forming El Niño conditions, then Tampa Bay Water is likely to have a wetter, cooler winter. If climatic conditions are indicating La Niña conditions, then a warm, dry winter and spring are likely. With El Niño conditions, the likelihood that the utility will need to produce water from their desalination facility is reduced because more water will be available from alternative sources, including rivers, reservoir storage, and groundwater. Demands are also likely to be lower under El Niño conditions. If La Niña conditions occur, however, use of the desalination plant is likely.

In the early 2000s, Tampa Bay Water decided that due to the complexity of their system and the strong correlation between available extraction rates and precipitation, that they needed a real time DSS. The DSS provides information on the availability of surface water and groundwater that is used in weekly and monthly extraction source decision-making, as well as part of establishing how they will configure basic extraction each season. Information from the DSS, which includes climate information, is also used by Tampa Bay Water in their demand and supply forecasting processes. Tampa Bay Water currently updates their 25-year demand forecast every year. The demand forecasting model includes inputs related to water use by sector, water use account, social and economic conditions, rainfall, and temperature. They also update, every five years, their Long-term Master Water Plan, which identifies potential water supply projects that could be designed and built to meet drinking water needs for the next 20 years.

Tampa Bay Water was one of four utilities documented in the WUCA companion white paper, *Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments*. Please visit www.wucaonline.org to access the white paper detailing Tampa Bay Water's recent climate downscaling work.

The DSS Models

The DSS is an interactive computer-based system that helps water managers and other decision-makers utilize data and models to solve complex, uncertain management issues. The DSS has three functional units: database, models and analytical tools, and a graphic user interface.

The operational models include the Optimized Regional Operations Plan model, the Short-term Demand-forecast Model, surface water artificial neural network models, and groundwater artificial neural network models. The planning models include the Long-term Demand-forecasting System), the Flow Modeling System, the Integrated Hydrologic Model, and the System-wide Reliability Model. These models relate weather/climate inputs (e.g., rainfall and temperature), as well as pumping or diversions, to outputs such as water levels, storage levels, or river flows.

The models take inputs from the database, including short-term, seasonal, and yearly climate projections and provide decision-makers with information they can use to help make better decisions in the form of graphs.

The DSS:

- Increased the agency’s efficiency in operating the new supply sources
- Enhanced effective management of Tampa Bay Water’s complex water supply/resource system
- Improved the agency’s data collection, storage, and retrieval process
- Facilitated regulatory compliance
- Provided for consistent and uniform decision-making in a complex and dynamic water supply environment
- Enhanced the ability of the agency to forecast supply availability and adjust operations accordingly.

Lessons Learned

- Planning for climate change requires understanding the relationship between source water and current climate.
- Through the DSS process, it became clear that the relationship among groundwater, surface water, and precipitation is not linear in Tampa Bay Water. To make effective decisions about risks and vulnerabilities, Tampa Bay Water needed and developed strong analytic tools to understand that relationship.

Learn More

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Tampa Bay Water is one of four utilities documented in the WUCA companion white paper, *Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments*. Please visit www.wucaonline.org to access the white paper detailing Tampa Bay Water's recent climate downscaling work.

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Alison Adams can be reached at AAdams@tampabaywater.org.

Interviewee

Alison Adams, Chief Technical Officer, is responsible for implementing programs that optimize Tampa Bay Water's water supply and maximize environmental protection across the region. Dr. Adams was instrumental in the development of the agency's first DSS, which has served as the gateway for staff to access and use the agency's data, models, and analytical tools in support of real-time and long-term decisions. Dr. Adams is the current Chair of the Water Utility Climate Alliance and co-founder of the Florida Water and Climate Alliance.

Seattle Public Utilities: Climate Change and Asset Management

Decision Examined: Climate Change and Asset Management

> *I like to think of Stage Gates as a border crossing: What papers do you need to have in order before you can go to the next place?*
>
> Paul Fleming, SPU, personal communication, March 2014

Seattle Public Utilities (SPU) spends approximately $800 million each year on O&M and capital improvement projects. The majority of those expenditures are not sensitive to or have a nexus with climate change. For investments in capital improvement projects, however, that are potentially sensitive to future climate changes SPU is dedicated to ensuring that climate considerations are embedded into those investments and the associated analysis that informs those investment decisions.

In this case study, we examine SPU's use of an asset management governance system, "Stage Gates," to make climate change consideration a routine aspect of capital planning and decision-making.

The Stage Gates Asset Management Governance System

The Stage Gates System is a governance, planning and project delivery system (Figure 9.1) that is used by SPU to rigorously assess different options for addressing capital utility system improvements, select a preferred option and deliver on that option. Within each phase, each Stage Gate requires specific analysis or activities to be completed by the project team before the project can progress to the next stage of the process.

To date, SPU has integrated climate-related questions into Stage Gate 1 and Stage Gate 2, the first two steps in the system, that are intended to raise awareness for the project team, the decision makers and ultimately the whole organization about how climate change could affect different options under consideration. These basic questions include, "*Is the project located in a basin that is now or will be tidally influenced?*" and "*Are the precipitation assumptions based on historical records?*"

Stage Gate 1 identifies the problem or opportunity and authorizes scope, schedule and budget to develop options for further scrutiny, including capital, O&M, and a "do nothing or continue as we are today" group of options.

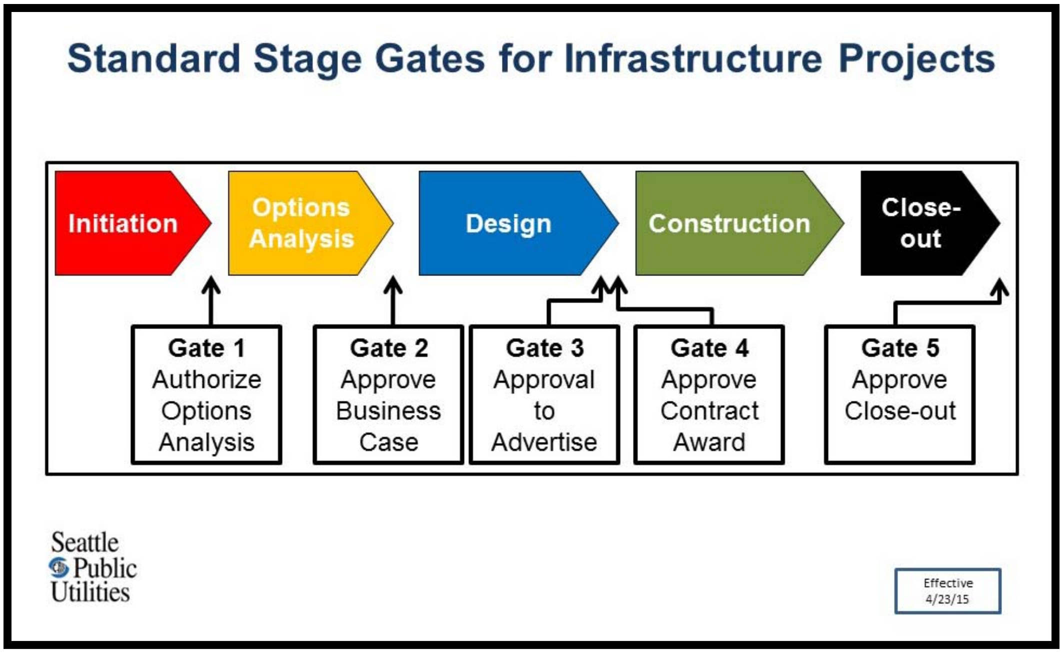

Figure 9.1. Stage Gates tiers.

Source: Seattle Public Utilities, 2015.

Stage Gate 2 examines the array of options and develops a triple bottom line (TBL) analysis for each option. At the conclusion of the options analysis the project team makes a recommendation, including scope, schedule, and budget to the Corporate Asset Management Committee for consideration and approval. If a project obtains Stage Gate 2 approval, it can move forward into the design phase.

Stage Gate 3 and Stage Gate 4 are the conclusion of the design phase and approve the project to be advertised (SG 3) and the Public Works contract to be awarded (SG 4). The project then is constructed, commissioned, accepted and culminates with Stage Gate 5 to officially close out the project.

Lessons Learned

- SPU wants to ensure that its capital investments, and the essential services that depend on those assets, are robust and resilient to a changing climate.
- Mainstreaming climate change considerations into capital improvement decisions can start off with basic awareness.

- There are real limitations in using climate projections, such as precipitation, in capital improvement projects, particularly urban drainage and wastewater projects. Additional work needs to be done to facilitate the inclusion of climate considerations into project planning and to bridge the gap between the information needs and current practices of decision makers and project planners and how climate projections are currently generated. This is both a management and an applied science challenge and opportunity.
- Going “upstream” to embed climate considerations into comprehensive system planning is a necessary complement to embedding climate considerations into specific projects.
- There is an opportunity to build off of SPU’s integration of race and social equity considerations into the Stage Gate System to replicate how those issues were embedded into Stage Gates as well as explore climate change and race and social equity issues can be considered jointly.

Learn More

SPU is one of four utilities documented in the WUCA companion white paper, *Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments*. Please visit www.wucaonline.org to access the white paper detailing SPU’s recent climate science and translational work.

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Paul Fleming can be reached at Paul.Fleming@seattle.gov.

Interviewee

Paul Fleming is the Manager of the Climate Resiliency Group at SPU. He is responsible for developing and implementing the climate change program and developing a carbon neutrality strategy for the agency’s corporate greenhouse gas emissions. Mr. Fleming is a visionary leader recognized globally for his efforts to make SPU one of the most advanced utilities in assessing and preparing for the impacts of climate change.

