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San Diego County
Water Authority

Water Demand Model and Forecast Update 2020

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Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction and Overview

1.1 Background and Purpose

The San Diego County Water Authority (Water Authority) provides wholesale water supplies to 24-member agencies including Pendleton Military Reservation. The service area of the Water Authority is home to about 3.3 million people. The service area of the Water Authority is characterized by a mixture of dense urban areas and rural, predominantly agricultural, areas. Persistent population growth coupled with the geographic, climatic, and economic diversity of the service area presents an ongoing planning challenge for ensuring adequate and reliable supplies of water.

Since the early-1990s, the Water Authority has maintained and used a set of water demand forecasting equations to support its long-term water supply planning efforts. The forecast originally contained deterministic equations for single-family, multifamily, and nonresidential water customer classes (Kiefer et al., 1996). The model was refined and expanded in the late 1990's to include an additional equation for forecasting agricultural demand. During this time, and in support of the Water Authority's Regional Facilities Master Plan, the equations were used to generate probabilistic, or range, forecasts of water demand (Kiefer and Porter, 2000). In 2008 and 2013, the Water Authority contracted Hazen and Sawyer, to update the deterministic equations and baseline water demand forecasts to support development of the 2010 and 2015 Regional Urban Water Management Plans. These projects built upon and expanded the prior work, updating forecasting equations for the single family, multifamily, nonresidential, and agricultural sectors, and extending the forecast horizon. In 2018, the Water Authority contracted Hazen and Sawyer to update the forecasting equations and water demand forecast through the year 2045.

The purpose of this report is to present the updated water demand forecasting equations and long-term water demand forecasts for the Water Authority service area. The new equations build upon the experience and recommendations from previous model development efforts and rely on a comprehensive set of historical water use data collected from member agencies. The forecasts of water use extend to the year 2045. Projections of future socioeconomic conditions, which drive the long-term forecast, are derived from official regional forecasts prepared by the San Diego Association of Governments (SANDAG), and specifically version 17 of SANDAG's Series 14 Regional Growth Forecast (SR14). The updated forecast is designed to capture total baseline demands without the effects of future water efficiency and conservation efforts. The forecasts provided in this report do not reflect the Water Authority's final long-range forecast.[1]

1.2 Organization of Report

This report documents the major steps involved in model and forecast redevelopment. The report is broken down into nine sections, with supporting appendices.

Following this introductory section, Section 2.0 discusses the collection and processing of historical water use, price, weather, demographic, and agricultural databases, and their sources, which help establish the

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[1] Refer to the Water Authority's adopted 2020 Urban Water Management Plan for the final demand forecast figures.

inputs necessary to derive new forecasting equations and water use forecasts. Section 3.0 describes the procedures used to develop econometric models for residential, nonresidential, and agricultural sectors.

Section 4.0 provides econometric estimation results and interprets the numerical relationships and the explanatory factors that are found to influence water use among the water use sectors and provides details on tests of model performance in replicating observed water use patterns. Section 5.0 describes the calibration and normalization process, and how forecasts at the sector and member agency-level are aggregated to form a baseline (without-future conservation) forecast of total Water Authority water production demands. Section 6.0 summarizes the baseline 2045 forecast results for the Water Authority and its member agencies, including a summary of SANDAG socioeconomic forecasts for the region.

Section 7.0 discusses the development of alternative weather scenario forecasts, including single and multiple (consecutive) dry-year demand forecasts. Section 8.0 extends the scenario analysis to evaluate prospective impacts on water use associated with a set of climate change projections representing a range of climate models.

Section 9.0 concludes the report, with a summary of findings and recommendations for future study efforts.

A series of supporting appendices, which are referenced in the main body of the report, are provided for specific details and data elements associated with the water use models and forecasts.

2. Data Collection and Database Development

Data collection for the project started in the fall of 2018 with a survey of the Water Authority's member agencies.[2] The survey included a brief questionnaire about water billing practices and requested available production and customer class water sales and account data for the 2013 to 2018 time period, as well as water rate schedules covering the same time period, and, where possible, a summary of water shortage management activities implemented over the last decade. All member agencies receiving the survey responded and for the most part provided complete questionnaires with little or no missing water use data. In coordination with the Water Authority several follow-up questions regarding the water use data were clarified. Archived data from past Water Authority demand analyses were also made available, which included water billing and pricing data spanning as far back as the 1990's.

2.1 Processing of Sectoral Water Use Data

The water sales and account data are generally classified into two or more customer classes. All agencies (except for Yuima[3]) segmented their residential water use classes into single-family and multifamily sectors. Water use of mobile home and other housing customer classes not associated with single-family detached structures was generally found to be assigned to the multifamily sector classification. As in previous studies, nonresidential customer classes were not consistently disaggregated into sub-classes. The nonresidential category was found to contain several sub-classifications including commercial, industrial, governmental, or public, urban irrigation, and miscellaneous other sales. Table 2-1 provides the general breakdown of sector classifications based on a survey of member agencies. Differences between current billing categories and those reported in the 2013 survey are highlighted in red. A red "0" in Table 2-1 indicates that the member agency did not report water use in 2018 for a category reported in 2013, while a red "1" indicates water use is reported in 2018 for a category not reported in 2013. For example, for the 2013 survey Lakeside provided a breakdown of water use for single-family and multifamily, whereas for the 2018 survey only residential numbers were provided.[4]

As in past forecasts, the difficulty of inconsistent nonresidential subclasses across member agencies continues to persist. However, some convergence seems to have occurred in terms of the institutional category, where it appears that some agencies have made some reassignments from the government category. Commercial and urban irrigation classes are the most common across agencies. It is still not clear the extent to which the commercial designation serves as a "catch-all" class where there are fewer subclassifications. Furthermore, uncertainty exists about the types of properties that are classified as urban irrigation and the degree to which these classes represent irrigation meters on properties that are residential or have business functions. Because member agencies do not follow the same classification scheme, it was again necessary to adopt a single composite nonresidential class for modeling.

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[2] Water use associated with Camp Pendleton is not included in this analysis. Therefore, Camp Pendleton did not receive a survey request.

[3] Yuima did not provide sales data for multifamily billing data.

[4] The example for Lakeside provides a case where historical data may be used to estimate a subclass breakdown for periods in the new data where subclasses were not specified.

Table 2-1

Breakdown of Customer Class Designations by Member Agency (Red figures denote differences from last survey)

Agency	Single Family	Multifamily	Commercial	Urban	Government	Construction	Fire Service	Construction/ Fire Service	Industrial	Public	Institutional	Agricultural	Other: Misc	Other: Export	Other: Recycled
CARLSBAD MUNI WATER DISTRICT	1	1	1	1	0	0	1	1	1	0	1	1	0	0	1
CITY OF DEL MAR	1	1	1	1	0	1	1	1	0	1	1	0	1	0	0
CITY OF ESCONDIDO	1	1	1	1	1	0	0	0	1	0	1	1	1	1	1
FALLBROOK PUBLIC UTILITY DISTRICT	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1
HELIX WATER DISTRICT	1	1	1	1	0	1	0	0	0	0	1	1	0	1	0
CITY OF OCEANSIDE	1	1	1	1	0	0	0	0	1	0	1	1	0	0	1
OLIVENHAIN MUNI WATER DISTRICT	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1
OTAY WATER DISTRICT	1	1	1	1	0	1	1	0	0	1	0	1	0	0	0
PADRE DAM MUNI WATER DISTRICT	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1
CITY OF POWAY	1	1	1	1	0	0	0	0	1	0	0	1	0	1	0
RAINBOW MUNI WATER DISTRICT	1	1	1	0	0	1	0	0	0	0	1	1	0	0	0
RAMONA MUNI WATER DISTRICT	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0
RINCON DEL DIABLO MUNI WATER DISTRICT	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1
CITY OF SAN DIEGO	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1
SAN DIEGUITO WATER DISTRICT	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1
SANTA FE IRRIGATION DISTRICT	1	1	1	1	0	0	0	0	0	0	1	1	1	0	0
SWEETWATER AUTHORITY	1	1	1	1	0	0	0	0	1	0	1	0	0	0	0
VALLECITOS WATER DISTRICT	1	1	1	1	0	1	0	0	1	0	1	1	0	0	0
VALLEY CENTER MUNI WATER DISTRICT	1	1	1	0	0	1	0	0	1	1	0	1	0	1	1
VISTA IRRIGATION DISTRICT	1	1	1	1	1	0	0	0	1	0	0	1	0	1	0
YUIMA MUNI WATER DISTRICT	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
LAKESIDE WATER DISTRICT	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**21**	**20**	**21**	**19**	**5**	**10**	**3**	**2**	**8**	**3**	**11**	**18**	**3**	**6**	**10**

🟦 **Single Family** 🟫 **Multifamily** 🟩 **Nonresidential** 🟥 **Agricultural** 🟧 **Other** 🟪 **Recycled**

Billing and meter reading do not occur at the same frequency for all member agencies and precise customer meter reading cycles can vary by customer. Therefore, billing frequency must be considered when evaluating a time series of class averages for billed consumption and accounts in order to characterize seasonal usage patterns according to calendar months. Most Water Authority member agencies tend to adopt monthly billing; however, several employ a bimonthly billing cycle, and some utilize both monthly and bimonthly customer billing cycles depending on customer class. The frequency of billing has changed over time for some member agencies.

Monthly billing cycles involve reading water meters of individual customers in approximate one-month-long time intervals that conceptually overlap with two consecutive calendar months. Thus, in order to assign monthly billing records to calendar months, a smoothing procedure was employed that averages the water use billed during the two billing periods that overlap with each calendar month.[5] In equation form, smoothing of monthly billing data for any given billing class may be written as:

$$q_M = \left(\frac{Q_M}{A_M}\right) * \left(\frac{A_M}{A_M + A_{M+1}}\right) + \left(\frac{Q_{M+1}}{A_{M+1}}\right) * \left(\frac{A_{M+1}}{A_M + A_{M+1}}\right) \qquad \text{Equation 2-1}$$

where:

q_M = smoothed average water use per account in any given month (M)

Q_M = the amount of water billed in any given month (M)

A_M = number of accounts billed in any given month (M)

Bimonthly billing cycles encompass water meter readings on approximate two-month time intervals, but not necessarily only two calendar months. Customers are typically divided into two large groups and each group is billed every second month. In some instances, the agency may read all customer meters every other month. As a result, bimonthly meter readings can contain water use occurring over a span of three calendar months. Smoothing of bimonthly water records was undertaken by weighting billed water use during the three billing periods that overlap the calendar month for billed consumption:

$$\begin{aligned} q_M = {} & \left[\left(0.25 * \frac{Q_M}{A_M} + 0.25 * \frac{Q_{M+2}}{A_{M+2}}\right) * \left(\frac{0.5 * A_M + 0.5 * A_{M+2}}{0.5 * A_M + A_{M+1} + 0.5 * A_{M+2}}\right)\right] \\ & + \left[\left(0.5 * \frac{Q_{M+1}}{A_{M+1}}\right) * \left(\frac{A_{M+1}}{0.5 * A_{M+1} + 0.5 * A_{M+2}}\right)\right] \end{aligned} \qquad \text{Equation 2-2}$$

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[5] Smoothing procedure adopted from *Urban Water Supply Management Tools*, Mays, Larry, 2004.

Table 2-2, Table 2-3, Table 2-4, and Table 2-5 show a breakdown of the maximum number of available smoothed water use observations available for econometric modeling by member agency for the single-family, multifamily, combined nonresidential, and agricultural sectors, respectively.[6] Additional screening and assumptions (beyond the application of the smoothing procedures) are employed to arrive at the final set of observations used to estimate forecasting equations.

Across the entire data archive, a maximum of 6,046 monthly water use observations are available for the single-family sector, with slightly less for the multifamily sector. The number of available modeling observations for the nonresidential and agricultural sectors is lower than in the residential sectors because of past changes in how these sectors were defined.

Table 2-2
Maximum number of Single-Family sector modeling observations by Member Agency

Agency	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Carlsbad Municipal Water District	287	4.75	287	4.75
City of Del Mar	286	4.73	573	9.48
City of Escondido	274	4.53	847	14.01
City of Oceanside	287	4.75	1,134	18.76
City of Poway	283	4.68	1,417	23.44
City of San Diego	286	4.73	1,703	28.17
Fallbrook Public Utility District	287	4.75	1,990	32.91
Helix Water District	286	4.73	2,276	37.64
Lakeside Water District*	130	2.15	2,406	39.79
Olivenhain Municipal Water District	280	4.63	2,686	44.43
Otay Water District	287	4.75	2,973	49.17
Padre Dam Municipal Water District	275	4.55	3,248	53.72
Rainbow Municipal Water District	281	4.65	3,529	58.37
Ramona Municipal Water District	268	4.43	3,797	62.80
Rincon Del Diablo Municipal Water District	287	4.75	4,084	67.55
San Dieguito Water District	248	4.10	4,332	71.65
Santa Fe Irrigation District	286	4.73	4,618	76.38
Sweetwater Authority	285	4.71	4,903	81.09
Vallecitos Water District	287	4.75	5,190	85.84
Valley Center Municipal Water District	286	4.73	5,476	90.57
Vista Irrigation District	283	4.68	5,759	95.25
Yuima Municipal Water District	287	4.75	6,046	100.00

*Note: Totals for Lakeside assume ability to split 2013-2018 annual residential data into subclasses and month.

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[6] Note that by construction, the smoothing procedures omit either 1 or 2 modeling observations at the end of a consecutive monthly data series, depending on whether the billing data reflect monthly or bimonthly billing cycles.

Table 2-3
Maximum number of Multifamily sector modeling observations by Member Agency

Agency	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Carlsbad Municipal Water District	287	4.98	287	4.98
City of Del Mar	286	4.97	573	9.95
City of Escondido	273	4.74	846	14.69
City of Oceanside	287	4.98	1,133	19.68
City of Poway	283	4.91	1,416	24.59
City of San Diego	286	4.97	1,702	29.56
Fallbrook Public Utility District	287	4.98	1,989	34.54
Helix Water District	286	4.97	2,275	39.51
Lakeside Water District*	130	2.26	2,405	41.77
Olivenhain Municipal Water District	280	4.86	2,685	46.63
Otay Water District	287	4.98	2,972	51.62
Padre Dam Municipal Water District	275	4.78	3,247	56.39
Rainbow Municipal Water District	281	4.88	3,528	61.27
Ramona Municipal Water District	268	4.65	3,796	65.93
Rincon Del Diablo Municipal Water District	287	4.98	4,083	70.91
San Dieguito Water District	248	4.31	4,331	75.22
Santa Fe Irrigation District	286	4.97	4,617	80.18
Sweetwater Authority	285	4.95	4,902	85.13
Vallecitos Water District	287	4.98	5,189	90.12
Valley Center Municipal Water District	286	4.97	5,475	95.09
Vista Irrigation District	283	4.91	5,758	100.00
Yuima Municipal Water District	n/a	n/a	5,758	100.00

*Note: Totals for Lakeside assume ability to split 2013-2018 annual residential data into subclasses and month.

