Estimating Future Water Demand for San Bernardino Valley Municipal Water District

Michelle E. Miro, David G. Groves, David Catt, Benjamin M. Miller

RAND Social and Economic Well-Being

Preface

This document was prepared for and funded by the San Bernardino Valley Municipal Water District (Valley District) and contains an independent evaluation of their Regional Urban Water Management Plan and an alternative approach to calculating future water demand in their service area. This research is intended to support water planning efforts and decisionmaking for the Valley District board and staff. This document may also be of interest to other water agencies in Southern California or those in the Western United States contending with the combined impacts of drought, population growth and climate uncertainty, as well as urban planners, water managers and related planners and practitioners.

RAND Social and Economic Well-Being is a division of the RAND Corporation that seeks to actively improve the health and social and economic well-being of populations and communities throughout the world. This research was conducted in the Community Health and Environmental Policy Program within RAND Social and Economic Well-Being. The program focuses on such topics as infrastructure, science and technology, community design, community health promotion, migration and population dynamics, transportation, energy, and climate and the environment, as well as other policy concerns that are influenced by the natural and built environment, technology, and community organizations and institutions that affect well-being. For more information, email chep@rand.org. Questions or comments about this report should be sent to the project leader, Michelle Miro (michelle_miro@rand.org).

Abstract

Water agencies in California regularly evaluate the water supply reliability for their service areas in an Urban Water Management Plan which is updated every five years. These plans generally compare the total demand for the agency with the total anticipated water supplies available to the agency. A careful evaluation of supply and demand projections can be used to help identify any vulnerabilities and can be used by decisionmakers to make more informed decisions about investments in water use efficiency and new supplies. The San Bernardino Valley Municipal Water District (Valley District) is taking the first step in a comprehensive evaluation of its supplies and demands by evaluating the demand projections used in its service area. The RAND Corporation provided an independent evaluation of the long-term demand methodology and assumptions used by Valley District's retail agencies, and then developed a single consolidated approach that reflects additional drivers and accounts for uncertainties in these drivers. The study team then used this approach to develop new demand forecasts for each retail agency that reflect a range of plausible future drivers of demand, including climate, population growth and per capita water use. This broader range of plausible future water demands was then analyzed with the goal of helping the Valley District better understand how water demand could evolve in the coming decades. This report suggests that the Valley District incorporate the demand forecasting approach developed in this study in future Regional Urban Water Management Plans. The analysis presented in this report also shows that the Valley District could monitor the drivers of water demand, including population growth, water use rates and temperature, to ensure the Valley District plans for a sufficient buffer between supply and demand into the future. This report is also relevant to water management efforts more broadly, as water supply agencies in California and the Western United States face similar uncertainties around water demand that impact their planning and management decisions.

Table of Contents

Figures

Tables

Summary

Water agencies in California regularly evaluate the water supply reliability for their service areas in an Urban Water Management Plan which is updated every five years. These plans generally compare the total demand for the agency with the total anticipated water supplies available to the agency. If supplies exceed demand, then the system is deemed to be reliable. But, what if the assumptions used to project demands and supplies are not accurate? What if there was a plausible condition(s) under which a water agency's demands would exceed its supplies? A careful evaluation of supply and demand projections can be used to help identify any vulnerabilities and can be used by decisionmakers to make more informed decisions about investments in water use efficiency and new supplies. Valley District is taking the first step in a comprehensive evaluation of its supplies and demands by evaluating the demand projections used in its service area.

Demand projections are critical to water resources planning and management. Yet, these projections are subject to uncertainty. The underlying drivers of demand – population, water use behavior, land use, economics, climate – are also uncertain, particularly over the planning horizons of long-term water management plans and major capital improvement plans. The San Bernardino Valley Municipal Water Valley District's (Valley District) 2015 Regional Urban Water Management Plan (RUWMP) describes how the region could meet its water demand through 2040. This long-term plan is based on estimates of retail demand over time that are drawn from a single set of assumptions about local population growth, conservation uptake, and weather dependent usage. To account for uncertainty in both supply and demand, the RUWMP increases total demand by 10%, which it terms the "Reliability Factor".

The RAND Corporation provided an independent evaluation of the long-term demand methodology and assumptions used by Valley District's retail agencies, and then developed a single consolidated approach that reflects additional drivers and accounts for uncertainties in these drivers. The study team then used this approach to develop new demand forecasts for each retail agency that reflect a range of plausible future drivers of demand, including climate, population growth and per capita water use. This broader range of plausible future water demands was then analyzed with the goal of helping the Valley District better understand how water demand could evolve in the coming decades. We compare the results of this analysis to the existing Reliability Factor and discuss ways that Valley District can incorporate this uncertainty analysis into its planning to help ensure that Valley District's long-term plans achieve District needs at a reasonable cost.

The first portion of the study concludes that the current modified unit water demand approach is a reasonable basis for water demand forecasting for the Valley District. The improved approach presented in this study, thus builds on this method by adding factors that represent climate warming and water use efficiency, and standardizing assumptions across all the

retail agencies. In addition, the new framework includes a more explicit treatment of uncertainty by introducing scenario factors that can be modified to reflect different plausible future conditions.

In the second portion of the study, RAND varied assumptions about demand to develop a wide range of plausible future demand projections. The resulting estimates generally fall within the range of demand estimated by the original RUWMP methodology with the added Reliability Factor. The new results, however, provide insight into the drivers of this range. The analysis revealed that if temperature and population growth increase to the higher end of their plausible ranges, the demand could reach the forecasted demand in the RUWMP with Reliability Factor. Importantly, if water use efficiency is not included in the evaluation, then plausible demand projections would slightly exceed the current projection with the Reliability Factor but would still be far below the projected available supplies during normal years. This highlights the value of continued, cost-effective water use efficiency programs that decrease per customer water use. Finally, the full range of plausible future demands suggests that the Reliability Factor, which accounts for uncertainty in both supply and demand, would be used up by uncertainty in demand alone.

This study only evaluates one side of the water management equation—demand. A complementary look at how supplies could vary into the future would provide a more comprehensive analysis that could be used to inform the development of a robust water management strategy.

Acknowledgments

Abbreviations

AF	Acre-Feet
AFY	Acre-Feet per Year
CMIP5	Coupled Model Intercomparison Project Phase 5
DWR	California Department of Water Resources
EVWD	East Valley Water District
GCM	General Circulation Model
GIS	Geographic Information System
IEUA	Inland Empire Utilities Agency
IRWD	Irvine Ranch Water District
LOCA	Locally Constructed Analogues
MAIN	Municipal and Industrial Needs (MAIN) Model
MWD	Metropolitan Water District
RCP	Representative Concentration Pathway
RUWMP	Regional Urban Water Management Plan
RHWC	Riverside Highland Water Company
SAR	Search and Rescue
SBBA	San Bernardino Basin Authority
SBMWD	San Bernardino Municipal Water District
SCAG	Southern California Association of Governments
SDCWA	San Diego County Water Authority
SWP	State Water Project
WUCA	Water Utility Climate Alliance
WVWD	West Valley Water District
Valley District	San Bernardino Valley Municipal Water District
YVWD	Yucaipa Valley Water District

1. Introduction

Water resources management is becoming increasingly challenging in Southern California. Water managers face uncertain future population growth and consumption patterns, temperature and precipitation change and drought severity and duration. The future ability of water management entities, such as the San Bernardino Valley Municipal Water District (Valley District), to provide adequate supplies to their service areas depends on balancing supply and demand. This requires consideration of a full range of plausible future supply and demand scenarios to ensure that demand does not exceed available supply.

To date, the Valley District has developed long-term planning documents to evaluate supplies and demands. In 2016, the Valley District, in cooperation with nine other water agencies, updated the San Bernardino Valley Regional Urban Water Management Plan (RUWMP), which describes how the region could meet water demands through 2040 (Water Systems Consulting Inc, 2016). More information on the Valley District and its member agencies can be found at http://www.sbvmwd.com. This document presents the supply and demand balance for the Valley District service area to 2040 based on estimated future water demand of its retail agencies and anticipated available supply for three scenarios: normal (average), single-year drought and multi-year (three years or more) drought. Since one of the primary management strategies is to store water in wet years for later use during droughts, the RUWMP also includes a wet year scenario.

On the supply side, the RUWMP accounts for the changing supply conditions associated with the different scenarios. Persistent drought periods, such as the ongoing drought – see Figure 1, could impact available supplies. For example, deliveries from the State Water Project (SWP), of which the Valley District has an annual entitlement of 102,600 acre-feet, are dependent on hydrological conditions not just in the Valley District's service area but across the state of California. In 2015, SWP deliveries to SWP Contractors were 5 percent of normal; SWP deliveries range from 35-70% for dry years and between approximately 80-100% for wet years (MWD, 2016).
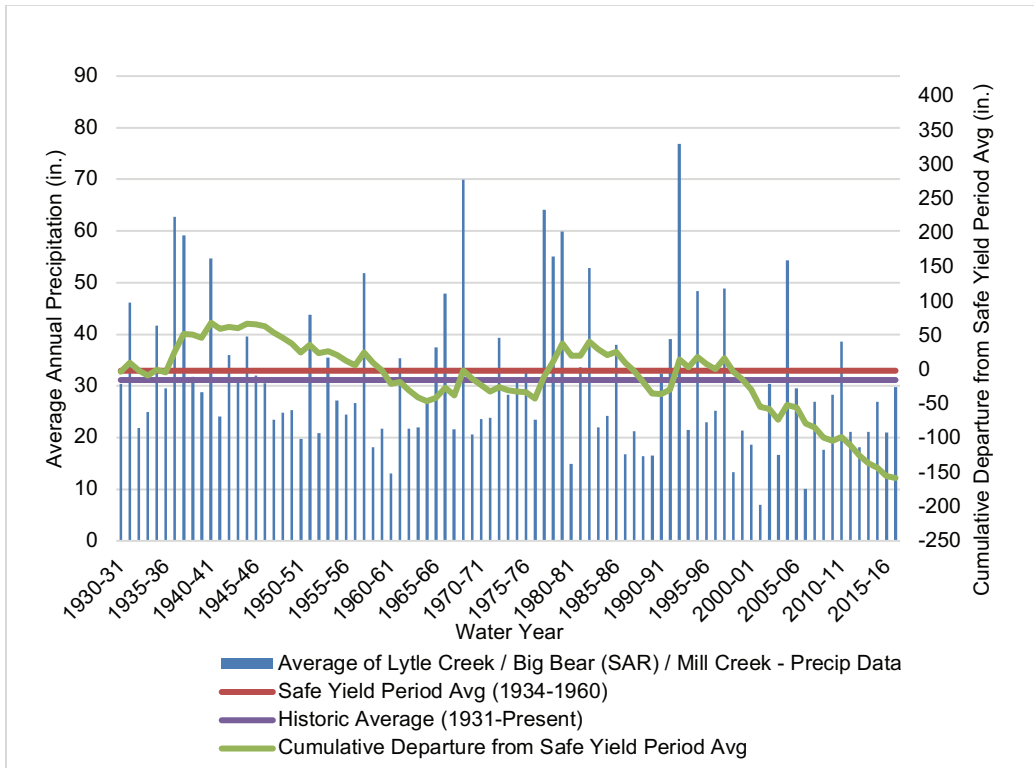
Figure 1. San Bernardino Basin Area Three Station Precipitation Index