International Upper Great Lakes: Decision Scaling – A New Planning Tool

Decision Examined: Use of a New Planning Tool – Decision Scaling

> *There is growing acceptance in the scientific community and among stakeholders that climate change must be addressed in decisions with implications for the long term future.*
>
> Casey Brown,
> University of Massachusetts

The International Upper Great Lakes Study (IUGLS) Board is responsible for preparing a Plan of Study (Plan) for the management of the upper Great Lakes, from Lake Superior downstream through Lake Erie. The IUGLS mandate requires that the Plan "assess the need for changes in the regulation plan in order to meet the contemporary and emerging needs, interests, and preferences for managing the system in a sustainable manner, including climate change scenarios…" (http://www.iugls.org/Mandate). The planning period used for analysis was originally through the end of the century but eventually focused on 2050 as the target planning horizon. As part of developing the Plan, which included significant investments in leading-edge climate science, the IUGLS Board determined that uncertainty of future climate conditions is irreducible, and therefore the Board would need to modify its planning analysis accordingly.

In this profile, we examine how the IUGLS Board used decision scaling in its planning analysis to consider climate vulnerability.

Decision Background

Decision-makers in the United States and Canada are faced with identifying how to manage lake levels for Lake Superior, Lake Michigan, Lake Huron, and Lake Erie in a manner that meets the needs of commercial fisheries, recreational fisheries and boating, the environment, water supply, and hydro-power generation, as well as managing coastal hazards and risks. In the past, decision-makers designed the Plan to optimize potential management options for the historical time series or for a stochastic model based on the historical time series. As part of the most recent planning process, the IUGLS Board determined that because of the large uncertainty about future hydrologic conditions and needs across their region, they would need to change not just the Board's planning analysis, but their planning objective. The new objective is to "identify a set of management actions that will perform near the top, regardless of which future occurs." Given this background, the Board decided to adopt a process, known as decision scaling, which uses a "stress test" to identify the climate changes that cause plans to fail, and then investigates whether such changes were likely.

A decision scaling analysis begins with a focus on planning objectives and the vulnerabilities that cause them not be met. Decision-makers explore the question, "What do we want to achieve, and what will prevent this?" Once climate conditions (or other uncertain factors) that cause failure are identified, the next question is, "Does climate science and climate model projections indicate that these vulnerabilities will occur and is it credible?"

The IUGLS Board selected the decision-scaling approach because other analytic approaches failed to meet the Board's needs. For example, the Board considered a multi-objective optimization framework, as well as a maximization of the expected value based on probabilities of future climate changes. However, these approaches are generally designed to help identify an optimal plan for the most likely future or for a future that can be described in probabilistic terms and focus on a single representation of the future. Even if the most likely future was correctly identified, the IUGLS Board had decided it would only be slightly more likely to occur than a number of other futures. The Board also rejected maximization of the expected value of the Plan performance because of the difficulty in estimating the probabilities of future climate on which such a calculation relies. Instead, with the selection of the decision-scaling process, the Board chose a process that prioritizes "robustness" as a decision criterion. Robustness is defined here as performing well over a wide variety of possible future climate conditions, and allows the Board to prepare for multiple representations of the future. Finally, the projections of future climate are used to indicate whether vulnerabilities are likely to be concerns or not, rather than being used to estimate future probabilities that drive (and confuse) the analysis.

Decision scaling

Decision scaling links the insights revealed from a bottom-up vulnerability analysis with the information from climate models.[7] This approach reveals the sensitivity of decisions to climate data and identifies the specific climate information that drives the decision. This, in turn, facilitates identifying which climate information a given analysis needs and a more thorough understanding of the system being operated.

The technique is an attempt to bring together the best of the bottom-up and top-down assessment and planning approaches. Figure 10.1 provides a visual illustration of the traditional top-down approach and a decision-scaling bottom-up approach.

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7. Bottom-up and top down analysis are discussed in more detail in the recent WUCA report *Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments* located at http://www.wucaonline.org/html/actions_publications.html.

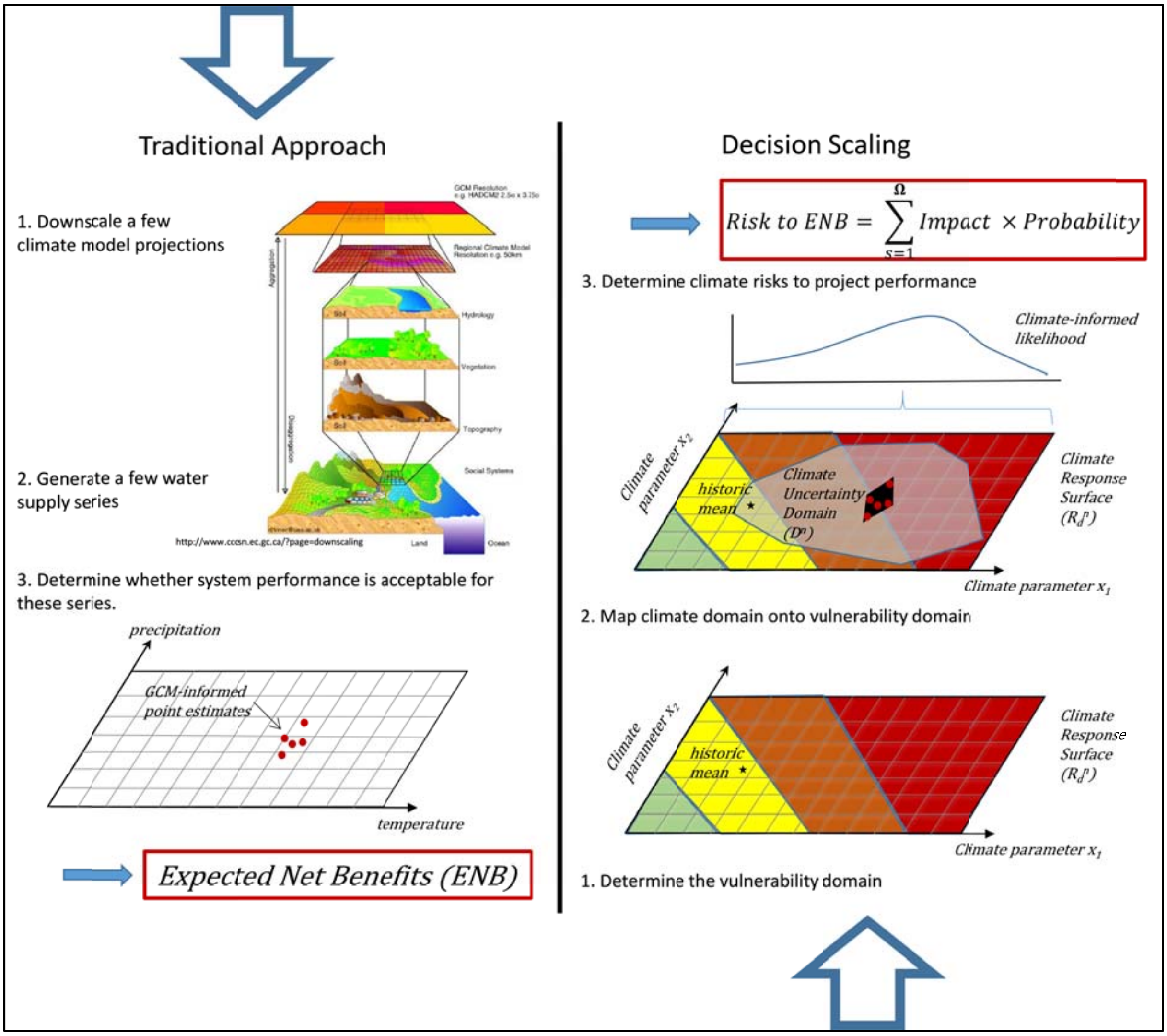

Figure 10.1. Bottom-up and top-down planning approaches to assess climate risks.

Source: World Bank, 2014.

Step One. The first step in decision scaling is to create a decision framework for the organization in question. To do this, an organization must provide its objectives (for example, meeting water supply needs for a set reliability level); the relevant processes that influence its ability to achieve these objectives (such as water rights); and the new options (like building a new reservoir) available to better meet the objectives, if an options appraisal is part of the analysis. This information-gathering step is accomplished through engagement with the organization and can be an iterative process. Typically for analysis of complicated systems, models will be identified or created. An important consideration is to identify parameters (which are examined in the stress tests in Step Two) that affect an organization's ability to meet its objectives, including those related to climate and those not related to climate. Developing a decision framework is crucial to ensuring that the analysis will be responsive to the organization's needs and that it will provide decision-relevant insights.

Step Two. Once the decision framework is complete, the next step is to identify vulnerabilities through the application of a "stress test." The goal of the stress test is to perturb the system, using the parameters identified in Step One and varying them in plausible ways until the "breaking points" of the system are clear. This will reveal the vulnerabilities of the system, as well as the parameters that cause them to fail (see Figure 10.2 and corresponding discussion as an example). A key to the stress test is that no probability assumptions are made. For example, the stress test reveals vulnerabilities to climate parameters without assigning probabilities to future climate projections. In an options appraisal analysis, such as in the Great Lakes application, the stress test is used to reveal the performance of each of the options in response to a range of parameters, and reveal the options that offer acceptable performance over the widest range of potential conditions (i.e., the robustness of each option). Computational models of the system, in combination with a stress testing algorithm developed specifically for the application, accomplish this process. The combination of parameters that trigger vulnerabilities may be described as *vulnerability scenarios*. They provide the basis for investigating the climate information to determine whether vulnerabilities pose risks.