Table 2-4
Maximum number of combined Nonresidential sector modeling observations by Member Agency

Agency	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Carlsbad Municipal Water District	227	4.89	227	4.89
City of Del Mar	226	4.86	453	9.75
City of Escondido	227	4.89	680	14.64
City of Oceanside	227	4.89	907	19.52
City of Poway	223	4.80	1,130	24.32
City of San Diego	227	4.89	1,357	29.21
Fallbrook Public Utility District	227	4.89	1,584	34.09
Helix Water District	226	4.86	1,810	38.96
Lakeside Water District*	130	2.80	1,940	41.76
Olivenhain Municipal Water District	220	4.74	2,160	46.49
Otay Water District	227	4.89	2,387	51.38
Padre Dam Municipal Water District	226	4.86	2,613	56.24
Rainbow Municipal Water District	227	4.89	2,840	61.13
Ramona Municipal Water District	226	4.86	3,066	65.99
Rincon Del Diablo Municipal Water District	226	4.86	3,292	70.86
San Dieguito Water District	226	4.86	3,518	75.72
Santa Fe Irrigation District	226	4.86	3,744	80.59
Sweetwater Authority	225	4.84	3,969	85.43
Vallecitos Water District	227	4.89	4,196	90.31
Valley Center Municipal Water District	226	4.86	4,422	95.18
Vista Irrigation District	224	4.82	4,646	100.00
Yuima Municipal Water District	n/a	n/a	4,646	100.00

*Note: Totals for Lakeside assume ability to split 2013-2018 annual nonresidential data into months.

Table 2-5
Maximum number of Agricultural sector modeling observations by Member Agency

Agency	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Carlsbad Municipal Water District	204	5.6%	204	5.6%
City of Del Mar	n/a	n/a	204	5.6%
City of Escondido	204	5.6%	408	11.1%
City of Oceanside	204	5.6%	612	16.7%
City of Poway	201	5.5%	813	22.2%
City of San Diego	n/a	n/a	813	22.2%
Fallbrook Public Utility District	204	5.6%	1,017	27.8%
Helix Water District	72	2.0%	1,089	29.7%
Lakeside Water District	n/a	n/a	1,089	29.7%
Olivenhain Municipal Water District	204	5.6%	1,293	35.3%
Otay Water District	204	5.6%	1,497	40.9%
Padre Dam Municipal Water District	204	5.6%	1,701	46.5%
Rainbow Municipal Water District	204	5.6%	1,905	52.0%
Ramona Municipal Water District	204	5.6%	2,109	57.6%
Rincon Del Diablo Municipal Water District	204	5.6%	2,313	63.2%
San Dieguito Water District	204	5.6%	2,517	68.8%
Santa Fe Irrigation District	204	5.6%	2,721	74.3%
Sweetwater Authority[7]	128	3.5%	2,849	77.8%
Vallecitos Water District	204	5.6%	3,053	83.4%
Valley Center Municipal Water District	203	5.5%	3,256	88.9%
Vista Irrigation District	201	5.5%	3,457	94.4%
Yuima Municipal Water District	204	5.6%	3,661	100.0%

2.2 Price Data

Water rate schedules were gathered from the survey of member agencies for the 2013-2018 time period. Archived price data collected from past Water Authority demand analyses are used through 2012. Volumetric prices used in modeling, reflect the “marginal” part of the water rate that can be avoided by reducing consumption, consistent with economic theory.

Residential and nonresidential sectors were matched with each respective year’s reported marginal (or volumetric) price of water. In the case of block pricing, the volumetric price associated with the second consumption block was selected. Thus, the volumetric prices should be considered as a statistical instrument or proxy for capturing the effects of water pricing. Prior to modeling all marginal prices were converted into real, inflation-adjusted, 2016 dollars using the Bureau of Labor Statistics, Consumer Price Index – All Urban Consumers for the Urban West (Series ID: CUUR0400SA0, CUUS0400SA0).

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[7] Note that Sweetwater data has agricultural use from past data surveys,but did not report any agricultural sales in the most recent survey.

2.3 Weather Data

Previous modeling efforts have utilized and tested several different sources for weather data including NOAA[8], DAYMET[9], and PRISM[10]. Previous modeling efforts have slightly favored the use of using monthly data from weather reporting stations in the NOAA network, despite cases of missing monthly data. NOAA was used as the source of historical weather data for this update.

For the update of the sectoral models, six San Diego area weather stations: Chula Vista, El Cajon, Escondido 2, La Mesa, San Diego (Lindbergh Field), and Vista 2 NNE, were used to construct a weather contour based on inverse-squared-distance weighting. The weights use the distances between the various stations and using the geographic centroid coordinates of each member agency to derive historical estimates for average maximum daily temperature and precipitation for each member agency.

Long-term monthly averages for each weather variable and member agency were calculated over a consistent historical period (1981-2018) to evaluate departures from normal historical climate. A regression-based method was employed to estimate departures from normal weather using natural-log transformations. The estimation of weather departures using natural log (LN) transforms takes the following form:

$$\begin{gathered} LN(Avg. Maximum\ Daily\ Temp)_t \\ = a_T + b_{T,1}S1_t + b_{T,2}C1_t + b_{T,3}LN(Precipitation + 0.01)_t + \epsilon_{T,t} \end{gathered} \qquad \text{Equation 2-3}$$

$$LN(Precipitation + 0.01)_t = a_P + b_{P,1}S1_t + b_{P,2}C1_t + \epsilon_{P,t} \qquad \text{Equation 2-4}$$

where the terms for parameter *a* represent model intercepts and the terms for the *b* parameters represent the estimated responses of the average maximum daily temperatures and precipitation to the independent variables specified in the equations. Departures from long term normal weather are taken as the residuals ($\epsilon_{T,t}$ and $\epsilon_{P,t}$) from the regression relationships. In this formulation, the terms S1 and C1 represent annual sine and cosine harmonics, respectively, which capture the systematic or long-term normal pattern of weather over the calendar year.[11] Because precipitation can lead to cooling, a precipitation term was added to the model for temperature.[12] Modeling historical weather in this way separates the normal seasonal cyclical pattern in weather from observed weather, so that seasonality in water use can be evaluated independently.

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[8] The National Oceanic and Atmospheric Administration (NOAA) provides online tools for extracting weather data from a national network of weather reporting stations (https://www.ncdc.noaa.gov/cdo-web/datasets/).

[9] DAYMET is a database made available from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) that provided gridded climatic data (http://daac.ornl.gov/).

[10] PRISM stands for “Parameter-elevation Relationships on Independent Slopes Model”, and provides gridded climatic data made available by the PRISM Climate Group (http://www.prism.oregonstate.edu/).

[11] Specifically, the terms S1 and C1 are calculated respectively as $Sine\left(\frac{2*pi*month}{12}\right)$ and $Cosine\left(\frac{2*pi*month}{12}\right)$. Note that another option is to specify a set of monthly binary variables, which provides a complete accounting of seasonality but is less parsimonious.

[12] A small adjustment of 0.01 is added to precipitation, so that cases where precipitation is zero do not become undefined when taking the natural logarithm.

Note for the Agricultural model, that in addition to or in lieu of the departures from normal weather variables, estimated precipitation values were related to historical monthly crop-weighted reference evapotranspiration rates (*ETc*), which reflect the amount of water required for optimal production.

2.4 SANDAG Demographic Data

The San Diego Association of Governments (SANDAG) Series 14 Regional Growth Forecast (version 17) provides socioeconomic and demographic assumptions for 2016-2050 in five-year increments for all Water Authority member agencies, with 2016 serving as the base year observation. These data were coupled with SANDAG demographic data collected during previous studies for the years 1995, 1996, 1997, 2000, 2004, 2008, and 2012 and used to interpolate a full demographic data series for 1995-2045 for use in modeling and forecast development. The driver and socioeconomic variables used to predict water demand correspond with the historical variables used in the estimation of unit usage rates for the single-family, multifamily, nonresidential, and agricultural sectors. The key demographic and socioeconomic variables used in the water demand forecast and derived from SANDAG's Series 14 Regional Growth Forecast (version 17) are shown by sector in Table 2-6 and are presented by member agency in Appendix A. Forecast assumptions and future socioeconomic trends are discussed in Section 6.

Like the price data, all median household income values were converted into real, inflation-adjusted, 2016 dollars using the Bureau of Labor Statistics, Consumer Price Index – All Urban Consumers for the Urban West (Series ID: CUUR0400SA0, CUUS0400SA0) prior to modeling.

With respect to housing density, SANDAG employed a different process than in the past for SR14. According to SANDAG, the data used for the land use acreage tabulations and density estimates were created in a separate process from the housing projection data. Thus, there is not a direct connection between housing stock estimates and the number of housing units used to derive housing density estimates.

Table 2-6 Key Variables Derived from SANDAG Series 14, 2050 Regional Growth Forecast

Variable	Sector
Number of occupied housing units	Single-Family and Multifamily
Average number of persons per household	
Median household income	
Housing density (average number of housing units per acre)	
Number of employees (total non-agricultural, non-mining employment)	Nonresidential
Number of employees per major industry grouping	
Irrigated acreage(2-acre threshold of continued agricultural viability)	Agricultural

Key nonresidential demographic data include:

- Total number of non-agricultural non-mining employees
- Number of employees per major industry grouping

SANDAG provided member agency employment estimates for the following 15 industry groups, which are generally defined using the North American Industry Classification System (NAICS):

- Agriculture and Mining
- Construction
- Education and Healthcare
- Finance and Real Estate
- Government
- Information
- Leisure and Hospitality
- Manufacturing
- Military
- Other Services
- Professional and Business Services
- Retail Trade
- Self-Employed
- Transportation, Warehousing, and Utilities
- Wholesale Trade

In past releases, SANDAG provided estimates of labor productivity, which were used to convert employment counts into measures of “effective employment” meant to capture output by major industry. The productivity series was not able to be provided in SR14. Furthermore, SR14 did not provide acreages for nonresidential land uses, which was used previously to derive “employment density” measures as an analog to housing densities in the residential sectors. As a result, and unlike before, these factors were not included in the estimation of the nonresidential model.

2.5 Agricultural Data

In addition to demographic figures, SANDAG also provided member agency agricultural acreage estimates for 2016 to 2050. Similar to other variables, these data are integrated with historical SANDAG estimates and interpolated to create a continuous timeseries. However, SANDAG employed a different methodology for estimating SR14 acreage than in past efforts. According to SANDAG, the SR14 input and output data are parcel-based and not sub-parcel-based, as in previous releases. Because of this change, the initial agriculture calculations included parcels that intersect the agriculture boundary as opposed to parcels that fell within the agriculture boundary. However, this new approach resulted in a significant increase in agricultural acres than estimated in the previous SR13 tabulation. Upon further discussions with SANDAG and the Water Authority, an alternate methodology was developed. SANDAG was able to identify the prior sub-parcel areas that were included in the SR13 dataset and reaggregate only the sub-parcel areas that had not been reclassified to another use.

Consistent with the data used to estimate unit usage rates for the agricultural sector, the Water Authority’s 2-acre threshold of continued agricultural viability data for 2016, 2020, 2035 and 2050 was used to predict future agricultural water demand. To attain data in five-year increments, SANDAG total irrigated acreage values for each member agency were interpolated between 2012 and 2016, 2016 and 2020, 2020 and 2035 and finally between 2035 and 2050. The forecast process used by SANDAG does not account for land converted into agriculture use over the period, but it does estimate the amount of farmland slated for conversion to residential or commercial use[13].

As in previous studies, a watering requirement variable was formulated to account for the distribution of irrigated acreage among various crop types and that different crops generally require a different amount of water for optimal production on both a monthly and average annual basis. The watering requirement variable is comprised of two elements specific to each member agency:

- Crop-specific irrigated acreage estimates
- Monthly crop-specific reference evapotranspiration rates (ETc)

The watering requirements variable is derived by weighting the monthly ETc values assigned to each agency’s crop types, by irrigated acreage estimates for each respective crop. The monthly crop-specific ETc values assigned to each member agency by the Water Authority for the previous forecast update was applied in the current study. Water Authority estimates of acreage by crop type provided in 2016 and 2019 was used to develop the weighting scheme, considering estimated changes in acreage. Similar to irrigated acreage, the objective is to introduce time variability into the weighted average irrigation requirements. The acreage breakdown is available for the following nine categories:

- AVO = Avocado Trees
- CST = Citrus, Subtropical Trees
- FNG = Fruits, Nuts, Grapes
- VFB = Vegetables, Flowers, Berries
- GRNHS = Greenhouses
- NURS = Nursery
- GHP = Grain, Hay, Pasture
- NON-IR = Non-irrigated Oat, Wheat, Range
- SOD = Sod Farms

This list was consolidated into six categories, as some crop types having similar watering requirements:

1. Citrus and Subtropical
2. Fruits and Vegetables
3. Avocados
4. Nursery and Green House
5. Sod Farm
6. Grain, Hay and Pasture

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[13] The SANDAG Series 13 forecast for Otay Water District in 2035 is approximately -36 acres. Consultation with SANDAG revealed that it is possible for observed acreage caught in the development/building process between agricultural and residential zoning to affect projected estimates in the forecast model. It is assumed that this is the case for Otay and for the purposes of forecasting, Otay Water District 2015 irrigated acreage at the 2-acre threshold is assumed to equal zero.

3. Forecast Framework and Econometric Estimation Procedures

The water use forecasting framework employed for the 2020 update follows past Water Authority water demand forecast efforts. The general framework predicts future water use using a “driver times average rate of use” approach. For the residential forecasts, drivers are single-family (SF) and multifamily (MF) households, respectively. For the nonresidential (NR) forecast, the driver variable is total non-agricultural, non-mining, employment, which is derivable from the SANDAG NAICS breakdown by industry. Average rates of use are measured on a per-unit basis as per household per day (gphd) for the residential forecasts, and as gallons per employee per day (gped) for the nonresidential forecasts. For the agricultural (AG) forecast, average unit usage rates are expressed in gallons per irrigated acre per day (gpad). For any particular time period and member agency, water use is calculated as:

$$SF\ Water\ Use = SF\ Households * SFgphd * number\ of\ days$$ Equation 3-1

$$MF\ Water\ Use = MF\ Households * MFgphd * number\ of\ days$$ Equation 3-2

$$NR\ Water\ Use = NR\ Employees * NR\ gped * number\ of\ days$$ Equation 3-3

$$AG\ Water\ Use = AG\ Irrigated\ Acres * AG\ gpad * number\ of\ days$$ Equation 3-4

Forecasted average rates of use, denoted by the terms gphd, gped, and gpad are predicted via a set of equations that relate changes in average rates of use to climatic, socioeconomic, and land use factors that influence water use within and among the water using sectors. The predictive equations for average rates of use are estimated using econometric methods. As in past projects, the econometric equations of single-family, multifamily, nonresidential, and agricultural use are developed using pooled time-series and cross-sectional member agency data on water use and water demand determinants. The cross-sectional (or geographic) component of the data permits a sound basis for estimating long-term relationships among socioeconomic variables and water use. The time-series component is ideally suited for estimating the effects of weather and systematic seasonal water use patterns.

3.1 Water Use Estimation Procedures

Three general specifications were tested within the context of estimating models for the sectoral rates of use. These are shown in Equation 3-5 through Equation 3-7 below, where q is used as the symbol for average rates of sectoral use (i.e., terms gphd, gped, and gpad of the general framework), and where the index i denotes a geographic cross-section (i.e., member agency) and the index t represents time. The equations explain variability in q as a linear function of X, which denotes any of J explanatory variables. The term b measures the response of q to a change in X, and a is the traditional model intercept term.[14]

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[14] Note that if q and X are transformed into natural logs before model estimation, then b_j are often called elasticities.