On the demand side, the RUWMP bases estimates of retail demand to 2040 on a single set of assumptions based on local population growth, constant per capita water use, and a fixed proportional increase in water demand during single and multiple-year dry periods, which are provided independently by each retail agency. Scientific literature and water management practice, however, identifies additional drivers of demand including changing climate conditions and water use behavior (including efficiency measures - conservation, technology) (Rinaudo, 2015; Pacific Institute, 2013; Gonzales and Ajami, 2017). These and the currently considered drivers are all subject to uncertainty, particularly over the planning horizons of long-term water plans, major capital improvement plans, and the RUWMP. Underestimates of demand could lead managers to plan for too little supply while overestimates of demand could result in stranded investments. Consideration of a broader range of plausible water demands can help ensure long-term water plans meets future water needs for the Valley District.

According to the analysis in the RUWMP, the Valley District has planned for sufficient supply to meet future estimated demand – see Figure 2. However, the Valley District also recognizes that both supply and demand are subject to future uncertainty. To account for uncertainty in supplies and demands, the RUWMP increases estimated demands by 10% which it terms the "Reliability Factor". In this study, the Valley District is evaluating the full range of plausible future demands as an independent review of the RUWMP Reliability Factor. This study

will provide a robust range of plausible demands to help ensure that Valley District's long-term plans achieve District needs at a reasonable cost.
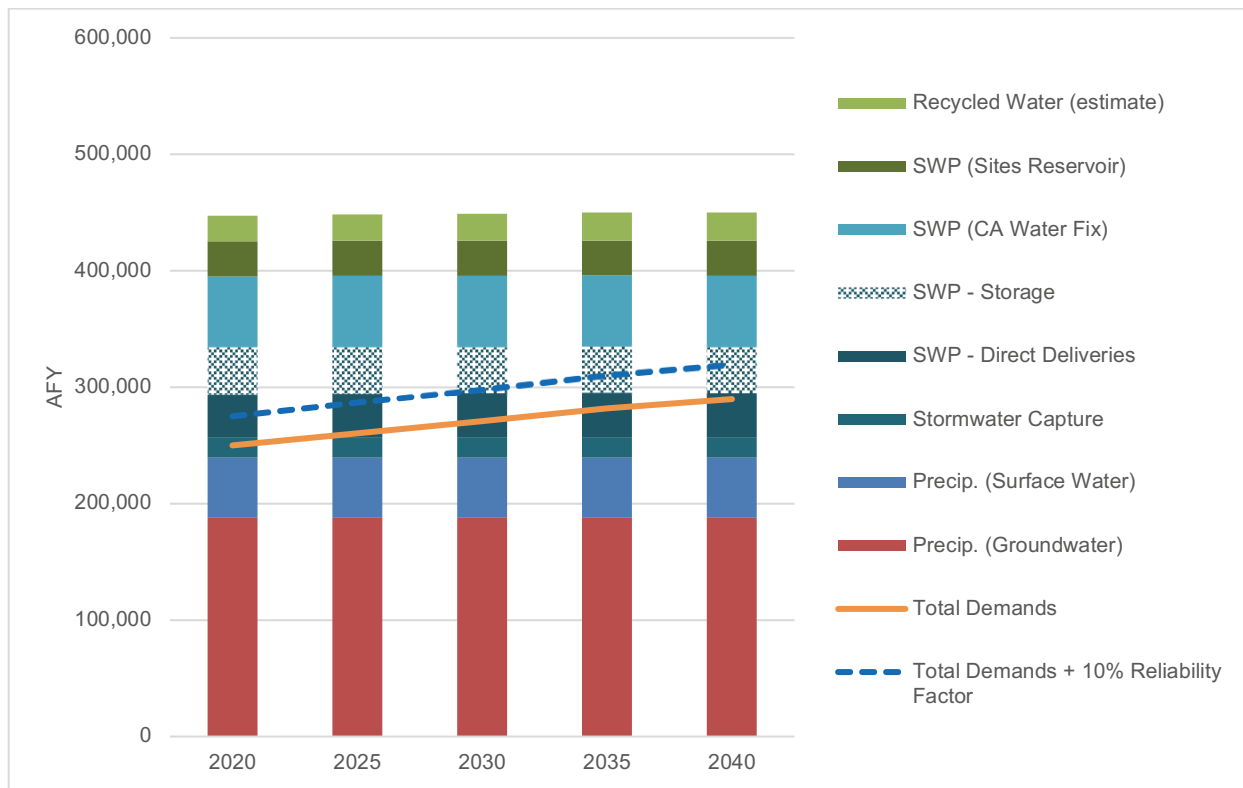
Figure 2. Regional Urban Water Management Plan (RUWMP) Supply and Demand Balance to 2040

This report summarizes the findings of study of the RUWMP demand forecasting methodology conducted by the RAND Corporation on contract with Valley District staff between January – September 2018. RAND researchers met regularly with Valley District staff to frame the analysis, obtain data from the RUWMP and present interim results. Interim and final results were also disseminated to Valley District staff and board members via in-person briefings. The final results of this analysis are included in this report. Chapter 2 details an independent review of the existing demand forecasts in the RUWMP. Chapter 3 describes the development of a standardized demand forecasting approach that adds additional demand drivers and considers specific uncertainties. Chapter 4 presents a review and synthesis of the full range of plausible future demand, how it compares to the Reliability Factor and how it may impact Valley District's long-term plans. Chapters 5 and 6 discuss study implications and next steps.

2. Independent review of RUWMP demand forecasts

In the first portion of the project, RAND performed an independent review and analysis of uncertainty in the Valley District's existing demand projections that were reported in the RUWMP. The project team first reviewed the existing forecasts, demand models and input data assumptions for each of the Valley District's retail agencies. These were then compared to methods and values from scientific literature and other Southern California agencies.

2.1 RUWMP demand forecasting approach

Valley District retail agencies each report their demand forecasts based on a modified unit water demand approach. Summaries of academic literature on water demand forecasting note that the unit water demand approach is the most common type of demand forecasting method used by utilities; more than 65% of utilities surveyed employed some form of the method in their demand analyses (Donkor et al., 2014). In a typical application of this method, demand is calculated by first establishing a per capita, or per customer (in the case of commercial, industrial or irrigation uses), water use for each category of usage. Categories of water use can include single-family residential, multi-family residential, commercial, industrial, agriculture, governmental, etc. and vary based on the service area. Per capita water use values are derived by the retail water agencies based upon their historical demand data. These per capita water use values are then multiplied by the expected number of users for each category over the forecasting horizon. Equation 1 describes this calculation for 2020 for a water agency with i water use categories. Values are annual totals.

$$Water\ Demand_{2020} = \sum_{i=1}^{n} Per\ customer\ water\ use_{i,2020} \times Number\ of\ customers_{i,2020} \qquad (1)$$

Valley District's retail agencies deviate from this method by replacing the per customer water use and number of users, the right-hand side of Equation 1, with annual water use data for each use category. These values are obtained from sales data. Note that water use for customer categories can be added together to calculate the total water demand for a given agency. To calculate water demand in future time periods, retail agencies multiply water use for each customer category by the estimated annual population growth rate for the agency's service area. Equation 2 describes this approach - the modified unit water demand method used in the RUWMP for 2020.

$$Water\ Demand_{2020} = \sum_{i=1}^{n} Water\ use_{i,2015} \times Population\ Growth_{2015-2020} \qquad (2)$$

The process for calculating a forecasted water demand, using East Valley Water District (EVWD) and 2020 as an example, is:

1) Determine a baseline water use in previous time period (2015) for each water use category (acre-feet);
2) Determine the population growth rate in water use categories from previous (2015) to forecasted (2020) time period (percentage);
3) Use Equation 2 to:
   a. Calculate the water use for each category in 2020;
   b. Sum these to the total water demand in 2020;
4) Repeat these steps for subsequent time periods. Use the calculated customer water uses in Step 3a as the baseline water use in Step 1.

An example of these values from EVWD is shown below in Table 1. In some cases, this population growth rate is constant across the planning horizon to 2040, and in other cases, retail agencies use a growth rate that varies every five years.

Table 1. EVWD Water Demand Forecast

Customer Types	Units	2015	2020[1]	2025	2030	2035	2040
Residential	AF	9,433.8	13,532.5	14,222.8	14,800.9	15,402.5	16,028.5
Multi-Family	AF	2,588.6	3,713.3	3,902.7	4,061.4	4,226.4	4,398.2
Commercial	AF	2,181.4	3,129.2	3,288.8	3,422.5	3,561.6	3,706.4
Irrigation Commercial	AF	1,536.7	2,204.3	2,316.8	2,410.9	2,508.9	2,610.9
Bulk Water	AF	44.8	64.3	67.6	70.4	73.2	76.2
Total Water Demand	AF	15,785.5	22,643.7	23,798.8	24,766.1	25,772.7	26,820.2

Source: RUWMP, 2016.

The total water demand values, shown in the last row of Table 1 for EVWD, represent forecasted water demand for normal hydrologic years. However, to account for variable hydrology in the Valley District service area, these values are further adjusted. To calculate estimated demand in wet years, forecasted total water demand is multiplied by 90%, representing a 10% decrease in water use. To calculate estimated demand in dry years, forecasted total water demand is multiplied by 110%, representing a 10% increase in water use. This is depicted in Figure 3.

