Purpose-Driven Climate Data Selection and Application

CASE STUDIES FOR WATER MANAGERS, PLANNERS, AND MODELERS

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As water utilities expand climate considerations across business functions and climate hazards—amid a rapidly growing landscape of climate model datasets—selecting data that are truly “fit for purpose” has become increasingly complex. To address this, the Water Utility Climate Alliance (WUCA) Climate Modeling Work Group sought to develop several case studies that would illuminate the factors behind the selection, processing, and application of climate model datasets in planning analyses.

WUCA Water Utility Climate Alliance

ASPEN GLOBAL CHANGE INSTITUTE

The purpose of the case studies was not to identify general “best practices” or create formal guidance, which has been done elsewhere (here,[1] here,[2] and here[3]). Rather, it was to capture the specific circumstances and priorities that drove each utility’s decisions—what climate data to use, in what ways, and for what analyses—providing practical, real-world examples for other utilities to learn from. The case studies were informed by interviews with key utility staff and consultants as well as supporting project documents.

Each of the four case studies follows a WUCA member utility through selecting and processing climate model data, establishing a data workflow, conducting project analyses, and applying the results to planning and decision-making. Three of the projects centered on future water supply and/or demand, and the fourth focused on infrastructure flood risk. Two projects were complete at the time of writing, and the other two were in their final phases. Each case study begins with a brief overview of the utility, followed by sections addressing:

- Project context
- Project methods, including data selection and processing
- Results of the analyses
- Use of results in decision support (intended and realized)
- Lessons learned

Each case study also includes links to additional resources that describe the project, climate data, and workflow—such as utility reports and peer-reviewed studies—and a utility contact for further questions.

In all four projects, the workflows began with an ensemble of runs from 15 to 35 CMIP5 or CMIP6 climate models. From there, they followed quite different paths in processing those model runs to construct discrete climate and hydrology scenarios for the subsequent impact modeling (Table 1), illustrating that there is no one “right” approach to using climate models to effectively inform planning. Unsurprisingly, the results from all four projects showed the potential for greater climate-related stresses and risks to the utility in the decades ahead—more severe droughts, larger flood events, reduced water supply, and/or increased water demand.

1 WUCA (Water Utility Climate Alliance). (2021). Leading Practices in Climate Adaptation. Prepared for the WUCA member agencies and adaptation community by the WUCA Leading Practices Committee and Aspen Global Change Institute.

2 Vano et al. (2018). DOs and DON’Ts for using climate change information for water resource planning and management: guidelines for study design. Climate Services 12, 1-13.

3 Lukas, J., and Vano, J. (2024). CMIP6 Frequently Asked Questions: A resource for water managers. A report for the Water Utility Climate Alliance. Aspen Global Change Institute.

TABLE 1.

Key attributes of the four case studies

UTILITY	AUSTIN WATER	PHILADELPHIA WATER DEPARTMENT	PORTLAND WATER BUREAU	SAN DIEGO COUNTY WATER AUTHORITY
Planning/ decisions to be informed	Integrated Water Resources Plan; implementation of conservation, reuse, and supply strategies	Planning and design of vulnerable infrastructure assets	Prioritizing water supply system projects in the Capital Improvement Plan	System optimization and capital improvement projects to meet future needs
What was modeled under climate change in the project analyses	Water supply	River flood levels	Water supply, water demand	Water demand
Time horizon(s)	2030, 2040… 2080, 2120	2020, 2030…2090	2050	2050
Climate model dataset used	CMIP6, screened, custom bias-corrected and downscaled (35 models, screened to 5 models)	CMIP5-LOCA (32 models)	CMIP6-LOCA2 (23 models)	CMIP6-LOCA2 Hybrid (15 models)
Emissions scenarios used	SSP1-2.6, SSP2-4.5, SSP5-8.5	RCP8.5	SSP3-7.0	SSP2-4.5, SSP3-7.0, SSP5-8.5
No. model runs/ scenarios used in system impact modeling	15, plus 48 add'l drought scenarios based on those runs	1 - ensemble mean	23 (supply); 3 (demand)	5
System impact models used	Statistical streamflow models; basin water availability model	Model to interpolate peak flows, elevations, and return intervals from FEMA data	System hydrologic model; water demand model; reservoir drawdown model	Water demand model

ADDITIONAL INSIGHTS

Practical considerations carry more weight than climate dataset attributes

The case studies show that utilities' choices in the selection, processing, and application of climate data are conditioned by many factors—including previous experiences with climate datasets and analyses, technical capacity (in-house and consultants), risk tolerance, input requirements for system impact modeling, and whether a dataset is already "at hand." While the inherent attributes of the climate model datasets (e.g., downscaling method, resolution, number of models) remain relevant, they generally played a secondary role compared to the practical considerations mentioned above.

System-specific impact models are key to making climate data usable

While it is natural to focus on the CMIP climate model datasets at the head of each "chain of models" deployed by the four utilities, the most important link in that chain may be the last one: a system-specific impact model that translates the climate and hydrology scenarios into corresponding system outcomes, couched in the terms familiar to internal and external audiences (e.g., reservoir drawdown dates, peak flood elevations, water supply yield). These models widely varied in their complexity, from a single-spreadsheet regression model to a water availability model involving several programs and hundreds of model nodes. Regardless of complexity, impact models need to balance simulation accuracy with ease of use and interpretability of output. (See WUCA Leading Practice: *Develop tools that allow information customization* [archived here] for related information and examples.)

Repeated engagements with climate data can build utilities' internal capacity

All four utilities had previously used similar climate model data to inform their planning, and in three cases, the project workflow was adapted or refined from a previous effort, rather than developed from scratch. (In the fourth case, a similar workflow had been applied in other river basins.) Utility staff reported gaining technical capacity and confidence over time as they became more familiar with climate data and the other links in the chain of models, generally taking on more of the workflow in subsequent analyses. WUCA meetings, training, and resources were cited as important in supporting this progress. Still, every case study project involved at least some level of external expertise—consultants and/or university researchers—to aid in the selection and application of climate model data, though the degree of reliance on these resources varied. (See WUCA Leading Practice: *Build and maintain in-house capacity* [archived here] for related information and examples.)

Explore the case studies at
www.wucaonline.org

The case studies were developed based on conversations with staff and consultants from the four utilities. Additional guidance and input came from WUCA project managers Keely Brooks and Nolie Templeton, and from WUCA's Climate Modeling Work Group.

We thank all who provided their insights!

Austin Water

CASE STUDY

MARCH 2026

In response to a severe and prolonged regional drought, **Austin Water** incorporated climate change into its long-range planning for the first time through Water Forward, a 100-year integrated water resource plan adopted by the Austin City Council in 2018. For the first five-year update of Water Forward in 2024, the utility revisited the climate and hydrology analyses and scenarios that support its evaluation of future water management strategies. In the process of implementing an improved workflow, Austin Water grew the in-house technical capacity and knowledge base it will apply to the next plan update in 2029.

Austin Water

WUCA Water Utility Climate Alliance

Downtown Austin

LESSONS LEARNED

Doing the work in-house improves the learning feedback loop

Look at streamlining the approach

Match the level of detail to stakeholder needs

Planning for uncertainty and drought resilience can enlarge the window for others

Build—and improve—on what you and others have done previously

Learn more about these lessons on page 13

SUMMARY

Utility	Austin Water
Contact	Marisa Flores Gonzalez Marisa.Flores@austintexas.gov
Project name	Water Forward 2024 Climate and Hydrology Analysis
Project timeline	Spring 2021 – Summer 2023
Geographic scope	Colorado River Basin (Texas)
Utility business functions affected	Drinking water
Objective	Develop projections of temperature and precipitation and associated hydrologic and water-supply scenarios, to test water management strategies across a wide range of possible future conditions
Potential decisions or actions to be informed	Implementation of several future conservation, reuse, and supply strategies
Variables, thresholds, and/or events of interest	• Monthly streamflows • Multi-year droughts • Frequency and magnitude of water shortages • Frequency of drawdowns to very low lake levels
Climate data used	CMIP6,* screened down to 5 global climate models, under SSP1-2.6, SSP2-4.5, and SSP5-8.5 emission scenarios (15 total projections), custom bias-corrected with PRISM data
Why those data were selected	• CMIP6: "latest and greatest" • The 5 chosen models performed well in simulating historical climate of the Colorado River Basin • Pre-processed CMIP6 data was unavailable, so custom bias-correction/downscaling was needed • Range of SSPs accounts for deep uncertainty in future emissions trajectory
Impact modeling performed	• Multivariate (neural network) streamflow models • Colorado Water Availability Model
Key attributes of this case study	• Early use of CMIP6, necessitating custom bias-correction and downscaling • Screening of CMIP6 models for performance • Intensive development and curation of severe drought scenarios

** For definitions of CMIP6 and other climate modeling terminology, see this glossary.*

Overview of the utility

Austin Water supplies water to approximately 1.17 million people through retail service and/or wholesale contracts across a 548-square-mile service area, serving about half of the 2.4 million people in the greater Austin area. The city of Austin sits astride its sole water source, the Colorado River, which is the longest river (860 miles) that flows entirely within the state of Texas. Many smaller cities around Austin draw from the Edwards Aquifer, not surface water.

Six reservoirs, collectively known as the Highland Lakes, impound the Colorado River within the city and upstream of Austin. The Lower Colorado River Authority (LCRA) owns and operates the dams for these reservoirs, the largest of which are Lake Travis (1.1 million acre-feet [MAF] storage plus a 0.776 MAF flood pool) and Lake Buchanan (0.880 MAF storage). The smaller Highland Lakes, including Lake Austin (21,000 acre-feet [AF]), are "pass-through lakes" operated within a narrower range than the main storage reservoirs. Austin Water has three water treatment plants with a combined capacity of 335 million gallons per day; two withdraw water from Lake Austin, and the third withdraws water from Lake Travis.

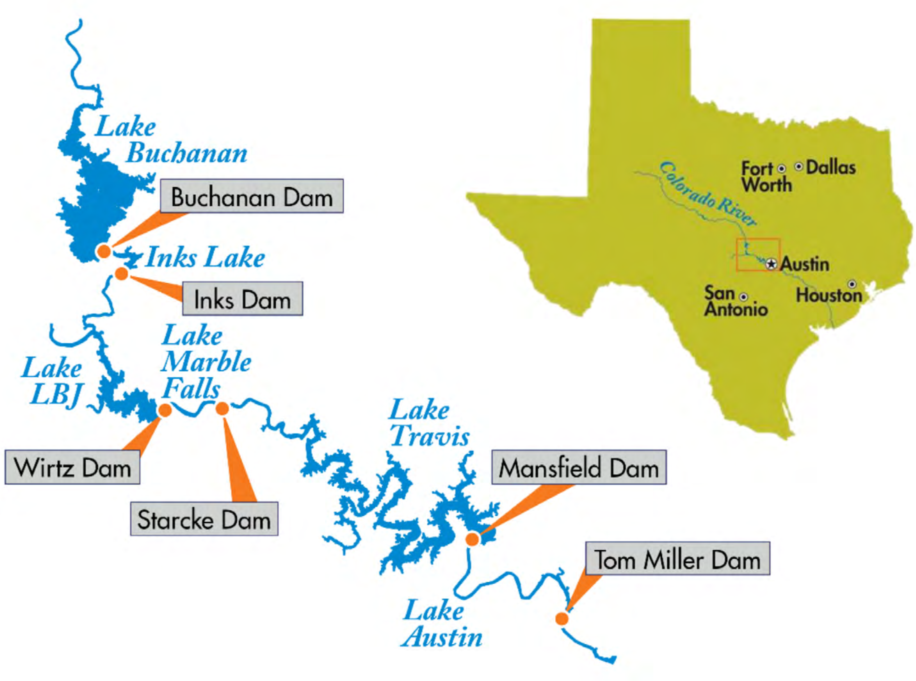

FIGURE 1.

Map showing the Colorado River and the six Highland Lakes, which provide the water supply and storage for Austin Water and users in the lower basin. Downtown Austin lies just downstream of Tom Miller Dam. (Source: LCRA.)

Austin Water has senior run-of-river diversion rights on the lower Colorado River and a contract with LCRA for firm water from the Highland Lakes. The lakes' total storage volume when full (>2 MAF) relative to Austin Water's annual demand (about 0.175 MAF) means that the system can readily weather droughts of one to four years but is vulnerable to more sustained severe droughts, like the 1947–1957 drought. Austin Water has developed a reclaimed water system (~5,000 AF/yr) for non-potable uses, oriented toward large commercial and industrial users, and is expanding the use of reclaimed water.

Austin has a subtropical climate with short, mild winters and hot summers. Annual precipitation in Austin averages 34" but has ranged from 10" to 58". The Colorado River Basin upstream of Austin receives less rainfall on average than the city itself. Like precipitation, runoff in the basin is highly variable; naturalized annual flow on the Colorado River at Austin has ranged from about 0.4 MAF to 5.5 MAF.

Project background

Over the 50 years leading up to the mid-2000s, Austin and the Colorado River Basin experienced no droughts as severe or sustained as the 1947–1957 drought, which had occurred when Austin Water served fewer than 150,000 people. But starting in 2008, naturalized annual streamflows fell below the long-term average for seven consecutive years, bottoming out in 2011, when only 11% of average inflows reached

Ullrich Water Treatment Plant, the largest of Austin Water's three water treatment plants the Highland Lakes. In terms of cumulative streamflow deficit over five-, six-, and seven-year periods, the 2008–2015 drought was worse than 1947–1957.

Confronted with this unprecedented drought in the context of a rapidly growing population and emerging impacts of climate change, Austin Water embarked on an ambitious effort to develop an integrated water resource plan, which became known as Water Forward 2018 (WF18). WF18 used 2070 as the principal planning horizon but looked even farther ahead, out to 2115. The plan's goal was to identify a portfolio of water conservation, reuse, and supply strategies whose implementation would allow Austin Water to meet future demands, even during severe drought, under a wide range of potential futures with regard to climate change and population growth. In addition to establishing a long-term roadmap for the utility, WF18 specified near-term investments and policy changes to be implemented before the plan's next update in five years.

WF18 was the first planning effort by Austin Water to be explicitly informed by climate model projections. The utility contracted with Katharine Hayhoe and her consulting team at ATMOS to develop and analyze the climate model data: 20 CMIP5 models run under the higher-emissions RCP 8.5 scenario,[1] and bias-corrected and statistically downscaled, an effort that built on work previously done for Austin's Office of Sustainability (now called Austin Climate Action and Resilience). The rest of the modeling workflow was very similar to the workflow for Water Forward 2024 (WF24), as described below. To address Austin Water's concern about future droughts, both the historical hydrology and the future-climate-adjusted hydrology were stochastically sampled to generate droughts worse than the 2008–2015 drought of record. In addition, the full historical hydrology was adjusted to reflect projected future climate conditions.