Ordinary Least Squares Specification:

$$q_{i,t} = a + \sum_{j=1}^{J} b_j X_{j,i,t} + \varepsilon_{i,t}$$

Equation 3-5

Cross-Sectional (Panel) Fixed Effects Specification:

$$q_{i,t} = a + \sum_{j=1}^{J} b_j X_{j,i,t} + \left(u_i + \epsilon_{i,t}\right)$$

Equation 3-6

Parks Specification

$$q_{i,t} = a + \sum_{j=1}^{J} b_j X_{j,i,t} + \left(u_i + \rho_i u_{i,t-1} + \epsilon_{i,t}\right)$$

Equation 3-7

The three specifications differ in the definition and assumptions regarding the nature of the error term, which measures the difference between an observed value of q and the predicted value of q. In ordinary least squares (OLS) the error term (ε) is assumed to be distributed normally around a mean of 0, with constant variance. The constant variance assumption can often be violated when using pooled data, which can affect inferences about the significance of model parameters.

In the geographic fixed effects panel model, part of the error term is assigned uniquely to geographic cross-sections (u), essentially acting as an adjustment to the model intercept. The geographic intercept adjustments tend to improve fit as they can capture non-modeled factors but are often highly correlated with socioeconomic differences.

The Parks specification adds another component to the error term, where the error component associated with each cross-section is also related to the error in the previous time period (via autoregressive parameter ρ). Unlike the other two specifications, the Parks specification assumes both a heteroskedastic and contemporaneously correlated form of cross-sectional error variance (u_i^2) in addition to first order autocorrelation. Furthermore, implementation of the Parks method requires a balanced data design, where each cross-section (e.g., member agency) has data spanning a consistent time frame.

A panel fixed effects model estimation methodology was ultimately selected for all sectoral models, as this specification was strongly favored in relation to OLS and Parks regression specifications based on Hausman and Lagrange multiplier tests. Unlike past modeling efforts, estimation results were accomplished in a single step for each water using sector. The updated sectoral models specify member agency fixed effects and interactions of these fixed effects with measures for seasonality, weather, and drought management actions occurring over the modeling time frame. This permitted estimation of member agency-specific weather parameters, while providing estimates of common socioeconomic parameters.

Because the number of billed accounts in any particular member agency and time period are known with relatively high certainty, estimation employs average water use per account in each sector as the dependent variable, where the average number of driver units (i.e., number of occupied houses, employees, or irrigated acres) per account is used as a regressor. The average number of driver units (i.e., households, employment, and acres) per account serves as an additional control for scale differences found across member agencies, which may not be fully captured by agency-specific fixed effects.

3.2 Choice of Estimation Period and Explanatory Variables

Choices regarding the span of the historical modeling period depended on the availability of consistent data across all member agencies, and, more importantly, the extent to which underlying trends in use can be measured adequately by available explanatory variables. In general, more modeling observations will increase the amount of variability, which can increase the reliability of parameter estimates, but also expose the modeling process to additional variability that cannot be explained due to several potential causes, such as unattributable shifts or trends in consumption, measurement errors, and simple randomness. In a few cases, data for some member agencies were left out of the regression process because of a relatively short time span of available data or if there were outstanding questions about data quality. In other cases, clear and specific outlying data points were identified within the regression analysis to preserve the number of observations available for modeling.

In general, model parameters are estimated over a balanced period spanning 180 months, or 15 fiscal years (July 2003 through June 2018). The modeling period includes time periods before, during, and after the Great Recession. The most recent severe drought period was also covered by the modeling period, and all models include variables aimed at accounting for the timing and severity of water use restrictions (e.g., voluntary versus mandatory and requested cutbacks). The potential for persistence in response to the severe recent drought restrictions is a challenge for modeling. Due to timing, there are simply more time periods available before and during the recent drought than after restrictions were relaxed.

In terms of variables, Table 3-1 lists the array of explanatory variables that were included within the econometric analysis. Measures of weather, seasonality, and price were specified within all sectoral models, along with variables accounting for the business cycle and water use restrictions associated with drought response.

To account for the influence of the macroeconomic fluctuations associated with economic business cycles, three macroeconomic data sources were evaluated for econometric modeling. These included the Economic Cycles Research Institute's (ECRI) and the Federal Reserve Bank of St. Louis economic database (FRED). Each provide publicly available data, such as ECRI's coincident and leading national indicators, and FRED's downloadable data sourced to the Bureau of Labor Statistics, such as the unemployment rate. Based on assessment of fit, all models incorporate the coincident economic index developed and published by ECRI. The ECRI index, while designed to gauge the national economy, is highly significant in accounting for the impact of the "Great Recession" and recovery in the economy on regional demands across each sector. The index is modeled in departure from normal form, which permits normalization of water use estimates for an economy following the long-term trend.

Residential equations consist of socioeconomic factors that have been shown to explain a considerable amount of cross-sectional variability across member agencies, such as household size, median household income, and housing density. The mix of employment across major industry groups represents the key set of explanatory variables in the nonresidential equation. The nonresidential equation defines variables that estimate the distribution of employment among a subset of the following 12 major industry groups as provided by SANDAG:

- Wholesale Trade
- Information
- Leisure and Hospitality
- Education and Health Services
- Government
- Transportation, Warehousing, Utilities
- Construction
- Professional Business Services
- Finance/Real Estate
- Retail
- Manufacturing
- Other Services

As mentioned above the nonresidential equation does not incorporate labor productivity or employment density due to changes in the data SANDAG provided in SR14.

Finally, the distribution of crop types and crop watering requirements remain as in the past fundamental factors within the agricultural equation. For the agricultural equation, the departure from normal watering requirements is specified, which embeds information on the distribution of crop types, reference crop moisture requirements, and observed precipitation.

Table 3-1 Explanatory Variables by Sector

Model Variables	Residential	Nonresidential	Agricultural
Time of Year/Season	✓	✓	✓
Temperature	✓	✓	✓
Precipitation	✓	✓	✓
ECRI Macroeconomic Index	✓	✓	✓
Water Supply Shortage Restrictions/Severity	✓	✓	✓
Real Marginal Price	✓	✓	✓
Household Size	✓		
Housing Density	✓		
Median Household Income	✓		
Mix of Industries		✓	
Mix of Crops			✓
Watering Requirements (ETc)			✓

3.3 Econometric Estimation Platform and Model Development Process

All water use equations are estimated using regression routines made available in both SAS and EViews statistical software packages. Most continuous variables were converted into their natural logarithms before estimation, thus yielding a set of multiplicative water use equations upon conversion to the raw scale. All equations were based on aa monthly time step and utilize smoothed water use data. Components for seasonality, weather, and drought response are unique to each member agency.

The model development process generally proceeded in the same way as past modeling efforts for the Water Authority. The goal of the modeling process was to develop water use models with rational coefficients (both in signs and magnitudes), as high of an explanatory power as practically possible, and an ability to produce predictions that on balance match closely with observed values on average. These objectives were approached through an iterative process of specifying alternative variables, screening, and applying corrections to outlying data, and by analyzing model residuals (i.e., prediction errors).

4. Estimation Results and Interpretation

This section summarizes the results of the econometric modeling process for the single-family, multifamily, nonresidential, and agricultural water use sectors. Appendix B provides statistical output for each estimated equation, including the estimates for the unique member-agency fixed effects, seasonality, weather, and drought restriction variables.

4.1 Residential Equations

The equation estimated for the single-family sector explains nearly 95 percent of the variability in single-family per account use among 3,600 historical observations (180 months x 20 member agencies). Meanwhile, the equation estimated for the multifamily sector explains about 97 percent of historical variability in the sample water use data. In the residential sectors, water use is found to increase with median income, persons per household, and general economic activity, and decrease with housing density and price. Table 4-1 provides a summary of the estimated coefficients for these variables for the single-family and multifamily equations. The coefficients all have rational signs and magnitudes based on experience and retain very high level of statistical significance.

Table 4-1 Residential Socioeconomic Coefficient Estimates

Variables	Single-family Model Elasticities	Multifamily Model Elasticities
Median income	0.4786	0.4808
Housing density	-0.1374	-0.1111
Real marginal price	-0.2321	-0.1241
Average household size	0.5894	0.3365
Economic index (detrended)	0.7060	0.5156

The listed parameters are called elasticities, in that they estimate the response of water use to a 1 percent change in the corresponding variable. For example, the coefficients of the socioeconomic variables for the single-family model can be interpreted as follows:

- A 1 percent increase in the real marginal price of water leads to a 0.23 percent decrease in average single-family water use
- A 1 percent increase in average household income leads to a 0.48 percent increase in average single-family water use
- A 1 percent increase in average single-family housing density leads to a 0.14 percent decrease in average single-family water use
- A 1 percent increase in average household size leads to a 0.59 percent increase in average single-family water use

While both sectors show a similar response to change in income, multifamily use is shown to be less responsive than the single-family sector to changes in housing density, price, household size and the economic index.

4.2 Nonresidential and Agriculture Equations

The equation estimated for the nonresidential sector explains about 87 percent of historical variability in the sample water use data. Meanwhile, the equation estimated for the Agriculture sector explains about 92 percent.

Table 4-5 provides a summary of the estimated socioeconomic coefficients for the nonresidential and agricultural equations. Water use in the nonresidential and agricultural sectors is more responsive to general economic activity than the residential sectors. Agricultural price elasticity is estimated to be considerably higher than in other sectors.

The mix of employment has a significant effect on water use in the region. Since the variables represent proportional shares, they should not be interpreted independently from one another. However, they indicate those sectors that are most associated with higher nonresidential water relative to mean regional consumption and the average industry mix across member agencies.[15]

Table 4-2 Nonresidential and Agricultural Socioeconomic Coefficient Estimates

Variables	Nonresidential Model Elasticities	Agricultural Model Elasticities
Real Marginal Price	-0.1899	-0.6524
Economic index (detrended)	0.9913	0.9145
% Employment by Industry		
Transportation, Warehousing, Utilities	0.4688	n/a
Prof. Business Services	0.4486	n/a
Wholesale trade	0.3783	n/a
Information	0.3437	n/a
Leisure and Hospitality	0.3220	n/a
Retail	0.2867	n/a
Education and Health Services	0.2857	n/a
Government	0.2031	n/a
Manufacturing	-0.1956	n/a
Other Services	-0.7788	n/a

4.3 Member-Agency Specific Climatic Parameters

As discussed previously, the sectoral equations are designed to generate member agency specific coefficients for weather variables. The member agency specific estimates are found in Appendix B. The weather variables are designed to measure the impacts of climatic variability, independent of the systematic effects of seasonality, and are expressed in departures from normal weather conditions. The weather variables include average maximum daily temperature and monthly precipitation. Most of the coefficient estimates for the climatic variables retain expected signs, and relatively few are found to be statistically insignificant at customary levels of confidence.

Table 4-3 contains an example of member agency-specific weather variables for the single-family multifamily, and nonresidential classes, in this case specific to the City of San Diego service area. In this

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[15] The coefficients for the employment mix variables were integrated into member agency fixed effects using an auxiliary regression equation shown in Appendix B.

example, single-family water use is more responsive to temperature and precipitation than in the multifamily sector. The nonresidential sector, which is most likely to contain dedicated irrigation accounts is most responsive.

Table 4-3 Weather Variables and Estimated Coefficients for M&I Sectors (City of San Diego example)

Variables	Single-family Model Estimates	Multifamily Model Estimates	Nonresidential Model Estimates (includes Irrigation class where identified)
Departure from Normal Avg Max Temp	0.3098	0.0618	0.4304
1-month lag Avg Max Temp Departure	0.2494	0.0492	0.3399
Departure from Normal Precipitation	-0.0237	-0.0123	-0.0327
1-month lag Precipitation Departure	-0.0178	-0.0064	-0.0267
2-month lag Precipitation Departure	-0.0057	-0.0017	-0.0120
3-month lag Precipitation Departure	n/a	n/a	-0.0133

For the Agricultural sector, precipitation is incorporated into a departure from normal crop requirements variable. Normal monthly crop requirements are estimated based on reference ET rates by crop, weighted by the estimated proportion of acreage among six crop types. Observed crop requirements substitute observed precipitation for long-term normal precipitation used to estimate normal requirements. The difference between observed and normal requirements (i.e., the departure from normal requirements) is used as the modeled variable, including up to two monthly lags. Table 4-4 provides an example of the departure from normal irrigation requirements variable using estimation results for Fallbrook. The greater the observed watering requirements relative to normal requirements, the higher is the estimated water use, with up to a 2-month lag.

Table 4-4 Weather Variables and Estimated Coefficients for AG Sector (Fallbrook example)

Climatic Variable	AG Model Estimates
Departure from Normal Irrigation Requirement	0.1273
1-month lag Requirement	0.1084
2-month lag Requirement	0.0280

4.4 Assessment of Predictions[16]

The sectoral equations were estimated using natural logarithmic transformations and the model fit statistics discussed above are indicative of good model performance. Further assessments involved the evaluation of predictions by retransforming predictions of the sectoral equations onto the raw scale and comparing these predictions to observed values.

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[16] Note that the assessment of predictions relates only to data and member agencies used in estimating the sectoral equations.

4.4.1 Monthly Predictions

Figure 4-1 provides a plot of prediction errors for the samples used to create the four sectoral equations, plotting absolute percentage prediction errors against the cumulative percent of the samples used for estimation. Meanwhile, Table 4-5 summarizes the prediction error values for customary thresholds, which are also identified on the chart. On the raw scale, the sample accuracy of the residential equations is very similar, with 95 percent of the model predicted values falling within about 20 percent of observed values. The prediction errors for the nonresidential and agricultural sectors are more skewed, which is expected based on past modeling efforts and the relatively high degree of variability in irrigation attributed to these sectors.[17] At the monthly time-step, the median prediction errors are less than 20 percent for all sectors.