---

[1] Unit water demands in 2020 for each category are adjusted to account for potential changes in consumption after the mandatory drought restrictions are phased out, the per capita consumption was assumed to rebound to the 2020 compliance target. Without this rebound factor, lower than normal values of water use in 2015 would have biased demand forecasts to lower values. The RUWMP describes the calculation of this factor.
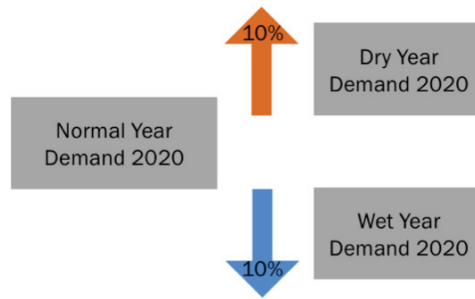
Figure 3. Modifications to normal year water demands to account for wet years and dry years

The 2015 RUWMP does include an additional factor intended to account for uncertainty in supplies and demands; all retail agency demands are multiplied by a 10% Reliability Factor thereby requiring supplies to exceed total demand by 10%. Figure 1 shows the supply and demand balance with the reliability factor added in (shown as a dashed line). Figure 4 below illustrates how the 10% reliability factor is added into the unit water demand approach employed by the Valley District's retail agencies. In reality, this factor is applied to the sum of the estimated demands of all retail agencies for each planning year.

Figure 4. Unit water demand approach with the reliability factor

2.2 Key assumptions in RUWMP demand forecasts

In California, research shows strong correlations between population and urban water use over the past several decades, making the modified unit water demand approach a reasonable method to estimate water demand (Christian-Smith et al, 2012). This methodology, however, makes general assumptions for population growth, climate and per consumer water use.

The RAND project team identified the following key assumptions in the existing RUWMP approach:
- A single estimate of population growth for each future five-year period is used.
- In some cases, a constant annual growth rate was used for all future years.
- After accounting for mandatory water use reduction targets by 2020, per customer water use rates are held constant.

- The number and distribution of customer types does not vary, which includes no consideration of land use changes over time.
- A 10% increase or decrease in demand to capture likely changes in demand due to dry or wet periods.
- Impacts of dry years are modeled the same for all user types —increasing demand by 10%.
- Uncertainties, such as changes in long-term climate are generally incorporated through the 10% Reliability Factor
- Demand projections are annual, which does not reflect any seasonal dynamics of demand.

More details on the project team's review of the RUWMP and relevant literature related to three key assumptions are included below.

2.2.1 Key assumption: Population growth

Population growth is a critical input into the existing demand forecasting approach and is considered a key driver of total water demand (Butler & Memon, 2005). Population growth data can come from planning departments within a city or local agency or from external planning organizations, demographic information or research. In the Valley District's service area, the Southern California Association of Governments (SCAG) produces estimates of population for 24 different incorporated cities or towns. These include estimates of population in 2008, 2020, and 2035. These estimates are based on data from the U.S. Census and California Department of Finance and constructed based on projections from relevant literature that predict declining fertility and mortality rates, constant levels of immigration, and fluctuating levels of domestic migration. Migration levels are driven in part by estimates of labor force supply and demand.

Many of the retail agencies rely on SCAG population growth estimates to drive their demand forecasts. While SCAG is widely used, the service areas of retail agencies do not always match exactly to a particular incorporated town or city. Eight of Valley District's retail agencies have produced their own estimates of the population within their service area based upon the total number of customer accounts, types of accounts, etc. These agencies typically estimated population in 1990, 2000, 2010, and 2015. Table 2 identifies which retail agencies have produced their own population estimates and provides more detail on the years that each agency produced population estimates. Table 3 details the annual population growth rates for each five-year period reported in the RUWMP for each participating retail agency.

Table 2. Population data source for retail agencies

Retail Agency	Agency-Specific Population Estimates
Bear Valley Mutual Water Co.	No
Colton	Yes[a]
East Valley Water District	Yes[a]
Fontana WC	No
Loma Linda	Yes[a]
Marygold MWC	No
Muscoy MWC	No
Redlands	Yes[b]
Rialto	Yes[a]
SBMWD	Yes[a]
South Mesa WC	No
Terrace WC	No
West Valley Water District	Yes[a]
YVWD	Yes[c]

Note: a. Population reported for 1990, 2000, 2010, and 2015, with forecasts every five years from 2015 to 2035; b. Population reported for 2000 and 2015, with forecasts every five years from 2015 to 2030; c. Population reported for 2000 and 2015, not agency forecasts.

Table 3. Annual population growth rates for RUWMP-participating retail agencies

	EVWD	Loma Linda	Redlands	SBMWD	WVWD	YVWD	Colton	Rialto	RHWC
2020	3.50%	1.30%	0.01%	0.60%	1.47%	1.33%	1.30%	0.90%	0.80%
2025	1.00%	1.20%	0.01%	0.70%	1.47%	1.57%	1.20%	1.20%	1.10%
2030	0.80%	1.20%	0.01%	0.70%	1.47%	1.61%	1.20%	1.20%	1.10%
2035	0.80%	1.20%	0.01%	0.70%	1.47%	1.59%	1.20%	1.20%	1.10%
2040	0.80%	1.20%	0.00%	0.70%	1.47%	1.55%	1.20%	1.20%	1.10%

2.2.2 Key assumption: Weather

Precipitation, humidity, temperature and other weather factors, such as wind, drive changes in water demand, particularly for outdoor irrigation. In the current demand forecasting approach, four annual weather scenarios are included – a normal (or average hydrologic) year, a single dry year, multiple dry years and a single wet year. In the single dry year scenario, many agencies increase demand by 10% compared to a normal year to account for hotter and dryer conditions. This 10% increase is applied across the projected normal year demands in 2020, 2025, 2030, 2035 and 2040. In three consecutive dry years, most agencies assume a 10% increase in demand, which is held constant across the three-year dry period. A minority of retail agencies (SBMWD, WVWD) assume the second and third year have less usage that the first year, likely to reflect the implementation of conservation measures. One retail agency (Redlands) assumes a 20% decrease in water demand in the first dry year and a 10% increase in demand for each of the following two years. Some agencies do not represent single or multiple dry years with any change in demand. For a wet year, all retail agencies represent demand as 10% less than a normal year. The 10% Reliability Factor is also intended to provide a buffer for uncertainty in this area.

2.2.3 Key assumption: Per capita and per customer water use

The current model assumes a constant per capita and per customer water use for all future years after 2020, after accounting for State of California (State) mandatory water use reductions by 2020. While per capita water use is adjusted to 2020 according to State guidelines, the forecasting methodology does not explicitly consider technology, conservation, land use, consumption patterns or economic effects on water use. This is a product of the unit water demand approach. The existing modeling framework scales 2015 customer type water demands for each retail agency by population growth, so the per customer water use in 2015 is adjusted to meet requirements for 2020 and is then held constant across future years. Some retail agencies do include line items for future residential or commercial demands in the RUWMP spreadsheet. For example, SBMWD includes an additional demand category for a neighborhood transformation plan starting in 2020 and WVWD includes an additional demand category for bottling, also starting in 2020.

A rebound factor[2] is calculated by comparing historical data to 2020 water use targets and assumes the same "rebound" for all categories of water use. However, these categories also differ in how much usage declined to meet the drought water use mandates. Specifically, single-family residential declined the most (around 20% for most utilities), multi-family declined much less (less than 10% for most utilities), and other categories varied but consistently were less than residential changes.

Other factors that influence per capita water use include the relationships between household income and water prices, as well as the general economic growth of a region. These have been

---

[2] "To account for potential changes in consumption after mandatory drought restrictions are phased out, the per-capita consumption was assumed to rebound to the 2020 compliance target" (San Bernardino Valley RUWMP, 2016).

shown to be significant predictors of annual water use (Gonzales and Ajami, 2017). Because the current model assumes a constant per capita and per consumer water use for all future years after 2020, it does not directly consider economic effects on water use.

2.3 Methods used by other agencies in Southern California and scientific literature

To evaluate the Valley District's demand forecasting method, the project team also looked at common demand forecasting methods noted in academic literature and used by other comparable water agencies in Southern California. These methods include unit water demand approaches, econometric models and land use models.

Academic literature generally acknowledges that there is no clear answer as to the best modeling approach for demand forecasting. Certain approaches may be more appropriate for short-term forecasting that impact system capacity and others are more appropriate for longer term forecasting. For longer term forecasting, there is some consensus that econometric modeling and scenario planning are superior approaches (Donkor et al., 2014). Scenario based approaches are essentially an extension of econometric modeling in which certain parameters in the econometric (regression) model are varied when there is a need to account for uncertainty among the parameters. These methods allow for incorporation of uncertainty in socioeconomic and climate variables that are known to impact demand yet may be deeply uncertain in the long run. In its 2012 study of California urban water demand, the Public Policy Institute of California mainly relied on econometric-based scenario planning to incorporate future climate change uncertainty (Christian-Smith et al., 2012).

The Irvine Ranch Water District (IRWD) employs a demand forecasting method that is similar to Valley District's approach. IRWD has compiled land use data across a variety of types of land uses within its service area and calculated water use factors for each land use category based on historical demands. Additionally, IRWD has also incorporated the effects of a tiered-rate conservation pricing on water use for each land use category. Land use types include single family and multi-family residential, commercial, industrial, institutional/governmental, landscape, and agricultural. Total demand is calculated by multiplying the number of land-use parcels by its water use factor across each category of land use. This method is similar to Valley District's approach in that units of demand are calculated based on average water use across different categories of demand, and these different categories are summed to calculate total demands in the future. IRWD also incorporates forecasted sales to other agencies and distribution system losses into its estimates.

The San Diego County Water Authority (SDCWA) relies on a combined approach of econometric demand modeling and scenario planning. SDCWA's main method of demand forecasting is an econometric model based on the U.S. Army Corps of Engineers Municipal and Industrial Needs (MAIN) model. The model relates historic water demand patterns to socioeconomic variables such as household income and consumer responses to water pricing

changes and physical variables like weather patterns to predict future municipal and industrial water demands. The model incorporates population and land use projections from San Diego's Regional Planning Agency to predict future water demands under normal historical conditions. SDCWA also collaborates with other organizations to project agricultural demands within its service area based on estimated crop type acreage and historic water use factors. The benefit of developing and using an econometric model to forecast water demands is that it allows for scenario planning in which different parameters within the model can be changed to represent potential futures. SDCWA developed its dry year scenario in compliance with the Urban Water Management Planning Act by modeling a scenario under maximum historic high temperature and lowest annual rainfall, holding all socioeconomic variables constant. Through its collaboration with other water utilities around the country in the Water Utility Climate Alliance (WUCA), SDCWA incorporated projections of the impact of climate change on water demands by using downscaled global climate models to modify temperature and precipitation parameters within its econometric model. Five future climate-affected water demand scenarios ranging from a warmer and wetter climate to a cooler and drier climate were produced with this approach. SDCWA also utilized the Alliance for Water Efficiency's Water Conservation Tracking Tool to develop a conservation scenario in which future water demand savings are achieved through passive building code-based savings and active demand management program savings. This tool is promoted by the California Department of Water Resources as an application to assist water providers in developing conservation potential estimates.