In 2017, as the WF18 effort was ongoing, Austin Water joined the Water Utility Climate Alliance (WUCA). This brought Austin Water staff into closer contact with staff at other WUCA utilities who had longer experience with using climate model data in planning, as well as with WUCA's informational and training resources. In December 2019, Austin Water hosted a two-day WUCA training focused on building resilience to a changing climate, which introduced the team to methods and outside experts who later were instrumental in the WF24 work.

Not long after the WF18 final report was released in November 2018, Austin Water began preparing for the next check-in for its strategic planning cycle—what would

1 Climate projections under the lower-emissions RCP4.5 scenario were also analyzed but were not used in the subsequent modeling and portfolio evaluation.

Davis Water Treatment Plant, with Lake Austin in the background

become WF24. Austin Water benefited from maintaining continuity from WF18 to WF24 with key team members who oversaw and handled the climate and hydrology analyses, including project manager Marisa Flores Gonzalez, technical task manager Helen Gerlach, and hydrologic modeler Richard Hoffpauir—a consultant who has worked closely with Austin Water for over 20 years.

As in WF18, Austin Water contracted with university researchers to incorporate climate model projections into WF24. Leveraging a standing interlocal agreement with the University of Texas (UT) at Austin, a UT team led by researchers[2] from the Jackson School of Geosciences was contracted to select, process, and analyze the climate model data. The utility also created a Climate Technical Advisory Group (CTAG) of two scientists and two technical staff with other water utilities, all with expertise in the analysis and application of climate data to water planning.[3]

Compared to WF18, the overall framework for WF24 went further in acknowledging and exploring uncertainties in future climate and hydrology, future growth, and future regional (i.e., LCRA) water supplies. The framework and methodological choices were more explicitly influenced by principles of decision-making under deep uncertainty, culminating in the use of RAND's Robust Decision-Making analytic framework to evaluate the portfolios of strategies, as described on page 11.

2 Zong-Liang Yang (professor and earth-system modeler) was the project lead; Sabiha Tabassum (then as a PhD student) performed much of the analytical work.

3 John Nielson-Gammon (Texas A&M University and State Climatologist), Julie Vano (Aspen Global Change Institute), Mohammed Mahmoud (then with Central Arizona Project), Laurna Kaatz (then with Denver Water).

Project methods and data selection

TIME HORIZON

The main planning horizon chosen for WF24 was 2080, an approximately 55-year look ahead that was "sufficiently long enough that if you have a big project that you need to implement, now you have some runway to plan for it," according to Hoffpauir. At nearer time horizons, water demands haven't grown as much, so planning for 2050 might not uncover the necessity for a major project. In all, the hydrologic, utility demand, and regional water supply scenarios were modeled at seven time-steps: 2030, 2040, 2050, 2060, 2070, 2080, and 2120. The use of a decadal time step through 2080 is aligned with the regional water planning performed in the Texas Water Development Board regional water planning process.

SELECTING AND PROCESSING CLIMATE MODEL DATA

When the WF24 analyses began in 2021, the new CMIP6 climate projections were available in their raw form, but no national- or global-scale datasets of pre-processed (bias-corrected and downscaled) CMIP6 projections had yet been released. Thus, the choice was either to use an already bias-corrected and downscaled CMIP5 dataset, as was done in WF18, or to process CMIP6 data "from scratch." Austin Water and the UT team opted for the latter course, reflecting a desire to use the "latest and greatest" data from the climate science community.

The UT team downloaded projections for the 35 CMIP6 Global Climate Models (GCMs) available at that time and regridded them using interpolation to a 1-degree (~100-km) grid,[4] with 27 grid boxes covering or bordering the Colorado River Basin. This resolution, and area, matched the datasets of observed precipitation, evaporation, and naturalized flow to be later used as inputs to the water availability model. The team then screened the GCMs based on three criteria:

1. High performance in replicating the historical climate patterns for the Colorado River Basin
2. Availability of daily data for all three emissions scenarios: SSP1-2.6, SSP2-4.5, SSP5-8.5
3. Only one GCM from a given modeling center, to maximize the models' independence from each other[5]

4 While this was technically the "downscaling" step, the endpoint (a 100-km grid) is coarser than the resolution of typical downscaled datasets (4 km to 25 km), though finer-grained than the raw GCM data.

5 For example, both the CNRM-CM6-1 and CNRM-ESM2-1 models had high performance, but they came from the same modeling center (CNRM; France), so only the former was selected.

For the performance screening, the team compared the GCMs' historical simulations of temperature, precipitation, and the number of dry days with observed gridded climate data,[6] as averaged across the 1979–2014 period. They looked at both the spatial pattern of those variables across the basin and the annual cycle of monthly values. As Hoffpauir noted, there was an assumption "that the historical performance is also a good indicator of future performance."

The UT team, in consultation with Austin Water and the CTAG, had set a target of five GCMs for the final ensemble, as a compromise between model diversity and computational feasibility given the complex workflow. Of the 10 GCMs that ranked highest in performance, five did not meet one of the other two criteria. The UT team analyzed the five remaining GCMs' projections under each of the three emissions scenarios (SSPs), using a single run per model-SSP pairing, so 15 projections in all. The use of the three SSPs, which increasingly diverge over the 21st century, was intended to broaden the exploration of potential climate impacts, compared with the focus on RCP8.5 in WF18.

The final step in preparing the climate model data was performing bias-correction of the projected daily minimum temperatures (Tmin), daily maximum temperatures (T*max*), and daily precipitation (P) over the 2015–2100 period for each of the 27 gridboxes. The PRISM gridded climate dataset (1981–2014) provided target distributions of observed daily values, to which the GCM-projected daily values were adjusted. The PRISM dataset was familiar to the Austin Water team from previous work and already had been downloaded for the project area.

IMPACT MODELING

The impact modeling had two parts: First, multivariate statistical (artificial neural network [ANN]) models were developed to translate the projected temperature and precipitation into streamflows. Unlike the multivariate linear regression models used in WF18, the ANN models were able to capture any non-linear responses of streamflow to climate. (The team had also considered using the projected runoff that is directly output by the five CMIP6 models, but lacked confidence that the GCM-simulated hydrology was robust.) Separate ANN models were developed for each of 43 control points in the Colorado River Basin for which 80+-year records of historical naturalized flows had been developed by the Texas Commission on Environmental Quality as inputs to the Colorado Water Availability Model (Colorado WAM).

6 Precipitation: NOAA CPC Global Unified Gauge-Based Analysis of Daily Precipitation; Temperature: U. of Delaware (UDEL) Global Gridded Air Temperature

Downtown Austin and Lady Bird Lake (Colorado River)

The second part was running the new, climate-adjusted streamflow sequences in the Colorado WAM to assess water availability for the entire basin, including the City of Austin. The Colorado WAM pairs a generalized water modeling program developed at Texas A&M University[7] with a set of basin-specific input files representing water rights, diversions, and reservoir operating rules, along with historical monthly precipitation, reservoir evaporation, and naturalized streamflows. The input files for the Colorado River (and other Texas river basins) are maintained by the Texas Commission on Environmental Quality. There are no “climate knobs” to turn with the Colorado WAM model parameters; the effects of climate change can only be simulated by adjusting the Colorado WAM input files. A simpler emulator of the Colorado WAM, known as the mini-WAM, was also created by Austin Water for the subsequent evaluation of portfolios of water management strategies, since running the very large ensemble of simulations in the Colorado WAM would not have been feasible.

OVERVIEW OF THE ANALYTICAL APPROACH

The climate and hydrology analyses for WF24 generally followed a “top-down” approach, i.e., starting with an ensemble of multiple climate models to demarcate the range of future conditions to be explored (Figure 2). Austin Water also incorporated elements of a “bottom-up” approach (i.e., starting with known system vulnerabilities) through the creation of drought scenarios that would stress the system more than the 2008–2015 event did.

7 The Water Rights Analysis Package (WRAP) modeling system, based on network flow programming (Wurbs 2025). The development of WRAP and 23 basin WAMs was mandated by a 1997 Texas law that established a uniform modeling platform for water resources across the state.

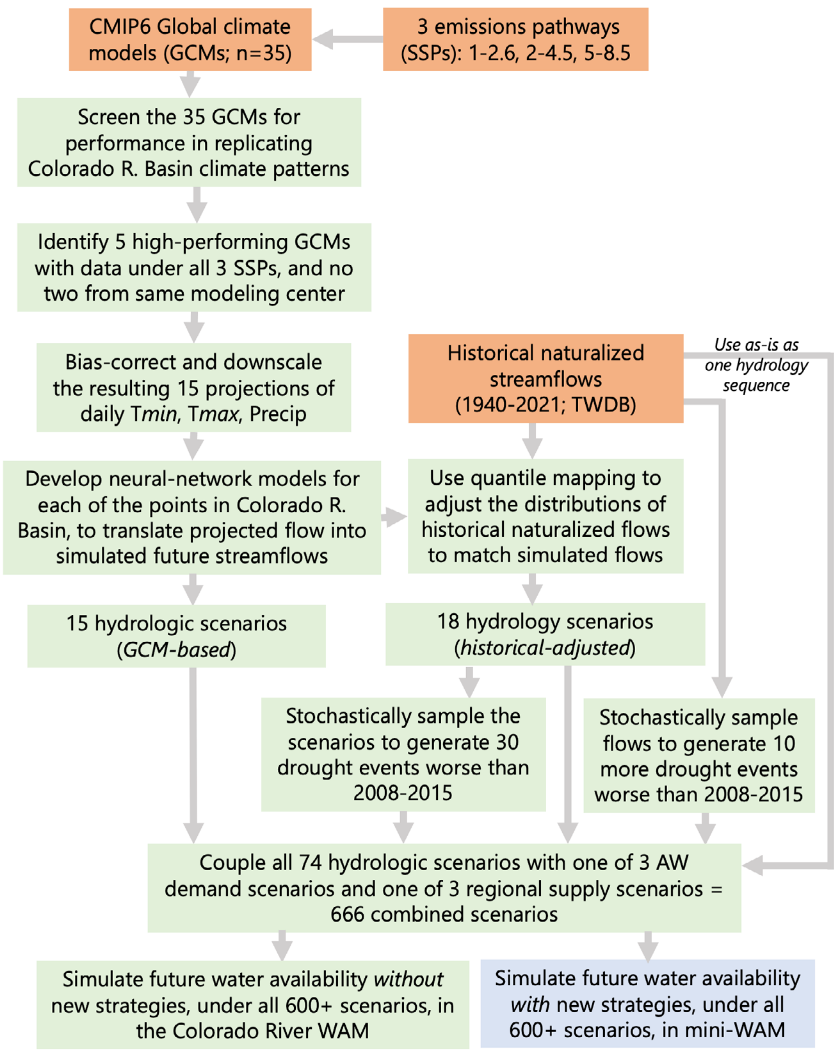

FIGURE 2.

Schematic of the WF24 climate and hydrology analyses. Orange shading indicates data and processing completed by others prior to the analyses. Green shading denotes the steps performed by Austin Water and its consultants. The analyses then fed into the evaluation of portfolios of water strategies (blue box).

The WF24 approach took the "feedstocks" of GCM-based simulated streamflows and historic naturalized streamflows, and through different methods generated 74 hydrologic scenarios, of which 40 had been explicitly curated to include sustained droughts with cumulative deficits greater than 2.0 MAF. (The other scenarios could also include such droughts.) "We didn't choose scenarios based on their plausibility or likelihood, or any sort of probability," Flores Gonzalez said. "We were taking the approach of identifying a wide range of potential futures," consistent with the precepts of decision-making under deep uncertainty. This wide range of hydrologic scenarios captured the major sources of uncertainty in future climate: emissions uncertainty, climate model (structural) uncertainty, and uncertainty from internal variability.

DATA HANDLING

To process and analyze the GCM data, the UT team used scripts and software packages in Python. The team initially employed the UT campus computing cluster to handle the large data files of the raw global CMIP6 projections. Once the projections were processed and “downsized” to the basin scale, further work could be performed on local desktops and laptops. To perform the ANN streamflow modeling, Hoffpauir used scripts and software packages in R.

EVALUATION OF WATER MANAGEMENT STRATEGIES AND PORTFOLIOS

As in WF18, the range of hydrologic scenarios developed in the WF24 climate and hydrology analyses fed into an evaluation of portfolios of water management strategies, culminating in the selection of a preferred portfolio that could meet Austin Water’s needs across the full 100-year planning horizon. While the portfolio evaluation was technically outside the scope of the climate and hydrology analyses (the focus of this case study), describing the portfolio evaluation process helps round out the picture of how and why the climate and hydrology analyses were conducted.

Austin Water had identified 17 strategies to help extend and supplement its core Colorado River water supplies, falling under the categories of conservation, non-potable reuse, potable reuse, new storage, and new supplies. These strategies were combined into nearly 2 million candidate portfolios. Each of these candidate portfolios was run in the mini-WAM under all of the 666 future scenarios and scored for performance, as averaged across all scenarios. “Performance” was defined as the average of three water supply metrics:

- Reliability: Frequency of shortage
- Resilience: Magnitude of shortage
- Vulnerability: Frequency of very low lake levels

Each candidate portfolio’s performance score was then plotted against the relative cost of that portfolio. The resulting cloud of plotted points had an abrupt curved edge on one side: the “Pareto front” representing optimal tradeoffs between performance and cost. Ten portfolios were selected from those plotted along and near the Pareto front, and these portfolios were evaluated under additional criteria beyond water supply: economic benefits, equity benefits, environmental benefits, and implementation benefits.

Outcomes and next steps

RESULTS OF THE ANALYSES

Expect lower average streamflows and more intense droughts

The key takeaways from the WF24 climate and hydrology analyses using CMIP6 were very consistent with the WF18 analyses, which used CMIP5. Unsurprisingly, projections from all five CMIP6 GCMs showed warmer temperatures and increased evaporation in future decades, with greater warming and evaporation increases under the higher-emissions scenarios. The models disagreed on the future trend in basinwide annual precipitation but showed a rough consensus that both the number of dry days and the number of extremely wet days (precipitation >2") would increase. When these projections of warming and more variable rainfall patterns were translated through the ANN streamflow models into future hydrology, the general outcomes were decreased average streamflows and more intense droughts in the coming decades (Figure 3).