Figure 10.2 depicts a climate response function, which shows the performance of the system over a wide range of future climates. Here a threshold on system performance (in this case reliability) was set and colors indicate the two resulting regions – the climates where the system can provide acceptable performance (blue) and the climates where the system fails (red). The climate response function was created using the stress test. Notice that it reveals the vulnerability of system to climate change, independent of any projections of change. Thus decision-makers now understand that if mean precipitation falls below about 25 inches per year they will need to adapt. We also learn that temperature does not have a large effect on this system. The interesting question is then whether these problematic future climates are likely to occur or not. Here, climate projections as well as historical trends can be used to help answer the question. The open circles indicate projected mean precipitation and temperature from an ensemble of general circulation model (GCM) simulations. The solid circles indicate historical averages from 1950 to

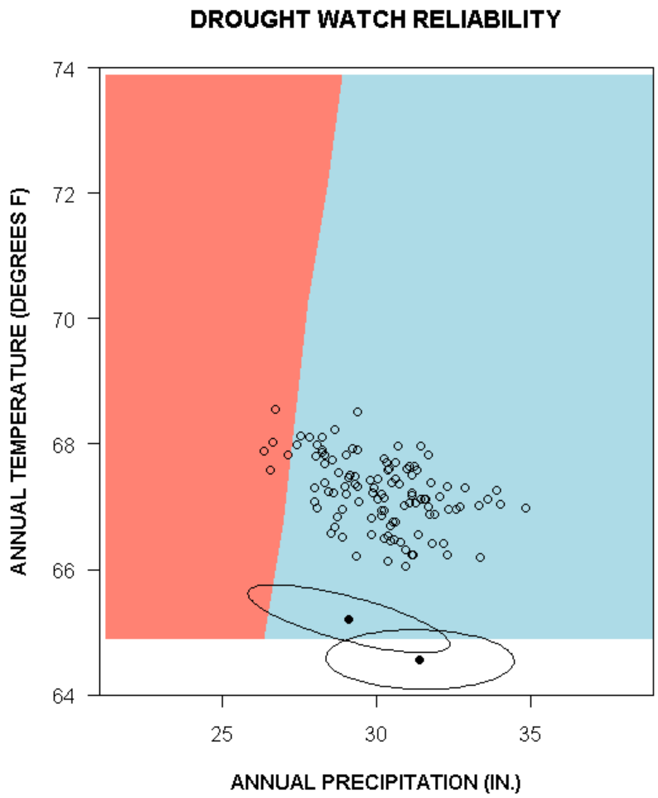

Figure 10.2. The reliability of a water supply system under a range of future possible climate conditions.

1974 and from 1975 to 1999, and the ovals indicate variability. At present the risk appears relatively low, given the small number of projections that fall into the red region. (This process is depicted in Step 2 of the Decision Scaling column of Figure 10.1.)

Figure 10.3 is an example climate response surface, which "graphically illustrates system performance over a range of conditions in climate space" (Moody and Brown, 2012). Each contour shows the number of performance violations that would be experienced for this plan as a function of change in mean climate (x-axis) and change in variability (y-axis). The x-axis shows percent change in mean net basin supply (NBS; essentially the net water inflow) and the y-axis shows the change in climate variability. Performance violations increase as the climate moves further from present conditions (both positive and negative changes) and as variability increases. If variability decreases the violations also decrease. Thus the contours have an arch like shape. For example, the candidate regulation plan evaluated here can provide acceptable performance for mean climate changes up to +5% or -15% of the long term average (less if variability increases; more if it decreases).

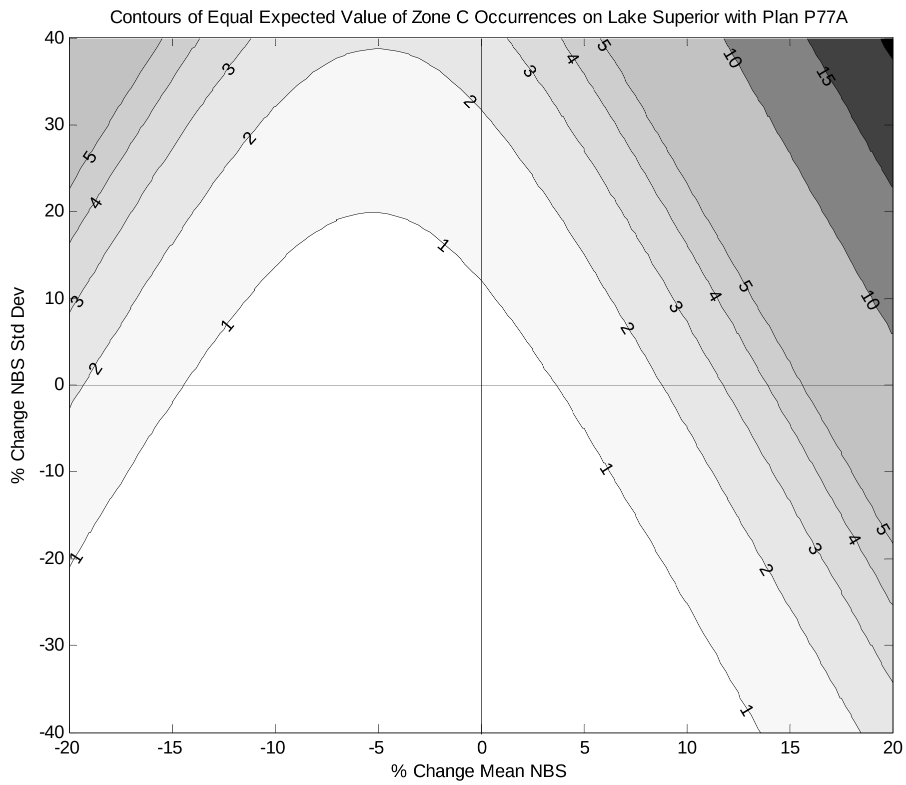

Figure 10.3. The contours of robustness of a candidate regulation plan. Each contour shows the number of performance violations that would be experienced for this plan as a function of change in mean climate (x-axis) and change in variability (y-axis). Performance violations increase as the climate changes increase in magnitude (both positive and negative changes) and as variability increases.

Source: Moody and Brown (2012), NBS is net basin supply.

Step Three. The third and final step in the decision-scaling process is to summarize the information available from weather and climate data in terms of the vulnerabilities identified in the stress test. The information may be summarized in terms of probabilities, generally described as subjective, or conditional on certain assumptions. This differs from the probabilistic approaches discussed early in the Decision Background of this case study because here probabilities are used as a sensitivity factor, rather than as assumptions. A major advantage of decision scaling is that alternative sources of climate information can be used and compared in terms of their implications for a decision, without having to use those sources in the chain of models. For example, in the Great Lakes study, climate futures based on historical statistics, dynamically and statistically downscaled GCM projections, and paleological data were all used to assess the likelihood of the identified vulnerabilities.

Step Three provides a credibility review. In essence, the review provides the opportunity to ask whether the climate conditions that would cause the plan to fail are likely to occur.[8] The IUGLS Board was able to look at alternative plans in terms of their performance under future climate conditions without concern as to the likelihood of those conditions. Then, they could evaluate the likelihood of the vulnerabilities based on alternative sources of climate futures, for example, climate change projections versus historical statistics. This comparison did not require additional runs through the modeling chain. By assessing plan performance under potential future climate conditions, rather than under a set of pre-determined scenarios produced by climate projections, the Board could use any source of future climate information to weigh the performance of a particular plan. This alleviated the tension between Board members who wanted to drive the analysis with climate change projections, versus those who wanted to use only historical statistics.

As a result of the decision-scaling process, the IUGLS Board selected a regulation plan that was considered robust against a wide range of climate changes, while acknowledging the current limited ability to state whether some of those changes would be more likely than others. However, given its recognition of this uncertainty, the Board drafted a strategy for adaptively managing the regulation plan, including a reorganization of the institutional structure to facilitate the long-term monitoring and management that operating under climate uncertainty will require.

Lessons Learned

The IUGLS Board shared the following insights into its experiences in planning for an uncertain future:

- Uncertainty is irreducible in planning for the future. It is not sufficient to plan for the most likely future – even if it could be identified, it may only be slightly more likely than a number of other plausible futures.

- Decision scaling begins with analysis of the system and performance objectives, and postpones assumptions about future climate that might limit the richness of the analysis. By beginning with a focus on the system and stakeholder objectives, it allows the tailoring of climate information to key concerns, risks, and objectives as defined by an individual organization.

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8. A note to the reader: It is important to recognize that climate model projection likelihood calculations are often developed based on climate projection agreement, which assumes the climate projections are headed on the correct trajectory of future conditions.

- Decision scaling allows evaluation of robustness in addition to traditional performance metrics, which allows decision-makers to identify actions that perform well across a wide range of future climates and other uncertainties.
- A bottom-up assessment process is easier for decision-makers to engage in; debates about downscaling approaches or climate model projection selection are avoided since the analysis is based on understanding sensitivity to climate change, rather than sensitivity to the climate projections that happen to be used.
- The decision-scaling approach produces an understanding of the performance of the system under a wide range of climate changes, independently of the probability that the climate projections might indicate about those future changes. This approach does not require that new climate projections be run through the system models as new projections become available. The system response changes only if the system changes. The risks associated with vulnerabilities can be instantly updated using the climate response function in the existing system. For example, in Figure 10.4 Decision A meets future needs under climate conditions shown in the light grey box (i.e., % in Temperature from 0% to 5% and changes in Precipitation up to about 11%).