The Metropolitan Water District (MWD) utilizes a similar approach to SDCWA. Instead of using a single econometric model, MWD has three econometric models that separately forecast water use for: i) single-family residences, ii) multi-family residences, and iii) commercial, industrial, and institutional water users.

The Inland Empire Utilities Agency (IEUA) uses two separate approaches to forecast water demand: an econometric approach similar to SDCWA's model and a GIS-based land-use model similar to IRWD's approach. Their land-use model uses five different categories of residential development along a spectrum of density. IEUA validates these approaches by comparing their results. Both models have been shown to predict within the error ranges of each other, providing strong confidence in each methodology. Through the use of both of these models, they have been able to incorporate scenarios into demand planning that account for climate change, land intensification (greater development), and passive and active conservation programs.

There are benefits and drawbacks to each of the approaches that other large Southern California water agencies use to forecast demand far into the future. RAND's key takeaways from local approaches and the scientific literature include:

- None of these approaches make water agencies any better at predicting the future, but some may allow for better modeling of the uncertainty of future parameters.
- More sophisticated approaches allow for the incorporation of future climate change impacts on demand, socioeconomic changes, and land-use changes.

- Econometric and GIS-based approaches also may be costly to implement and constrained by data availability.
- More sophisticated demand forecasting requires strong central governance and planning approaches among wholesale agencies.

2.4 RAND's Independent Assessment

Based on the review of the current methodology, we present three key findings and recommendations.

1. Overall, the modified unit water demand approach is a good starting foundation that is straightforward, commonly used and supported in the literature. The Valley District retail agencies, however, use different approaches and customer type categories to develop estimates for the RUWMP. To improve transparency and traceability of forecasted changes in demand, the Valley District should standardize its methodology across all retail agencies.
2. The Valley District methodology uses the Reliability Factor to account for the uncertainty of the potential changes to climate that are occurring, such as warming, and that may continue into the future. Retail agencies consider and expect per capita water rates to decline over time. They incorporate the State of California mandated reductions by 2020 and then forecast changes in demand based solely on population growth from 2020 onwards. While the effects of per capita water use and warming could offset one another, the management options to mitigate warming on the one hand and encourage efficiency on the other hand, may be different. Including these factors explicitly can increase the understanding of what is driving demand projections.
3. The Valley District's use of a Reliability Factor has been useful to ensure that demand does not unexpectedly outpace supplies. The Reliability Factor does not identify the specific sources of the uncertainty, nor can it highlight the specific conditions that would lead demand to exceed the RUWMP's demand estimate. As such, we recommend evaluating uncertainty explicitly and developing a range of demand projections to compare to supply projections. Identifying the causes of any increase in demand, such as this study, may be useful in identifying potential areas for investment.

The next section describes RAND's approach to incorporating the recommended key drivers of demand as well as the results of an analysis that considers uncertainty in future projections of demand.

3. A standardized demand forecasting approach that adds additional demand drivers and considers uncertainty

The goal of this part of the study is to augment the Valley District's unit water demand approach with the additional factors that are key drivers for water demand, identified in the previous section, and identify the plausible range of these factors to more explicitly evaluate uncertainty. The methodology presented in this section also presents a standardized demand forecasting method across all retail agencies. To achieve this, the project team maintained the RUWMP unit water demand approach for simplicity and transparency and used consistent assumptions across all retail agencies. RAND added three additional factors to reflect uncertainty – i) a climate factor that models changes in water demand per degree increase in temperature; ii) an efficiency factor that models changes in water demand due to conservation, technology adoption, water use behaviors and other drivers of changes in per customer water use; and iii) a population growth factor that models a range of population growth rates. Figure 5, below, illustrates these additions.

Figure 5. Updated unit water demand model with additional factors to reflect key drivers of demand

The values of each of the variables included in these factors are described in this section. For each, the best available data and scientific studies were utilized to identify a plausible range of for each factor. Assumptions made to define these ranges were consistent across all agencies, and unique demands for each retail agency were calculated with this updated approach for each RUWMP planning year to 2040. The project team maintained the approach used in the RUWMP for calculating wet and dry years, a 10% decrease or increase in annual demand, respectively.

3.1 Climate factor methodology

Research on the main drivers of water demand show that changes in maximum temperature are the largest explanatory variable for changes in urban water demand (Chang et al., 2014). Should temperatures continue to increase in Southern California, this would alter demand patterns across the region. To more explicitly model the range of effects of changing temperature

on water demand, a climate factor that represents the percent increase in annual water demand for each degree increase in temperature was incorporated into the RUWMP unit water demand model. This approach is uniformly applied to all retail agencies. The climate factor was calculated based on the following equation:

$$Climate\ adjusted\ \Delta Demand = \Delta T_{GCM,\ RCP} \times \Delta Demand\ per\ °F \tag{4}$$

where $Climate\ adjusted\ \Delta Demand$ is the magnitude of the change in demand due to temperature in a given period; $\Delta T_{GCM,\ RCP}$ is the cumulative change in temperature from 2015 to each five-year period; and $\Delta Demand\ per\ °F$ is the percent change in demand per degree increase in temperature.

The variable $\Delta Demand\ per\ °F$ was derived from scientific studies that examined how total urban water consumption across all customer types changed per degree increase in temperature. Studies from Western states were used to ensure usage patterns and climate were reasonably similar to the Valley District's service area. Lott, et al. (2014) show a 0.2 – 4.3% increase in water demand in Nevada for each 1°F increase in temperature. Kenney et al., (2008) find a 2% increase in water demand for each 1°F increase in temperature in Colorado. Balling and Gober (2007) present a 1.5% increase in demand for each 1°F increase in temperature in a study of Arizona. For this study, the project team used the range of 0-2.5% to represent the change in demand per 1°F increase in temperature.

Maximum annual average temperature data from ten downscaled global climate models (GCM)[3] selected for California were downloaded from California's Cal-Adapt database or the years 1986-2040 for the San Bernardino service area. See Figure 6 for an example of this data (California Energy Commission, 2018). The years 1986-2005 are historical data, and the years 2006-2040 include two future scenarios[4] that were averaged for this study. The difference from the 1986-2015 baseline temperature and each of the ten downscaled GCMs was calculated to develop the range of plausible future temperature change to 2040. The range used in this study was 0.3702°F to 6.505°F increase in temperature by 2040.

---

[3] Climate projections have been downscaled from global climate models (GCMs) in the Coupled Model Intercomparison Project (CMIP5) archive. Downscaling was performed with the Scripps Institution Of Oceanography's Localized Constructed Analogs (LOCA) statistical technique, which produced GCM output at a 6km spatial resolution.
[4] Future scenarios available in the Cal-Adapt database include RCP 4.5 and RCP 8.5. More information can be found on Cal-Adapt's website at: http://cal-adapt.org/tools/annual-averages/

Figure 6. Projected average annual maximum temperature over San Bernardino, CA from Cal-Adapt's database.
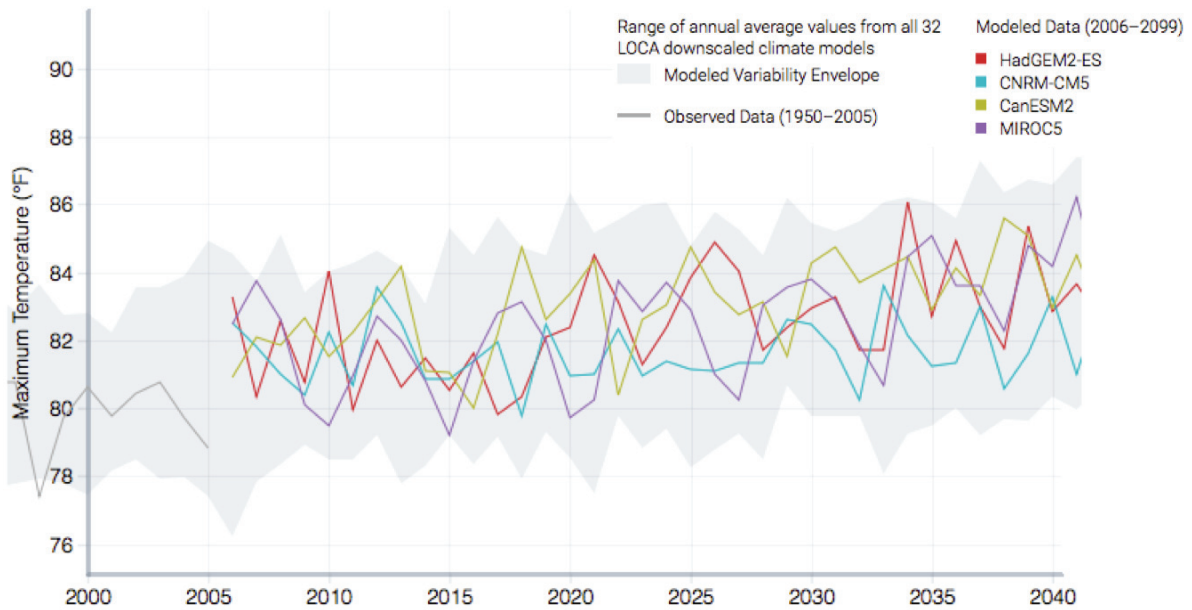
3.2 Efficiency factor methodology

To reflect plausible changes in per customer water use over time, RAND developed an efficiency factor that represents varying rates at which sectors become more efficient in their usage of water over time. This improvement in efficiency could be due to the adoption of new technology in the sector, changes in water use behavior in the sector, or any other factors that influence average per customer usage. Relevant studies on this topic were used to inform the plausible range for this factor, which is calculated based on the following equation:

$$Adjusted\ Demand_{Water\ use\ type} = Demand \times Efficiency\ factor_{Water\ use\ type} \qquad (5)$$

where $Demand$ is the total retail agency demand for the previous time period; $Efficiency\ factor_{Water\ use\ type}$ is the percent decrease in water use due to efficiency gains for each five-year period; $Adjusted\ Demand_{Water\ use\ type}$ is the water demand in the next time period that reflects efficiency gains. This equation is used simultaneously with the climate and population factors to calculate an adjusted demand based on all three factors.