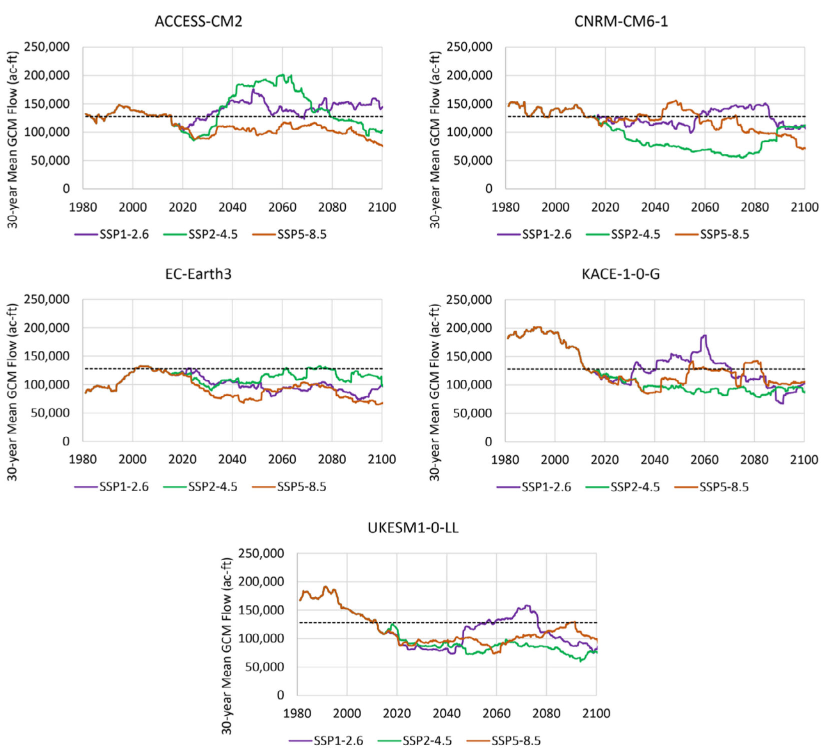

FIGURE 3.

Results of the streamflow modeling using direct-from-GCM sequences of temperature and precipitation, showing monthly flows (30-year running means) for the Colorado River at Austin. Across the five CMIP6 GCMs and 15 streamflow traces, the projected flows (2015–2100) are mostly lower than the average observed flows for the 1983–2016 period (dashed black lines). (Source: Austin Water.)

Without new water strategies, water shortage during drought occurred in a high fraction of future scenarios

The water-availability modeling of future hydrology and drought scenarios using the Colorado WAM showed that without any new water strategies, over 30% of the 666 future scenarios at 2060 would have resulted in unmet demands for water during drought. At 2080, over 60% of the scenarios would have resulted in unmet demands.

The preferred portfolio of strategies led to large reductions in water supply vulnerability

Of the 10 candidate portfolios subjected to further evaluation beyond water supply, the top-scoring or preferred portfolio ranked fourth of 10 in water supply performance alone, but it was superior across the other criteria to the three portfolios with higher water supply scores. When the implementation of the preferred portfolio of water strategies was factored into the Colorado WAM runs, the proportion of the 666 future scenarios that resulted in unmet demand at 2060 dropped from >30% to 3%, and from >60% to 15% at 2080.

The Austin Water team noted that even with the use of different climate models, a different approach to streamflow modeling, and a different approach to evaluating the portfolios, the preferred portfolio of strategies in WF24 was very similar to the one that had been chosen in WF18, incorporating conservation, potable and non-potable reuse, aquifer storage and recovery, an off-channel reservoir, and desalination of brackish groundwater. So not only was the preferred portfolio robust under a wide range of future climate and growth scenarios, but its general makeup was not dependent on the particular set of Water Forward analytical methods.

USE IN DECISION SUPPORT BEYOND WF24

The project team anticipates additional uses of the WF24 climate and hydrology analyses as Austin Water moves toward incorporating climate change more broadly into planning and decision-making across the utility. The most likely areas for use in the near term are infrastructure planning and capital improvements planning. Flores Gonzalez noted that the ongoing WUCA Climate Resilient Engineering Design project, in which Austin Water is participating, could also help the utility to design future projects (i.e., ones that were identified in WF24) to be more resilient to the climate futures shown in the WF24 analyses.

Lessons learned

DOING THE WORK IN-HOUSE IMPROVES THE LEARNING FEEDBACK LOOP

Flores Gonzalez observed that when performing the WF18 climate and hydrology analyses, Austin Water had less insight into the choices the consultants made about data and methods. For WF24, using its experiences from WF18, the Austin Water team was more involved in the decisions made by the UT team about the CMIP6 models. Further, the team was able to learn from the CTAG's "live peer-review process." For WF24, Hoffpauir also took on the development of the streamflow models, tightening the learning loop for Austin Water. This closer involvement with the WF24 analyses gave the Austin Water team confidence that for the next plan update, they also could move the handling of CMIP climate projections in-house.

LOOK AT STREAMLINING THE APPROACH

As project manager, Flores Gonzalez looks to improve the planning process by considering "how we can get at robust answers and solutions using approaches that are a little bit less resource intensive or more agile." Part of the answer has been moving more of the analytical work in-house, which has saved Austin Water both money and time. But the team is also finding tools and approaches to conduct the analyses in less intensive ways. For example, using a freely available "off-the-shelf" downscaled climate projection dataset such as CMIP6 LOCA2 in Water Forward 2029 (WF29) will avoid the costs of developing a custom dataset.

MATCH THE LEVEL OF DETAIL TO STAKEHOLDER NEEDS

Both the WF18 and WF24 planning processes were advised by the Water Forward Task Force, a group of citizens appointed by the City Council. While some task force members had technical expertise in water or other areas, others came with broader community perspectives. The team realized that it was often sufficient, and appreciated, to keep the explanations at a high level, while noting that Austin is following the practices at the utilities in respected peer cities (e.g., other WUCA member agencies).

PLANNING FOR UNCERTAINTY AND DROUGHT RESILIENCE CAN ENLARGE THE WINDOW FOR OTHERS

Austin Water has benefited from strong support to consider long-term climate and hydrologic risks in its planning efforts. Through this work, the utility has found that focusing on concepts such as preparing for future uncertainty and building resilience to droughts more severe than the drought of record resonates well with a wide range of stakeholders. These framing approaches help create common ground, even among audiences who may connect more naturally with resilience planning than with discussions of climate change.

BUILD—AND IMPROVE—ON WHAT YOU AND OTHERS HAVE DONE PREVIOUSLY

Even in the analyses for WF18, Austin Water and its partners did not start from scratch; the approach for processing the CMIP5 climate projections built on work that ATMOS had previously done for Austin's Office of Sustainability. For WF24, while the overall workflow for the climate and hydrology analyses was similar to WF18, the steps were iterated upon and adjusted based on experience both internal and external to Austin Water. The updated method for generating and evaluating portfolios of water strategies drew on RAND's extensive past work, specifically an application in Monterrey, Mexico.

The Austin Water team is now well into preparing for the analyses for the next iteration, WF29, with Young-Hoon Jin as the technical task lead and Richard Hoffpauir as a consulting hydrologist. Besides using the CMIP6 LOCA2 downscaled dataset, the team plans to switch from using ANN statistical models to using GR4J—a widely used "conceptual" (physics-informed) rainfall-runoff model—in order to translate the projected climate into streamflows. By using this new approach to streamflow modeling, the team can learn more about the strengths and weaknesses of the WF18 and WF24 methods and results, while leveraging the large body of research and practice on applying the GR4J model.

Further reading

OTHER INFORMATION ABOUT THE PROJECT

- Austin Water. 2024. Water Forward 2024 Plan Report. November 2024, 64 pp. https://austin.widen.net/view/pdf/aur3rgfpgd/AW_WaterForward_Plan_2024.pdf
- Austin Water. 2024. Appendix D: Climate and Hydrology Analysis. Appendix to the Water Forward 2024 Plan Report. November 2024, 118 pp. https://austin.widen.net/s/lbsxtjnvv2/final-appendix-d---climate-and-hydrology-analysis

RESEARCH OUTPUTS ABOUT THE METHODOLOGY/DATASET(S)

- Gerlach, H., Deeds, D., Tabassum, S., Hoffpauir, R., Yang, Z., Passalacqua, P., Persad, G., Niyogi, D., Wu, W., and Flores Gonzalez, M. (2025). Selection and Use of GCM Projections in Planning for Future Water Supply. *AWWA Water Science, 7*(3), e70022. https://doi.org/10.1002/aws2.70022

OTHER RELEVANT LITERATURE/WEBPAGES

- Voosen, P. (2025). Local predictions of climate change are hazy. But cities need answers fast. *Science, 388*(6751). https://doi.org/10.1126/science.zmq4rob

Explore other case studies at www.wucaonline.org

This case study was developed by Jeff Lukas (Lukas Climate Research and Consulting and AGCI) and Julie Vano (AGCI) based on conversations with staff from the Austin Water. Additional guidance and input came from WUCA project managers Keely Brooks (Southern Nevada Water Authority) and Nolie Templeton (Central Arizona Project), and from WUCA's Climate Modeling Work Group.

We thank all who provided their insights!

Philadelphia Water Department

CASE STUDY

OCTOBER 2025

In September 2021, torrential rains associated with Hurricane Ida caused severe flooding along the lower Schuylkill River, damaging and threatening **Philadelphia Water Department** (PWD) facilities. For the PWD, this was a "wake-up call" about the utility's vulnerability to non-tidal riverine flooding. PWD quickly responded by conducting an analysis to assess future flooding risk under climate change, understand the Ida flooding in that context, and inform adaptive management of critical facilities.

Schuylkill River

LESSONS LEARNED

Updating the flood analyses reinforced the wisdom of adaptive management

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There are multiple approaches for climate-informed flood analysis; results will vary with the approach

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Handling of uncertainty can be tailored to risk tolerance

Learn more about these lessons on page 11

PHILADELPHIA WATER DEPARTMENT

WUCA Water Utility Climate Alliance

SUMMARY

Utility	Philadelphia Water Department
Contact	Climate Change Adaptation Program; pwd.ccap@phila.gov
Consultant	CDM Smith
Project name	Non-tidal riverine flood analysis
Project timeline	Fall 2021 – Spring 2022
Geographic scope	Schuylkill River watershed
Utility business functions affected	Drinking water
Objective	Incorporate ongoing and future climate change effects into flood elevations for the non-tidal reaches of the Schuylkill River to inform planning and design of vulnerable assets
Potential decisions or actions to be informed	Harden or relocate assets vulnerable to flooding
Variables, thresholds, and/or events of interest	Streamflows, elevations, and return intervals of design flood events, e.g., 10-year, 50-year, 100-year, 500-year
Climate data used	CMIP5*with LOCA downscaling, RCP8.5 emissions pathway (32 projections)
Why those data were selected	The only downscaled CMIP dataset that has an associated set of hydrologic projections run with the VIC model for the contiguous U.S., including the Schuylkill watershed
Impact modeling performed	• VIC hydrologic model to generate future runoff events (modeling was already incorporated in the CMIP5-LOCA hydrology data) • Spreadsheet model to interpolate streamflows, elevations, and return intervals from FEMA Flood Insurance Study (FIS data)
Key attributes of this case study	• An extreme event created a window of opportunity to produce new risk information and have it accepted by stakeholders • Rapid, lower-cost assessment of future risk leveraged an existing methodology and FEMA datasets • Used a simple regression model to generate site-specific numbers in lieu of a much more complex impact model • Provided one set of numbers to stakeholders to represent the future risk, while explaining the uncertainties

** For definitions of CMIP5 and other climate modeling terminology, see this glossary.*

Overview of the utility

Philadelphia Water Department (hereafter PWD) serves 1.7 million customers with drinking water (>300 MGD) and over 2 million customers with stormwater and wastewater services. PWD's water supply portfolio is entirely from surface water: about 60% from the mainstem Delaware River and 40% from the Schuylkill River (Figure 1), which is a tributary of the Delaware. PWD has two water treatment plants on the Schuylkill (Belmont and Queen Lane) and one on the mainstem Delaware (Baxter).

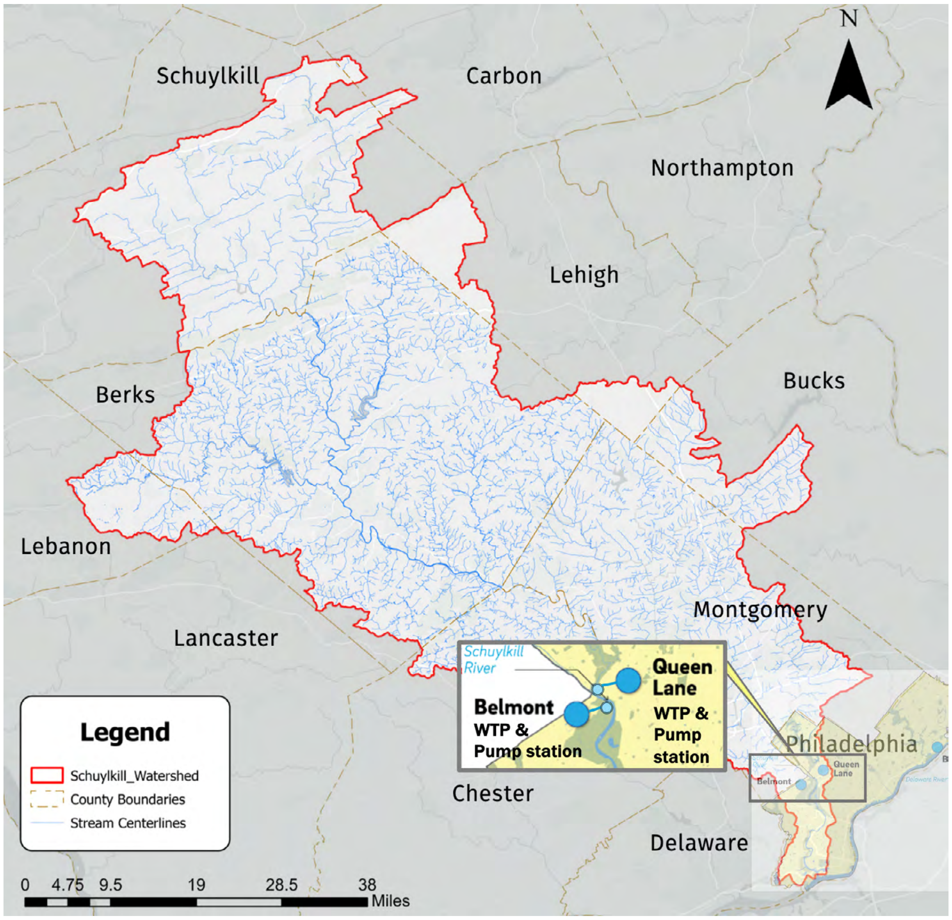

FIGURE 1.