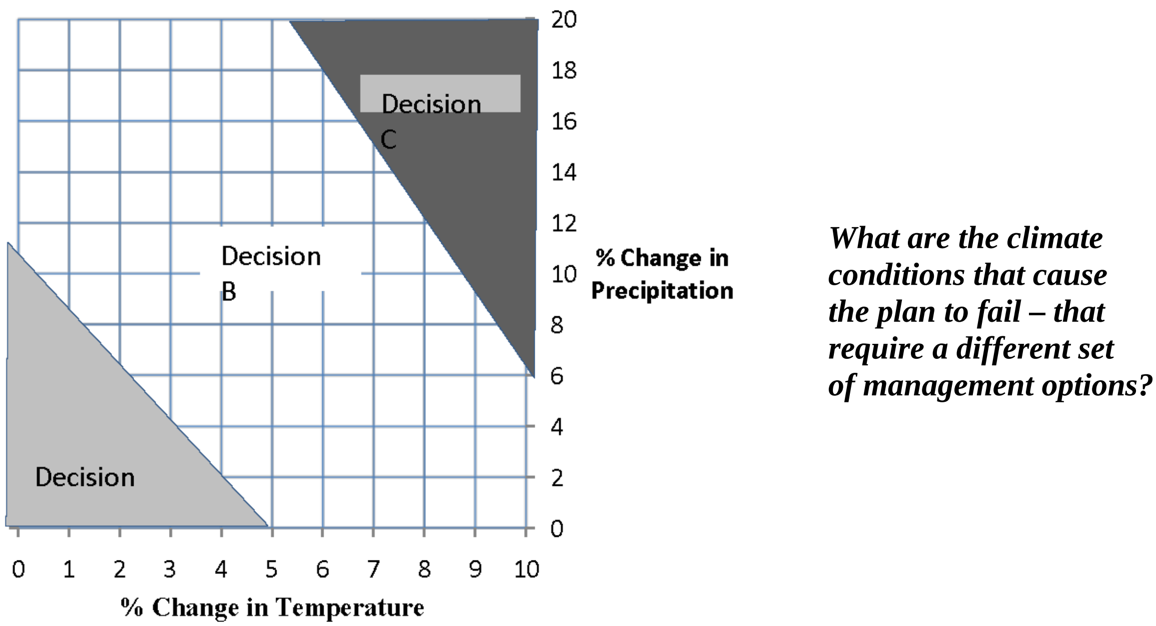

Figure 10.4. Climate-response function.

Source: Brown, 2011.

- High-stakes debates over which models, scenarios, and runs inform an analysis are avoided until the likelihood of vulnerabilities needs to be assessed. At that point, the implications of choice among the different futures are apparent.

- Rather than driving the analysis with a pre-selected set of scenarios, the scenarios of interest are defined by the analysis, as the combination of factors that cause vulnerabilities become clear. This, then, is the entry point for the climate information.

- The decision-scaling approach uses a bottom-up analysis to understand the system and how it responds to climate change. By using that understanding to put climate projections into a relevant context, one can determine those projections that should cause concern and those that should not.

Learn More

To learn more, we recommend that readers review the following articles:

Brown, C. 2011. Decision-scaling for Robust Planning and Policy under Climate Uncertainty. World Resources Report, Washington DC. Available: http://www.wri.org/sites/default/files/uploads/wrr_brown_uncertainty.pdf.

Brown, C. and R.L. Wilby. 2012. An alternate approach to assessing climate risks. *Eos Trans AGU* 93(41):401. doi:10.1029/2012EO410001.

Brown, C., W. Werick, D. Fay, and W. Leger. 2011. A decision analytic approach to managing climate risks – application to the Upper Great Lakes. *Journal of the American Water Resources Association* 47(3). doi: 10.1111/j.1752-1688.2011.00552.x.

Moody, P. and C. Brown. 2012. Modeling stakeholder-defined climate risk on the Upper Great Lakes. *Water Resources Research* 48(10). doi:10.1029/2012WR012497.

Whateley, S., S. Steinschneider, and C. Brown. 2014. A climate change range-based method for estimating robustness for water resources supply. *Water Resources Research* doi: 10.1002/2014WR015956.

World Bank. 2014. Beyond Downscaling: A Bottom-up Approach to Climate Adaptation for Water Resources Management. The World Bank, Washington, DC. Available: http://alliance4water.org/resources/AGWA_Beyond_Downscaling.pdf.

William Werick can be reached at [insert email].

About Our Interviewee

Mr. William Werick is an IUGLS Board member. He worked for the Corps of Engineers from 1968 until his retirement in April 2004; during his time, Mr. Werick worked on the Great Lakes as a surveyor, dredging specialist, and planner for the Buffalo district. He worked on special assignments throughout the United States, and, during his last 14 years with the Corps of Engineers, as a senior planner at the Corps of Engineers Institute for Water Resources near Washington, DC.

Sydney Catchment Authority: Two Short Stories

1. Developing and using plausible ranges of future climate conditions
2. A need for more sophisticated modeling and assessments

In this case study we profile two decisions for the Sydney Catchment Authority (SCA) regarding their use of climate assessment data in the planning process.

The Decision Background

Until 2010, SCA predominantly relied on historical climate data to assess and plan for their future water supply and quality needs. In 2010 SCA completed a climate change impact assessment (Assessment) as a first step in identifying key agency vulnerabilities to climate change.

The Assessment was designed to highlight how variations in climate might affect water quantity, water quality and catchment conditions, as well as SCA's day-to-day operations, infrastructure, and business resilience and regulatory compliance.

The Assessment selected two possible future scenarios to represent the plausible range: one that is warmer and stormier (i.e., an increase in frequency and severity of extreme precipitation events) and one that is hot, dry, and stormy. SCA considers each scenario to be equally plausible.

The 2010 Assessment was based on 2009 regional level climatic projections of temperature and rainfall developed by the University of New South Wales (NSW). The projections are based on one general circulation model (GCM) with a grid size of 200 km x 300 km. The results were statistically downscaled to a 50 km x 50 km grid size. NSW noted that there is a high degree of uncertainty around coastal areas. The climate in the Sydney catchment area is influenced by interactions between the southern circulation patterns driven by the Southern Annual Mode (SAM) and Antarctica and Indian Ocean sea surface temperatures, and northern circulation patterns more closely correlated with the El Niño Southern Oscillation (ENSO). They also noted that rainfall is more difficult to model than other climatic parameters such as air pressure and temperature. In addition, the GCM model data used, taken from the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC AR4), is based on scientific data from at least 5 years before the time of use – and that greenhouse gas emissions and global warming observations are tracking at or above the worst-case scenario considered by the IPCC in 2007. Therefore, SCA was concerned that AR4 projections could potentially be insufficient to meet their planning needs.

One of the key findings from the Assessment process relates to the large, compounding uncertainties, included in data developed as part of the Assessment process. The SCA concern regarding uncertainty is captured in the quote below, taken from the SCA 2010 Assessment (SCA, 2010, pp. 2–3):

> Projections of future climate have large uncertainties because current models are unable to capture the complexity of feedback mechanisms in the earth-atmosphere-hydrosphere system. Although the science of climate modeling is rapidly improving, models and projections at best present a range of possible futures to consider in scenario and business planning… current projections of future climate scenarios have large uncertainties because of changing estimates on emission levels, differences between the global climate models, problems in the simulation of realistic flood and drought cycles (hydrologic persistence).

The Assessment found that while the SCA has a high degree of preparedness for many of the potential impacts of climate change, additional investments in infrastructure, modeling, and incorporating climate assessment in other planning processes are necessary to increase their preparedness for a broader range of potential impacts.

A list of the top 10 climate actions needed at SCA, taken from the 2010 Assessment, is provided in Figure 11.1.

Action 1 – Ensuring climate change scenarios are realistic
Action 2 – Reducing SCA's carbon footprint
Action 3 – Quantifying the impact of climate change on water quantity and quality
Action 4 – Increasing flexibility in the water supply system
Action 5 – Improving SCA's capacity to monitor short-duration events
Action 6 – Reviewing strategies and plans for sensitivity to climate change scenarios
Action 7 – Reviewing design specifications of existing critical infrastructure
Action 8 – Building explicit consideration of climate change into new business initiatives and project designs
Action 9 – Increasing preparedness to manage concurrent or extreme incidents
Action 10 – Improving communication and knowledge exchange on climate change

Figure 11.1. Top 10 climate actions for SCA.

Source: SCA, 2010.

Decision 1: Developing and Using Plausible Ranges of Future Climate Conditions

SCA, like many water agencies, is struggling with how to incorporate climate change into their decisions. As part of their first attempt at incorporating data from the Assessment into their 25-year water supply planning process, SCA determined that the uncertainty in climate modeling is too large to justify the use of assigning probabilities to climate model projections. This is similar to United Utilities (UU) decision that planning at the median 50% range is probably no more reliable than planning at the 75% percentile.

In this case study we examine why SCA decided not to rely upon probabilities and instead to consider the wider range of plausible events in their planning process.

Using climate assessment data to identify the future

One of the insights SCA developed in applying the findings from the Assessment in their 25-year long-term planning process is that the values assigned to the probability that any specific climate condition – warmer, stormier, drier – may occur in the future are based on so many compounding uncertainties that probability values may not be useful in establishing priorities. So, instead of using assigned probability values, SCA has decided to examine the wide range of plausible future climate conditions. SCA wants to ensure they examine the complete range of possible climate conditions – not just those deemed most likely to happen based on climate projection agreement and probabilities.

SCA is concerned that due to the large compounding uncertainties surrounding projected future climate events, it is uncertain if the range is even complete – let alone if the certainty is large enough to assign probabilities that are useful. However, because this is how the data are provided, it is difficult not to use the assigned probabilities.

The range of potential climate conditions identified in the Assessment is defined by SCA to be the range of *plausible events*. Planning for the range of plausible future events enables SCA to remove the uncertainty associated with probabilities and treat events as equally likely. Although they may not plan to take expensive infrastructure actions to meet the implications of a full range of plausible future climate conditions, they do want to identify signposts or trigger points to identify if a specific future is becoming increasingly likely. Agencies may also want to ensure they keep options open to meet the full range of plausible futures.

Decision 2: A Need for More Sophisticated Modeling and Assessments

At the same time that SCA determined that large uncertainty about the future means they need to use a range of plausible conditions in planning for the future, they also determined that they need to update their climate assessment modeling techniques. SCA identified that their number one climate change related action needs to be *ensuring that climate change scenarios are based on the best available science*.

In this case study, we examine SCA's decision to make updating and improving the modeling used in their Assessment process their number one climate-related planning priority.