To determine the plausible ranges of water use efficiency, demand was divided into three main sectors: residential (single and multi-family), commercial and industrial. For most retail agencies, these customer types constituted the majority of their customer base. To determine a unique efficiency factor for each category, the project team drew from the literature on changes in water usage over time where such information was available. For example, DeOreo et al

(2016) find that residential water use declined by 22% from 1999 to 2016. This translates to an average household using 98.5% of the prior year's water each year. For multi-family housing, an analysis of data from multi-family structures in Phoenix found that water usage declined approximately 30% from 1996 to 2014, or households using 98.0% of the prior year's usage each year (The City of Phoenix, 2018). Coomes, et al. (2010) study water usage in a variety of cities, finding trends in commercial water usage vary widely – they find no decline in Cincinnati, a 67.4% decline over 30 years in Cleveland (96.3% of the prior year's usage) and a 15% decline over 10 years in Dallas. Among industrial users, Coomes et al (2010) find a 74.2% reduction over 30 years. This large decline is consistent with large declines advertised by some industries, such as Coca-Cola noting that it has reduced water consumption by 27% over 12 years (Coca Cola, 2018).

Because many of these were isolated studies and could be location dependent, the project team adopted a conservative plausible range for the efficiency factor of 0-15% reduction in water use by 2040. Each of the three customer types – residential, commercial and industrial – have the same plausible range, but vary independently in the analysis. The same range and methodology are applied uniformly across all retail agencies.

3.3 Population growth factor methodology

The RAND project team calculated a minimum and maximum rate of average annual population growth rate for each retail agency for each future year in the RUWMP. These minimum and maximum values represent the bounds of the plausible range of population growth rates unique to each retail agency. To develop these ranges, each retail agency was matched to the incorporated area(s) that best correlated with the retail agency's service area or physical location, as shown in Table 4. This was accomplished by comparing maps of retail agency service areas to the boundaries of incorporated regions.[5] Using population projections from the Southern California Association of Governments (SCAG), which are available to 2035, RAND calculated the average annual growth rate from 2020-2035 for each incorporated area. These are also showing in Table 4.

---

[5] RAND used the following sources for maps of retail agency service areas:
http://www.sbvmwd.com/Home/ShowDocument?id=5660, https://demos3.calcad.com/CSDA/, https://www.eastvalley.org/199/District-Map, and https://wvwd.org/DocumentCenter/Home/View/12. The project team matched retail agencies to incorporated areas that significantly overlapped with their service area. When no map of the retail agency's service agency was available the agency was matched to the incorporated area where the retail agency's address was located, or to the nearest incorporated area(s).

Table 4. Matching Retail Agencies to SCAG Regions

Retail Agency	Associated SCAG Incorporated Area(s)	Average Annual Growth Rate (2020-2035**) from SCAG	Average Annual Growth Rate (2020-2040) from RUWMP
EVWD	Highland City	0.93%	1.38%
Loma Linda	Loma Linda City	1.15%	1.22%
Redlands	Redlands City	1.02%	0.01%
SBMWD	San Bernardino City	0.82%	0.68%
WVWD	Fontana, Rialto, Grand Terrace	0.94%*	1.47%
YVWD	Yucca Valley Town	0.87%	1.53%
Colton	Colton City	1.12%	1.22%
Rialto	Rialto City	0.87%	1.14%
RHWC	Highland City	0.93%	1.04%

Note: *An average of the average annual population growth rates from Fontana, Rialto and Grand Terrace Cities.
**SCAG Population forecasts were only available until 2035s

The project team then developed a standardized range of plausible population growth rates across all agencies. The percent difference between the SCAG-derived average annual population growth rates (Table 5) and the growth rates reported in the RUWMP (see Table 3) was calculated for each retail agency. The average percent difference between SCAG and RUWMP population growth rates was approximately (+/-) 20%. On the extreme ends, some retail agencies reported population growth rates in the RUWMP that were 0.5% of SCAG projections (Redlands), others reported nearly 400% more (EVWD). The average percent difference from RUWMP reported growth rates to SCAG-derived rates across all retail agencies was used as a standardized scalar to develop minimum and maximum plausible population growth rates for each retail agency for each planning year. Table 5 below shows the minimum and maximum rates used in this study.

Table 5. Minimum and Maximum Values - SCAG-Adjusted Average Annual Population Growth Rates

	EVWD	Loma Linda	Redlands	SBMWD	WVWD	YVWD	Colton	Rialto	RHWC
2020	2.80-4.20%	1.04-1.56%	0.00-0.01%	0.48-0.72%	1.18-1.76%	1.07-1.60%	1.04-1.56%	0.72-1.08%	0.64-0.96%
2025	0.80-1.20%	0.96-1.44%	0.00-0.01%	0.56-0.84%	1.18-1.76%	1.26-1.88%	0.96-1.44%	0.96-1.44%	0.88-1.32%
2030	0.64-0.96%	0.96-1.44%	0.00-0.01%	0.56-0.84%	1.18-1.76%	1.29-1.93%	0.96-1.44%	0.96-1.44%	0.88-1.32%
2035	0.64-0.96%	0.96-1.44%	0.00-0.01%	0.56-0.84%	1.18-1.76%	1.27-1.91%	0.96-1.44%	0.96-1.44%	0.88-1.32%
2040	0.64-0.96%	0.96-1.44%	0.00-0.01%	0.56-0.84%	1.18-1.76%	1.24-1.86%	0.96-1.44%	0.96-1.44%	0.88-1.32%

4. Evaluation of the range of plausible future demand

To explore how uncertainty about the different demand drivers (i.e. climate factor, efficiency factor, population growth factor) would affect future Valley District demand values across a range of factors, the project team developed six experimental designs shown below in Table 6 by the range of each factor. The *Baseline* design is intended to reproduce the demands forecasted in the RUWMP and validate the model's results. The *Temperature* design only considers the impact of increased temperature and does not consider other factors. The *Growth* design only adds a range of plausible population growth rates to the baseline case. The *Temp+Growth* design considers the combined effects of increased temperature and population growth. The *Efficiency* design only incorporates efficiency improvements into the baseline cases. The *All* design is representative of the range of plausible ranges for all three factors developed for this study. The project team then utilized a software process for iterating through the plausible bounds for each factor for each experimental design and recorded the results.

Table 6. Experimental Designs for Future Demand

	Baseline (RUWMP)*	Temperature	Growth	Temp+Growth	Efficiency	All
Temp Change	0	0.37-6.5°F	0	0.37-6.5°F	0	0.37-6.5°F
Temp Sensitivity	0	0-2.5%	0	0-2.5%	0	0-2.5%
Average Annual Population Growth	1.08%	1.08%	0.86-1.29%	0.86-1.29%	1.08%	0.86-1.29%
Residential Efficiency	0	0	0	0	0-15%	0-15%
Commercial Efficiency	0	0	0	0	0-15%	0-15%
Industrial Efficiency	0	0	0	0	0-15%	0-15%

Note: Temperature change represents changes to 2040. Efficiency gains represent changes to 2040. *A 10% reliability factor was also added to the baseline scenario to best reflect the RUWMP approach

The baseline case, shown below in Figure 7, shows the results of the study's standardized demand forecasting approach and is intended to reflect the demands in the RUWMP. The approach used in this study is standardized across all agencies, so it does not perfectly reproduce the RUWMP forecasts (in brackets). However, a close representation of the demands projected

in the RUWMP is a critical step in validating the standardized model. The 2040 forecasted demand comes within 2% of the RUWMP, which indicates the baseline design and the model is performing properly. Note that the 2015 demand is significantly higher than the RUWMP-reported demand. This is because actual water demand in 2015 was depressed due to mandatory drought restrictions. By adjusting 2015 to what it would have been under normal years, one can see in Figure 7 a natural and logical progression of demand over time that tracks with the average population growth rate from the RUWMP of 1.08%.
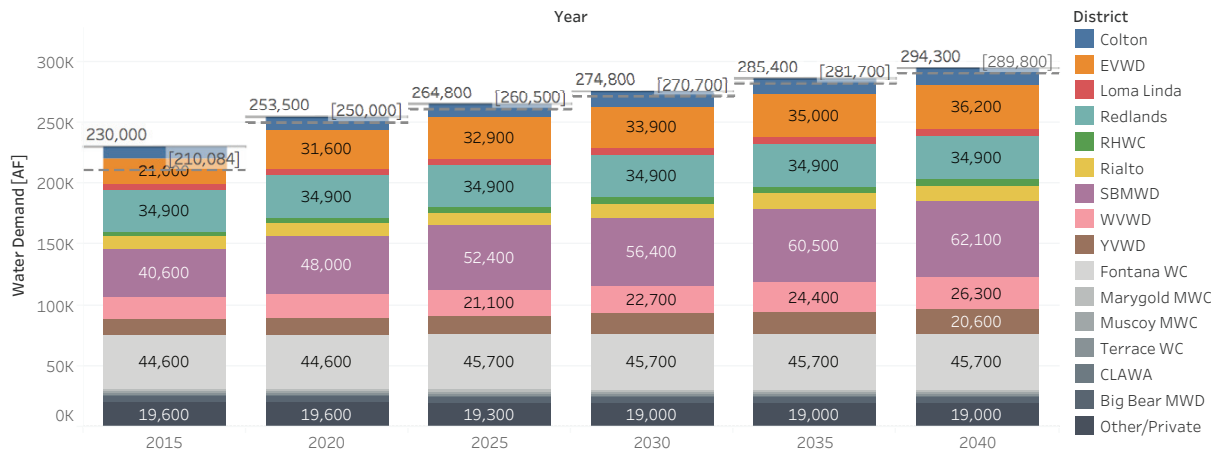

Figure 7. Results of the baseline case that reproduces demand forecasts in the RUWMP.

Note: The number in brackets are the actual demand for 2015 and the RUWMP projection for future years. These values do not incorporate the Reliability Factor. The demand forecasting approach used in this study is standardized across all agencies, so it does not perfectly reproduce the RUWMP values.