Map of the Schuylkill River watershed, highlighting the City and County of Philadelphia in yellow. The inset shows the location of the Belmont and Queen Lane water treatment plants and their associated pump stations. (Modified from the East Falls and Manayunk Flood Mitigation Study and a graphic by the Philadelphia Water Department.)

Project background

By 2021, PWD had performed multiple climate change analyses to inform operations and planning, including capital improvement plans (CIP). But the previous work on flooding risk under future climate change focused exclusively on coastal inundation and sea level rise, which pose significant risks to PWD along tidal portions of the Delaware and Schuylkill. Non-tidal riverine flooding on the Schuylkill or other tributaries was not seen as a major source of vulnerability.

The flooding and damage were a "wake-up call"

On September 1–2, 2021, the former Hurricane Ida—now a "post-tropical" storm, but still carrying abundant tropical moisture—passed over southeastern Pennsylvania, producing several hours of torrential rainfall near and west of the storm track. Within Philadelphia, a total of two to five inches of rain fell. North and east of the city, higher up in the Schuylkill and Delaware watersheds, seven to ten inches fell, leading to major flooding of area creeks and rivers. The Schuylkill at Philadelphia stream gauge recorded a peak stage of 16.35 feet, less than 1 foot below the all-time record.

The flood caused extensive inundation and damage to property and infrastructure along the Schuylkill, including Interstate 676, a SEPTA rail line, and much of the Manayunk neighborhood. PWD's Belmont Raw Water Pump Station was damaged, and the Queen Lane Water Treatment Plant was threatened. According to Allison Lau, an engineer with PWD's Climate Change Adaptation Program (CCAP), the flooding and damage were a "wake-up call" for the utility—but also provided a "window of opportunity" to look at how climate change is impacting non-tidal riverine flooding.

Mark Maimone, Climate Change Discipline Lead with CDM Smith, had collaborated with PWD for many years on many studies and engineering analyses, including on climate change impacts. He and colleagues at CDM Smith had recently completed a project for FEMA (Maimone and Adams 2023) for which they developed decadal climate change factors for river basins across the contiguous U.S.—factors that could be used to adjust design flood elevations (DFEs) to reflect future climate risk. Among those U.S. basins was the greater Delaware-Mid-Atlantic basin (HUC4), but to get a finer-resolution look at PWD's watersheds, Lau and Maimone decided to deploy the same approach for a new analysis focused on just the Schuylkill River.

Besides rapidly responding to the Ida damage and its implications for the system, the Schuylkill analysis was also well-timed to inform a master planning and capital investment process, the Water Revitalization Plan, which kicked off in 2019. Among the 15 major drinking-water projects identified in the plan, two are related to the Ida flooding on the Schuylkill River: the Belmont Pump Station upgrade and the Queen Lane Water Treatment Plant replacement (to begin in 2026). Other facility improvements could also benefit from more robust information about future non-tidal riverine flood risks.

Project methods and data selection

There were two main parts to the PWD non-tidal riverine flood analysis. The first used the same downscaled climate projections and methods as in the FEMA-funded work to produce decadal delta change factors (DCFs) specific to the Schuylkill River. This part was carried out by Mark Maimone and CDM Smith. The second part applied the decadal change factors to update the design flood elevations and associated flows previously published for the FEMA FIS dataset, then estimated future flows and elevations across a range of flood return intervals, not just the 10-year, 50-year, 100-year, and 500-year events estimated in the FIS. This part was carried out by PWD (Lau and Julia Rockwell, CCAP manager) with guidance from Maimone.

TIME HORIZON AND ASSUMPTIONS ABOUT THE FUTURE

The methodology for the analysis produces decadal change factors for each decade from 2020 through 2090. To calculate the climate change-adjusted design flood elevations and report the results, PWD focused on the 2060s and 2090s. The analysis assumed that existing land-use patterns would be constant through the analysis period, though Maimone and Lau acknowledged that land use (e.g., fraction of impervious surfaces) will in fact change over time.

SELECTING AND PROCESSING CLIMATE MODEL DATA

At the time of CDM Smith's FEMA project, only climate projections from CMIP5 models were available in downscaled form suitable for modeling at the basin (HUC4) scale; downscaled CMIP6 was still a year or two away. Of the numerous options for downscaled CMIP5, the LOCA (Localized Constructed Analogs) downscaled CMIP5 dataset (Pierce et al. 2016) was the only one for which fine-scale hydrology projections had been run with the physics-based VIC hydrologic model, for all basins in the contiguous U.S.[1] CDM Smith also evaluated LOCA against two other

1 CMIP5 MACA projections have also been run in the VIC model, but the modeled hydrology is available only for selected stream gauges in the Western U.S.

Planning informs PWD's investment in large-scale infrastructure

downscaled CMIP5 datasets, MACA and BCSD, comparing the historical period simulations (1950–2005) from those three datasets with observed precipitation (daily, annual, average) and temperature (daily). They found that the statistics from the LOCA historical simulations best matched Philadelphia's observed climate records.

The "CMIP5-LOCA-VIC" hydrology projections were produced by NCAR for a consortium led by Reclamation and USACE, and made available in 2020 via the GDO-DCHP data portal: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. The CMIP5-LOCA-VIC dataset includes downscaled projections from 32 climate models run once each under RCP4.5 and RCP8.5, so 64 projections total.

CDM Smith and PWD considered reducing the 32-member model ensemble, either through grouping the models into response quadrants (e.g., hot-dry, cool-wet, etc.) or according to each model's independence from the others, but ultimately they opted to use the entire LOCA ensemble (32 models). This decision was consistent with the Philadelphia Office of Sustainability's use of the entire LOCA ensemble in its city-wide vulnerability assessment.

For the PWD analysis, CDM Smith downloaded only the CMIP5-LOCA-VIC data for those 12-km grid cells covering the Schuylkill River basin, a task facilitated by the "Tributary Area" selection tool in the GDO-DCHP portal. While the nationwide FEMA project used all of the CMIP5-LOCA projections (32 models run once each under RCP4.5 and RCP8.5, or 64 projections), the PWD analysis used only the 32 projections run under RCP8.5. This choice was consistent with PWD's programmatic climate change guidance[2], which recommends using RCP8.5 to reflect PWD's low risk tolerance for interruptions to its critical services.

Philadelphia City Hall

IMPACT MODELING

The PWD analysis leveraged the existing FEMA FIS design flood elevations and flows, bypassing the need to perform new locally specific hydrology and hydraulic modeling (e.g., with HEC-RAS) to simulate flood elevations at different flows. The only new modeling required was a spreadsheet model to interpolate elevations and flows between the four design floods in the FEMA FIS data (10-year, 50-year, 100-year, 500-year). This greatly simplified the workflow and reduced the potential time investment in the project.

One downside of using the FEMA FIS data was that the calculations for design flood elevations for the Schuylkill had been last revised in 2007 using gage data through 2002, as well as hydraulic assumptions, data, and modeling performed by USACE in 1996. Lau acknowledged that these FEMA/USACE data were outdated, but short of PWD building their own hydraulic model of the Schuylkill, their analysis had to rely on the FIS numbers.

Another downside of relying on the FIS numbers was the inability to reliably extrapolate peak flows and elevations for any future design floods that exceeded the

2 PWD Climate-Resilient Planning and Design Guidance (v 1.1, March 2024)

FIS 500-year event peak flow and elevation. Because the FIS-published river cross-sections of the Schuylkill only extend to that 500-year level, the contours of the potentially inundated area above that level are unknown (see Figure 3).

OVERVIEW OF THE ANALYTICAL APPROACH

A summary of the data and steps in the Schuylkill flood analysis is shown in Figure 2. Essentially, the approach examines the 32 hydrologic projections to see how the highest-runoff days in the Schuylkill watershed have changed from the 1986–2005 reference period to each of eight future periods (centered on 2020 to 2090). The percentage change, or delta change factor (DCF), is then applied to the FEMA FIS peak flows for the four design floods.

To develop this approach for the FEMA project, CDM Smith ran many sensitivity analyses to determine the best number of daily runoff events to pool within the historical and future periods for calculating the DCFs, eventually landing on 20 events. When using fewer than 20 events, the results were too volatile, with abrupt changes in the DCFs from decade to decade that are not physically meaningful.

Note that the step to calculate the DCF for the Schuylkill for each future period involved averaging across the 32 CMIP5-LOCA-VIC projections. This means that there is only one hydrologic future depicted in the final outputs. While the project leads were well aware of the broad range of climate futures (i.e., the magnitude of temperature and precipitation changes) across the 32 projections, the CCAP guidance document recommends reporting only the ensemble average. According to Maimone, this practice is consistent with what PWD stakeholders wanted: "We'll tell them about all the uncertainty, but they want one number."

Fairmount Water Works Garden, Philadelphia Art Museum

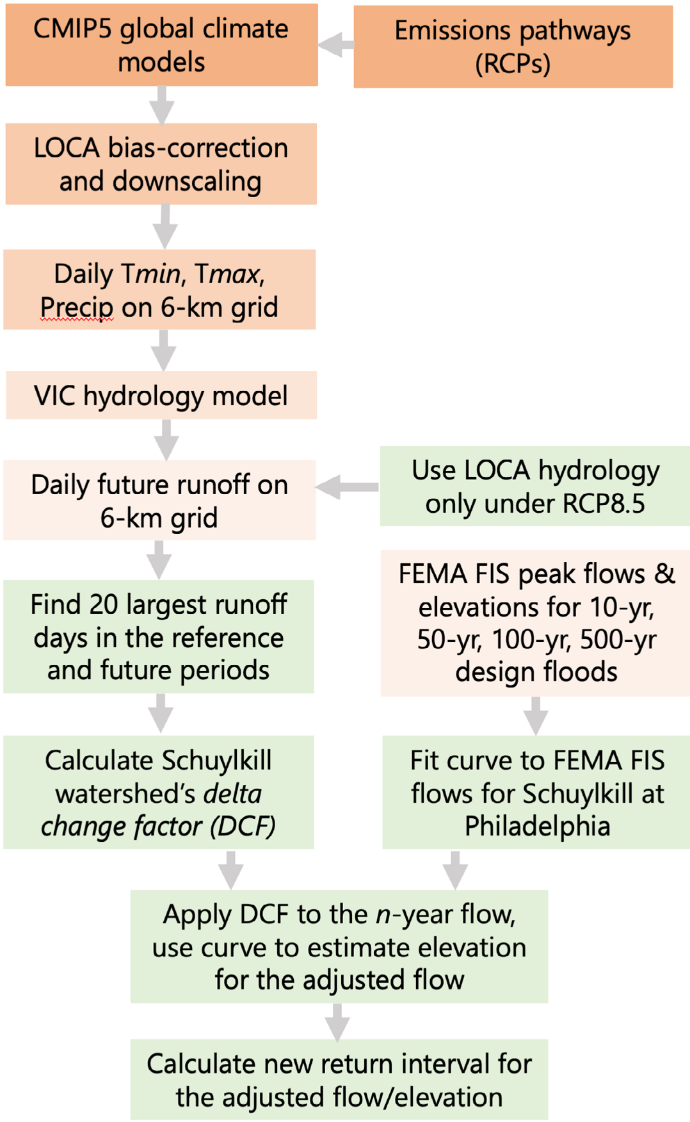

FIGURE 2.

Schematic of the Schuylkill riverine flooding analysis. Orange shading indicates data and processing completed by others prior to the analysis. Green shading denotes the steps performed by CDM Smith and PWD.

DATA HANDLING

The CMIP5 LOCA VIC data—which are large files of several gigabytes for each gridcell—was downloaded, handled, and processed on CDM Smith's computers. The R codes that CDM Smith used to calculate the Schuylkill flood DCFs from the CMIP5 LOCA VIC data had already been developed for the FEMA project. Once the DCFs were calculated, these data were passed to PWD; the subsequent calculations—using FIS data to derive new flood flows/elevations—were done on a spreadsheet.

Outcomes and next steps

RESULTS OF THE ANALYSIS

Severe flooding will become more frequent

PWD's non-tidal riverine flood analysis depicts a future with significant increases in design flood peak flows and elevations on the Schuylkill River; peak flows would increase by 32% in 2060 and by 60% in 2090 under RCP8.5, compared to the 1986–2005 reference period (Figure 3). Conversely, the peak flows and elevations associated with the current FIS design floods would occur at shorter intervals, on average. For example, the FIS 500-year event becomes a 100-year event in the hydroclimatology of 2060 and only a 40-year event in 2090. Similarly, the level of the 2021 Ida flooding is estimated as a 65-year event in the (outdated) FIS data, but that level is a 30-year event under current conditions (2020) and would be rated as a 6-year event in 2090.

At the Belmont RWPS: Flows and Associated River Elevations for RCP8.5									
		Return interval							
Decade (year)	DCF	10-year		50-year		100-year		500-year	
	RCP8.5	Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88	Flow (cfs)	Elev. (ft.) NAVD88
2020	24%	91,969	23.1	136,711	28.9	159,082	32.3	212,523	42.2
2030	28%	94,408	23.4	140,336	29.4	163,300	33.0	218,159	43.4
2040	29%	95,169	23.5	141,467	29.6	164,616	33.2	219,917	43.8
2050	25%	92,250	23.1	137,128	28.9	159,567	32.4	213,172	42.3
2060	32%	97,731	23.8	145,275	30.1	169,047	33.9	225,837	45.1
2070	41%	103,998	24.5	154,592	31.6	179,889	35.8	240,321	48.5
2080	53%	113,308	25.7	168,431	33.8	195,992	38.8	261,833	54.0
2090	60%	118,106	26.3	175,563	35.1	204,291	40.5	272,920	57.0

FIGURE 3.

Delta Change Factors (DCFs) by decade, and the associated peak flow and elevation of the Schuylkill at the Belmont Raw Water Pump Station at each design flood return interval. The orange shading indicates results with more inherent uncertainty since the elevations are extrapolated beyond the envelope of the underlying FEMA FIS data, i.e., the current 500-year event. (Philadelphia Water Department)

Facility operators see the increasing risk

The details of how this increasing risk would impact specific elevations and infrastructure on the Schuylkill made a strong impression on the PWD facility operators who saw the project team's first presentation of the results, according to Lau and Maimone. With memories of the Ida flooding still fresh, the operators were alarmed by the vulnerabilities that the PWD facilities would face in a rapidly warming future. Interestingly, presenting the risk in terms of flood return intervals (e.g., Ida as a 6-year event in 2090) appeared to resonate more with the operators as a metric of vulnerability than the increases in flood elevations.