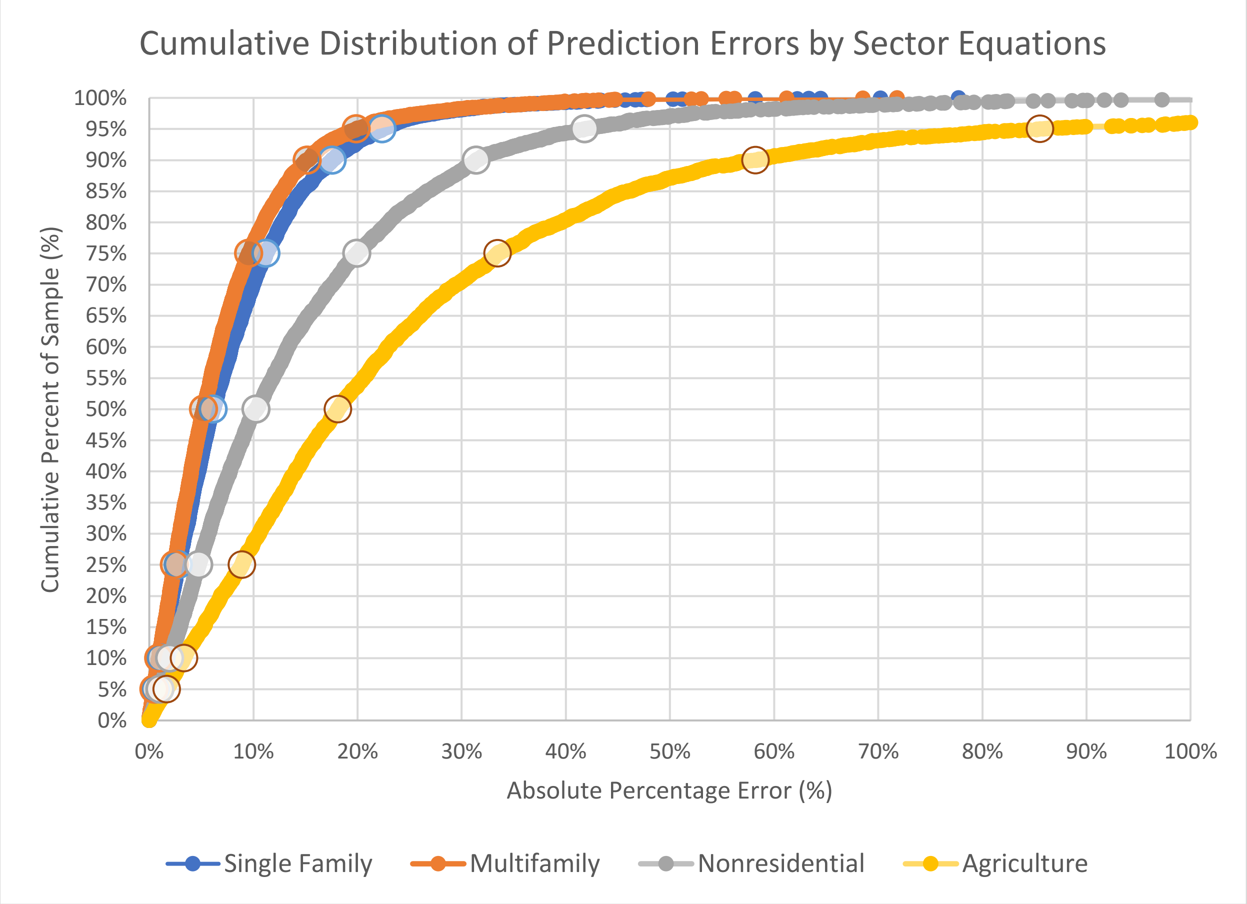

Figure 4-1 Cumulative Distribution of Prediction Errors by Sector Equations

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[17] An examination of the most extreme monthly prediction errors for the agricultural sector revealed that the highest errors were highly concentrated in the "low season" months of January, February, March, and December and in the member agencies Poway, Ramona, Yuima, and Padre Dam.

Table 4-5 Summary of Prediction Errors for Selected Sample Thresholds

Sector	Cumulative Percentage of Sample						
	5%	10%	25%	50%	75%	90%	95%
Single Family	+/- 0.6%	+/- 1.1%	+/- 2.8%	+/- 6.1%	+/- 11.2%	+/- 17.6%	+/- 22.4%
Multifamily	+/- 0.5%	+/- 0.9%	+/- 2.4%	+/- 5.2%	+/- 9.6%	+/- 15.2%	+/- 19.9%
Nonresidential	+/- 1.1%	+/- 2.0%	+/- 4.8%	+/- 10.3%	+/- 20.0%	+/- 31.4%	+/- 41.8%
Agricultural	+/- 1.7%	+/- 3.3%	+/- 8.9%	+/- 18.1%	+/- 33.5%	+/- 58.2%	+/- 85.5%

4.4.2 Annual Predictions

Table 4-6 through Table 4-9 summarize fit and annual prediction errors by member agency for each sector equation. The fit (R^2) statistics are generated based on regressing predictions on the raw scale to observed values for each member agency and then for the Water Authority as a whole, by weighting member agency predictions by the number of accounts served. Meanwhile, the range or prediction errors are based on comparing the annual average of predictions to the annual average of observed water use values.

The tables readily demonstrate two benefits associated with monthly and geographic disaggregation and the “bottom-up” approach to forecasting. First, errors for any specific month tend to offset each other to arrive at relatively more accurate predictions for aggregations of months, such as years. Second, the errors for member agencies also tend to offset each other, resulting in smaller differences between predicted and observed use for the Water Authority as a whole. For example, across the 15 fiscal year estimation period, annual average percentage errors for the Water Authority are very low and show little bias, ranging from -0.03 percent for the single-family sector to 1.2 percent for the agricultural sector. On an annual basis, mean absolute prediction errors at the Water Authority level are all under 15 percent, ranging from 3.5 percent for the multifamily sector to 14.1 percent for the agricultural sector.

These results suggest the sectoral equations are suitable for forecasting water use for the Water Authority. However, the member agency fit statistics suggest that for some sectors there is still a considerable range of historical variability left unexplained, especially for the more heterogeneous sectors, which is a tradeoff of estimating the equations from pooled time-series cross-sectional data. Still, based on the fit statistics alone, the predictions are superior to using simple historical means for forecasting purposes. The next section describes the calibration procedures used to finalize the sector equations for forecasting purposes.

Table 4-6 Summary of Single-Family Sector Annual Prediction Errors by Member Agency

Member Agency	Model Fit (R-Square)	FY Obs	Annual Percent Error			Annual Absolute Percent Error		
			Min	Mean	Max	Min	Mean	Max
Carlsbad Municipal Water District	0.91	15	-11.15	0.08	8.00	0.82	4.68	11.15
City Of Del Mar	0.90	15	-7.21	0.00	5.68	0.10	3.31	7.21
City Of Escondido	0.84	15	-14.99	-0.26	21.16	0.82	7.75	21.16
City Of Oceanside	0.96	15	-5.91	-0.01	5.51	0.06	2.23	5.91
City Of Poway	0.77	15	-16.34	-0.54	10.30	0.10	5.92	16.34
City Of San Diego	0.91	15	-6.74	-0.02	8.75	1.05	3.38	8.75
Fallbrook Public Utility District	0.90	15	-6.24	-0.17	10.88	0.10	3.62	10.88
Helix Water District	0.95	15	-7.20	0.05	9.24	0.10	4.31	9.24
Olivenhain Municipal Water District	0.90	15	-11.63	0.09	9.05	1.30	5.68	11.63
Otay Water District	0.94	15	-4.24	0.03	10.87	0.24	3.24	10.87
Padre Dam Municipal Water District	0.96	15	-5.21	-0.12	7.00	0.14	2.96	7.00
Rainbow Municipal Water District	0.84	15	-15.19	0.23	17.04	1.36	7.83	17.04
Ramona Municipal Water District	0.93	15	-16.32	0.32	11.53	0.93	6.75	16.32
Rincon Del Diablo Municipal Water District	0.91	15	-11.84	-0.05	14.30	0.14	4.64	14.30
San Dieguito Water District	0.87	15	-9.06	0.01	10.11	0.28	4.24	10.11
Santa Fe Irrigation District	0.89	15	-13.09	-0.06	12.36	1.57	7.78	13.09
Sweetwater Authority	0.89	15	-10.10	0.22	16.93	0.96	5.42	16.93
Vallecitos Water District	0.93	15	-10.10	0.08	7.04	0.93	4.86	10.10
Valley Center Municipal Water District	0.91	15	-15.75	0.25	22.56	0.86	7.74	22.56
Vista Irrigation District	0.93	15	-10.18	-0.05	4.34	0.16	3.36	10.18
Water Authority*	**0.95**	**15**	**-6.90**	**-0.03**	**6.75**	**2.84**	**4.18**	**7.17**

Table 4-7 Summary of Multifamily Sector Annual Prediction Errors by Member Agency

Member Agency	Model Fit (R-Square)	FY Obs	Annual Percent Error			Annual Absolute Percent Error		
			Min	Mean	Max	Min	Mean	Max
Carlsbad Municipal Water District	0.87	15	-5.07	0.07	9.36	0.07	2.35	9.36
City Of Del Mar	0.71	15	-6.30	0.02	11.04	0.04	3.17	11.04
City Of Escondido	0.59	15	-22.62	0.26	36.79	0.02	10.96	36.79
City Of Oceanside	0.89	15	-5.69	0.02	3.48	0.26	2.23	5.69
City Of Poway	0.69	15	-21.32	0.23	14.11	0.31	8.42	21.32
City Of San Diego	0.82	15	-4.79	0.01	4.38	0.14	2.24	4.79
Fallbrook Public Utility District	0.90	15	-7.70	0.10	6.54	0.04	3.44	7.70
Helix Water District	0.68	15	-8.06	0.16	12.68	0.12	4.49	12.68
Olivenhain Municipal Water District	0.76	15	-11.94	0.16	10.53	0.33	5.37	11.94
Otay Water District	0.05	15	-16.03	0.48	23.68	0.27	7.82	23.68
Padre Dam Municipal Water District	0.75	15	-8.96	0.04	10.54	0.96	5.26	10.54
Rainbow Municipal Water District	0.81	15	-21.84	0.01	19.01	0.03	7.16	21.84
Ramona Municipal Water District	0.88	15	-12.95	0.28	15.07	0.01	6.61	15.07
Rincon Del Diablo Municipal Water District	0.78	15	-7.76	-0.08	6.56	0.34	3.22	7.76
San Dieguito Water District	0.71	15	-8.05	0.17	9.26	0.27	5.10	9.26
Santa Fe Irrigation District	0.90	15	-7.56	-0.08	6.47	0.55	3.52	7.56
Sweetwater Authority	0.81	15	-10.04	0.19	11.49	1.20	5.41	11.49
Vallecitos Water District	0.70	15	-10.61	0.13	8.41	0.29	4.23	10.61
Valley Center Municipal Water District	0.79	15	-19.60	0.37	26.45	1.85	7.38	26.45
Vista Irrigation District	0.71	15	-9.19	0.12	8.19	0.39	4.48	9.19
Water Authority*	**0.95**	**15**	**-3.30**	**0.20**	**5.46**	**1.46**	**3.51**	**7.13**

Table 4-8 Summary of Nonresidential Sector Annual Prediction Errors by Member Agency

Member Agency	Model Fit (R-Square)	FY Obs	Annual Percent Error			Annual Absolute Percent Error		
			Min	Mean	Max	Min	Mean	Max
Carlsbad Municipal Water District	0.92	15	-7.81	-0.07	5.56	0.09	2.53	7.81
City Of Del Mar	0.89	15	-16.18	-0.62	11.88	0.13	5.13	16.18
City Of Escondido	0.75	15	-15.59	-0.78	15.11	0.79	7.08	15.59
City Of Oceanside	0.93	15	-7.97	-0.01	10.69	0.07	3.52	10.69
City Of Poway	0.71	15	-23.47	0.01	29.79	3.79	11.03	29.79
City Of San Diego	0.90	15	-8.03	-0.10	8.59	0.22	3.66	8.59
Fallbrook Public Utility District	0.84	15	-17.46	1.24	25.32	0.29	13.88	25.32
Helix Water District	0.84	15	-17.24	0.13	12.16	0.66	5.70	17.24
Olivenhain Municipal Water District	0.85	15	-15.71	0.47	31.64	0.99	9.84	31.64
Otay Water District	0.78	15	-18.79	0.52	18.83	0.70	9.31	18.83
Padre Dam Municipal Water District	0.65	15	-21.60	0.72	27.55	0.41	11.62	27.55
Rainbow Municipal Water District	0.45	15	-44.01	5.52	63.59	4.03	32.74	63.59
Ramona Municipal Water District	0.77	15	-24.01	0.46	38.21	0.79	13.40	38.21
Rincon Del Diablo Municipal Water District	0.76	15	-26.43	2.74	42.11	7.64	22.46	42.11
San Dieguito Water District	0.43	15	-23.15	0.71	39.78	0.16	11.59	39.78
Santa Fe Irrigation District	0.86	15	-8.59	-0.83	13.17	0.04	6.56	13.17
Sweetwater Authority	0.72	15	-21.16	0.51	26.32	0.52	11.00	26.32
Vallecitos Water District	0.91	15	-9.20	-0.02	8.69	0.05	5.05	9.20
Valley Center Municipal Water District	0.75	15	-28.87	2.25	50.73	0.91	16.42	50.73
Vista Irrigation District	0.91	15	-11.72	-0.06	6.40	0.25	4.22	11.72
Water Authority*	**0.90**	**15**	**-9.41**	**0.20**	**5.81**	**3.02**	**6.08**	**11.08**

Table 4-9 Summary of Agricultural Sector Annual Prediction Errors by Member Agency

Member Agency	Model Fit (R-Square)	FY Obs	Annual Percent Error			Annual Absolute Percent Error		
			Min	Mean	Max	Min	Mean	Max
Carlsbad Municipal Water District	0.79	15	-16.46	-1.68	13.09	2.30	7.50	16.46
City Of Escondido	0.62	15	-27.80	-0.82	39.07	1.89	18.03	39.07
City Of Oceanside	0.84	15	-16.36	-0.12	21.70	0.51	8.36	21.70
City Of Poway	0.32	15	-55.90	-7.81	53.72	3.11	26.65	55.90
Fallbrook Public Utility District	0.86	15	-31.54	1.61	67.61	1.21	17.96	67.61
Helix Water District	0.64	5	-13.69	-1.72	10.01	2.11	7.47	13.69
Olivenhain Municipal Water District	0.49	15	-47.85	2.78	86.16	2.13	22.64	86.16
Otay Water District	0.65	15	-51.60	5.38	86.07	3.46	31.19	86.07
Padre Dam Municipal Water District	0.65	15	-48.04	-1.06	47.91	0.04	18.82	48.04
Rainbow Municipal Water District	0.79	15	-23.14	0.68	43.12	1.37	13.13	43.12
Ramona Municipal Water District	0.75	15	-66.89	1.21	164.99	0.80	33.78	164.99
Rincon Del Diablo Municipal Water District	0.82	15	-30.56	3.47	144.87	0.25	21.69	144.87
San Dieguito Water District	0.26	15	-32.40	2.64	55.30	3.46	21.47	55.30
Santa Fe Irrigation District	0.62	15	-48.43	2.51	54.30	0.49	16.64	54.30
Sweetwater Authority	0.56	9	-35.34	-0.81	18.25	0.11	10.50	35.34
Vallecitos Water District	0.88	15	-20.33	-0.12	15.90	0.97	6.94	20.33
Valley Center Municipal Water District	0.85	15	-22.48	0.51	31.91	0.01	13.92	31.91
Vista Irrigation District	0.90	15	-20.97	0.24	14.50	0.45	8.65	20.97
Yuima Municipal Water District	0.86	15	-19.32	-1.18	64.63	3.21	15.81	64.63
Water Authority*	**0.84**	**15**	**-11.64**	**1.23**	**28.54**	**7.32**	**14.09**	**29.52**

5. Procedures for Calibrating Equations

The evaluation of fit and prediction errors described above indicate that the sectoral water use equations form a suitable basis for forecasting at the Water Authority level, but that additional calibrations would permit a better representation of member agency specific forecasts. Furthermore, the effects of weather variability and the presence of conditions that would not be considered normal for planning purposes need to be considered and accounted for to derive a "normalized" starting point for the baseline forecast. The sections below describe the calibration and normalization procedures, along with all other adjustments that were made prior to employing the sectoral equations for forecasting.