The range of projected demands for the *All* experimental design are shown in Figure 8. When accounting for the full plausible range of the climate, efficiency and population growth factors, demand forecasts for a normal year could increase to between 269,500 AF and 323,600 AF by 2040. These values are 9% below and 10% above the baseline projected demand by 2040, which falls just within the 10% Reliability Factor. Note that other plausible, but highly unlikely combinations of the uncertainty factors not included in the sample developed for this study could lead to a projected demand that exceeds the RUWMP projection with the Reliability Factor[6]. This indicates that all plausible cases identified in this study fall within the reliability factor used by the Valley District in the RUWMP.

---

[6] The sampling procedure used in this study does not guarantee that a sample exists that uses extreme values for each input. This is considered acceptable, as such a combination, while being technically plausible, would be highly unlikely.
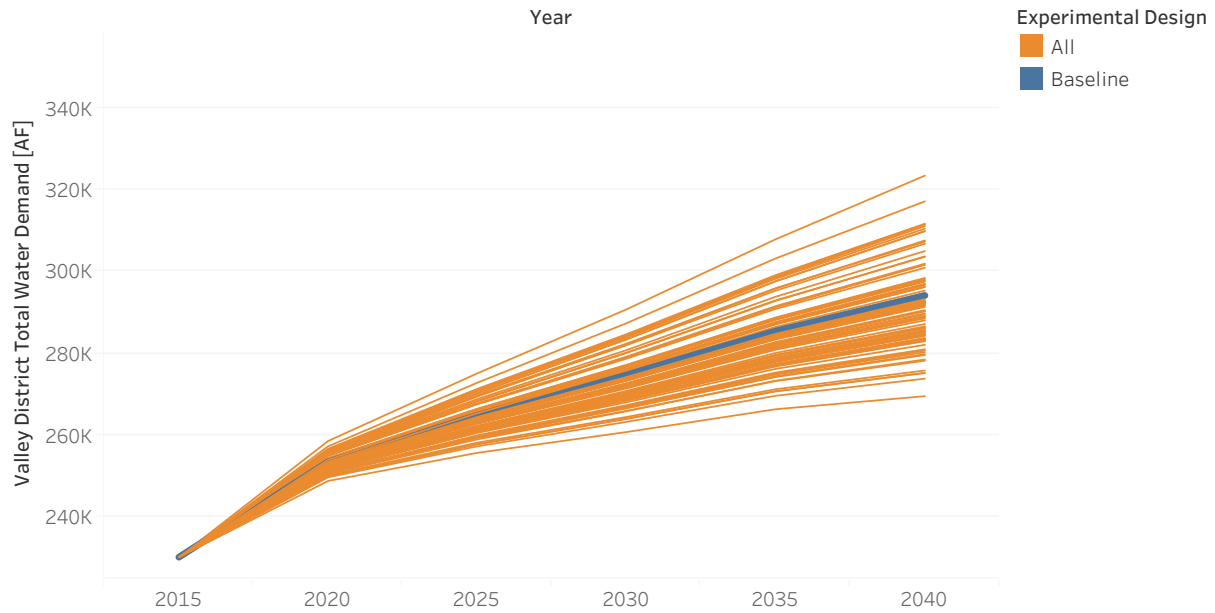
Figure 8. Plausible range of future demand due to uncertainty in climate, efficiency and population growth.

Next, the project team explored how the demand projections varied across the different experimental designs to better understand the drivers of this range. Figure 9 examines the deviations from the baseline 2040 normal year water demand (294,300 AF, without the Reliability Factor) just due to climate warming. As expected, we see that the more sensitive customer water demand is to temperature (horizontal axis) and the higher the change in temperature is projected to be (vertical axis), the larger the deviations are from normal year water demand. In an extreme case, water demand could increase by more than 26,000 AFY in a normal year due to temperature alone. This is shown in the red figure in the upper right of Figure 9. These results quantify the sensitivity of demand to the range of future temperature increases and temperature sensitivity considered in this study.
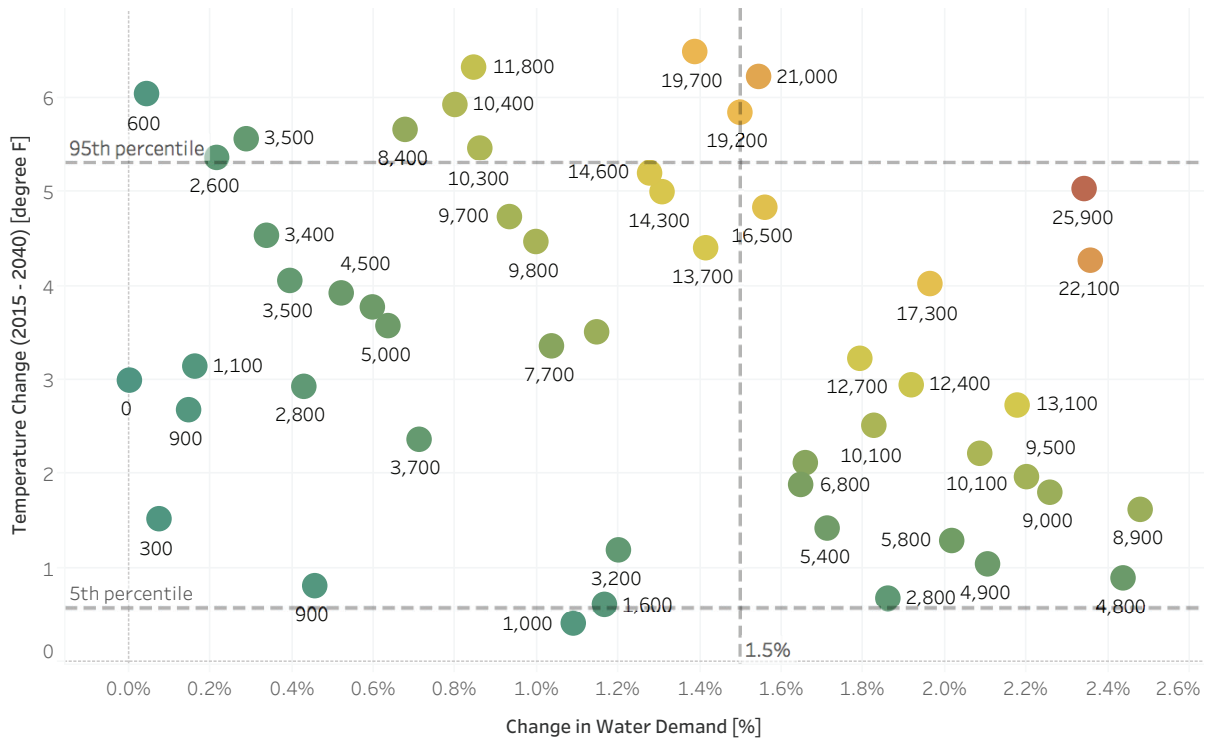
Figure 9. Difference from 2040 total demand (AF) in baseline case due to temperature increase (y-axis) and sensitivity of demand to changes in temperature (x-axis).

Note: The dashed horizontal lines show the 5th and 95th percentiles of temperature changes from the climate models used to derive the range. The vertical line shows the change in water demand estimated for Phoenix, AZ—a location with similar climate characteristics. Red circles indicates a larger difference in total demand and greener a smaller difference in total demand.

The results below in Figure 10 show the range of demand in 2040 for each of the experimental designs. The *Temp* only design summarizes the results shown in Figure 9. The *Growth* Only design shows that adding uncertainty about population growth, expands the range of 2040 demand but is still within the Reliability Factor. The *Temp+Growth* design is the only design that slightly exceeds the Reliability Factor because it does not include the reductions in demand due to water use efficiency. The *All* design, results in a maximum plausible demand that is identical to the Reliability Factor. The results show that increases in efficiency, due to demand management (i.e. conservation, regulations, technology adoption, etc.), can be used to offset increases in demand from hotter temperatures and population growth. Figure 11 shows that in dry years the same is true – demand management strategies and investments could keep demands within the Reliability Factor.
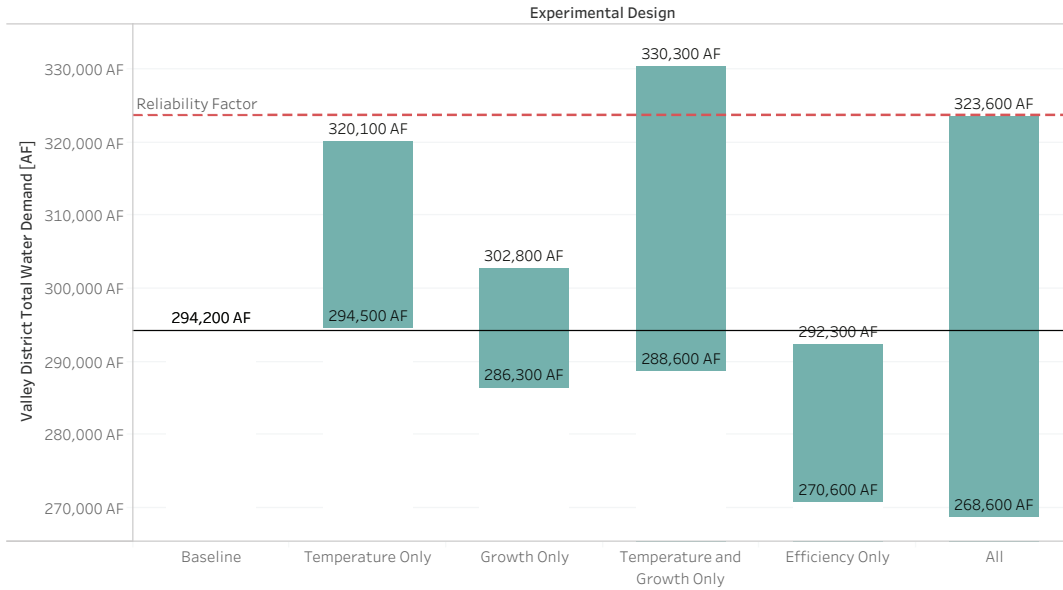
Figure 10. Range of plausible demands in 2040 by experimental design for a normal year

Note: The baseline value (294,200 AF) in the figure above, is the estimated 2040 normal year demand under assumptions from the RUWMP using a standardized approach. The red dotted line indicates the 10% Reliability Factor for the standardized approach.