USE AS DECISION SUPPORT

Informing infrastructure design hardening for resilience

Based on the results of the analysis, PWD investigated an alternative location for the Belmont Pump Station, at a higher elevation and upstream of the existing facility, though there has not yet been a decision or action. As the Water Revitalization Plan moves forward, the results of the analysis will inform implementation of at least two projects: the retrofit/move of the Belmont Pump Station and the replacement of the Queen Lane WTP based on the Raw Water System Intake. There are three alternatives for improving the Belmont Pump Station. These include rehabilitating the existing facility, constructing a new pump station at the current location, or building a pump station at a new, higher elevation site.

Supporting community resilience planning beyond utility assets

In response to the Ida flooding, the East Falls and Manayunk neighborhood development corporations carried out their own flood mitigation study, which was released in July 2024. The "Future Flooding" section of that study, carried out by AKRF, Inc., used the approach from PWD's analysis, including Delta Change Factors (DCFs) for the Schuylkill River provided by PWD, to project how many additional properties in the neighborhoods would be inundated in 10-year and 100-year design flood events in 2050 and 2090, compared to the current FEMA FIS elevations.

Lessons learned

UPDATING THE FLOOD ANALYSES REINFORCED THE WISDOM OF ADAPTIVE MANAGEMENT

Lau says that understanding the potential changes in flood frequencies has been very important and impactful for PWD. The detailed findings helped inform what alternative sites would be feasible and whether it would be possible to retrofit the Belmont Pump Station at its current location to the design flood elevation. The findings of the analysis also reinforced the wisdom of adaptive management, in which adjustments to plans and operations are made systematically and iteratively as conditions change and new information becomes available.

THERE ARE MULTIPLE APPROACHES FOR CLIMATE-INFORMED FLOOD ANALYSIS; RESULTS WILL VARY WITH THE APPROACH

While using downscaled hydrology projections to calculate DCFs showed significant increases in the design flood peak flows and elevations for the Schuylkill under RCP8.5—as it has for most basins across the U.S.—the change factors turned out to be smaller than what one would obtain using a simpler method based on Clausius-Clapeyron (C-C) scaling. C-C scaling says that changes in extreme rainfall will follow the increase in the atmosphere's capacity to hold water vapor as temperatures warm: +7% per degree C of warming.[3]

A joint study by CDM Smith and PWD staff (Maimone et al. 2023) conducted after the Schuylkill analysis laid out two potential approaches for handling C-C scaling to project future changes in future extreme precipitation events, and compared them to the VIC model runoff approach. Using a C-C approach for a future PWD flood analysis for the Schuylkill would require a hydrology and hydraulic model of the watershed to translate from extreme precipitation events to flood elevations and peak flows.

Having worked with these different approaches to evaluating future change in extreme precipitation and flooding, Maimone says one should put a lot of thought into the choice of approach: "The results can be very, very different depending on what method you choose." He also noted that if one derives future change factors (DCFs) from projected precipitation, the percent changes will be much smaller than those derived from projected runoff (as in the PWD project). Thus one should not apply precipitation-derived change factors directly to historical runoff or peak flows, such as FIS data.

CDM Smith is currently evaluating the CMIP6 LOCA2 downscaled temperature and precipitation projections, which became available in 2023. If the projected changes point to substantial differences in storms and flooding compared to CMIP5 LOCA, that would prompt PWD to redo the non-tidal riverine flood analysis with the CMIP6-based dataset.

HANDLING OF UNCERTAINTY CAN BE TAILORED TO RISK TOLERANCE

The discussion above underscores that there can be no certain answer to the

3 C-C scaling of extreme precipitation is broadly supported by observational evidence, although precipitation extremes in warm-season convective events (i.e., thunderstorms) can show "super-C-C" scaling, increasing by roughly 15% per degree C of warming.

question "How will non-tidal riverine flood risk for PWD change in the future?" There is significant uncertainty in the climate inputs (e.g., CMIP5 model projections) and also sensitivity of the outputs to the various methodological decisions and assumptions. While it is important to understand the sources of uncertainty, it is also appropriate to deliberately constrain uncertainty to reflect the risk tolerance of the system being analyzed.

As noted earlier, PWD's decision to model and report flood risk only under RCP8.5, and not RCP4.5, was made because of the low risk tolerance associated with the critical infrastructure and services at issue. That inherently conservative approach had the effect of tilting the analysis toward the higher end of the broad range of plausible future flooding outcomes, regardless of the other specifics of the methodology. (Focusing on the ensemble mean under RCP8.5 simplified the presentation of future risk while deemphasizing extreme-high-end outcomes.) If the findings under RCP8.5 had pointed the utility toward an action that appeared excessively costly relative to the values at risk, there was flexibility under PWD's Climate Resilience Planning and Design Guidance to use a lower estimate of future climate change instead (e.g., the RCP4.5 ensemble mean).

Further reading

OTHER INFORMATION ABOUT THE PROJECT

- Rockwell, J. 'Keeping Pace with Evolving Climate Science: Planning for Climate Change at the Philadelphia Water Department.' Presentation to SE PA-AWWA Spring Conference, April 2024 (slides 30-39).

RESEARCH OUTPUTS ABOUT THE METHODOLOGY/DATASET(S)

- Maimone and Adams (2023). A practical method for estimating climate-related changes to riverine flood elevation and frequency.
- Maimone et al. (2023). Three methods of characterizing climate-induced changes in extreme rainfall: a comparison study.

OTHER RELEVANT LITERATURE/WEBPAGES

- PWD Climate-Resilient Planning and Design Guidance (v 1.1, March 2024)
- East Falls and Manayunk Flood Mitigation Study (July 2024)

Explore other case studies at www.wucaonline.org

This case study was developed by Jeff Lukas (Lukas Climate Research and Consulting and AGCI) and Julie Vano (AGCI) based on conversations with staff from the Philadelphia Water Department. Additional guidance and input came from WUCA project managers Keely Brooks (Southern Nevada Water Authority) and Nolie Templeton (Central Arizona Project), and from WUCA's Climate Modeling Work Group.

We thank all who provided their insights!

Portland Water Bureau

CASE STUDY

OCTOBER 2025

The **Portland Water Bureau** (PWB) has used climate model projections to inform planning for over 25 years, and over this time has built substantial in-house capacity to conduct these analyses. Implementing the latest CMIP6 model projections in supply and demand forecasts brought new opportunities—and challenges. But the key to making the forecasts *usable* is a simple reservoir storage and drawdown model that translates the complex stream of outputs into familiar supply metrics.


Bull Run Lake

LESSONS LEARNED

Investing in internal capacity has paid off for PWB

Getting organizational buy-in to new processes takes time and effort

Speaking in familiar terms aids understanding

Kick the tires on new climate data first—and expect bumps in the road

Climate change is not the only source of future uncertainty in demand

Learn more about these lessons on page 13

PORTLAND WATER BUREAU
FROM FOREST TO FAUCET

WUCA
Water Utility Climate Alliance

SUMMARY

Utility	City of Portland Water Bureau (PWB)
Contact	Kavita Heyn, kavita.heyn@portlandoregon.gov
Project name	Adaptive Planning 2025 Supply and Demand Forecasting
Project timeline	2021 – Fall 2025
Geographic scope	Bull Run Watershed (102 sq. mi.) and PWB service area (225 sq. mi.)
Utility business functions affected	Water supply
Objective	Produce a range of long-term forecasts of water supply and water demand, and resulting system outcomes
Potential decisions or actions to be informed	• Prioritizing the water supply system projects in the Capital Improvement Plan • Investment in secondary groundwater source
Variables, thresholds, and/or events of interest	• Streamflow • Reservoir drawdown start, duration, end • Minimum storage, with and without groundwater use • Total groundwater pumped, days of pumping, maximum pumping rate • Average day, summer average, peak day, and indoor base demands
Climate data used	CMIP6* LOCA2, under SSP3-7.0
Why those data were selected	• CMIP6 models capture the relevant atmospheric circulation patterns • LOCA2 is focused on better representing short-term extremes • Option of SSP3-7.0; intermediate between RCP 4.5 and 8.5 used in previous analyses
Impact modeling performed	• System hydrologic model (based on PRMS) • Demand model • Reservoir-drawdown model
Key attributes of this case study	• First five-year supply-demand update in a continuous adaptive planning process • In-house technical capacity makes routine updates more feasible • First use of CMIP6 by PWB for supply and demand forecasting

** For definitions of CMIP6 and other climate modeling terminology, see this glossary.*

Overview of the utility

The Portland Water Bureau (PWB) currently serves just under one million customers with drinking water in Portland, Oregon, and 19 surrounding cities and water districts, through both retail and wholesale contracts. PWB's primary water source is surface water from the Bull Run Watershed, about 25 miles east of Portland. The watershed is a temperate rainforest that receives 135 inches of precipitation annually, on average. The mix of rain and snow during the long wet season, and a dry summer climate, generates a complex annual hydrograph with generally elevated streamflows from November through May, multiple flow peaks, and low flows from June through October.

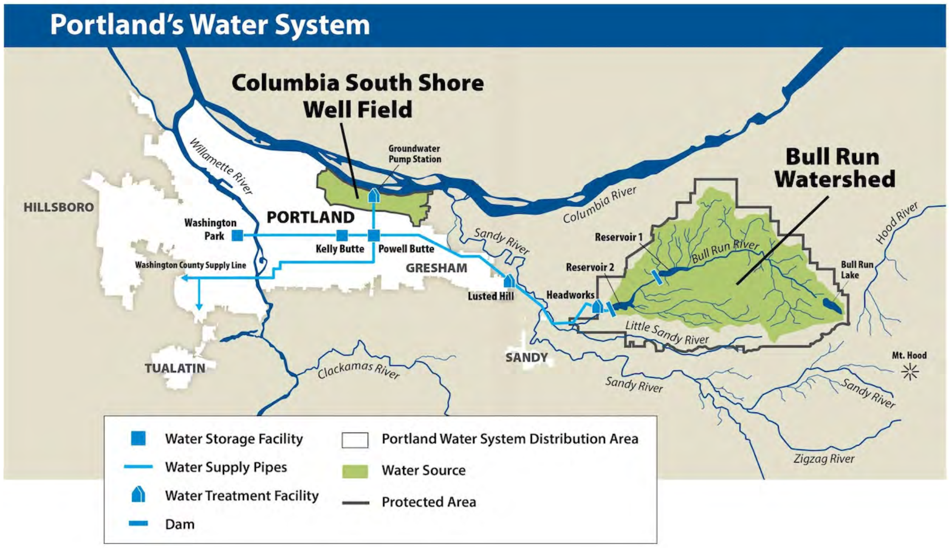

FIGURE 1.

Map of the Portland Water Bureau (PWB) water system, with the primary water source (Bull Run Watershed) and secondary source (Columbia South Shore Well Field) shaded in green. (Source: Portland Water Bureau.)

Two reservoirs in the Bull Run Watershed currently provide 9.8 billion gallons (30,500 acre-feet) of usable storage, typically drawn down within the window of May through October and refilling in the late fall and winter. The diversion pool and headworks are located just below the lower reservoir (Reservoir 2 in Figure 1). All diverted Bull Run water is treated at two separate treatment facilities located between the watershed and the service area. The utility is in the process of building a new filtration facility in the next few years that will change the location and full method of treatment. The two dams in Bull Run comprise the Portland Hydroelectric Project (36 MW capacity). The lower dam outlet works are set up so that PWB can selectively release colder "bottom water" into the river to meet downstream temperature targets.

PWB's secondary water source is groundwater from the Columbia South Shore Well Field (CSSWF), which can supply 80–95 MGD, sufficient to cover wintertime (indoor base) demands alone. In a typical year, the CSSWF is operated for one month in the late summer, when reservoir storage is at maximum drawdown. Treatment of CSSWF water is less intensive and occurs at the well field pump station. Because of the availability of two supply sources, Kristin Anderson, hydrology lead for PWB, says, "We don't have the same vulnerabilities or supply stresses that are occurring regionally."

Project background

Since the late 1990s, PWB's per capita water demand has sharply decreased—due to plumbing codes, water use efficiency, and densification—and average retail system demand has decreased by 35% from 2000 to 2025, even as the overall population in the service area has grown by 18 percent over the same period. Also, three of PWB's largest wholesale customers and one smaller wholesaler are about to end their contracts in July 2026, which will reduce total system demand by 30 to 35 percent. However, in a warming climate with longer and hotter summers, PWB expects it will still need the resilience provided by both of its supplies to ensure not just customer demand but regulatory commitments for endangered salmonids in the Bull Run Watershed can be met into the future.

PWB has a long history of using climate projections to inform its long-range planning. In 2001, PWB's Infrastructure Master Plan was one of the first water-sector planning studies to incorporate global climate models. However, the single, upward future demand trajectory assumed in the Master Plan was soon rendered obsolete by the unexpected declines in demand described above. This experience of rapidly shifting demand and supply dynamics and the need to change course is what led PWB away from trying to deterministically predict the future—whether for demand or supply—and toward adaptive planning and scenario planning frameworks that more fully acknowledge uncertainty.

For another decade, PWB lacked the in-house capacity to perform periodic climate change analyses and continued to outsource this work to university researchers. In 2014, PWB worked with university- and NOAA-affiliated researchers on the WUCA-sponsored Piloting Utility Modeling Applications (PUMA) project. In PUMA, four WUCA utilities used customized modeling tools to develop actionable climate science for planning purposes. PWB's goal was to set up a hydrologic model for the Bull Run Watershed and develop a customized downscaled CMIP5-MACA dataset.

Around that time, PWB hired a dedicated water-resource modeler, Ben Beal, so that the utility could more readily update previous analyses with new climate data and other information and perform sensitivity tests. Kavita Heyn, PWB's Adaptive Planning, Demand Management & Climate Division Manager, says that there has been a long-term savings to the utility by building this internal capacity, and the intentional investment of in-house modeling positioned the utility to be able to undertake a new, more adaptive, scenario-based approach to its planning in the coming years.