5.1 Normalization and Calibration of Unit Use Estimates

Baseline forecasts of per unit use for each member agency (i), sector (s), and month (m) for any given forecast year (Y) depend on "normalized" base (B) starting estimates of unit use ($\tilde{q}$). These starting estimates are modified (or scaled) over time by assumed changes in the values of explanatory variables defined in each sector equation (X_j) from base starting values and the estimated response of water use to these changes (β):

$$q_{i,s,m,Y} = \tilde{q}_{i,s,m,B} * \prod \left(\frac{X_{j,i,m,Y}}{X_{j,i,m,B}} \right)^{\beta_j}$$

Equation 5-1

Normalized estimates of per unit use are derived by comparing the mean of predictions in the raw scale with mean predictions obtained by assuming "normal" values for a defined set of variables that can be characterized in that way over the base period (*B*):

$$k_{i,s,m,B} = \left. \frac{\bar{\hat{q}}_{i,s,m}(X_{norm})}{\bar{\hat{q}}_{i,s,m}(X)} \right|_{B}$$

Equation 5-2

The ratios of these predictions are used to define a set of normalizing factors (*k*) that scale the mean of observed values ($\bar{q}$) for the base period into the normalized values ($\tilde{q}$):

$$\tilde{q}_{i,s,m,B} = \bar{q}_{i,s,m,B} * k_{i,s,m,B}$$

Equation 5-3

The mean and normalized unit rates of use are defined in terms of water use per household per day for the residential sectors, water use per employee per day for the nonresidential sector, and water use per irrigated acre per day for the agricultural sector. Appendix C provides the values of the normalizing factors used for the forecast.

5.2 Selection of Calibration Period

The selection of the base period (B) defines the data over which the sectoral equations are calibrated. For this forecast, the base period was defined by three fiscal years. Two of the three selected fiscal years come before the most recent drought period, specifically FY 2013 and FY 2014. The third selected fiscal year is FY 2018 and represents the last full fiscal year of member agency water billing data compiled for the forecast update. The selection of these time periods was intended to balance pre-drought conditions with post-drought conditions that may still be dampened due to the severe water use restrictions. Thus, implicitly, this calibration strategy assumes at least a partial recovery to pre-drought conditions.

5.2.1 Selection of Normalizing Variables

The explanatory variables employed to define "normal" conditions included all weather variables (including agricultural watering requirements), the economic index, and the drought severity indicators. Normalization entailed:

- Setting all departure from normal weather variables to values of 0 – i.e, assuming historical normal weather conditions
- Setting the detrended value of the economic index to a value of 0– i.e, assuming long-term trend economic growth
- Setting any drought severity indicators to a value of 0– i.e, assuming no water supply shortage restrictions

5.3 Calculating a Baseline Sectoral Forecast

A volumetric baseline monthly forecast for any member agency is calculated using the calibrated and normalized unit use equations for each sector, the number of days in any given month, and projections of future driver units (N) and explanatory variables (X) for each sector:

$$\begin{aligned} Q_{i,s,m,Y} &= N_{i,s,m,Y} * q_{i,s,m,Y} * days_m \\ &= N_{i,s,m,Y} * \tilde{q}_{i,s,m,B} * \prod \left(\frac{X_{j,i,m,Y}}{X_{j,i,m,B}}\right)^{\beta_j} * days_m \end{aligned}$$

Equation 5-4

As discussed previously, driver units are number of households for the residential sectors, number of employees for the nonresidential sector, and irrigated acres for the agricultural sector.

An annual volumetric forecast for the Water Authority reflects a sum across 22 member agencies, 4 sectors, and 12 months[18]:

$$Q_y = \sum_{i=1}^{22} \sum_{s=1}^{4} \sum_{m=1}^{12} Q_{i,s,m,Y} \qquad \text{Equation 5-5}$$

5.4 Additional Adjustments

In addition to the calibration of the sectoral equations, the following steps were performed prior to forecast preparation:

- Incorporation of miscellaneous metered water uses that could not be classified into the primary water use sectors and other differences between the amount of water produced and delivered/sold to sectoral customers (including apparent and real water losses)
- Incorporation of unaccounted-for water losses occurring in the delivery chain between the Water Authority and its members

Procedures for incorporating these uses into the forecast are described below.

5.4.1 Member Agency Other/Unclassified Use Factors

In addition to water sales to customers designated by the single-family, multifamily, nonresidential, and agricultural sectors, the total production demands of any member agency include miscellaneous classes of water use that could not be readily classified into these sectors or are unmetered, plus any remaining differences that represent a mix of apparent and physical water losses. These uses of water are not directly accounted for within the predictive equations for M&I and agricultural sectors.

To account for these uses, a Member Agency Other/Unclassified water use factor, or multiplier, was created for each member agency to estimate Other/Unclassified use as a fixed fraction of total sectoral sales (i.e., the sum of single-family, multifamily, nonresidential, and agricultural sales). Using a database of total use by source of supply provided by the Water Authority, Member Agency Other/Unclassified use was calculated as the difference between the sum of total production (TP) from all of seven sources and the sum of sectoral sales (QS)[19] evaluated over the 3-fiscal year (36-month) base period used for calibration of the sectoral models. The Member Agency Other/Unclassified water use factors are then derived by dividing Other/Unclassified water use by the Total Production over the 36-month period for each member agency:

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[18] Note that the index for member agencies in Equation 5-5 does not count Camp Pendleton and combines South Bay ID and National City as Sweetwater Authority. Thus, the sum is over 22 instead of 24 member agencies.

[19] The seven sources are inclusive of Groundwater, Brackish Groundwater, MWD, Quantification Settlement Agreement, Seawater Desalination, Reclamation and Surface water source categories.

$$u_i = \sum_{t=1}^{36} TP_{i,t} \Big/ \sum_{t=1}^{36} QS_{i,t} \qquad \text{Equation 5-6}$$

For any member agency (i) and forecast year (Y), the Member Agency Other/Unclassified water use factors are used to scale predictions of sectoral use (QS) as defined above into predictions of total production demands (QP):

$$QP_{i,Y} = QS_{i,Y} * (1 + u_i) \qquad \text{Equation 5-7}$$

Appendix D provides a table of the Member Agency Other/Unclassified water use factors, along with the information that was used in their derivation.

5.4.2 Water Authority UAW Factor

Assumptions regarding system losses occurring in the delivery chain between the Water Authority and member agencies were made in consultation with Water Authority personnel. In any given forecast year (*Y*), Water Authority Unaccounted Water (*UAW*) is assumed to be a fixed fraction of member agency production demands (*TP*):

$$UAW_{i,Y} = QP_{i,Y} * \frac{w}{1 - w} \qquad \text{Equation 5-8}$$

The same multiplier *w* is used uniformly across member agencies to estimate and allocate Water Authority unaccounted-for water to each member agency (*i*). The value of *w* assumed for the forecast is 0.01 (or 1 percent).

With the adjustment for Water Authority UAW, one arrives at a prediction of total demands (*QT*) for any given forecast year and member agency:

$$QT_{i,Y} = QP_{i,Y} + UAW_{i,Y} \qquad \text{Equation 5-9}$$

5.4.3 Forecast Aggregation and Derivation of Water Authority Forecast

Figure 5-1 summarizes the calibration steps and forecast aggregation process for any given member agency.

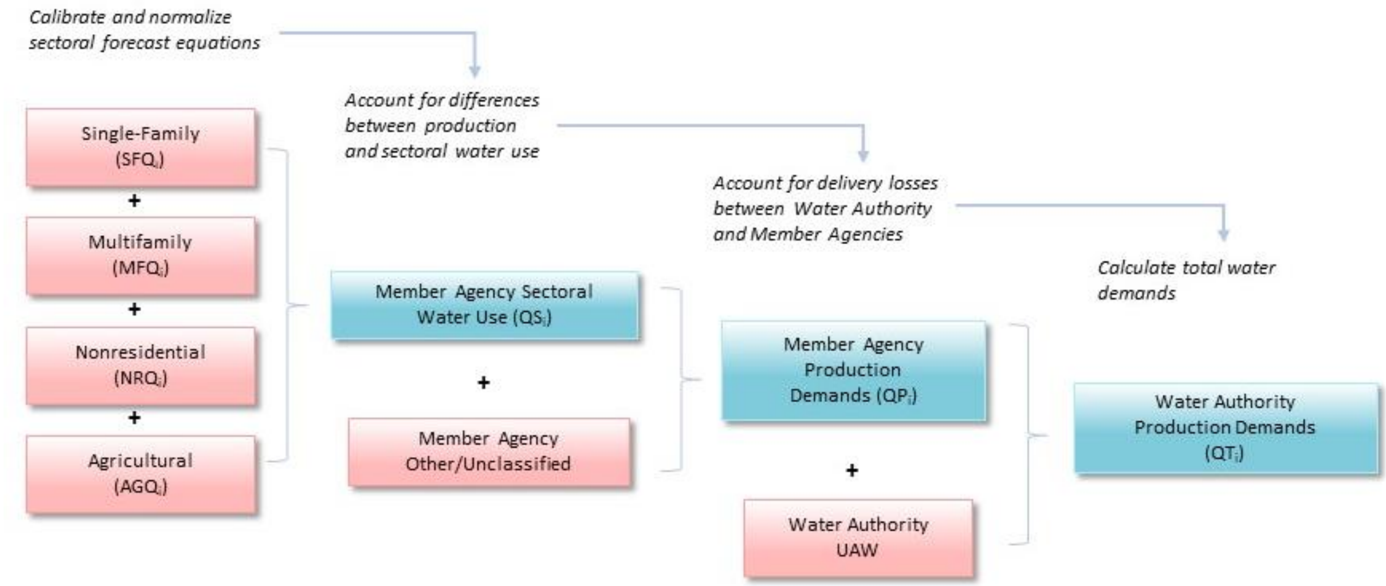

Figure 5-1 Model Calibration and Forecast Development Process

A summation of total annual demands over all member agencies produces the aggregate Water Authority total demand forecast:

$$QT_Y = \sum_{i=1}^{22} QT_{i,Y} = \sum_{i=1}^{22} \left(1 + \frac{w}{1-w}\right) * (1 + u_i) * \sum_{s=1}^{4} \sum_{m=1}^{12} \left(N_{i,s,m,Y} * \tilde{q}_{i,s,m,B} * \prod \left(\frac{X_{j,i,m,Y}}{X_{j,i,m,B}}\right)^{\beta_j} * days_m\right)$$

Equation 5-10

The next section describes the development of the baseline forecast, including socioeconomic inputs into the calibrated and normalized equations, forecast assumptions, and results.

6. Development of Baseline Water Use Forecast

6.1 Introduction

Using the calibrated water use equations and additional adjustments outlined above, baseline forecasts of future water demand were prepared for the Water Authority and its member agencies out to the year 2045 in 5-year increments. The equations and the calibration procedures discussed in Section 5.0 produce forecasts of water use on a monthly time step for each water use sector and Water Authority member agency. The forecasting tool provides water demand forecasts at this most disaggregated level. Although forecasts are generated at monthly level, this section provides forecasts aggregated to a calendar year basis by water use sector for the Water Authority as a whole. Total baseline production demands are also reported at the member agency level. Appendix E contains member agency level forecasts disaggregated by water use sector.

6.2 Forecast Input Data and Assumptions

The baseline forecasts are deterministic and therefore assume no uncertainty or variability concerning the forecasting equations and projected input variables. Additional assumptions made in consultation with Water Authority staff were employed in the development of the baseline M&I water use forecasts. These include the following:

- Values for the marginal price of water reflect observed values through 2020. The Water Authority's projected annual increase in the M&I Treated All-In Rate is assumed over the years 2021-2025 for all sectors after which, marginal prices are held constant in real (inflation-adjusted) terms.[20] The M&I and agricultural marginal price projections for each member agency are provided in Appendix F.
- Estimates of member agency Other and Unaccounted Water (UAW) use are held constant in proportional terms at values derived over the model calibration period.
- The forecast does not include estimates of impacts from future passive or active water conservation efforts, nor reductions in use from water supply shortage restrictions.
- An additional constant factor of 1 percent is assumed for estimating water losses occurring in the delivery of water from the Water Authority to member agencies.
- Long-term normal values are assumed for the weather variables precipitation and average maximum daily temperature.
- Long-term average macroeconomic growth is assumed implicitly by setting the departure from economic trend variable to a value of 0.
- Future values of all other socio-demographic variables assume the values reported in SANDAG's Series 14 regional demographic forecast.

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[20] The calculation of real growth rates for marginal prices implicitly assumes a 3 percent annual rate of inflation in nominal values.

- Refinements were made to the baseline forecast to account for additional demand estimates developed outside of the model. The Water Authority provided refinements to projected demand for four member agencies (Carlsbad, Padre Dam, Rincon Del Diablo, San Diego). These refinements are integrated in the baseline forecast and climatic scenarios.[21]

6.3 Regional Demographics Trends

Changes in baseline forecast water use over time are affected by trends in the key demographic variables that drive future water needs. Recall from Section 3.0, that the water use forecasting technique adopted for the Water Authority predicts future water use using a “driver times average rate of use” approach. Average per unit water use is produced by the sectoral water use equations, whereas future values of driver variables are determined externally.

Table 6-1 provides a summary of the forecasted values of socioeconomic variables at the Water Authority level, including SANDAG’s most recent historical observation for 2016 as a reference starting point. These values reflect weighted averages derived from SANDAG demographic projections of Water Authority member agency variables, with the exception of the values for real marginal price, which reflect a weighting of price data obtained directly from the member agencies through 2020. The base average values reflect the 3-year average in the calibration period. In addition, Table 6-1 summarizes the average percent change and average annual percent change over the entire forecast horizon from SANDAG’s most recent historical year 2016 to 2045. Information is also provided on average annual percent change for 2025-2045 to distinguish anticipated trends expected to occur during the forecast period. Member agency projection values for the variables in Table 6-1 are provided in Appendix A.

6.3.1 Residential Households

Occupied single-family and multifamily units (or households) serve as drivers for the residential sectors. SANDAG demographic projections show the addition of 323,709 total occupied housing units, 84,326 single-family and 239,383 multifamily from 2016 to 2045, with 72 percent of the growth occurring during the forecast period (2025-2045). Total residential households are expected to increase by 20 percent during the 2025-2045 forecast period, reflecting an annual average growth rate of 0.9 percent. The number of multifamily households are projected to increase 35 percent between 2025 and 2045. Meanwhile number of single-family households is projected to increase by only 8.5 percent over the same time period.

As shown in Appendix A, City of San Diego accounts for about 66 percent of the total regional increase in the forecast of occupied multifamily housing units between 2025 and 2045. The following five agencies are each expected to experience an increase in multifamily households of more than 65 percent between 2016 and 2045 - Valley Center (151 percent), Otay (95.7 percent), Rainbow (79.6 percent), Vallecitos (68.5 percent), and City of San Diego (68.2 percent).

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[21] Carlsbad, Padre Dam, Rincon Del Diablo, and San Diego forecast refinements resulted in a 4,376 acre feet reduction in 2045 demands Water Authority-wide.