Figure 11. Range of plausible demands in 2040 by experimental design for a dry year

Note: The baseline value (294,200 AF) in the figure above, is the estimated 2040 dry year demand under assumptions from the RUWMP using a standardized approach. The red dotted line indicates the 10% Reliability Factor for the standardized approach.
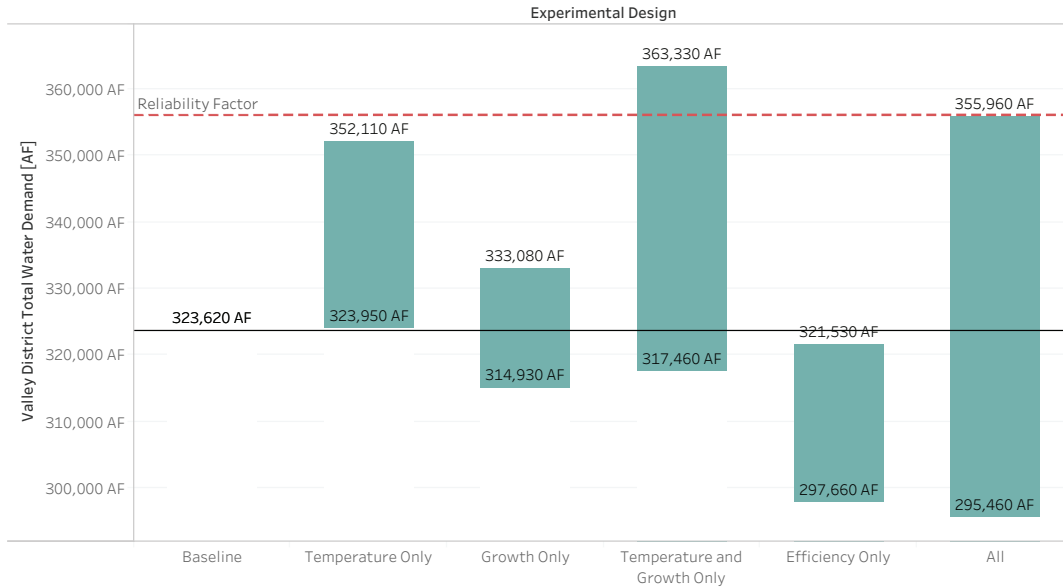
Figure 12 illustrates the number of cases where demand was above (red) and below (blue) the RUWMP (baseline) estimated demand in 2040 for the *All* experimental design. The figure shows that standardization of the methodology and exploring uncertainty leads to a wide range of demand—about half below the baseline (blue) and half above the baseline (red). However, for long-term planning and risk management those cases that fall above the baseline value are those that could strain the management system and are more critical to consider.
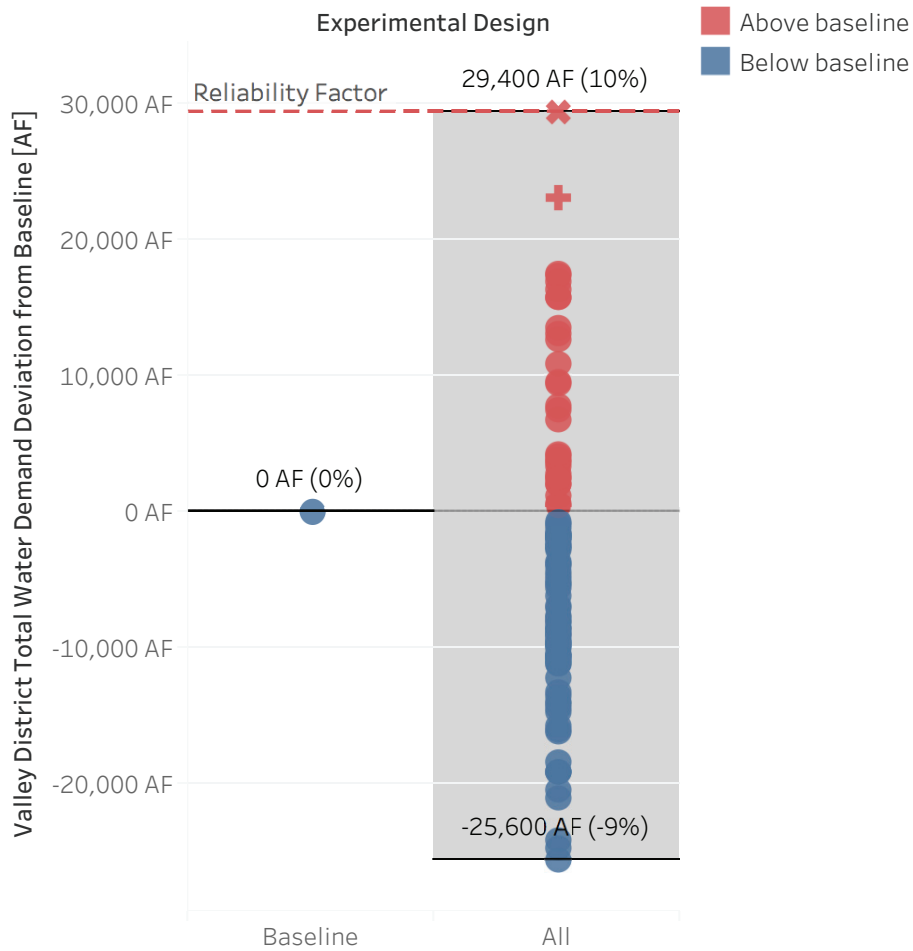
Figure 12. Difference from 2040 baseline for the All experimental design for all cases for a normal year

Note: The x and + indicate the top two highest demand results.

To better understand under which conditions the new demand methodology would suggest higher demands than forecasted in the RWUMP, Figure 13 plots the input values (standardized between 0 and 1) that correspond to each of the results in which 2040 forecasted demand is higher than the baseline. The original design samples generally uniformly across the standardized range. This figure, thus shows, that the median temperature change and sensitivity that would lead to high demand are 4.8 °F and 1.8%, respectively. For demand to be higher than the baseline, temperature and growth rates need to be on the high end of the uncertainty ranges established and the three efficiency parameters would need to be lower. These results thus suggest conditions that Valley District could monitor over time to anticipate how demand would evolve in the coming decades.
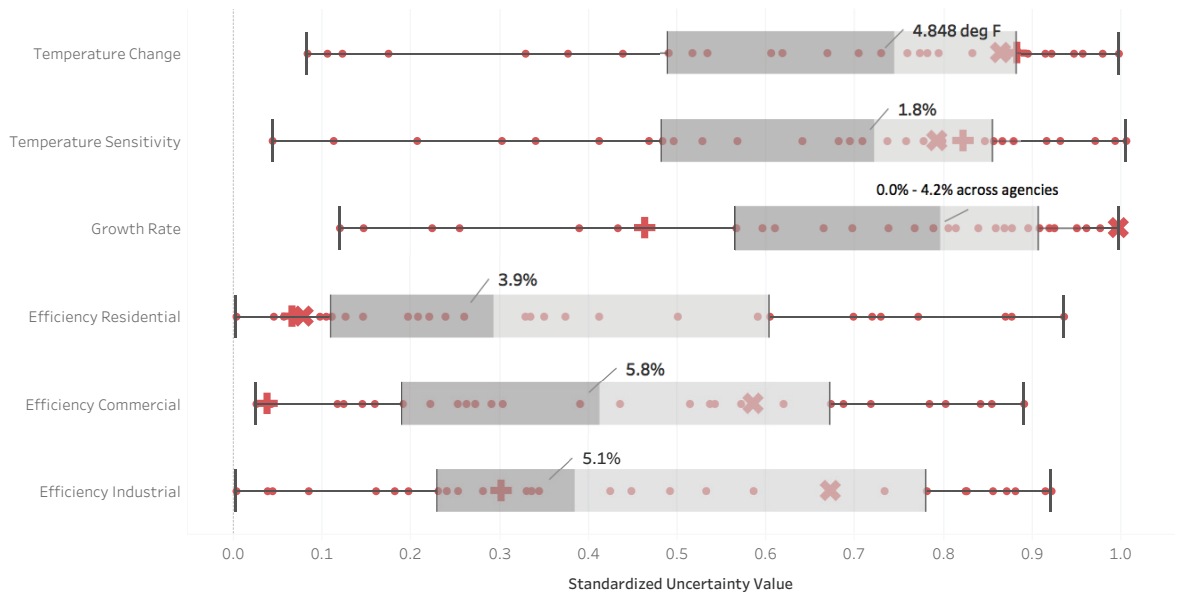
Figure 13. Standardized (0-1) input values for projections in which 2040 demand is larger than the baseline.

Note: The labeled results are values of the non-standardized input parameter (e.g. temperature change) for values near the median for each input. The "x" and "+" result correspond to the two highest demand results shown in Figure 12.

5. Implications

This study updated a standardized methodology for estimating a range of demand projections for the Valley District. For the ranges of uncertainties considered, the RUWMP estimate with the Reliability Factor was shown to capture the upper range of plausible water demand, with the highest projection almost exactly matching the RUWMP projection with the Reliability Factor. For a single dry year, the highest projection also meets the RUWMP projection with the Reliability Factor. While the Reliability Factor is broad enough to capture plausible increases in demand due to uncertainty in the drivers of demand, it does not identify the specific causes for the changes in demand. Our analysis suggests that the existing 10% Reliability Factor utilized by Valley District to account for uncertainty, is likely to be sufficiently broad to address the range of uncertainties in the drivers of demand, including climate warming, efficiency improvements and population growth. However, because this Reliability Factor is intended to account for uncertainty in both supply and demand, more research is needed to understand whether the Reliability Factor is capturing the full range of uncertainty for the Valley District.

The analysis suggests that demand could exceed the RUWMP estimate with the Reliability Factor due to warming and/or higher than expected population growth. We also find that efficiency improvements can be used to offset increases in demand. The range of demands forecasted in this study also suggests that the Valley District's demand could be higher than estimated in the RUWMP if temperature and population growth increase more than projected, over time, and water use efficiency is less than projected.

While a complementary look at future supplies is necessary to make sound recommendations on how to ensure supply meets demand, a few lessons can be drawn from the analysis presented here. First, the Valley District and retail agencies should compare observed population growth and climate conditions with the results of this study to be able to anticipate if demands are being contained within the projected Reliability Factor. Demand scenarios should also be more closely considered in the context of current supply projections. Under the highest estimated demand and including non-RUWMP participants, normal year demand is forecasted to 323,600 AF. This is within the current reliability factor for a normal year and falls below the estimated supply from the RUWMP of 366,608 AF. For dry years, the highest estimated demand is 355,960 AF, which nearly meets the reliability factor of 355,982 AF. This value essentially meets the available supply according to the RUWMP dry year supply estimate of 356,283 AF in 2040.