In the late 2010s, after a decade of learning from WUCA peers about the flexibility afforded by adaptive and scenario planning approaches, PWB integrated climate modeling into a scenario-planning approach for the 20-year update of its Supply System Master Plan, released in 2021. The plan encompassed four future scenarios to help the utility prepare for a range of future conditions. Each scenario had different levels of supply stress (as driven by demand, changes in climate and hydrology, water quality, and available water) and funding availability for supply system investments:

- ***Economic Woes***—Very Low Supply Stress and Very Constrained Funding
- ***Rosy Outlook***—Low Supply Stress and Stable Funding
- ***Thorny Prospects***—High Supply Stress and Constrained Funding
- ***Low Flows***—Significant Supply Stress and Stable Funding

Aerial view of Bull Run Reservoir #1 and the upper Bull Run Watershed, February 2025. (Image: Wikipedia user Tedder, under CC BY 4.0.)

PWB also committed to a five-year update cycle for its supply and demand forecasting to more routinely inform investments in the supply system; the project described here is the first such update. Heyn says that since PWB can't do everything in the next five-year part of the Capital Improvement Plan, the updated forecasts will help the utility prioritize the 20 or so supply-system projects listed in the Plan. In particular, quantifying the Bull Run Watershed's future yield helps PWB better understand future needs from its secondary groundwater system, and how it should invest to assure overall supply reliability.

The five-year update is also an opportunity to revisit PWB's four future scenarios in light of the new supply and demand forecasts and ask key questions: Does it appear that PWB is heading toward one scenario more than others? Is the future expected to be outside the range of the original planning scenarios? Regular reassessment of needs, given new information about future climate and hydrology as well as changing conditions on the ground, is integral to PWB's adaptive planning framework.

Project methods and data selection

TIME HORIZON

For the ongoing (2025) update of supply and demand forecasting as part of PWB's continuous adaptive planning process, the look-ahead is 25 years, to 2050. While climate projection data would support a longer view forward, given the uncertainty that grows in the outer years, the utility has decided to focus on a 25-year window and update the analysis more regularly to forecast further out in time. In the next (2030) update, the time horizon will likely extend to 2060.

SELECTING AND PROCESSING CLIMATE MODEL DATA

PWB previously used CMIP5 projections in several analyses and plans. As CMIP6 data started trickling out from modeling centers worldwide, PWB collaborated with researchers at Portland State University (PSU) to more closely examine the "raw" CMIP6 data. In particular, Heyn says, PWB wanted to learn how well the CMIP6 models reproduced the broad-scale synoptic atmospheric circulation patterns known to be major influences on water supply in the Bull Run Watershed and the service area. For example, in the winter and spring of 2014–2015, a persistent high-pressure ridge over the Pacific Northwest led to both below-normal precipitation and record-warm temperatures.

The PSU study found that the CMIP6 models as a group were able to simulate these circulation patterns with reasonable fidelity (Taylor et al., 2023), generating more confidence in using CMIP6 for regional precipitation and temperature projections. Another layer of comfort in using CMIP6 was added by the information in the CMIP6 FAQ developed by WUCA and released in December 2024. But, Heyn says, it was having the in-house capacity to do the data handling, modeling, and analyses that

Dam 1 and Reservoir 1, Bull Run Watershed

clinched PWB's decision to use CMIP6 for the efforts described in this case study, as opposed to sticking with CMIP5.

Once the decision was made to use CMIP6, PWB chose to use the CMIP6-LOCA2 downscaled dataset because of its ready availability and the focus by its developers on more accurately representing short-term climate extremes (Pierce et al., 2023). While most of the previous CMIP5 work used CMIP5-MACA data, as mentioned above, PWB also used CMIP5-LOCA data, in a broad-scale extreme-heat analysis. Compared to CMIP5-MACA or CMIP5-LOCA, the CMIP6-LOCA2 dataset also had the advantage of more emissions scenario options to consider. The two downscaled CMIP5 datasets (LOCA and MACA) offered only either RCP4.5 (which felt too "optimistic" to PWB) or the high-emissions RCP8.5 ("doomsday"). The LOCA2 dataset includes projections run under the analogues of these two RCPs (SSP2-4.5; SSP5-8.5), as well as SSP3-7.0, which felt more "in the middle"—and which PWB chose to use for the new analyses.

For the supply and demand forecasting, PWB originally intended to screen out the so-called "hot models" that had been previously identified in the CMIP6 ensemble. But when Beal plotted projections from all 23 models in the LOCA2 data under SSP3-7.0, the hot models as a group weren't outside the bounds of the non-hot models for the region of interest, so all of the hot models were kept in. According to Beal, the presence of the hot models hedges for uncertainty to some degree; e.g., if future greenhouse gas emissions end up higher than assumed in SSP3-7.0, or if the Earth's climate sensitivity turns out to be on the higher end. The final ensemble PWB is using consists of one run (run 1) from each of the 23 models, or 23 runs in all. (The full LOCA2 dataset includes a total of 92 runs, from 23 models each run one to ten times under SSP3-7.0—but using only one run per model means that the models are equally weighted in the ensemble.)

One issue that arose was that as Beal initially analyzed the LOCA2 data, he found that the average monthly temperatures over the Bull Run watershed in LOCA2 over the historical period (1985–2011) were cooler, by 1°F to 3°F, than the 1985–2011 monthly averages of the set of gridded climate observations that had been used to calibrate the PWB's hydrologic model. These discrepancies are not uncommon, especially in areas of high topographic relief in which station observations are interpolated both horizontally and vertically; the underlying station data and interpolation algorithms can differ between gridded climate products.

In this case, Beal was concerned the temperature discrepancy would lead to an underestimation of the impacts of warming on the watershed's snowpack and runoff. Since recalibrating PWB's hydrologic model to match the LOCA2 historical averages was not feasible, Beal performed a secondary bias correction on the LOCA2 data using a quantile-mapping method applied to each calendar month and each GCM cell within the area of interest, effectively shifting the LOCA2 values, historical and future, a few degrees warmer, such that the historical LOCA2 simulations matched the existing gridded climate observations.

IMPACT MODELING

The supply side of the forecasting uses PWB's hydrologic model of the Bull Run Watershed, which was developed in the mid-2010s with the USGS's Precipitation-Runoff Modeling System (PRMS) platform. Inputs to PRMS are observed or modeled daily minimum temperature, daily maximum temperature, and daily precipitation. (Observed or modeled daily solar radiation is also input if available; otherwise it is estimated within PRMS, as was done in this case.)

On the demand side, PWB implemented a new econometric, regression-based demand model that estimates the relationship between water demand and several drivers—weather, population, densification/land use, economic conditions, wholesale contracts, passive efficiency, water and sewer rates, and climate change—and then can translate the assumed future changes in those drivers into future demand

Infrastructure in Portland's groundwater well field

levels. This model was developed by Hazen and Sawyer, replacing a previous, more complicated demand model with a smaller set of drivers (weather, population, and water price). Notably, the new model enables PWB to generate separate forecasts of retail and wholesale demand, and within the retail demand to segment the forecast by customer class (single-family, multifamily, and commercial/nonresidential). The two required weather inputs to the new demand model are observed or modeled monthly average daily maximum temperature, and monthly fraction of days with precipitation.

Finally, a simple but effective reservoir-storage-and-drawdown model ties supply and demand together and translates the scenarios into concrete system impacts. Developed by Dave Evonuk of PWB's engineering planning group, the drawdown model was developed on the set of historical Bull Run streamflows and applies decision curves to the reservoir model to indicate when different rates of groundwater pumping might be needed to supplement the Bull Run supply. The outputs of the model are systems performance metrics most relevant to PWB:

- Annual reservoir drawdown start and end dates; duration of drawdown
- Minimum annual storage with and without groundwater use
- Total groundwater volume pumped; days of groundwater pumping; maximum pumping rate

OVERVIEW OF THE ANALYTICAL APPROACH

The supply forecasting follows a fairly standard "top-down" chain-of-models approach for climate change assessment and provides PWB with a range of future supply and reservoir storage metrics for analysis and planning purposes. As of August 2025, PWB's updated supply modeling is still in process, due to be completed by the end of the year.

The demand forecasting uses a different approach, in which monthly values representing three different percentile levels (90th, 50th, 10th) for the two variables (average daily maximum temperature, fraction of days with precipitation) are calculated from the ensemble of 23 LOCA2 climate projections under SSP3-7.0, separately for each month from 2025–2050. Three different combinations of percentiles are then used in the demand modeling:

- ***Median future climate:*** 50th percentile temperature, 50th percentile precipitation
- ***Hot/Dry future climate***: 90th percentile temperature, 10th percentile precipitation
- ***Warm/Wet future climate:*** 10th percentile temperature, 90th percentile precipitation

Internal utility staff convene to discuss adaptive supply planning and updated forecasts on a regular basis

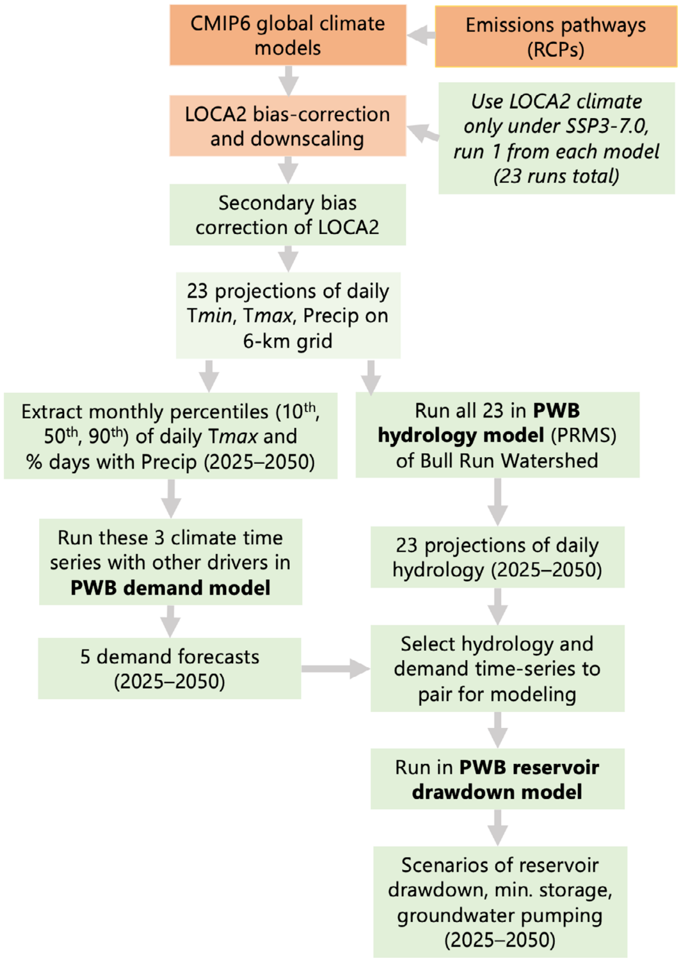

FIGURE 2.

Schematic of the chain of models approach for the Adaptive Planning 2025 Supply and Demand Forecasting. Orange shading indicates data and processing completed by others prior to PWB's analyses. Green shading indicates the steps performed by PWB.

PWB has input these climate scenarios along with changes to other drivers in the demand model, and has produced five different demand forecasts that bracket a range of potential changes to climate and other demand drivers:

- Baseline demand drivers + Median future climate
- Higher-than-baseline demand drivers + Median future climate
- Lower-than-baseline demand drivers + Median future climate
- Higher-than-baseline demand drivers + Hot/Dry future climate
- Lower-than-baseline demand drivers + Warm/Wet future climate

This range creates a "cone of uncertainty" around the demand forecasts where current conditions for the different forecasts are the same, but as one goes farther out toward the 2050 time horizon, the forecasts increasingly diverge from each other.

Portland skyline

In the final step, the climate-informed hydrologies from PRMS are then combined with all or a subset of the demand forecasts and run through the reservoir drawdown model to simulate future supply performance metrics.

During the last supply and climate modeling update in 2019, a Shiny visual app/dashboard was used to show all the different future reservoir supply simulations. For the ongoing update, PWB anticipates developing a combination of statistical graphics, such as cumulative distribution functions, tables with key metric thresholds, and dashboard simulations to present and interpret the results for stakeholders.

DATA HANDLING

PWB initially obtained the LOCA2 data for its area of interest from a consultant, ICF. When the historical-period bias issue described above emerged, Beal downloaded the netCDF files directly from the LOCA2 server to compare with the files provided by ICF. All the computing and storage is being done in-house and on-site at PWB. Beal uses R to analyze the data, and the outputs are typically CSV files, leading to a significant number of raw, intermediate, and final daily modeling products amounting to approximately 10GB of time-series data. He noted that the hydrologic model is quick to run, as is the reservoir-drawdown model, so most time is spent preparing and aggregating the data, not on the runs themselves.

Lessons learned thus far

INVESTING IN INTERNAL CAPACITY HAS PAID OFF FOR PWB

PWB's up-front investment in internal technical capacity has reduced the barriers to routine modeling and analysis, builds internal stakeholder trust, and, ultimately, facilitates its continuous adaptive planning cycle. PWB staff can handle complex climate, hydrology, and other datasets, and run these data in their impact models. However, as Heyn points out, this level of internal expertise and complex modeling isn't required in order for a utility to use adaptive planning or scenario planning methods, and simpler methods are available for utilities with fewer resources.

GETTING ORGANIZATIONAL BUY-IN TO NEW PROCESSES TAKES TIME AND EFFORT

A utility's full consideration of climate change often involves new processes as well as new types of information. For PWB, successfully implementing scenario planning and the five-year adaptive planning update cycle has required buy-in from engineers, operations staff, finance staff, customer service, and other groups. Heyn, Evonuk, and Cindi Lombard—PWB's project manager for the Supply System Master Plan—have facilitated workshops and convened work groups for the past four years, "creating space for different members from all groups across the entire Bureau to work together to be involved in some of the data sharing and decision making," according to Evonuk.

SPEAKING IN FAMILIAR TERMS AIDS UNDERSTANDING

The reservoir drawdown model has been critical in translating climate change analyses into the specific metrics used internally at PWB, such as the duration of groundwater pumping. Anderson says that the cross-organizational understanding of climate change impacts would be much less robust if "we couldn't speak in metrics that people are already working in."

KICK THE TIRES ON NEW CLIMATE DATA FIRST—AND EXPECT BUMPS IN THE ROAD

Heyn cautions utilities to do some research ahead of time and not jump into using new models (e.g., CMIP6) without some understanding of what they'll be dealing with. Even then, one should anticipate that there will be issues. PWB did quite a bit of "due diligence" before adopting CMIP6 and LOCA2, but still ended up with an unexpected data-mismatch requiring a secondary bias correction on LOCA2, to align with their existing customized historical climate dataset.