Using climate assessment data in other planning models

SCA is concerned with how the uncertainty included in the Assessment trickles down into other planning models. SCA relies heavily on predictive models and analytical tools to inform catchment and reservoir management decisions and early warning systems, and a changing climate will challenge the validly of many of these tools. SCA feels it is vital that data inputs from climate modeling be as robust as currently feasible. The agency found that the underlying climate modeling in the 2010 Assessment was not very rigorous. For example, the 2010 Assessment used a single climate model and the model outputs could not simulate multi-year correlations (persistence) of drought and rain periods.

As a result, SCA was seeking funding to conduct more-refined modeling, including downscaling, across their catchment area. The Office of Heritage and Environment (OEH), which is an office of the NSW Government Department of Premier and Cabinet, had a similar proposal across the state. SCA and OEH decided to collaborate and, with a handful of other organizations,[9] created the NARCliM (NSW/ACT Regional Climate Modelling) project. The NARCliM project will produce a set of regional climate projections for southeast Australia that covers a range of likely future changes in climate.

In addition, SCA is building improved models of catchment stream flow and transport of pollutants during wet weather events, as well as reviewing models for simulating catchment runoff, pollutants in stream flows, in-stream fate and transport of pollutants, as well as groundwater-surface water interactions under climate change scenarios.

9. Collaborators include the NSW Climate Change Research Center, the ACT Environment and Sustainable Development Directorate, Sydney Water, OEH, SCA, Hunter Water, the NSW Department of Transport, the NSW Department of Primary Industry, and the NSW Office of Water.

SCA has begun to review the 2010 Assessment and is factoring in work being done across industries, such as the NARCliM project. As part of the review and reassessment, SCA is examining if impacts identified in the 2010 Assessment are still current, and whether they should still be used to identify the plausible range of future climate conditions. They hope to complete their reassessment soon. Using the information generated from the reassessment, SCA will review which actions should be implemented, prioritize the actions (the list of current actions is presented in Figure 11.1), and then seek funding to implement them. In conducting the review, SCA has identified the following questions to address:

- Can risks be further quantifiable?
- Which on-the-ground actions can help us prepare for it?
- How should SCA interact with other agencies to address this issue?

SCA plans to revisit this prioritization process every two years, asking the following questions:

- Has the organization changed?
- Have projected impacts been realized?
- Are there changes in organization or planning priorities?

Lessons Learned

- Due to the large compounding uncertainties associated with assessment data, it is better to make planning decisions based on the range of plausible future climate conditions than to use a single probabilistic-based value

- One of the big insights for SCA is the importance of using climate assessment data that is recent and credible in their planning. They set a new planning priority to stay on top of emerging techniques and methods for developing climate projections and to fund additional research to identify, to the best of their ability, the range of plausible climate changes for their region.

Learn More

Public web portal to access NARCliM data. Available: http://climatechange.environment.nsw.gov.au/.

SCA. 2010. Climate Change Impact Assessment. Sydney Catchment Authority. Available: http://www.sca.nsw.gov.au/__data/assets/pdf_file/0007/36898/Climate-Change-Impact-Assessment-2010.pdf.

Due to recent governance changes, the SCA is now known as WaterNSW, and this new organization is responsible for the management of bulk water supply across most of the State of New South Wales (NSW).

Greg Green can be reached at Greg.Greene@sca.nsw.gov.au.

Interviewees

Greg Greene is the Manager of Environment and Heritage at SCA. Although he wears many hats, one of his passions is helping SCA incorporate future climate change modeling into decision-making to become more adaptive and flexible when it comes to long-term planning.

Sonoma County Water Agency: Using an Independent Science Review Panel in Planning

Decision Examined: Creating an Independent Science Review Panel

> *Everything we do should be guided by the science, and there is not always agreement on what the science and data are saying, let alone how you interpret it.*
>
> Grant Davis, SCWA

The Sonoma County Water Agency's (SCWA's) Board of Directors wants to ensure that all of their decisions are based on the best available science. Because of the myriad of scientists involved in studying the upper Russian River – a primary water supply source – and the range of climate projections, the SCWA Board authorized a cooperative agreement with the Mendocino County Russian River Flood Control and Water Conservation District, the Russian River Water Conservation Council, and the California Land Stewardship Institute to contribute funding to establish the Independent Science Review Panel (ISRP). The ISRP will advance decision-making based on the best available science. In this case study, we examine the drivers for creating the ISRP and how the ISRP will contribute to SCWA's long-term planning under an uncertain and variable climate.

The Decision Background

The upper Russian River watershed has numerous water-related conflicts and stressors (e.g., industrial water supply needs versus fisheries, climate change and agriculture demands). Although there are several organizations involved in studying and working on various issues, there was little coordination or synthesis of these activities. The ISRP was established to fill this gap by providing a comprehensive analysis of the physical and ecological system, as well as to identify data gaps. This information will be used by decision-makers to prioritize and coordinate studies and monitoring programs, to leverage resources, and hopefully avoid duplicating efforts.

The need for better information to make better management decisions motivated the formation of the ISRP. A team of people – from SCWA, the Mendocino County Russian River Flood Control and Water Conservation District, the Sonoma County Water Coalition, the National Marine Fisheries Service, and two agricultural representatives – reviewed 16 applications for panelist membership on the ISRP. The reviewers were looking for qualified candidates who:

1. May not have direct experience in the Russian River watershed but who do have expertise with the relevant scientific issues in this area

2. Have limited financial conflicts of interest with the wine-grape industry, environmental organizations, water agencies, or regulatory agencies directly involved in water issues in the Russian River watershed (http://www.russianriverisrp.org/).

In the end, the reviewers selected eight people to serve on the ISRP. These members represent diverse scientific backgrounds, including geology, aquatic ecology, fish biology, and sustainable business practices. As outlined on the organization's website (http://www.russianriverisrp.org/), the ISRP was tasked to:

1. Establish a sound scientific basis for future water supply and watershed management decision-making for the Russian River

2. Provide objective scientific review and recommendations on watershed monitoring, water management, agriculture frost protection programs, and implementation of the lower summer minimum in-stream flows specified in the federal Russian River Biological Opinion on Salmon and Steelhead.

Lessons Learned

- Water agency decision-makers find it difficult to understand and sort through science inputs
- A panel of science experts is a great way to better understand science-based uncertainties
- Collaboration is key; a science panel is a forum for collaboration
- Advisory panel members should not have a conflict of interest or already work in the target area.

Decision-makers and analysts in the Russian River watershed did not have a location to share new information, ensure that the information was accurate, and obtain support for how to use science information as part of their decision-making efforts. Although the ISRP is the first formal attempt at a science panel, there have been other informal groups of experts tasked to produce specific documents or articulated particular points of view (e.g., agricultural water versus municipal water requirements).

Learn More

SCWA press release on ISRP creation: http://www.scwa.ca.gov/lower.php?url=press-releases&article=russian-river-watershed-independent-science-review-panel-established-2012-02-22.

Russian River ISRP website: http://www.russianriverisrp.org/.

Grant Davis can be reached through the following website: http://www.scwa.ca.gov/.

Interviewee

Grant Davis is the General Manager for the SCWA. His main responsibilities include managing SCWA's core functions of water delivery, wastewater management, flood protection, and environmental sustainability.

Southern Nevada Water Authority: Testing the Climate Resilience Evaluation and Awareness (CREAT) Tool

Decision Examined: Using CREAT in Climate Adaptation Planning

The Southern Nevada Water Authority (SNWA) is concerned about the additional impact of climate change on drought conditions. This concern led them to participate in an exercise with the U.S. Environmental Protection Agency (EPA) to demonstrate the use of the recently released CREAT, version 2.0. SNWA was interested in CREAT because it offered a ready-to-use method for assessing climate risks and identifying opportunities for adaptation.

In this case study, we examine how SNWA used CREAT to identify climate-related threats to their overall system and evaluate adaptation measures. We also examine SNWA's decision to test a newer version of CREAT (version 3.0) in future adaptation planning.

The Decision Background

The CREAT framework

SNWA used the general CREAT framework (Figure 13.1) and accompanying software to assess risks and to start developing adaptation options under multiple climate scenarios. This process included:

- Developing climate scenarios
- Identifying potential threats and associated impacts to SNWA assets under each scenario
- Assessing the likelihood and consequence (i.e., risk) of identified threats under a baseline future in which SNWA does not implement any additional adaptation measures
- Identifying adaptation measures to reduce identified risks
- Evaluating the costs and risk reduction potential of various adaptation options.

Although CREAT provided the basic framework for the analysis, SNWA supplemented the analysis with additional data and studies in order to fully assess risks and identify and evaluate adaptation options. SNWA's process is described in more detail below.

Figure 13.1. CREAT framework.

Source: U.S. EPA, 2014.

SNWA risk assessment process

First, SNWA worked within CREAT to set up the parameters of the analysis and to develop alternative climate scenarios. Within CREAT, scenarios are defined as projected changes in climate with respect to average conditions (temperature and precipitation), extreme events (intense precipitation), and sea level rise (not applicable to the SNWA analysis). Specifically, CREAT develops three scenarios relative to current conditions: hot and dry (i.e., increase in temperature, decrease or minimal increase in precipitation), warm and wet (i.e., some increase in temperature, but greater increase in precipitation), and a central model projection between these two extremes. SNWA evaluated projected conditions for 2035 and 2060 under each scenario.

For each climate scenario, the project team identified 17 possible threats to utility assets. The threats included in the final analysis are presented in Figure 13.2.