Table 6-1 Forecast Trends in Selected Demographic Factors 2016-2045

Drivers	**Forecast Year**						**Absolute Change**	**Percent Change**	**Average Annual Percent Change**	**Absolute Change**	**Percent Change**	**Average Annual Percent Change**
	2016	**2025**	**2030**	**2035**	**2040**	**2045**	**2016-2045**			**2025-2045**		
Occupied Single-Family Households	658,025	684,199	701,705	718,823	731,795	742,351	84,326	12.82%	0.42%	58,152	8.50%	0.41%
Occupied Multifamily Households	436,749	501,795	554,044	607,076	648,729	676,132	239,383	54.81%	1.52%	174,337	34.74%	1.50%
Total Employment (non-ag mining)	1,535,422	1,611,976	1,680,007	1,753,706	1,819,777	1,875,464	340,042	22.15%	0.69%	263,488	16.35%	0.76%
Total Occupied Households	1,094,774	1,185,994	1,255,749	1,325,899	1,380,524	1,418,483	323,709	29.57%	0.90%	232,489	19.60%	0.90%
Total Irrigated Agricultural Acreage	40,171	38,057	37,446	36,835	36,780	36,723	-3,448	-8.58%	-0.31%	-1,334	-3.51%	-0.18%
Residential Demographics												
Single-Family Units Per Acre	4.58	4.59	4.64	4.68	4.70	4.69	0.12	2.52%	0.09%	0.10	2.27%	0.11%
Single-Family Persons Per Household	2.91	2.84	2.75	2.67	2.63	2.61	-0.30	-10.28%	-0.37%	-0.23	-8.11%	-0.42%
Single-Family Real Marginal Price	$6.46	$6.75	$6.75	$6.75	$6.74	$6.74	0.28	4.40%	0.15%	-$0.01	-0.09%	0.00%
Multifamily Units Per Acre	27.67	30.51	I33.65	37.52	40.69	42.49	14.83	53.58%	1.49%	11.99	39.29%	1.67%
Multifamily Persons Per Household	2.71	2.71	2.64	2.57	2.54	2.53	-0.18	-6.47%	-0.23%	-0.18	-6.46%	-0.33%
Multifamily Real Marginal Price	$6.97	$7.11	$7.12	$7.13	$7.13	$7.12	0.15	2.22%	0.08%	$0.02	0.23%	0.01%
Median Household Income $2016	$75,019	$77,596	$78,571	$79,557	$80,592	$81,712	6,693	8.92%	0.30%	$4,116	5.30%	0.26%
Nonresidential Demographics												
Major Industry Employment	1,487,842	1,554,394	1,622,425	1,696,124	1,762,195	1,817,882	330,040	22.18%	0.69%	263,488	16.95%	0.79%
Construction	75,475	79,125	82,750	86,798	90,545	93,773	18,298	24.24%	0.75%	14,648	18.51%	0.85%
Manufacturing	107,518	111,540	115,980	120,940	125,380	129,069	21,551	20.04%	0.63%	17,529	15.72%	0.73%
Wholesale Trade	44,703	46,556	48,484	50,647	52,610	54,269	9,566	21.40%	0.67%	7,713	16.57%	0.77%
Retail Trade	145,725	151,108	157,166	163,733	169,693	174,592	28,867	19.81%	0.63%	23,484	15.54%	0.72%
Transportation, Warehousing, Utilities	29,198	30,410	31,685	33,119	34,423	35,524	6,326	21.67%	0.68%	5,114	16.82%	0.78%
Information	23,543	24,505	25,527	26,681	27,727	28,599	5,056	21.48%	0.67%	4,094	16.71%	0.78%
Finance and Real Estate	72,266	75,278	78,454	82,022	85,263	87,992	15,726	21.76%	0.68%	12,714	16.89%	0.78%
Professional and Business Services	232,635	242,948	253,511	265,366	276,175	285,423	52,788	22.69%	0.71%	42,475	17.48%	0.81%
Leisure and Hospitality	184,543	192,457	201,223	209,994	218,433	225,574	41,031	22.23%	0.69%	33,117	17.21%	0.80%
Other Services	53,926	56,155	58,506	61,149	63,543	65,557	11,631	21.57%	0.68%	9,402	16.74%	0.78%
Government	217,576	229,332	239,944	250,695	259,180	266,288	48,712	22.39%	0.70%	36,956	16.11%	0.75%
Education and Health Services	195,645	204,446	213,395	223,427	232,543	240,320	44,675	22.83%	0.71%	35,874	17.55%	0.81%
Self-Employment	105,089	110,534	115,800	121,553	126,680	130,902	25,813	24.56%	0.76%	20,368	18.43%	0.85%
% Construction	5.07	5.09	5.10	5.12	5.14	5.16	0.09	1.69%	0.06%	0.07	1.34%	0.07%
% Manufacturing	7.23	7.18	7.15	7.13	7.11	7.10	-0.13	-1.75%	-0.06%	-0.08	-1.06%	-0.05%

Drivers	Forecast Year						Absolute Change	Percent Change	Average Annual Percent Change	Absolute Change	Percent Change	Average Annual Percent Change
	2016	**2025**	**2030**	**2035**	**2040**	**2045**	**2016-2045**			**2025-2045**		
% Wholesale Trade	3.00	3.00	2.99	2.99	2.99	2.99	-0.02	-0.64%	-0.02%	-0.01	-0.33%	-0.02%
% Retail Trade	9.79	9.72	9.69	9.65	9.63	9.60	-0.19	-1.94%	-0.07%	-0.12	-1.21%	-0.06%
% Transportation, Warehousing, Utilities	1.96	1.96	1.95	1.95	1.95	1.95	-0.01	-0.42%	-0.01%	0.00	-0.11%	-0.01%
% Information	1.58	1.58	1.57	1.57	1.57	1.57	-0.01	-0.58%	-0.02%	0.00	-0.21%	-0.01%
% Finance and Real Estate	4.86	4.84	4.84	4.84	4.84	4.84	-0.02	-0.34%	-0.01%	0.00	-0.05%	0.00%
% Professional and Business Services	15.64	15.63	15.63	15.65	15.67	15.70	0.07	0.42%	0.01%	0.07	0.45%	0.02%
% Leisure and Hospitality	12.40	12.38	12.40	12.38	12.40	12.41	0.01	0.04%	0.00%	0.03	0.22%	0.01%
% Other Services	3.62	3.61	3.61	3.61	3.61	3.61	-0.02	-0.50%	-0.02%	-0.01	-0.18%	-0.01%
% Government	14.62	14.75	14.79	14.78	14.71	14.65	0.02	0.17%	0.01%	-0.11	-0.72%	-0.04%
% Education and Health Services	13.15	13.15	13.15	13.17	13.20	13.22	0.07	0.53%	0.02%	0.07	0.51%	0.03%
% Self Employment	7.06	7.11	7.14	7.17	7.19	7.20	0.14	1.95%	0.07%	0.09	1.26%	0.06%
Nonresidential Real Marginal Price	$5.04	$6.42	$6.42	$6.42	$6.41	$6.41	1.37	27.18%	0.83%	-0.01	-0.16%	-0.01%
Agricultural Demographics												
Agricultural Real Marginal Price	$5.84	$6.00	$6.00	$6.00	$6.00	$6.00	0.16	2.69%	0.09%	$0.00	-0.07%	0.00%
Total Irrigated Acreage	54,064	52,453	51,890	51,327	51,239	51,152	-2,912	-5.39%	-0.19%	-1,301	-2.48%	-0.13%

Notes:

1) All values are weighted averages across all utilities.

2) Total employment includes military employment

San Diego is projected to have the largest total increase in single-family households with the addition of 17,601 new households between 2025 and 2045, which amounts only to about a 6 percent increase. During this same period, Yuima is expected to have the highest relative increase in single-family households with a projected increase of 131 percent. Valley Center, Rainbow, Ramona, and Fallbrook agencies are projected to realize 25 to 50 percent increases in occupied single-family housing by 2045.

6.3.2 Real Marginal Price

The real marginal prices and corresponding growth rates over the forecast horizon listed in Table 6-1 reflect the implicit effects of different rates of growth among member agencies. Values for the marginal price of water reflect observed values through 2020 and then as noted above, the Water Authority’s projected annual increase in the M&I Treated All-In Rate is assumed over the years 2021-2025 is applied to the 2020 values for all member agencies and sectors. After 2025 marginal prices are held constant in real (inflation-adjusted) terms. Table 6-2 provides the underlying Water Authority “rate ramp” from 2021 to 2025 in nominal and real terms, which assumes a 3 percent annual rate of inflation.

Table 6-2 Projected Annual Marginal Price Change for 2021-2025

	Calendar Year Ending				
	2021	**2022**	**2023**	**2024**	**2025**
Percent change in nominal M&I Treated All-In Rate over previous calendar year	6.20%	6.60%	5.70%	6.20%	8.80%
Assumed real (inflation-adjusted) change over previous calendar year	3.20%	3.60%	2.70%	3.20%	5.80%

6.3.3 Housing Density

Housing density, defined as the number of housing units divided by developed acres by housing type, is another important variable defined in both residential models. Water Authority-wide, multifamily housing density is expected to increase by 11.99 units per acre (39.3 percent) between 2025 and 2045. This increase is weighted heavily toward projections for the City of San Diego where multifamily housing density is projected to increase by 16.65 units per acre (46.8 percent). Ramona shows the next highest increase in density at 9.69 units per acre (41.39 percent) followed by Otay at 6.28 units per acre (30.5 percent). While Escondido reports the greatest overall increase in multifamily density at 14 units per acre (65.6 percent) between 2016 and 2045, most of this projected change occurs between 2016 and 2025, as the increase for the 2025 and 2045 forecast period is substantially smaller at 5.36 units per acre.

Single-family housing density is generally expected to increase as well, but to a smaller extent than the multifamily sector. Water Authority-wide, single-family density is projected to increase by about 0.1 unit per acre between 2025 and 2045. The City of San Diego is expected to have the largest absolute increase in single-family housing density of 0.38 units per acre, equating to a 6 percent relative increase by 2045, followed by Vista with an absolute change of 0.26 units per acre, which is about an 11 percent increase in single-family density. Yuima and Ramona are projected to have relative increases about 10 percent as well, but it is worth noting the average density for these agencies is less than 0.6 units per acre, and as a result the absolute impact is extremely low (less than .06 units per acre) for these and other similar low-density agencies.

6.3.4 Household Size

While residential housing density is expected to increase, average household size (persons per household) is expected to decrease. Both residential sectors are projected to have similar changes in average household size Water Authority-wide between 2025 and 2045 with projected decreases of 0.23 persons per household (8 percent) in the single-family sector and 0.18 persons per household (6.5 percent) in the multifamily sector. All agencies are projected to decrease in household size across both sectors except for Rainbow and Rincon which are projected to experience slight increases in multifamily household size through 2045. In the single-family sector, the largest reductions in average household size are projected for the City of San Diego (0.30 persons per household) and Lakeside (0.28 persons per household), which equate to an 11.0 and 9.9 percent decrease respectively. This is followed by Olivenhain and Otay where the decreases all exceed the Water Authority-wide average reduction of 0.23 persons per household.

6.3.5 Median Household Income

Averaged across the Water Authority, real median income is expected to increase by about 5.3 percent in real (inflation-adjusted) terms through the 2045 forecast horizon. As shown in Table 6-1, median incomes are projected to increase at an annualized rate of 0.26 percent. Income growth rates vary by member agency and are projected to range between +2.3 percent in Vallecitos to +9.5 percent in Otay by 2045. The City of San Diego and Yuima are also projected to experience relatively low increases in median income (just under 3.5 percent over the forecast horizon).

6.3.6 Employment

Total non-agricultural, non-mining, employment – the driver variable for the nonresidential sector in the Water Authority service area – is projected to grow by 263,488 employees (16.4 percent) over the 2025-2045 forecast period, which represents an annual average rate of growth of 0.76 percent per year. The City of San Diego accounts for about 50 percent of the projected increase in employment in the region over the forecast period. Otay is projected to be the second largest contributor to regional employment growth accounting for the addition of about 35,000 employees in the region between 2025 and 2045. While Sweetwater and Helix are still projected to have slightly higher number of total employees in 2045, Otay will surpass Carlsbad by 2045 becoming the fourth largest member agency in terms of total non-agricultural, non-mining employment.

Region-wide, there are no dramatic shifts projected in the distribution of employment among the NAICS groupings between the 2025 to 2045 forecast period. Collectively, Professional and Business Services, Government, Education and Health Services, Leisure and Hospitality and Retail Trade account for more than 63 percent of projected total employment market share in both 2025 and 2045. The Professional and Business Services industry is projected to contribute an additional 42,475 employees to the region between 2025 and 2045. The City of San Diego accounts for nearly half of this increase; collectively Otay and Vallecitos will account for an additional 25 percent of the regional growth in this industry. Regionally, employment in each industry is projected to increase by about 15.5 to 18.5 percent during the forecast period, except for military employment which is projected to remain relatively constant throughout the forecast horizon. The Construction industry is slated to have the highest overall percentage increase among the employment groupings at 18.5 percent, while Retail Trade is projected to experience the lowest percentage growth at 15.5 percent.

6.3.7 Agricultural Irrigated Acreage

Finally, Table 6-1 shows a decrease in the projected number of irrigated agricultural acres, which is the driver variable for agricultural water use model. Using the Water Authority member agency recommended 2-acre threshold, approximately 3,448 fewer irrigated acres are expected to be devoted to agricultural production by 2045, which is approximately 9 percent lower than the 2016 starting value of 40,171 acres. Among agencies with agricultural water use, the largest absolute decreases for the 29-year period in irrigated acreage are projected to occur in Valley Center (836 acres), Rainbow (455 acres) and Escondido (266 acres). The largest proportional declines in irrigated acreage are projected to occur in the service areas of Otay (49 percent), Carlsbad (36 percent), Vista (20 percent).

6.4 Water Authority Baseline Forecast Results

Table 6-3 summarizes the baseline forecast results for the Water Authority service area (excluding Camp Pendleton), while Figure 6-1 illustrates the sectoral disaggregation over the 2025-2045 forecast horizon.[22] The forecasts are a result of making direct use of the data summarized in Table 6-1within the calibrated and normalized sectoral equations. Total baseline production demands are projected to increase at annualized average rate of 0.7 percent per year to about 691,552 acre-feet by 2045.[23] This represents a 15 percent (90,148 acre-feet) increase in total baseline production demands between 2025 and 2045. Total baseline M&I demands are forecasted to increase by 16.5 percent (91,729 acre-feet) at an annual average rate of 0.77 percent between 2025 and 2045. Baseline M&I production demands are directly influenced by growth in housing and the level and mix of employment in the region, as well as by the assumptions about future values of socioeconomic variables contained in the sectoral models.

The largest absolute sectoral increase results from forecasted increases in the nonresidential demand (33,531 acre-feet), followed closely by a forecast of 30,626 acre-feet of additional demands from the multifamily sector. An additional 16,346 acre-feet of projected demands stem from the single-family sector. Multifamily demands are projected to increase in percentage terms by more than 30 percent, followed by nonresidential demands at 21 percent and single-family demands at 7.3 percent between 2025 and 2045.

In contrast to the long-term projected growth trend in M&I sector demands, agricultural water use is forecasted to decrease slightly by about 3.4 percent over the forecast horizon to 45,415 acre-feet in 2045, reflecting an annual average decrease of 0.17 percent per year from 2025 to 2045. The projected decline

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[22] Figure 6-1 annual forecast values are based on interpolation of SANDAG 5-year increment demographic projections.

[23] The baseline demand forecasts summarized in this section do not include Camp Pendleton and known near term annexations, which are added and discussed in the Water Authority's 2020 Urban Water Management Plan.

in agricultural use is tied to the expected decrease in acres devoted to agricultural uses, as well corresponding increases in real (i.e., inflation-adjusted) agricultural water rates prior to 2025. However, it should be acknowledged that due to lack of available data, potential trends in other variables that affect agricultural water use, such as significant changes in crop types, foreign competition, and the demand for agricultural commodities, are not accounted-for in the model. Nevertheless, the implied rate of change in agricultural demand relative to the other sectors suggests that agricultural demand will account for approximately 7 percent of total Water Authority baseline production demands by 2045.