CLIMATE CHANGE IS NOT THE ONLY SOURCE OF FUTURE UNCERTAINTY IN DEMAND

It is common for a utility to use the range of climate-model and hydrology projections to represent future uncertainty in changes to water supply. But water demand is a different beast entirely, with many other highly uncertain drivers besides climate: population, housing density, economic conditions, the price of water, efficacy of conservation actions. PWB has factored this suite of drivers, along with climate change, into its range of future demand scenarios.

Further reading

OTHER INFORMATION ABOUT THE PROJECT AND ITS BACKGROUND

- Campbell, E., and K. Heyn. *Decision-Making in the Face of Uncertainty: The evolution of climate adaptation and supply planning at the Portland Water Bureau.* Presentation for WUCA technical training: Building Resilience to a Changing Climate, June 2024.

RESEARCH OUTPUTS ABOUT THE METHODOLOGY/DATASET(S)

- Taylor et al. (2023). CMIP6 model fidelity at simulating large-scale atmospheric circulation patterns and associated temperature and precipitation over the Pacific Northwest.
- Pierce et al. (2023). Future Increases in North American Extreme Precipitation in CMIP6 Downscaled with LOCA.

OTHER RELEVANT DOCUMENTS AND WEBPAGES

- Portland Water Bureau. (2021). Portland Water Supply System Master Plan. June 2021, 98 pp.

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This case study was developed by Jeff Lukas (Lukas Climate Research and Consulting and AGCI) and Julie Vano (AGCI) based on conversations with staff from the Portland Water Bureau, including: Kavita Heyn (Adaptive Planning, Demand Management and Climate Division Manager), Kristin Anderson (Bull Run Water Resources Manager), Ben Beal (Water Resource Modeler) and Dave Evonuk (Engineering Planning Manager, Principal).

Additional guidance and input came from WUCA project managers Keely Brooks (Southern Nevada Water Authority) and Nolie Templeton (Central Arizona Project), and from WUCA's Climate Modeling Work Group.

We thank all who provided their insights!

San Diego County Water Authority

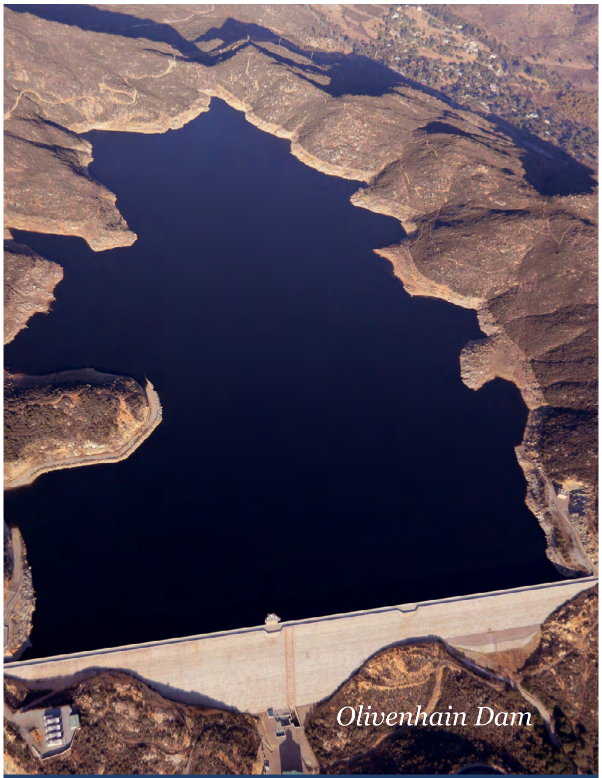
CASE STUDY

NOVEMBER 2025

Every five years, a state-mandated planning cycle (Urban Water Management Plan) prompts **San Diego County Water Authority** (SDCWA) to update its long-range water demand forecasts. The 2025 update presented an opportunity to revisit the potential impacts of climate change on demand, using new (CMIP6) climate model data in a time-tested approach. These updated demand forecasts will also inform the agency's broader scenario planning approach for its decadal Water Facilities Master Plan. Recent unusually wet years demonstrated that drought is not the only climate vulnerability SDCWA needs to prepare for.

San Diego County Water Authority

WUCA Water Utility Climate Alliance



Olivenhain Dam

LESSONS LEARNED

Forecasting demand under climate change involves many confounding factors

Climate change projections that look 25 years out may prove useful much sooner

As a water portfolio changes, new climate vulnerabilities may emerge

Learn more about these lessons on page 12

SUMMARY

Utility	San Diego County Water Authority (SDCWA)
Contact	Jeremy Crutchfield, jcrutchfield@sdcwa.org
Project name	SDCWA Water Demand Forecast Update
Project timeline	2025 – Summer 2026
Geographic scope	SDCWA service area, 1,325 sq. mi.
Utility business functions affected	• Water supply
Objective	• Produce updated demand forecasts for 2030–2050 • Understand how climate change could impact system water demand in 2050
Potential decisions or actions to be informed	• Informing capital improvement projects and system optimization needs to meet demands • Supporting financial planning through the Long-Range Financing Plan • Optimizing monthly to annual operations
Variables, thresholds, and/or events of interest	• Monthly average daily maximum temperature (T*max*) • Monthly precipitation • Monthly irrigation requirement (ET*c*)
Climate data used	CMIP6* LOCA2-Hybrid, under 3 SSPs (emissions scenarios)
Why those data were selected	• LOCA2-Hybrid data are optimized for California • Data developed by local researchers (Scripps Institution of Oceanography)
Impact modeling performed	• Econometric water demand modeling
Key attributes of this case study	• Well-established approach, updated with new climate model data • Five climate scenarios were used to capture the range of potential future climate changes across the climate models and emissions scenarios • Climate change is acknowledged as just one of several highly uncertain influences on future water demand

** For definitions of CMIP6 and other climate modeling terminology, see this glossary.*

Overview of the utility

SDCWA is the wholesale water supplier in San Diego County. SDCWA serves water to 22 member agencies representing large-scale metropolitan areas, agricultural regions, and a large federal military base, with a total population of approximately 3.3 million. While the footprint of agriculture in the service area has decreased over time, crop irrigation still represents 6% of total water use. The impacts of drought on water supply and use are buffered by local storage reserves secured by SDCWA and its member agencies, currently totaling over 250,000 acre-feet.

SDCWA and its member agencies have an increasingly diverse water portfolio, consisting of both local and trans-basin sources, and including surface water, groundwater, desalinated seawater, supplemental water transfer, and recycled water. The next increment of local supply includes several potable reuse projects under

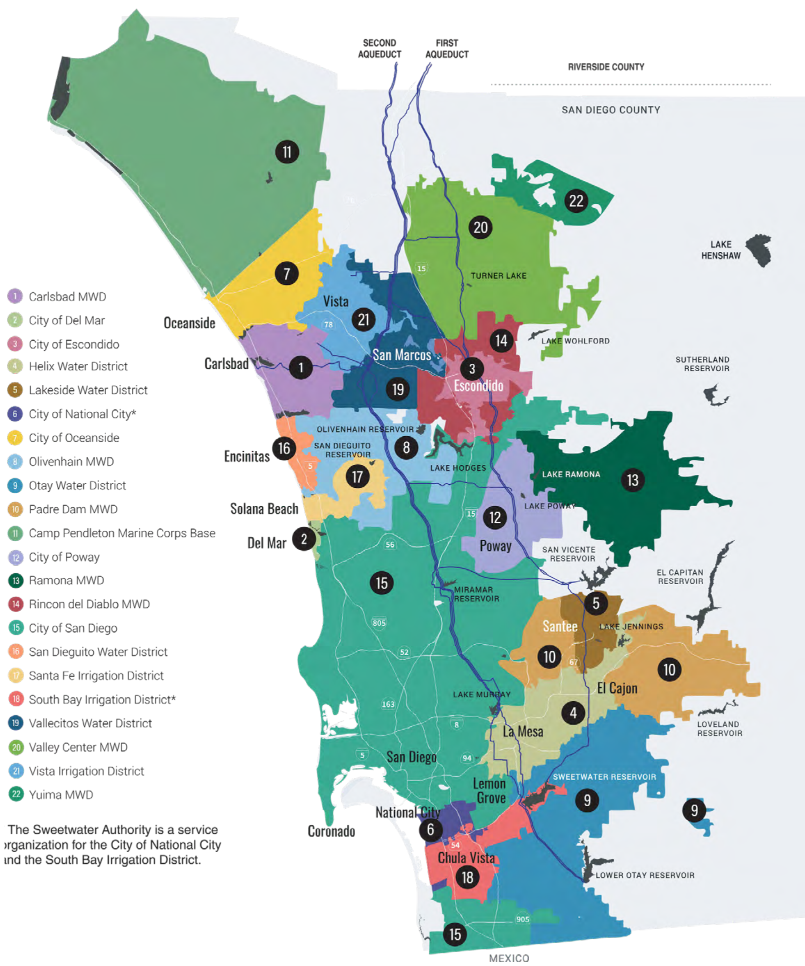


FIGURE 1.

Map of the San Diego County Water Authority (SDCWA) service area, its 22 member agencies, and key infrastructure. The First and Second Aqueducts each can convey both State Water Project and Colorado River water. (Source: SDCWA.)

development. SDCWA's trend toward diversification over the last 25 years has greatly reduced its reliance on water purchased from Metropolitan Water District of Southern California that is sourced from the State Water Project and the Colorado River. This water is subject to large swings in availability and cost due to drought impacts and other factors. SDCWA acquired highly reliable Colorado River supplies through a long-term Quantification Settlement Agreement (QSA) consisting of conserved water transfer from the Imperial Irrigation District and the concrete lining of sections of the All-American and Coachella canals. These Colorado River supplies accounted for over 60% of SDCWA's total portfolio over the last seven years.

Since 2000 there has been an equally dramatic trend in SDCWA's water use, spurred by its aggressive conservation and efficiency measures, along with the lasting impacts of drought restrictions. Total per capita potable water use declined from about 216 gallons per day (gpd) in Fiscal Year (FY) 2000 to 113 gpd in FY 2024. Systemwide use of potable water (excluding use of recycled water) declined over that same period by about 40% to about 414,000 acre-feet, despite a 16% increase in the service area's population. Inflation, the cost of water, climate change, reduced water demand, and other factors continue to put upward pressure on water rates in San Diego County and across the state.

SDCWA desalination pumps and pipes

Project background

Like other California municipal providers, SDCWA is required by the state's Urban Water Management Act to update its Urban Water Management Plan (UWMP) every five years, with the 2025 plan coming due in July 2026. At minimum, a UWMP must assess the reliability of water sources given expected demand over a 20-year future time frame, under "normal" weather conditions, in a dry year ("single dry"), and over five consecutive dry years ("multi-dry"). A UWMP must consider the effects of climate change on supply and demand, but these effects are not required to be quantitatively incorporated into the reliability assessment. For both the 2020 and 2025 UWMPs, SDCWA modeled the effects of climate change on demand, though these effects were not included in the formal reliability assessment. According to Seevani Bista, Principal Water Resources Specialist with SDCWA, while the California Water Code "does not prescribe that we have to do quantitative climate-change-related projections," SDCWA does produce "a separate forecast based on climate change scenarios."

For the 2025 UWMP update, SDCWA is revising its full suite of long-range demand forecasts (Water Demand Forecast Update). As with the demand forecasts developed to inform the 2020 UWMP, much of the work is being carried out by consultant Hazen and Sawyer (Hazen), led by Jack Kiefer, Hazen's practice lead for water demand forecasting. SDCWA and its member agencies are collecting and confirming the historical demand information and historical weather data. Hazen is updating the econometric model, processing the input data and revisiting the explanatory variables and trends therein, and recalibrating the regression equations used to forecast demand for different sectors. Hazen is also developing climate model inputs to update those demand scenarios that do incorporate climate change, following a similar approach to previous climate-informed demand forecasts.

The contract with Hazen for the 2025 update includes training for SDCWA staff on understanding and using econometric model output for scenario analysis, including the climate-impacted demand scenarios. In the longer term, following a broader trend among Water Utility Climate Alliance (WUCA) member utilities,[1] SDCWA is considering coordinating with its member agencies to develop a long-range demand forecast for future UWMPs rather than developing a sophisticated model using outside consulting services.

1 WUCA Summary Report: Representing Climate Change Impacts in Water Demand Modeling. (October 2022).

Twin Oaks Valley Water Treatment Plant

USE OF DEMAND FORECASTS BEYOND THE UWMP

The long-range demand forecasts and overall water supply assessment produced for the UWMP are also critical inputs for SDCWA's Water Facilities Master Plan (Master Plan). The Master Plan identifies and prioritizes capital improvement projects (CIPs) needed to meet future demands while emphasizing operational flexibility, system resilience, and climate and earthquake preparedness. In the most recent (2024) update of the Master Plan, supply and demand forecasts developed for the 2020 UWMP—assuming continuation of the historical climate—were used as a reference scenario (1A/1B), or baseline. This baseline was used to compare several other future scenarios as part of a scenario-planning approach:

- **Scenario 2A/2B** – Capture the range in uncertainty in the scale and timing of local water supply development
- **Scenario 3A/3B** – Climate change impacts to demand only (3A) and to both demand and supply (3B)
- **Scenario 4** – Reduction in demands due to additional conservation efforts to reduce indoor and outdoor water use

- **Scenario 5A/5B** – Abrupt disruption scenarios: seismic events (5A) and wildfires (5B)
- **Scenario 6** – Member agencies transition from untreated SDCWA water to treated SDCWA water, impacting delivery rates
- **Scenario 7** – Temporary interruptions in local potable reuse supplies and increased reliance on SDCWA

These scenarios illustrate the wide range of events and impacts that utilities consider in their planning; climate change (3A/3B) is one of many. The 3B scenario incorporated climate change impacts on demand and supply more extreme than those developed for the UWMP, by incorporating a multi-year drought worsened by climate change.[2] According to Anjuli Corcovelos, Senior Water Resources Specialist with SDCWA, "We want to be prepared for potential deviations or scenario changes even beyond what's in [the UWMP]. And we have the flexibility to do that in [the Master Plan]." Because the Master Plan is updated on a decadal cycle, the supply and demand forecasts for the 2030 UWMP, as well as the 2025 UWMP update, will be available to inform the next Master Plan in the mid-2030s. Recognizing that much can change over 10 years—new science, new facts on the ground, changes to the system—SDCWA is developing a tool that can be used to explore and test customized "what if" scenarios in periods between the Master Plan efforts.