The analysis further suggests that investments in water use efficiency could be worthwhile. While supply-side strategies are often the focus of investments in long-term water planning, this study shows that demand management strategies can also shield the Valley District from uncertainties in climate and population growth. Demand management strategies could

mitigate increases in demand due to temperature and are often less expensive compared to large supply-side investments. Gains from these relatively inexpensive options can make a difference in water security when the gap between supply and demand is small.

To continue to track how and why demands could shift in the future, the Valley District should recommend to its retail agencies that the standardized model presented in this study be adopted by all agencies and be used for future updates. This includes the use of a more explicit representation of the key drivers of demand, namely: i) increased temperature, ii) efficiency improvements and iii) a range of population growth for each retail agency, which allows for a range in the number of future users. This would allow for a more explicit treatment of uncertainty and a continued understanding of how and when climate, population and per customer water use are driving demand closer to available supply. The Valley District could also track how these drivers impact demand over time, quantify temperature or population growth thresholds that could cause demand to exceed available supply and develop targeted demand management strategies to mitigate high rates of demand growth. With this approach, the Valley District could also present the advantages of demand reduction programs (e.g. conservation, technology, turf replacement) by quantifying their impact on demand.

The findings and modeling approaches presented in this report are also relevant to water management efforts more broadly, as water supply agencies in California and the Western United States face similar uncertainties around water demand that impact their planning and management decisions.

6. Next Steps

The future ability of the Valley District to provide adequate supplies to their retail agencies depends on how their investments and management decisions balance supply and demand. Because of uncertainty regarding the drivers of supply and demand, their future values are not known. Instead, management and investment decisions should consider a full range of plausible future supply and demand. This study evaluated existing RUWMP demand forecasting methods and compared them with an analysis of demand drivers. In this case, the current method of utilizing a 10% Reliability Factor, was found to be sufficiently broad to capture the range of uncertainties in demand modeled in this study. To achieve a more complete level of certainty about the Reliability Factor, Valley District should consider a similar evaluation of the supplies it plans to depend upon.

The RUWMP planning process requires at a minimum the evaluation of hydrologic conditions that do not fully encompass the experienced hydrology within the Valley District service area, nor do they incorporate a broad range of plausible future conditions. The RUWMP considers wet, normal, dry and multiple dry year conditions. Minimum state requirements for the UWMP program only require evaluation of a three-year drought. However, Valley District has experienced a 20-year drought between 1945-65 and is currently in a 20-year drought with no end in sight. In addition, studies show that even longer droughts are possible (Meko et al., 2017). Figure 14 depicts the reconstructed hydrologic record of California over the last several centuries and shows the significant variability in the magnitude and duration of drought. Further, the California Department of Water Resources allows the incorporation of longer possible droughts into water resources planning, requiring at a minimum the consideration of three-year dry periods (California Department of Water Resources, 2016). Executive Order B-37-16 requires local water agencies to develop and implement contingency plans for periods of drought lasting at least five years, as well as more frequent and severe drought conditions (State of California, 2016).
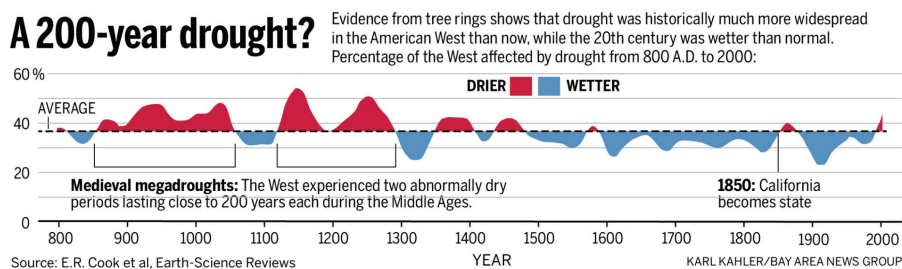

Figure 14. Reconstructed hydrologic regime of California (The Mercury Times)

The results of this study showed that in a single dry year, demands could be about equal to planned supplies. This also means that the Reliability Factor, intended to account for uncertainty in demand and supply, is fully used up by demand alone. This leaves no margin for error. The Valley District could perform a similar analysis of the RUWMP future supply estimates, to have a more complete understanding of whether the Reliability Factor is able to capture uncertainty in both demands and supplies. The Valley District could also perform a time series analysis to understand the cumulative impact of drought conditions and increased temperature on multiple dry years. Analysis of the plausible range of multiple dry year supplies would give the Valley District a better understanding of how often demand may exceed supply. This future analysis could also quantify the conditions under which demand surpasses supply, so the Valley District can better plan for such conditions.

References

Balling, R.C. and P. Gober, "Climate Variability and Residential Water Use in the City of Phoenix, Arizona". *Journal of Applied Meteorology and Climatology*,Vol., 46, 1130–1137, https://doi.org/10.1175/JAM2518.1

Butler, D., and F. Ali Memon, eds. <u>Water demand management</u>. IWA Publishing. January 2005.

California Department of Water Resources, "2015 Urban Water Management Plans Guidebook for Urban Water Suppliers," 2016: https://water.ca.gov/LegacyFiles/urbanwatermanagement/docs/2015/UWMP_Guidebook_Mar_2016_FINAL.pdf

California Energy Commission. "Annual Averages" Cal-Adapt. As of December 19, 2018: http://cal-adapt.org/tools/annual-averages/#climatevar=tasmax&scenario=rcp45&lat=38.59375&lng=-121.46875&boundary=locagrid&units=fahrenheit

Chang, H., Praskievicz, S., and H. Parandvash, "Sensitivity of Urban Water Consumption to Weather and Climate Variability at Multiple Temporal Scales: The Case of Portland, Oregon," *International Journal of Geospatial and Environmental Research*: Vol. 1. June 2014: https://dc.uwm.edu/ijger/vol1/iss1/7

Christian-Smith, J., Heberger, M. and L. Allen, "Urban Water Demand in California to 2100: Incorporating Climate Change," *Pacific Institute*. August 2012: http://pacinst.org/wp-content/uploads/2014/04/2100-urban-water-efficiency.pdf

Coomes, P., Rockaway, T., Rivard, J., & Kornstein, B. "North America residential water usage trends since 1992." *Water Research Foundation,* 2010.

Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O. "Residential end uses of water, version 2." *Water Research Foundation*. 2016.

Donkor, E. A., Mazzuchi, T. A., Soyer, R., & Alan Roberson, J. "Urban Water Demand Forecasting: Review of Methods and Models". *Journal of Water Resources Planning and Management*. 2012, doi: 10.1061/(ASCE)WR.1943-5452 .0000314.

Gonzales, P and NK Ajami, "An integrative regional resilience framework for the changing urban water paradigm". *Sustainable cities and society*. January 2017: https://doi.org/10.1016/j.scs.2017.01.012

Inland Empire Utilities Agency. "Land Use Water Demand Model," As of March 2016: https://www.ieua.org/download/land-use-model-process-03-07-16/

Irvine Ranch Water District, "2015 Urban Water Management Plan," As of January 2017: https://www.irwd.com/images/pdf/doing-business/environmental-documents/UWMP/IRWD_UWMP_2015_rev_01-03-17_FINAL.pdf

Kenney, D. S., Goemans, C., Klein, R., Lowrey, J., and K. Reidy, "Residential Water Demand Management: Lessons from Aurora, Colorado," *Journal of the American Water Resources Association (JAWRA).* 2007. 44(1):192-207. doi: 10.1111/j.1752-1688.2007.00147.x

Lott, C., Tchigriaeva, E., Rollins, K., Stoddard, S., Planner, S. R., & Authority, T. M. W., "Residential water demand, climate change and exogenous economic trends," *Agricultural and Applied Economics Association's 2014 AAEA Annual Meeting.* 2014. https://ageconsearch.umn.edu/bitstream/170660/2/AAEA_paper_CLott.pdf

Meko, D., Woodhouse, C. and E. Bigio, "University of Arizona Southern California Tree-Ring Study," *California Department of Water Resources.* December 2017: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Water-Basics/Drought/Files/Publications-And-Reports/UofAZ-SoCal-tree-ring-report-dec-2017.pdf

Metropolitan Water District of Southern California, "Integrated Water Resources Plan 2010 Update – Technical Appendix," As of December 2018: http://mwdh2o.com/PDF_About_Your_Water/2.1.2_IRP_Appendix.pdf

Metropolitan Water District of Southern California, "MWD Water Sales and State Water Project Conditions 1990-2015". As of December 2018: http://www.mwdh2o.com/PDF%202016%20Background%20Materials/Chart%20-%20MWD%20Water%20Sales%20and%20SWP%20Conditions%20-%20All%20Years%20(1990-2015).pdf

Pacific Institute "Water Rates: Water Demand Forecasting", January 2013: http://pacinst.org/wp-content/uploads/2013/01/water_rates_water_demand_forecasting.pdf

Rinaudo, J.D. "Long-Term Water Demand Forecasting," *Understanding and managing urban water in transition.* Springer, Dordrecht, 2015. pp. 239-268.

San Diego County Water Authority "San Diego County Water Authority DRAFT 2015 Urban Water Management Plan," April 2016: https://www.sdcwa.org/sites/default/files/files/publications/2015%20UWMP%20-%20Public%20Review%20Draft%20(4-29-2016).pdf

Southern California Association of Governments, "Growth Forecasting. Southern California Association of Governments". As of December 2018: http://www.scag.ca.gov/DataAndTools/Pages/GrowthForecasting.aspx

State of California, "Executive Order B-37-16: Making California Water Conservation a Way of Life". As of December 2018: https://www.gov.ca.gov/wp-content/uploads/2017/09/5.9.16_Attested_Drought_Order.pdf

The City of Phoenix, "Evaluating Water Conservation Potential Within the Multifamily Sector", Water Services Department. As of December 18, 2018: https://ceregportal.com/wsi/documents/sessions/2015/2015-T-1542.pdf

The Coca Cola Company, "Improving Our Water Efficiency", Water Stewardship and Replenish Report, http://www.coca-colacompany.com/stories/setting-a-new-goal-for-water-efficiency

Water Systems Consulting, "2015 San Bernardino Valley Regional Urban Water Management Plan" *San Bernardino Valley Municipal Water District*. As of December 2018: http://www.sbvmwd.com/home/showdocument?id=4196