Threat	Description
* Low Lake	1075-1000 ft are trigger levels to shortage (13,000 to 20,000 acre-feet per year) on CRB Note: Below elevation 1025, shortages may exceed 20,000 acre-feet per year.
* Extreme Low Lake	<1000 ft amsl - Loss of capacity to draw water
* Warm H2O	Warm water inflow and/or warm water in distribution system
H2O Demand	Changing evaporative demand for residential/commercial landscapes may cause consumptive use to rise. Greater system demand. Rising maximum daily temperatures, increasing number of extreme heat days may impact peak demand during summer months. Lengthening of the (Landscape) growing season is expected.
H2O Quality	Separate from warm water to include changing concentrations of TDS, Bromide and TOC
Pwr Grid	The number of cooling degree days are expected to rise (and the number of heating degree days will fall), causing increased strain on the power grid.
Pest	Invasive species
Fire	Rise in wildfires
Flood	Extreme flooding
GW recharge	Reduced groundwater recharge
Runoff time	Change in timing of runoff (Distribution volume and temperature challenges)
Snow	Reduced winter snowpack accumulation
Wetlands	Loss of wetlands
High Temps	Higher working temperatures
High H2O Cost	Increasing cost of water
Unhealthy Environment	Unhealthy environment (air quality i.e. high ozone or high particulate levels)
Living Cost	Higher cost of living (power, gas, food, medical care, etc.)

Figure 13.2. Potential climate-related threats identified by SNWA.

Source: U.S. EPA, 2014.

To evaluate potential threats, it was necessary for SNWA to obtain data from outside of CREAT. For example, SNWA relied on an assessment conducted by the Desert Research Institute to assess potential groundwater impacts under alternative climate scenarios. SNWA's in-house limnologist performed an analysis to evaluate the impact of climate change on water temperature and quality at various Lake Mead elevations. In addition, SNWA used information available from the U.S. Bureau of Reclamation's (Reclamation's) Colorado River Supply and Demand Study to characterize threats associated with changes in lake levels at Lake Mead, including the likelihood of occurrence.

SNWA prioritized potential threats by focusing on the hot and dry scenario, which is the scenario of greatest concern for SNWA given recent drought trends. Under this scenario, participants identified lower lake levels (1,000–1,075 ft) and extreme lower lake levels (< 1,000 ft) at Lake Mead as critical threats. Warmer water, which can result in water quality challenges, and impacts to the local power grid were also identified as critical. SNWA identified critical threats as such based on the likelihood of their occurrence under a given climate scenario (quantitative information obtained outside of the CREAT model), as well as the potential severity of their impact.

Next, SNWA began to identify assets (including water and environmental resources, infrastructure, and personnel) that might be impacted by the climate-related threats identified as critical. Initially, SNWA cast a very wide net to identify potentially impacted assets. However, it soon became apparent that they would need to limit the scope of their analysis. The agency therefore focused only on assets identified as being critical to their mission (i.e., ensuring adequate future water supplies for the Las Vegas Valley). Using this guidance, SNWA ultimately identified seven key assets that could potentially be impacted by critical threats.

The next step in the CREAT process was to develop a baseline risk assessment, as well as a resilience analysis, for each priority threat/asset pair identified. This process is intended to provide the data needed to gauge the effectiveness of potential adaptation options and to develop adaptation plans. Figure 13.3 describes the baseline risk assessment and resilience analysis process.

SNWA completed a baseline analysis for each priority asset/threat pair in both time periods of the hot and dry scenarios. SNWA then performed a resilience analysis to assess potential adaptation measures for two of the priority asset/threat pairs. Specifically, participants discussed and assessed adaptation options to reduce the threat of extreme low lake levels on Lake Mead and the threat of warmer water temperatures for their water treatment process. SNWA designed adaptation packages based on their general approach to planning, which involves pursuing lower-cost options first and considering additional actions when certain thresholds or trigger events are reached. SNWA then used CREAT to calculate risk-reduction units (RRUs) associated with each package.

Although the CREAT tool helped SNWA develop “a good first cut assessment” for specific threats and assets, SNWA is currently revisiting the assessment to develop a more comprehensive suite of adaptation options (i.e., for all critical threats and assets). SNWA will continue to assess threats and assets outside of CREAT (based on quantitative data), and is developing better cost estimates for potential adaptation options. In addition, SNWA will continue to rely on RRUs generated by CREAT to evaluate adaptation options, but will also prioritize costs, and take into account key considerations such as whether the option is a no-regrets or low-regrets option, whether it addresses multiple threats, how it might impact energy use, and the reversibility of the option.

Baseline risk assessment	Resilience analysis
1. Identify existing adaptive measures: this includes any actions or infrastructure planned or currently being used to reduce the consequences of a threat on an asset. 2. Assess consequences: for each asset/threat pair and time period, severity of the impact is assessed across five consequence categories. Within the tool, users can modify these categories, their definitions, and the weights assigned to them. SNWA's consequence categories were defined in terms of capital investment costs, operational/equipment impacts, water shortage duration, environmental impacts, and loss of life. Impacts are assessed qualitatively (e.g., low, medium, high). 3. Review results: CREAT provides a summary of results for the impacts associated with each threat/asset pair. Results display the overall qualitative metrics for likelihood, if applicable, and consequence.	*1.* Identify potential adaptive measures: identify any additional actions that are possible to reduce the consequences of a threat on an asset. *2.* Adjust consequences: adjust the baseline consequences to a new level based on any changes once potential measures are implemented. This is done qualitatively within CREAT but consequences can be quantified by the user. *3.* Assign adaptive measure contributions: each potential measure used receives a fraction of the "credit" for assessed reduction consequences following implementation. Some measures may provide a larger gain in resilience than others, and providing these fractions better informs decisions when considering performance of adaptive measures across several assets and threats. *4.* Review results: CREAT provides a summary of all risk assessment results for each asset/threat pair.

Figure 13.3. CREAT baseline risk assessment and resilience analysis process.

Source: U.S. EPA, 2014.

Benefits and challenges of CREAT for SNWA

One of the biggest benefits of the CREAT exercise was that it brought together participants from different departments within SNWA to develop a process for planning under climate change uncertainty. Through this exercise, SNWA developed an understanding of how to conduct climate change specific risk assessment, and began to identify and evaluate potential adaptation options. The process also helped SNWA identify key questions to address in future planning sessions.

Some of the more challenging steps within CREAT provided an opportunity for SNWA to question existing assumptions, refine the use of terminology, and think critically about the definition of threats and the assessment of consequences from those threats (U.S. EPA, 2014). This was useful not only for SNWA, but also for EPA, as they continue to think about refinements to the tool.

Throughout the process, it was necessary for SNWA to bring in outside data and conduct additional analyses to fully assess risk and evaluate adaptation options. For example, although CREAT provided future monthly precipitation and temperature projections for the different assets, SNWA needed to rely on their own system models to translate the projected changes into impacts to water availability and quality, which made the process very resource intensive. Another challenge SNWA found with version 2.0, was that the effectiveness of adaptation actions were measured in terms of their cost, but also with the unit-less risk reduction unit (RRU), which is difficult to communicate to decision makers approving high cost adaptation actions. While SNWA did not find CREAT version 2.0’s risk assessment component of the tool to be particularly user-friendly, the organization has since worked closely with EPA and other water utilities on improvements to version 3.0. EPA was very receptive to tool improvements, and version 3.0 will include a more intuitive web-based user interface, updated climate projection data (CMIP5), a modular approach such that adaptation planning can occur without completing a full risk assessment, and a move away from RRUs as a measure to monetized risk reduction which will be easier to communicate to stakeholders and decision makers. Because of these changes, SNWA does plan on continuing to be involved in tool improvements, does plan on testing CREAT v3.0, and potentially continue to use this tool for SNWA risk assessment and adaptation planning in the future.

Going forward, SNWA will test the viability to use CREAT v3.0 for risk assessment and adaptation planning; and will rely on information gleaned from applying the CREAT process.

Lessons Learned

- CREAT provided SNWA with a process to think critically about threats and consequences while planning for climate change

- The process was very data and time intensive, and required information from numerous departments

- CREAT’s evaluation of adaptation options in version 2.0 was difficult to convey to non-CREAT users because of the use of the qualitative RRUs. CREAT v3.0 will monetize the marginal cost of climate change adaptation, rather than using a unit-less risk reduction unit, and therefore will be more conducive to communicating to key stakeholders and decision-makers.

- SNWA will test CREAT v 3.0 going forward, and may continue to use this version for future risk and adaptation planning. Regardless of whether SNWA uses the newer version of the tool in the future, SNWA benefitted greatly from the information shared between departments and gleaned from the process.

Learn More

CREAThelp@epa.gov.

U.S. EPA. 2014. *Climate Resilience Evaluation and Awareness Tool 2.0 Exercise with Southern Nevada Water Authority*. EPA 817-S-13-002. January. Available: http://water.epa.gov/infrastructure/watersecurity/climate/upload/epa817s13002.pdf.

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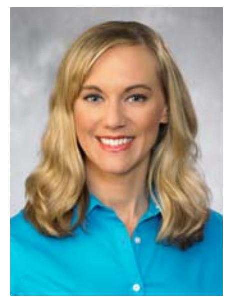
Interviewee



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Conclusion

Summarized below are five general themes emerged from the case study interviews. These themes stems from commonalities identified in two or more case studies presented in the white paper.

- ***The utilities interviewed are bringing climate considerations into a variety of their decision processes.*** Although we expected to find that agencies are incorporating climate information into their long-term water supply planning decisions, we also found that even agencies not currently engaged in a long-term planning process are incorporating climate into aspects of their decision-making processes. These utilities have found that the time for climate adaptation is now.

- ***Climate change projections are not predictions of the future.*** Climate projections are based on information that is highly uncertain, including how greenhouse gas concentrations will change over time, the ways these emissions affect the global climate system, and how these global changes may manifest locally. As such, climate projections provide a broad range of potential climate futures. Many interviewees found that the degree of uncertainty surrounding climate projections – both the range of projections and the inability to determine their predictive capabilities – is so large that applying probabilities, or accepting a likelihood that one future is more likely to occur than another, is not helpful in their decision-making. Instead, many utilities are now developing and incorporating plausible ranges of possible change into their decision-making.

- ***The relationship between the change in climate and the change in water availability is not linear. Therefore, climate projections alone do not provide adequate information for good decision-making.*** This is because small changes in precipitation can turn into big changes in flows available for capture, and warmer temperatures will have different impacts depending on the hydrologic situation. Many of the utilities interviewed for this project found that a hydrologic model is vital for translating and understanding the broader implications of climate change for their agencies, in terms of key aspects such as changes in flows and demand.