Project methods and data selection

TIME HORIZONS AND ASSUMPTIONS ABOUT THE FUTURE

While the state standard for UWMPs requires a minimum 20-year horizon, SDCWA uses a 25-year horizon (through 2050) for the demand forecasts and supply reliability assessment in the 2025 UWMP. For the main demand analysis, the demands are forecasted at five-year increments from 2030 to 2050, assuming the historical baseline climate at each time step. For the climate change demand forecast scenarios, the climate projections are analyzed over two different future periods: mid-century (2045–2065) and late century (2080–2100).[3]

2 The climate change portion of the 3B scenario is taken from the "hot-dry" mid-century scenario in the San Diego Watershed Basin Study, Task 2.2 technical memo (2016).

3 Since the other demand drivers (e.g., population) are only projected out to 2050, as described below, the late-century (2080–2100) climate change demand forecast scenarios effectively pair a late-century climate condition with the mid-century conditions for the other drivers.

SELECTING AND PROCESSING CLIMATE MODEL DATA

For the 2020 update of the demand forecasts, Hazen used CMIP5 LOCA projections, under both the RCP4.5 and RCP8.5 scenarios, to derive the climate change demand forecast scenarios. Going into the 2025 update, new LOCA projections based on CMIP6 (LOCA2) had become available in two versions: the “standard” North America-wide dataset (6-km resolution) and a special “hybrid”[4] higher-resolution (3-km) dataset covering only California, based on a subset of 15 CMIP6 models shown to simulate well the historical climate patterns for California. Kiefer said that for Hazen, the fact that the LOCA2-Hybrid projections were optimized for California was the key factor in selecting them for the 2025 UWMP demand forecasts. Also, the LOCA2 developers are based locally in San Diego, at the Scripps Institution of Oceanography, and SDCWA has a history of working with Scripps researchers to obtain data and guidance for utility analyses.

The full LOCA2-Hybrid dataset includes 129 future projections in all: 15 models run from 1 to 10 times under one, two, or all three of the SSPs (emissions scenarios): SSP2-4.5, SSP3-7.0, SSP5-8.5). Based on informal guidance from the LOCA2 developers, Hazen started the approach with all 129 runs to encompass the full breadth of the available data and their inherent uncertainties.

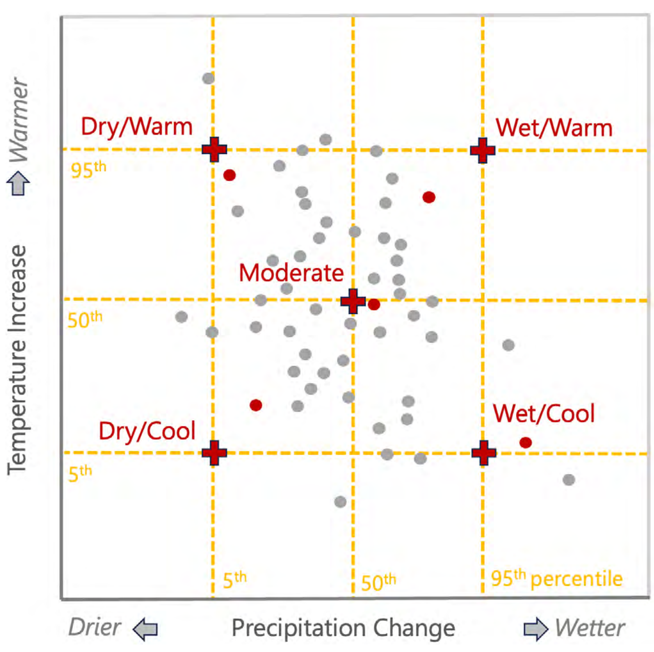


FIGURE 2.

Conceptual schematic showing the method for generating the five climate scenarios. All of the climate model runs (gray and red dots) are plotted according to the future precipitation change and future temperature change indicated by each run. Those model runs (red dots) that are plotted closest to each of the five ideal scenarios (red crosses) are selected to represent those scenarios. See the text for more details.

4 The term “hybrid” refers to the dataset being a hybrid of statistical downscaling (e.g., “regular” LOCA and LOCA2) and dynamical downscaling (i.e., using regional climate models). In LOCA2-Hybrid, future simulations with a regional climate model are used as the source of weather patterns (the *localized constructed analogs*, or LOCA) to statistically downscale the raw, coarser global climate model output. See this webpage for additional details.

Following a method first used for the 2015 UWMP, Hazen then calculated the change in annual average maximum daily temperature (T*max*) and the change in annual precipitation across the grid cells covering the SDCWA service area. This calculation was performed for the 129 projections for each of the future periods relative to the historical baseline. Then, Hazen calculated the 5th, 50th (median), and 95th percentiles of T*max* change and precipitation change across the projections (Figure 2). When the percentiles are plotted as lines, their crossing points demarcate five scenarios covering most of the range of the potential climate futures, in terms of T*max* change and precipitation change:[5]

- 95th percentile T*max*, 95th percentile precipitation ("Warm/Wet")
- 95th percentile T*max*, 5th percentile precipitation ("Warm/Dry")
- 5th percentile T*max*, 95th percentile precipitation ("Cool/Wet")
- 5th percentile T*max*, 5th percentile precipitation ("Cool/Dry")
- 50th percentile T*max*, 50th percentile precipitation ("Moderate")

To populate the details of these scenarios, of the 129 sets of projected changes in T*max* and precipitation (i.e., individual model runs), the one that plots nearest to each scenario is selected, resulting in five model runs that represent the five scenarios.

IMPACT MODELING

The demand modeling involves separate econometric equations, or models, for each of four use sectors:

- Single-family residential
- Multi-family residential
- Non-residential (i.e., businesses, manufacturing)
- Agricultural

The models, calibrated using a regression procedure, relate changes in average rates of water use—per household, per employee, or per acre—to the climatic, socioeconomic, and land-use factors that influence water use within and among the water-using sectors. Additional model terms are used to capture variation specific to each member agency in SDCWA. The climatic or weather factors include monthly departure from normal T*max* and monthly departure from normal precipitation, with lagged terms to represent delayed responses to weather. For the agricultural model only, the factor is monthly crop irrigation requirement (ET*c*), which is calculated from

5 This specific projection-selection methodology was first described in Water Research Foundation Project 4263 (2013). *Changes in Water Use Under Regional Climate Change Scenarios*.

temperature and precipitation and weighted by assumed acreage by crop.

After the models are calibrated, trends and other analytical tools (e.g., demographic models) are used to estimate the values of the non-weather factors at five-year increments from 2030 to 2050. The baseline demand modeling runs do not incorporate climate change; instead, one of two "weather scenarios" is input to the models along with each set of non-weather factors (for 2030, 2035, 2040, etc.):

- "Normal weather" – Based on the averages over a 30-year period
- "Single dry" – Based on the most stressful (hot-dry) recent year; for the 2020 and 2025 UWMPs, the year 2014 was chosen

To quantify the "multi-dry" scenario (five consecutive dry years), the demand that is calculated for the "single dry" year is followed by four years for which scaling factors are used to increase demand.

OVERVIEW OF THE ANALYTICAL APPROACH

The overall use of the climate models follows a "period-change" approach; the difference or change between a modeled baseline period and a modeled future period is used to adjust a historical climate condition or climate record (Figure 3). First, the five individual model runs are selected for each of the two climate projection periods (2045–2065; 2080–2100) as described earlier. Then, the resulting 10 sets of projected changes in average maximum daily temperature (T_{max}; degrees F) and annual precipitation (%) are used to adjust the "normal weather" scenario, which is the historical (1991–2020) average T_{max} and annual precipitation as calculated from several local weather stations, and validated with the PRISM gridded climate dataset. This baseline for the "normal weather" scenario is calculated separately for the locations of each of the 22 member agencies, to reflect the climatological variation across the SDCWA service area, especially the temperature gradient from the coast to inland locations.

Next, the four sector demand models described above are re-run with the 10 sets of climate-change adjusted values of T_{max} and annual precipitation substituted for the original "normal weather" values. All the other inputs to the demand models are the ones previously estimated for 2050. This results in new demand numbers whose increase or decrease over the demand that was previously calculated for 2050 (i.e., without climate change) reflects only the additional influence of climate change.

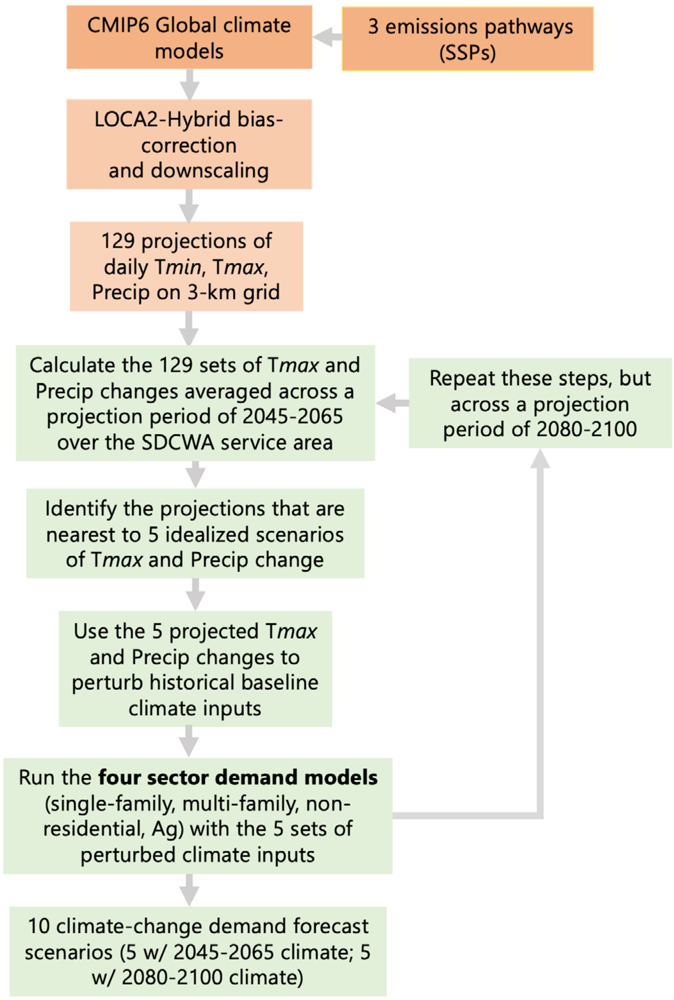


FIGURE 3.

Schematic of the approach to develop the climate change demand forecasts for the SDCWA Water Demand Forecast Update. Orange shading indicates data and processing completed by others prior to the analysis. Green shading denotes the steps performed by SDCWA with Hazen.

DATA HANDLING

The CMIP6 LOCA2-Hybrid data were obtained by Hazen as netCDF files from Cal-Adapt's Amazon Web Services bucket: https://cadcat.s3.amazonaws.com/index.html#loca2/aaa-ca-hybrid/. Most of Hazen's processing of the LOCA2 data was done using Python, with the output further processed and summarized in Excel. These spreadsheets were then loaded into SAS, Eviews, and/or PowerBI for the demand model calculations.

Lessons learned

FORECASTING DEMAND UNDER CLIMATE CHANGE INVOLVES MANY CONFOUNDING FACTORS

Kiefer highlighted that estimating the weather-response relationships that are then used to calculate climate change effects on demand is based on analysis of historical water use data and weather, in which many other confounding factors are present: water pricing, water shortage response, conservation, socioeconomic indices, and land use. Going forward, changes in these other factors may dampen or amplify the sensitivity of demand to each increment of temperature and precipitation, and so the historical correlations between water use and weather may not hold in the future. The uncertainties across all of the factors, including climate change, support the use of scenario planning or other approaches that consider multiple possible trajectories for future demand.

CLIMATE CHANGE PROJECTIONS THAT LOOK 25 YEARS OUT MAY PROVE USEFUL MUCH SOONER

In water year 2023, several potent atmospheric rivers hit southern California, and San Diego County experienced very wet and cool conditions overall; it was the coolest year since 1999. As a result, SDCWA's potable water use in 2023 dipped to a record low for the 21st century. In the winter season of 2023–2024, more atmospheric rivers heralded a second consecutive wet year, and SDCWA's "conventional" demand projections as mandated for the UWMP ("normal," "dry-year," "multi-dry") were not capturing the use pattern that was occurring. However, says Bista, the demand forecast for the "cool-wet" climate change scenario for 2045, developed for the 2020 forecast update, did provide useful guidance as to what would happen in a second wet year, and SDCWA was able to anticipate a slightly larger drop in water use in 2024.

AS A WATER PORTFOLIO CHANGES, NEW CLIMATE VULNERABILITIES MAY EMERGE

Historically, the main climate vulnerability that SDCWA has prepared for is drought and water shortages. The primacy of drought as the key vulnerability across all of California's urban water systems is reflected in the state-mandated UWMP reliability assessments. The investments made by SDCWA over the last 20-plus years shielded the region from cutbacks during the recent droughts. But as SDCWA reshaped its water portfolio after 2000 to reduce drought vulnerability, among other motivations, it became more vulnerable to the financial impacts of demand reductions—and resulting "oversupply"—during wet years. After large infrastructure investments in desalination, and given long-term agreements to purchase fixed amounts of water annually through the QSA, the back-to-back wet years of 2023 and 2024 brought unexpected disruption to both system operations and financial planning. SDCWA has realized that these periodic wet/cool conditions need to be part of its scenario planning, alongside overall warmer and drier futures, and is currently exploring options to provide water to other water agencies through intrastate and interstate exchanges.

Further reading

OTHER INFORMATION ABOUT THE PROJECT

- SDCWA 2020 Water Demand Forecast Update. (July 2021). (The methodology used for the 2020 update is very similar to that used for the 2025 update.)

RESEARCH OUTPUTS ABOUT THE METHODOLOGY/DATASET(S)

- Krantz et al. (2021). Memorandum on Evaluating Global Climate Models for Studying Regional Climate Change in California. (Describes the selection of 15 climate models for the LOCA2-Hybrid dataset.)

OTHER RELEVANT LITERATURE/WEBPAGES

- WUCA Summary Report: Representing Climate Change Impacts in Water Demand Modeling. (October 2022).

Explore other case studies at www.wucaonline.org

This case study was developed by Jeff Lukas (Lukas Climate Research and Consulting and AGCI) and Julie Vano (AGCI) based on conversations with staff from the San Diego County Water Authority. Additional guidance and input came from WUCA project managers Keely Brooks (Southern Nevada Water Authority) and Nolie Templeton (Central Arizona Project), and from WUCA's Climate Modeling Work Group.

We thank all who provided their insights!