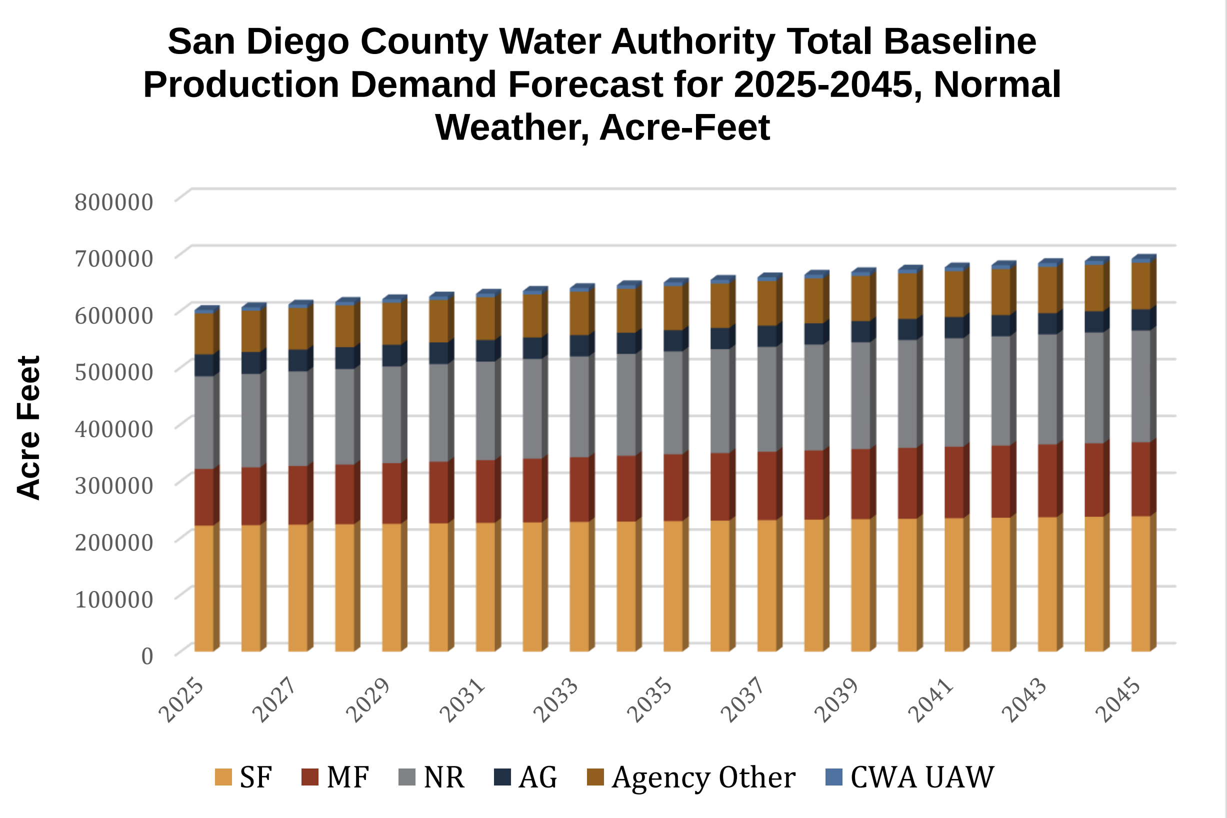

Figure 6-1 San Diego County Water Authority Total Baseline Production Demand Forecast for 2025-2045, Normal Weather, Acre-Feet

Table 6-3 Total Baseline Production Demand Forecast for 2025-2045 (Normal Weather, Acre-Feet)

Sectors	Forecast Year					Absolute Change	Percent Change	Average Annual Percent Change
	2025	2030	2035	2040	2045	2025-2045		
SF Demand	221,933	225,840	229,912	233,927	238,279	16,346	7.37%	0.36%
MF Demand	99,705	108,639	117,478	124,819	130,331	30,626	30.72%	1.35%
NR Demand	163,085	171,820	181,142	189,753	196,615	33,531	20.56%	0.94%
Agency M&I Other/UAW	64,141	66,820	69,838	72,384	74,450	10,309	16.07%	0.75%
Total Baseline M&I Demand	548,864	573,119	598,370	620,883	639,675	90,812	16.55%	0.77%
M&I UAW	5,544	5,789	6,044	6,272	6,461	917	16.55%	0.77%
Total Baseline M&I Production Demand	**554,408**	**578,908**	**604,414**	**627,154**	**646,137**	**91,729**	**16.55%**	**0.77%**
Ag Demand	38,663	38,004	37,347	37,301	37,255	-1,408	-3.64%	-0.19%
Agency Ag Other/UAW	7,863	7,790	7,717	7,712	7,707	-156	-1.99%	-0.10%
Total Baseline Ag Demand	46,526	45,794	45,064	45,013	44,961	-1,565	-3.36%	-0.17%
CWA AG UAW	470	463	455	455	454	-15.81	-3.36%	-0.17%
Total Baseline Ag Production Demand	46,996	46,257	45,519	45,468	45,415	-1,581	-3.36%	-0.17%
Total Baseline Production Demand	**601,404**	**625,165**	**649,933**	**672,622**	**691,552**	**90,148**	**14.99%**	**0.70%**

*Note: The Water Authority provided refinements to projected demand for four member agencies (Carlsbad, Padre Dam, Rincon Del Diablo, and San Diego). Numbers displayed do not include Camp Pendleton demands and demands associated with near term annexations.

6.5 Member Agency Baseline Production Results

Table 6-3 summarizes the Water Authority’s member agencies total baseline production demands over the 2025-2045 forecast horizon. Recall that the Water Authority demands shown in Table 6-2 reflect an aggregation of these member agency demands. Thus, SANDAG and other forecast assumptions operate at the member-agency level to produce projected trends at the Water Authority level. The disaggregated sectoral results for each member agency are provided in Appendix E. As mentioned above, Carlsbad, Padre Dam, Rincon, and San Diego baseline demands were refined by the Water Authority and integrated into the results discussed below and in Appendix E.

All Water Authority's member agencies are forecast to have higher total baseline production demands by 2045. The largest absolute increase in forecast demand between 2025 and 2045 is in the City of San Diego. The vast majority of the projected increase in City of San Diego demand is associated with growth in the multifamily and nonresidential sectors. Otay Water District has the next largest projected absolute change in baseline production demands as well as the largest projected percent change of any agency. Otay demands are projected to increase by 13,162 acre-feet or 32 percent over the 2025-2045 period. Vallecitos is projected to experience the next highest percent increase at 27 percent.

Projections of water use among the primary water using sectors underlie the total baseline production forecasts summarized in Table 6-3. As noted above, assumed future values of demand determinants influence the forecasts by means of the sectoral predictive equation. Tables 6-4, 6-5, 6-6, and 6-7 highlight the relative roles of socioeconomic variables in affecting the member agency forecasts for the single-family, multifamily, nonresidential, and agricultural sectors, respectively. The tables provide estimated forecast impact factors, which show the relative influence of explanatory variables in producing the forecast change in demands between the 2025 and 2045.[24] The product of the individual impact factors provides a perspective on the total forecast in sectoral demands between 2025 and 2045 and equates to the ratio of projected 2045 demands to the demands associated with 2025.[25]

6.5.1 Single-Family Demand

Table 6-5 indicates that 3 member agencies are projected to experience a more than 40 percent increase in single-family water use by 2045. Analysis of the underlying factors suggest that projected increases in single-family housing units is generally the most contributing factor for the projected increases in single-family demand. Projected changes in income generally have about a 2-4 percent influence on the forecasts. Generally speaking, member agencies with lower rates of change in projected housing can attribute a larger portion of projected increases in single-family demands to projected increases in income,

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[24] Impact factors are calculated for each model variable (v) listed in Tables 6-4, 6-5, 6-6, and 6-7 using estimated model elasticities (e), in conjunction with 2025 values (X2025) and 2045 forecast values (X2045) for each model variable. The following generalized formula is used:

$$Impact\ Factor_v = \left(\frac{X2045_v}{X2025_v}\right)^{e_v}$$

[25] The impact factors estimated for Carlsbad, Padre Dam, Rincon Del Diablo, and San Diego are reflective of application of the sectoral models and not of the forecasts that were provided for these agencies independently.

however this change is generally offset by changes in persons per household. Projected changes in housing density in general have low impacts on single-family demands. However, several of the member agencies (Yuima, Padre Dam, Ramona, Valley Center, Rainbow and Fallbrook) demonstrating the higher rates of change in single-family water use between 2025 and 2045 are less dense than the Water Authority average, which, by means of differential geographic growth patterns, makes changes in housing density an important determinant of forecasted Water Authority demands.

6.5.2 Multifamily Demand

Table 6-6 presents estimated impact factors for the multifamily demand forecast. As shown, projected increases in housing units generally drives the multifamily forecasts. While the impact of income is similar to that of the single-family sector, the multifamily sector tends to be more responsive to changes in housing density and less responsive to changes in persons per household. Increases of multifamily housing density are forecast for most (but not all) member agencies, the impact of which dampens the effects of housing and income growth in most of the areas. Because the City of San Diego represents the Water Authority's largest customer, the projected 35 percent change in its multifamily water use contributes substantially to the total Water Authority multifamily demand forecast accounting for nearly 60 percent of the Authority's projected increase in multifamily demands. Three member agencies (Otay, Valley Center, and Rainbow) are expected to experience more than 70 percent growth in multifamily demands.

6.5.3 Nonresidential Demand

Table 6-7 presents the estimated impact factors for the nonresidential sector. Recall that total employment and the mix of employment among major NAICS groups were specified in the predictive equations for the nonresidential sector. Shifts in the distribution of employment over time among the NAICS groupings produce fairly complex effects on the nonresidential forecast. In addition to the forecast changes in the distribution of employment, these effects represent the impacts of differences in estimated model coefficients among the NAICS categories – some of which are negative and some of which are positive.

Seven member agencies are projected to experience an increase in nonresidential demand of more than 30 percent from the 2025 values. Projected growth in total employment, the driver variable, is generally the most important single contributing factor. Analysis of the impact factors for the major industry categories suggest that, treated as a group, shifts in the distribution of effective employment play a role in producing the projected changes in nonresidential demand over the forecast horizon. The impacts of shifts in and out of industries are very specific to individual member agencies. After total employment, it appears that relative shifts into the Professional & Business Services is the top influencer responsible for an 11 to 18 percent increase in nonresidential demands for Vallecitos, Otay, Lakeside, Padre Dam and Yuima. This impact is partially due to a large positive response to increases in the proportion of employment (relative to other industries) as well as the projected growth for this industry in these areas.

Table 6-4 Total Baseline Production Demand Forecast by Member Agency for 2025-2045 (Normal Weather, Acre-Feet)

Sectors	Forecast Year					Absolute Change	Percent Change	Average Annual Percent Change
	2025	2030	2035	2040	2045	2025-2045		
Carlsbad Municipal Water District	22,931	23,209	23,791	24,421	24,962	2,031	8.86%	0.43%
City Of Del Mar	1,284	1,336	1,350	1,370	1,394	110	8.59%	0.41%
City Of Escondido	25,003	25,392	25,783	26,251	27,092	2,089	8.36%	0.40%
City Of Oceanside	28,854	30,139	30,930	31,435	31,968	3,113	10.79%	0.51%
City Of Poway	11,914	12,209	12,543	12,809	13,063	1,149	9.64%	0.46%
City Of San Diego	227,023	237,840	248,212	256,186	261,177	34,154	15.04%	0.70%
Fallbrook Public Utility District	12,014	12,395	13,033	13,464	13,789	1,776	14.78%	0.69%
Helix Water District	35,469	36,836	38,196	39,406	40,352	4,883	13.77%	0.65%
Lakeside Water District	4,643	4,849	4,923	5,060	5,173	530	11.42%	0.54%
Olivenhain Municipal Water District	24,719	25,045	25,289	25,490	25,835	1,116	4.52%	0.22%
Otay Water District	40,645	43,475	46,486	50,212	53,808	13,162	32.38%	1.41%
Padre Dam Municipal Water District	14,258	15,022	15,974	16,607	17,141	2,882	20.22%	0.92%
Rainbow Municipal Water District	19,787	20,584	21,705	22,347	22,715	2,928	14.80%	0.69%
Ramona Municipal Water District	6,187	6,407	6,843	7,168	7,384	1,197	19.36%	0.89%
Rincon Del Diablo Municipal Water District	9,967	10,241	10,493	10,893	11,252	1,285	12.89%	0.61%
San Dieguito Water District	7,944	8,122	8,257	8,522	8,808	864	10.87%	0.52%
Santa Fe Irrigation District	11,279	11,650	11,847	12,036	12,201	922	8.17%	0.39%
Sweetwater Authority	23,927	24,568	25,197	26,368	27,097	3,170	13.25%	0.62%
Vallecitos Water District	19,494	20,243	21,015	22,506	24,747	5,253	26.94%	1.20%
Valley Center Municipal Water District	23,102	23,776	24,956	25,887	26,812	3,711	16.06%	0.75%
Vista Irrigation District	20,944	21,701	22,515	23,365	23,850	2,906	13.87%	0.65%
Yuima Municipal Water District	10,014	10,124	10,596	10,821	10,932	918	9.17%	0.44%
SDCWA Service Area	601,404	625,165	649,933	672,622	691,552	90,148	14.99%	0.70%

6.5.4 Agricultural Demand

Finally, based on SANDAG projections of irrigated lands for agriculture, member agency agricultural demand is expected to decline over the forecast period in all member agencies that serve agricultural customers, except for Helix and Lakeside whose demands are projected to remain constant over the forecast horizon due to no net increase or decrease in acreage. Again, the overall decline in expected agricultural use is directly related to projected decreases in total acreage devoted to agricultural purposes. With the exception of Helix and Lakeside, forecast factors for irrigated acres are all below 1.0 which signifies that projected changes in these influential variables are driving projections of agricultural use downward.

In absolute terms, decreases in agricultural demands for Valley Center (516 AF), Rainbow (366 AF) and Escondido (222 AF) are projected to account for nearly 80 percent (1,103 AF) of the total 1,408 AF decrease projected to occur in this sector by 2045. Carlsbad, followed by Otay, Vista and Rincon del Diablo demands are projected to have the largest relative decreases in demand ranging from 10-15 percent of the 2025 values; however, collectively their demands account for about 7 percent of the total projected reductions in agricultural demands.