- ***Planning methods and tools need to allow utilities to plan for more than one future.*** As water agencies began considering climate change in their planning, many found that planning for multiple futures is the key to preparing for the decades ahead. Agencies have begun using planning methods that identify a set of management actions to meet the needs presented by a range of plausible futures (i.e., are robust across plausible futures). Methods used in the case studies examined include scenario planning and robust decision-making, and tools include the Climate Resilience Evaluation and Awareness Tool and decision-scaling.

- ***Public involvement is now a top priority.*** Many agencies interviewed noted the importance of bringing their various internal agency departments, governing board members, and/or customers along for the whole decision-making process rather than just informing these stakeholders of the recommended plan at the end of the planning process. Benefits of stakeholder involvement range from early support for a planning approach to a better understanding of customer values.

Appendix A: A Decision Support Planning Methodology Fact Sheet

This appendix provides a brief overview of DSPMs examined in the case studies, commonly used by utility professionals and some new DSPMs that are emerging as good mechanisms for planning for multiple futures. Some are methods, some are tools, some support long-term planning, some short-term planning, and some both.

This information is provided in the form of a fact sheet to make it easy to access and share with others. For more detailed information about multiple outcome planning approaches and other case study examples, please see the 2010 WUCA white paper, "Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning," available at www.wucaonline.org.

Decision Tool Fact Sheet: Short definitions for common analytics used in decision-making

System models

A system model provides an understanding of how your utility as a whole, including its hydrologic, structural, legal, treatment, and distribution aspects, responds to both current and future climate. Understanding your system is important because the relationship between climate factors and the water system being managed is not linear. A system model can include any of the following components: a hydrologic model of groundwater; a hydrologic model of surface water; a model that connects surface and groundwater; a model that connects climate, such as temperature, precipitation, and evapotranspiration, to other components; or a model of the treatment chain, collection, storage, and distribution system and legal structures. **A system model helps establish the direct relationship between your system and climate and/or streamflow; the relationship is not linear. Oftentimes, a hydrologic model needs to be developed to aid in this analysis.**

If you don't have your own hydrologic model, you don't have jack. You need to understand the non-linearity of your system to the current climate in order to understand future risks.

Alison Adams,
Tampa Bay Water

Climate vulnerability assessment

A climate vulnerability assessment provides **an understanding of the aspects of your system that are vulnerable to climate.** You can develop a vulnerability assessment using two primary approaches. A **top-down analysis** typically begins with a climate assessment, based on General Circulation Models (GCMs), emissions scenarios, and perhaps downscaled data. Climate change data are then imposed on the system's model to identify where climate impacts are likely to create vulnerabilities. A **bottom-up analysis** starts with what you already know about your utility and how it may be vulnerable to climate-related events (e.g., climate parameter tipping points that would cause critically low reservoir levels). It then applies climate change information to identify the probability of the changes occurring (i.e., the likelihood that a critical tipping point may be reached). Both approaches depend upon a fundamental understanding of your system's response to climate. When you use vulnerability assessment outputs, you must consider the high-consequence, low-probability events, and not just the means or averages. An average drought is not the one you are concerned about; it is the high-consequence but plausible one that needs to be considered.

Climate information in decision-making is new to us. What we really care about is, how do we use these methods to inform our planning process and how can we adapt them to fit the culture of our organization?

Kavita Heyn,
Portland Water Bureau

Decision Tool Fact Sheet: Short definitions for common analytics used in decision-making

Decision scaling

Decision scaling combines bottom-up and top-down vulnerability assessment to support planning analysis. This tool provides decision-makers with outputs that **identify the aspects of their system, based on their own system models, which are vulnerable to climate.** Then, it applies climate model projections to **identify if those climate conditions are projected to take place in the future.** The first step in the decision-scaling process is to develop a system model (or use an existing model) that represents the relationship between current climate conditions and the performance of the water system. The system model is then tested with a variety of combinations of climate conditions to identify which set of conditions create system vulnerabilities. Once you have identified the climate conditions that create system vulnerabilities, you can work with a climate scientist to determine whether those conditions are plausible – even if they are not highly probable – in the future.

Traditional long-term planning

A traditional long-term planning process provides an agency with information it can use to select the set of management actions that best meets future agency objectives at the lowest cost, using a subset of the historical record to represent future conditions.

Scenario planning

Scenario planning allows an agency to identify the management actions that meet the needs of a number of possible futures – not just one. Developing a set of multiple futures frees decision-makers from the need to agree upon one vision of the future; instead, managers can **examine a range of plausible futures**. Each scenario typically results in a strategy that includes a set of potential management actions and associated costs, based on a plausible representation of supply, demand, and treatment conditions. Each scenario in scenario planning describes one plausible future based on one or more or a combination of identified drivers of change (i.e., uncertainties such as climate change or economy stability). Decision-makers can use the outputs of a scenario process to identify management actions that are similar across all scenarios in the near-term, as well as the management actions that are only needed to prepare for high-consequence futures.

Decision Tool Fact Sheet: Short definitions for common analytics used in decision-making

Robust decision-making

Robust decision-making (RDM) is both a powerful analytic tool and a computationally intensive process that accommodates a wide range of decision-maker needs. RDM allows the decision community to **develop plans that describe a specific set of potential management options, test each plan against a wide range of uncertainties, and do this for a number of performance metrics.** An agency begins the RDM process by developing plans that describe unique sets of potential management actions available to utilities to meet future needs. The agency (or outside expert) then develops a mathematical relationship between the utility's hydrologic system and each management action across a large number of future scenarios. Next, decision-makers identify important performance metrics; RDM has the computer capability to analyze more than one simultaneously. Once the plans and the performance objectives are identified, and the agency is confident that the relationship expressed in the system model is accurate, then RDM tests each plan to identify if it can meet the objective function across a broad array of scenarios that reflect the range of uncertainties. The RDM model elements are laid out in the U.S. Bureau of Reclamation case study in the Figure A.1.

Uncertainties (X)	Decisions, options, or levers (L)
• Colorado River water demand • Future stream flow or water supply climate drivers • Reservoir operations post-2026	• Current management • Four portfolios comprised of individual demand reduction and supply augmentation options
Relationships or models (R)	**Performance metrics (M)**
• Colorado River Simulation System (CRSS)	• Water deliveries (9 metrics) • Electric power resources (2 metrics in 3 locations) • Water quality (1 metric in 20 locations) • Flood control (3 metrics in 10 locations) • Recreational resources (2 metrics in 13 locations) • Ecological resources (5 metrics in 34 locations)

Figure A.1. Summary of uncertainties, policy levers, relationships, and metrics used in the Bureau RDM process. Source: RAND, 2012.

Advisory groups

An advisory group provides decision-makers with both a process for including others and, depending upon the members, an opportunity to learn more about a specific aspect of the decision, science of an uncertainty, or group/community values. Many agencies are using advisory groups to either oversee the entire decision process or to provide expert oversight for one particular aspect of the decision. For example, advisory groups composed of climate scientist are frequently used to guide selection and application of the GCM and to downscale data.

Decision Tool Fact Sheet: Short definitions for common analytics used in decision-making

Other useful tools and methods

This fact sheet is not intended to be an inclusive list of decision support tools used by water utilities. Useful tools and methods are continuously emerging. For example, a new tool named Multiple Objective Evaluation Algorithms is being used to systematically evaluate different, sometimes conflicting, objectives simultaneously. Additionally, Dynamic Adaptation Policy Pathways, a new method being used in the Netherlands, is a multiple-outcome planning approach that uses unique visualization tools to examine timing and sequencing differences across adaptation strategies.

Embracing Uncertainty: A Case Study Examination of How Climate Change is Shifting Water Utility Planning

Stratus Consulting and Denver Water. 2015. *Embracing Uncertainty: A Case Study Examination of How Climate Change is Shifting Water Utility Planning*. Prepared for the Water Utility Climate Alliance (WUCA), the American Water Works Association (AWWA), the Water Research Foundation (WRF), and the Association of Metropolitan Water Agencies (AMWA) by Stratus Consulting Inc., Boulder, CO (Karen Raucher and Robert Raucher) and Denver Water, Denver, CO (Project Manager Laurna Kaatz). May 12.

This fact sheet is part of the larger research project cited above. The full report can be accessed at www.wucaonline.org.

Appendix B: Project Objectives, Background, and Methodology

This appendix provides a review of the project's objectives; background information on research that precluded and inspired this study, including a survey summarized by Eric Gordon of the Western Water Assessment [a National Oceanic and Atmospheric Administration-funded Regionally Integrated Sciences and Assessments (RISA) program] in 2013, and the methodology applied to case study selection.

Project Objectives

The purpose of this case study white paper is to enhance the knowledge base of the water utility sector by delivering practical and relevant information to water utility managers and planners about how climate change information and uncertainty are being incorporated into water utility planning and decision-making. While this is a necessary step for considering and implementing adaptation strategies, the project does not seek to evaluate adaptation options for the water utility sector. Instead, the project focuses on decisions made and key adaptation strategies identified from a case study experience.

Project Background – Summary by Eric Gordon (Western Water Assessment) for WUCA, 2013

In 2010, WUCA laid out a generalized four-part framework for adapting to climate change in a Decision Support Planning Methods (DSPM) white paper presenting "multiple-outcome planning techniques to water utilities interested in incorporating climate change into their planning" (hereafter referred to as "the DSPM report")[1]:

1. **Understand**: Utilities develop an understanding of climate science, climate change projections, techniques for downscaling projections to regional scales, the capabilities and limitation of the data for applied uses, and begin to gain the skills necessary to evaluate future climate information.

1. The full citation for the DSPM report is Means III, E., M. Laugier, J. Daw, L. Kaatz, and M. Waage, 2010, "Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning," Report of the Water Utility Climate Alliance. The report is available at http://www.wucaonline.org/assets/pdf/pubs_whitepaper_012110.pdf.

2. **Assess**: Utilities use the understanding gained in the first step to perform analyses aimed at identifying potential impacts on their water systems from climate change and to better appreciate vulnerabilities to future climate changes.

3. **Plan**: In light of the looming challenges of climate change, utilities begin the process of identifying adaptation strategies and incorporating climate change into water utility planning.

4. **Implement**: Utilities make decisions and implement actions aimed at adapting to climate change and reducing system vulnerabilities.

The DSPM report sought to address the third step in the framework by providing an overview of decision support planning methods and several short case studies.

The DSPM report was intended to assist in part three of the framework by identifying possible methods for utilities seeking to begin planning for the effects of uncertain climate change impacts by describing five multi-outcome planning methods: Traditional Scenario Planning, Decision Analysis, Robust Decision-Making, Real Options, and Portfolio Planning. Short case studies were also provided to illustrate the actual use of the DSPMs by water utilities (where applicable). The common tie across these approaches is adjusting or refining traditional planning methods to consider multiple different futures.

Building directly off of those initial case studies, WUCA wanted to further support water utilities as they began incorporating climate change information into their planning processes by developing a detailed case study white paper illustrating the use of the method, decisions made, and barriers encountered by a handful of utilities with experience in multiple-outcome planning. A survey was initiated to identify candidates for this case study white paper. (This project background summary and the survey questions can also be found at www.wucaonline.org.) After the survey was initially administered, it became clear that it could also provide a more diverse picture of the use of various DSPMs and the variety of ways in which utilities are or are not planning for climate change.

The survey used both multiple-choice and open-ended questions and was designed to test how far utilities have progressed through the climate adaptation framework, establish if and how utilities have changed their traditional planning methods, and, if so, whether the modified method resembled one of the DSPMs laid out in the white paper. By assessing planning methods and asking respondents directly whether they accomplished steps in the adaptation framework and what DSPM most closely described their actual planning methods, the survey helped illustrate the degree to which WUCA's decision support efforts were relevant to utilities and garnered more examples to demonstrate how DSPMs can be used in adaptation planning efforts.

Survey findings

Although the survey results described cannot be considered representative of water supply entities in general, they do demonstrate that across a range of utility types, sizes, and geographic locations, climate change is prompting a variety of different types of responses. A few respondents indicated that climate change is not the most pressing issue for them, especially in light of challenges such as storm recovery or population growth, but many others described how climate change has resulted in major shifts in planning, such as ending their traditional reliance on observed hydrology and climatology.

Among those that did indicate changes in planning methods or considerations, it is evident that climate adaptation looks different in different contexts. Responses to the challenges of climate change impacts ranged from merely being able to mention it explicitly in planning documents to adding it in as a factor in long-term planning to adopting new planning methods in light of climate and other stressors.

A number of common themes did emerge from the responses, however. Many responding utilities described taking the first steps in climate change adaptation by participation in various learning networks or conducting risk or vulnerability assessments. For those that described having taken more concrete action, the most common responses included incorporating climate change considerations into resource planning and using climate change in capital planning and infrastructure design decisions. Only a few respondents indicated having engaged in detailed planning expressly for climate adaptation.

The survey results also demonstrated relatively little familiarity with the strict definitions of the DSPMs described in the DSPM report. Responses to an open-ended question about DSPMs indicated that many respondents' definitions of their actual planning methods were not necessarily in line with strict definitions provided in the DSPM report. This implies a need for both greater clarification and illustration of the various DSPMs and more outreach efforts to give utilities an opportunity to become more familiar with the definitions and applications of each of the methods. Furthermore, this exemplifies the need for leadership on multi-outcome DSPM. In addition, these responses provide a cautionary note for future survey design – the DSPMs are likely too complicated or unfamiliar to be described in a very brief preamble to a survey question.

That confusion may explain why such a large number of respondents described their planning methodology as some variation of scenario planning. Those responses were also likely based on the customary water planning practice of testing supply systems against past scenarios, such as extreme weather events or extended droughts. This provides some evidence that the more formal Scenario Planning method may be the most palatable way to introduce utilities to planning for climate uncertainty. It is also worth noting the number of other sophisticated methods used, including variations on Robust Decision-Making.

The international respondents, especially those from Australia, gave some insight into how the influence of different political, geographic, and climatic contexts may shape attitudes toward water supply planning. Some of the Australian respondents emphasized public stakeholder-driven processes and triple-bottom-line outcomes as important aspects of their planning methodologies. Those same respondents also used more quantitative planning methods to account for myriad future uncertainties. In contrast, U.S.-based utilities were more likely to focus solely on ensuring adequate supply and tweaking existing planning methods to anticipate or factor in climate change impacts.

It is unclear, however, how much of these differences are driven by variations in the pace of climate change or cultural factors. In order to do a more comprehensive international comparison, metrics are needed to evaluate outcomes. Nonetheless, utilities in both contexts can learn from each other and share knowledge as climate challenges continue.

Case Study White Paper Question of Inquiry

Based on the DSPM white paper and the survey, a set of key questions was developed that prompted this research, including:

- What prompted the need to adjust your planning method?
- What approach was chosen and why?
- What barriers were encountered during the planning process and strategy implementation stages?
- How were you able to obtain organizational buy-in to adjust your planning method and/or "sell" this new approach to your stakeholders?
- What level of support did you need or want and how much engagement was there from upper management and boards or city council members?
- Have you implemented any adaptation strategies or made decisions based on climate change information upon completion of the most recent planning iteration?
- How has this changed the way you view long-term planning?
- Did you discover any surprise findings or new ways of thinking about your system?
- Have you been able to change your organization's thinking from static to dynamic in terms of decisions made outside of the planning group or department?

- What documents, tools, and other supporting information did you use, and from which organizations did they originate?
- Have you established, or do you plan to establish, any relationships or partnerships with others who share the same water/resource/basin moving forward?

Case Study Selection Methodology

Thirty water agencies in the United States, United Kingdom, and Australia (listed in Table B.1) were identified as having modified their agencies' decision-making processes in order to incorporate climate assessment information. They were identified based on the previous survey findings and conversations with professionals in the field and WUCA team members.

A matrix was then developed (Table B.1) that listed each agency with the type of decision that could be examined in an interview. Key staff from WUCA, AWWA, AMWA, WRF, and Stratus Consulting team members worked together to select over 20 agencies to interview. The selection criteria was designed to ensure that the final product included a wide range of geographic locations so that a variety of climate-related issues were included, a range of utility sizes, and a wide range of decision types. Based on the interviews, case studies were developed for 13 agencies.

Table B.1. Agencies interviewed

Agencies interviewed	Agency tool/method for planning under uncertainty: Potential area for interview focus
Inland Empire Utilities Agency	Water supply – source management objectives, inputs, comparison of analytic outputs
Sydney Catchment Authority (Australia)	Use of 10 key action statements Water supply New approach to move risk and vulnerability assessments into action New objective – future-proof supply
Denver Water	Water supply – objectives, inputs, use of outputs, comparison of analytic outputs
California Department of Water Resources	Long-term water supply Regulatory – review of past decisions with new considerations for climate Development of new inputs for California agencies

Table B.1. Agencies interviewed

Agencies interviewed	Agency tool/method for planning under uncertainty: Potential area for interview focus
Water Corporation of Western Australia	Climate-proof supply Operational and infrastructure Water supply Cynfin model – new approach to move risk and vulnerability assessments into action Analytics – use of triple bottom line and Monte Carlo assessment techniques
City West Water, Australia	Long-term water supply Acceptance criteria Communication – evaluation criteria – new set for action plans Inputs to scenario planning Outputs – need to communicate trade-offs and build support
Bureau of Reclamation	Robust decision-making Monitoring and review objectives – adaptation roadmap guides decisions
Mass Water Resources Authority	Outreach Trigger planning Redundancies and conservative planning Collaboration/new objective – ensure all players – electric, transportation, etc. – are moving in same direction
Metropolitan Water District of Southern California	Capital project planning Regulatory – use of weighting factors to deal with uncertainty – including climate change Development of processes and procedures with EPA
Albuquerque Bernalillo County Water Utility	Analytics – switched from spreadsheet to predictive model
City of Phoenix	Water supply – shortage assessment framework developed to guide actions in anticipation of – and not in reaction to – shortages
Contra Costa Water District	Demand projections – new approach to dealing with uncertainty
East Bay Municipal Utility District	Emissions – annual inventory and action plan
Miami Dade Sewer and Water	Regulatory Communication New objective – work with regulators Response to Consent Decree requires building a foundation of understanding and support
Metropolitan Vancouver	Capital planning – recently added climate change to decision process

Table B.1. Agencies interviewed

Agencies interviewed	Agency tool/method for planning under uncertainty: Potential area for interview focus
New York Department of Environmental Protection	Analytics – experimenting with switching from scenario planning to robust decision-making
Tualatin Valley Water District	Use of information by Board Members Decision of the Board to require a minimum of two supply sources
Tampa Bay Water	System model
Seattle Public Utilities	Stage gates
Southern Nevada Water Authority	CREATE model
United Utilities (United Kingdom)	Use of uncertainty – demographics, customer behavior, demand Analytics Decision process overview
International Upper Great Lakes	Decision-making in local planning Community response to a changing landscape and climate Compares use and understanding of uncertainty in decisions by scientists and others
Sonoma County Water Agency	Expert panels
Additional case study ideas – identified as having a potential story – but not followed-up with an interview	
Hunter Council, AU: climate change	Developed outstanding decision framework for making good decisions under climate change
United Water Delaware	
Artesian Water New Castle – Department of Special Services	
Melbourne Water	
Arizona Department of Resources	
City of Phoenix	
City of Tucson	
City of Calgary	
Eugene Water & Electric	
City of Oswego	
City of Hillsboro	