Table 6-5 Influence of Socioeconomic Variables on Single-Family Forecast by Member Agency

	Occupied Housing Units	Income	Housing Density	Persons per Household	Marginal Price	Product
Yuima Municipal Water District	2.31	1.02	0.98	0.98	1.00	2.25
Valley Center Municipal Water District	1.51	1.03	1.00	0.97	1.00	1.50
Rainbow Municipal Water District	1.42	1.03	1.00	0.97	1.00	1.42
Ramona Municipal Water District	1.32	1.03	0.99	0.96	1.00	1.28
Fallbrook Public Utility District	1.26	1.04	0.99	0.95	1.00	1.23
Rincon Del Diablo Municipal Water District	1.13	1.04	0.99	0.97	1.00	1.13
Padre Dam Municipal Water District	1.14	1.04	1.00	0.95	1.00	1.12
Vista Irrigation District	1.13	1.04	0.99	0.96	1.00	1.11
City Of Escondido	1.09	1.04	1.00	0.97	1.00	1.09
Otay Water District	1.08	1.04	1.00	0.95	1.00	1.07
Santa Fe Irrigation District	1.08	1.03	1.00	0.96	1.00	1.07
Vallecitos Water District	1.07	1.01	1.01	0.98	1.00	1.07
City Of Poway	1.06	1.03	1.00	0.97	1.00	1.06
Lakeside Water District	1.09	1.04	1.00	0.94	1.00	1.06
Carlsbad Municipal Water District	1.06	1.03	1.00	0.97	1.00	1.06
San Dieguito Water District	1.05	1.03	1.00	0.98	1.00	1.06
Sweetwater Authority	1.05	1.03	1.00	0.97	1.00	1.05
Helix Water District	1.06	1.03	0.99	0.96	1.00	1.04
City Of Del Mar	1.03	1.02	1.00	0.98	1.00	1.04
City Of Oceanside	1.03	1.03	1.00	0.97	1.00	1.03
Olivenhain Municipal Water District	1.05	1.03	1.01	0.95	1.00	1.02
City Of San Diego	1.06	1.02	0.99	0.93	1.00	1.00

Table 6-6 Influence of Socioeconomic Variables on Multifamily Forecast by Member Agency

	Occupied Housing Units	Income	Housing Density	Persons per Household	Marginal Price	Product
Valley Center Municipal Water District	1.84	1.03	1.00	0.97	1.00	1.85
Rainbow Municipal Water District	1.77	1.03	1.00	1.01	1.00	1.85
Otay Water District	1.74	1.04	0.97	0.98	1.00	1.73
Vallecitos Water District	1.39	1.01	0.98	0.99	1.00	1.36
City Of San Diego	1.42	1.02	0.96	0.98	1.00	1.35
Vista Irrigation District	1.28	1.04	0.98	0.98	1.00	1.26
San Dieguito Water District	1.26	1.03	0.98	1.00	1.00	1.26
Sweetwater Authority	1.27	1.03	0.97	0.99	1.00	1.26
Padre Dam Municipal Water District	1.23	1.04	0.99	0.99	1.00	1.25
Ramona Municipal Water District	1.28	1.03	0.96	0.96	1.00	1.22
Helix Water District	1.24	1.03	0.98	0.97	1.00	1.22
City Of Escondido	1.17	1.04	0.98	0.98	1.00	1.17
Rincon Del Diablo Municipal Water District	1.16	1.04	0.98	1.00	1.00	1.17
Fallbrook Public Utility District	1.14	1.04	0.98	0.97	1.00	1.13
Carlsbad Municipal Water District	1.11	1.03	0.99	0.99	1.00	1.12
City Of Oceanside	1.10	1.03	0.99	0.99	1.00	1.12
Lakeside Water District	1.10	1.04	0.99	0.97	1.00	1.09
Santa Fe Irrigation District	1.08	1.03	0.99	0.99	1.00	1.08
City Of Poway	1.09	1.03	0.99	0.97	1.00	1.08
City Of Del Mar	1.04	1.02	1.00	1.00	1.00	1.06
Olivenhain Municipal Water District	1.06	1.03	0.99	0.97	1.00	1.04

Table 6-7 Breakdown of Influence of Socioeconomic Variables on Nonresidential Sector Forecast by Member Agency

		Distribution of Employment											
Member Agency	**Total Employment**	**Manufacturing**	**Wholesale**	**Retail**	**Trans./Ware./Utilities**	**Information**	**Professional & Business Services**	**Education & Health Services**	**Leisure & Hospitality**	**Other Services**	**Government**	**Marginal Price**	**Product**
Vallecitos Water District	1.35	1.04	0.94	0.99	1.06	1.01	1.18	0.97	1.00	0.98	0.98	1.00	1.542
Otay Water District	1.57	0.98	1.01	0.99	0.93	1.01	1.13	0.94	1.02	1.01	0.95	1.00	1.511
Lakeside Water District	1.31	0.90	1.12	0.98	0.98	1.10	1.11	0.98	0.95	1.02	0.98	1.00	1.441
Padre Dam Municipal Water District	1.24	1.01	1.01	0.98	1.03	1.00	1.12	0.99	1.00	0.98	0.99	1.00	1.375
Yuima Municipal Water District	1.68	1.00	0.87	1.01	0.85	1.00	1.11	1.02	1.16	0.89	0.93	1.00	1.361
Rainbow Municipal Water District	1.49	0.89	1.00	1.01	1.01	0.97	1.03	1.12	0.94	0.95	0.97	1.00	1.324
City Of Poway	1.18	1.03	0.95	0.98	0.97	0.98	1.03	1.15	1.04	1.00	0.99	1.00	1.304
Helix Water District	1.15	1.00	1.00	0.98	0.99	1.01	1.02	1.02	1.00	1.04	1.00	1.00	1.224
Rincon Del Diablo Municipal Water District	1.11	1.02	0.98	1.02	0.97	1.03	1.04	0.98	1.13	0.94	1.00	1.00	1.216
City Of Oceanside	1.19	1.00	0.97	1.02	0.96	0.99	1.00	1.03	0.98	1.06	1.00	1.00	1.215
Santa Fe Irrigation District	1.07	1.01	0.98	1.02	1.06	0.99	1.00	1.00	1.00	1.02	1.01	1.00	1.157
City Of Del Mar	1.08	1.00	0.99	1.15	0.99	0.99	0.98	1.00	0.99	0.99	1.00	1.00	1.155
City Of San Diego	1.14	1.00	1.01	1.01	1.01	1.00	0.99	1.01	1.00	0.99	1.00	1.00	1.151
Valley Center Municipal Water District	1.29	0.97	0.94	1.05	0.97	1.00	1.02	1.02	1.06	0.90	0.97	1.00	1.146
Vista Irrigation District	1.10	1.01	0.98	0.99	0.98	1.00	1.04	1.00	1.03	1.00	1.01	1.00	1.135
Carlsbad Municipal Water District	1.13	0.99	0.98	0.99	0.98	1.02	0.98	0.99	1.00	1.04	1.01	1.00	1.122
San Dieguito Water District	1.07	1.00	0.98	1.00	1.00	1.03	1.00	1.00	0.99	1.02	1.02	1.00	1.116
Fallbrook Public Utility District	1.11	1.01	0.98	0.98	0.98	0.99	0.99	1.01	0.99	1.06	1.01	1.00	1.110
Sweetwater Authority	1.17	1.02	0.98	0.98	0.98	0.98	1.07	0.98	1.06	0.91	1.00	1.00	1.110
Olivenhain Municipal Water District	1.07	1.01	1.01	1.00	0.98	1.01	1.00	1.01	0.99	1.01	1.01	1.00	1.107
Ramona Municipal Water District	1.10	0.98	1.00	1.00	0.97	0.99	1.00	0.98	0.99	1.06	1.01	1.00	1.084
City Of Escondido	1.08	0.99	0.98	1.00	0.98	1.00	0.99	1.00	1.00	1.03	1.01	1.00	1.068

Table 6-8 Breakdown of Influence of Socioeconomic Variables on Agriculture Sector Forecast by Member Agency

	Acres	Price	Product
Helix Water District	1.00	1.00	1.00
Lakeside Water District	1.00	1.00	1.00
Yuima Municipal Water District	0.99	1.00	0.99
Ramona Municipal Water District	0.99	1.00	0.99
City Of Oceanside	0.98	1.00	0.98
Olivenhain Municipal Water District	0.98	1.00	0.98
City Of Poway	0.97	1.00	0.97
Fallbrook Public Utility District	0.97	1.00	0.97
City Of San Diego	0.97	1.00	0.97
Santa Fe Irrigation District	0.97	1.00	0.97
Rainbow Municipal Water District	0.97	1.00	0.97
Sweetwater Authority	0.96	1.00	0.96
Valley Center Municipal Water District	0.96	1.00	0.96
Vallecitos Water District	0.96	1.00	0.96
Padre Dam Municipal Water District	0.94	1.00	0.94
City Of Escondido	0.93	1.00	0.93
San Dieguito Water District	0.93	1.00	0.93
Vista Irrigation District	0.89	1.00	0.89
Rincon Del Diablo Municipal Water District	0.88	1.00	0.88
Otay Water District	0.86	1.00	0.86
Carlsbad Municipal Water District	0.85	1.00	0.85

7. Development of Alternative Weather Scenarios

7.1 Development of Hot Dry Index

A monthly hot-dry index (MHDI) is calculated for each member agency (a) and monthly observation (m) as the sum of the estimated weather effects for each sector model (j). The weather effects for each sectoral model are derived from the historical weather values (W) and weather model parameters (β) assigned to the weather variables in each model (i), which vary by member agency:

$$MHDI_{a,m,j} = exp\left(\sum_{,} \beta_{a,i,j} W_{a,i,m,j}\right)$$

The monthly index values are then summed across the month of any given annual period to derive a set of annual index values (AHDI) for each member agency and sector:

$$AHDI_{a,j} = \sum_{m=1}^{12} MHDI_{a,m,j}$$

Finally, the annual sector indices are weighted by the proportion of total annual water sales attributed to each sector (w) to define the final hot-dry index (HDI) values used to evaluate and select the hot-dry periods for scenario development:

$$HDI_{a} = \sum_{j=1}^{4} w_{j} * AHDI_{a,j}$$

The weights are based on the estimated proportion of sales by sector for the 3-year model calibration period.

7.2 Selection of Hot/Dry Scenario

The weather conditions used to represent the single-year hot/dry scenario were selected according to the following four steps:

1. Calculate HDI for each calendar year in the historical weather series for each member agency
2. Determine the maximum value of HDI for each member agency across all years in the historical weather series
3. Select the calendar year where HDI=max(HDI) for each member agency and retain weather data for the selected calendar year for each member agency

Table 7-1 lists the calendar years containing the maximum of HDI by member agency. As shown, calendar year 2014 was retained more often than any other year in the historical weather series as the hot-dry year (18 out of 22 cases). In consultation with the Authority, the weather data for year 2014 were selected for all agencies to represent the hot-dry scenario.

Table 7-1 Selected Calendar Years for Hot/Dry Weather Scenario

Agency	Single Year Hot/Dry Periods	
	Calendar Year	HDI Value
FALLBROOK PUBLIC UTILITY DISTRICT	2014	14.26
RAINBOW MUNICIPAL WATER DISTRICT	2014	29.57
VISTA IRRIGATION DISTRICT	2014	10.65
VALLEY CENTER MUNICIPAL WATER DISTRICT	2014	28.23
YUIMA MUNICIPAL WATER DISTRICT	2014	22.90
SANTA FE IRRIGATION DISTRICT	2014	19.01
SAN DIEGUITO WATER DISTRICT	2014	13.91
OLIVENHAIN MUNICIPAL WATER DISTRICT	2014	20.27
RINCON DEL DIABLO MUNICIPAL WATER DISTRICT	2007	17.99
RAMONA MUNICIPAL WATER DISTRICT	2014	10.60
HELIX WATER DISTRICT	1989	13.85
OTAY WATER DISTRICT	2014	7.58
PADRE DAM MUNICIPAL WATER DISTRICT	2014	6.83
CITY OF DEL MAR	2014	5.88
CITY OF ESCONDIDO	2007	34.85
SWEETWATER AUTHORITY	2008	4.58
CITY OF OCEANSIDE	2014	13.37
CITY OF POWAY	2014	7.38
CITY OF SAN DIEGO	2014	4.13
CARLSBAD MUNICIPAL WATER DISTRICT	2014	9.74
VALLECITOS WATER DISTRICT	2014	16.95
LAKESIDE WATER DISTRICT	2014	4.79
Mode	2014	

7.3 Derivation of Hot/Dry Forecast Scenarios

The development of the hot/dry water demand forecasts involved the substitution of weather conditions associated with the years 2014 and 1983 into the sectoral water demand forecasting equations. Table 7-2 displays the results of the single year hot/dry scenario for each sector and forecast year. As expected, the hot/dry scenario results in higher water demand forecasts. For example, under the hot/dry scenario, baseline production demands are about 8 percent higher (55,239 AF) in 2045 than the corresponding baseline forecast under 1981-2010 normal weather conditions.

Table 7-2 Hot/Dry Forecast Scenarios

	Sector	2025	2030	2035	2040	2045
Hot/Dry Weather (Acre Feet)	SF	239,485	243,878	248,501	252,940	257,722
	MF	101,599	110,703	119,721	127,215	132,832
	NR	178,702	188,347	198,683	208,247	215,872
	AG	44,969	44,204	43,439	43,387	43,333
	Other / UAW	85,052	88,105	91,577	94,584	97,031
	Total Production	**649,808**	**675,237**	**701,922**	**726,373**	**746,791**
Absolute Difference Hot/Dry Weather from Normal Weather Baseline	SF	17,552	18,038	18,589	19,013	19,443
	MF	1,894	2,064	2,243	2,396	2,501
	NR	15,618	16,527	17,541	18,494	19,257
	AG	6,306	6,199	6,093	6,086	6,079
	Other / UAW	7,034	7,244	7,523	7,762	7,959
	Total Production	**48,405**	**50,072**	**51,989**	**53,751**	**55,239**
% Difference Hot/Dry Weather from Normal Weather Baseline	SF	7.9%	8.0%	8.1%	8.1%	8.2%
	MF	1.9%	1.9%	1.9%	1.9%	1.9%
	NR	9.6%	9.6%	9.7%	9.7%	9.8%
	AG	16.3%	16.3%	16.3%	16.3%	16.3%
	Other / UAW	9.0%	9.0%	9.0%	8.9%	8.9%
	Total Production	**8.0%**	**8.0%**	**8.0%**	**8.0%**	**8.0%**

In terms of absolute impact, the single-family and nonresidential sectors contribute equally with each accounting for an increase in forecasted demands of about 19,000 AF under the Hot/Dry scenario. Although the single-family sector is projected to have higher demands overall, the 10 percent increase in nonresidential sector demands under the Hot/Dry weather scenario in 2045 is proportionally greater than that of the single-family sector which is estimated to be only 8 percent higher under these same weather conditions. However, in percentage terms, the impact of the hot/dry scenario is greatest for the agricultural sector, which is relatively more sensitive to weather (particularly precipitation). The multifamily sector is shown to be less responsive to the hot/dry weather scenario than the other three sectors.

7.4 Consecutive Dry Year Scenario Development

As discussed above, the weather coefficients of the sectoral water demand equations can be used to generate weather scenarios for any given set of monthly weather data, for example for a given hot/dry year. However, conceptually, it is possible that the persistence of drier than normal weather could intensify rates of water use in absence of intervention, such as in the form of water use restrictions. Because the sectoral forecasting equations by construction treat time periods independently, other statistical methods were derived to evaluate potential or “latent” demands that could develop with persistence of dry weather conditions.

Trends in historical total regional water use (supplied from all sources) were correlated with trends in observed Water Authority weather conditions to develop a set of factors to describe the potential impact of consecutive dry years. Specifically, the running 12-month average of regional water use (USE12) was modeled as a function of the following variables:[26]

- 12-month running average of the ratio of observed to normal average maximum daily temperature (MAXT12)
- 24-month running average of the ratio of observed to normal precipitation (PRCP24)
- 36-month running average of the ratio of observed to normal precipitation (PCRP36)
- 48-month running average of the ratio of observed to normal precipitation (PCRP48)
- 60-month running average of the ratio of observed to normal precipitation (PCRP60)
- Departure from long-term economic trend, as measured by the economic index used in the sectoral models (DECRI_index)
- Linear time trend counter (TREND)

Except for the linear time counter, all variables were transformed into natural log form prior to estimating the model using ordinary least squares regression. The sampling period was restricted in an attempt to remove periods most likely to have been under the most severe drought periods. Table 7-3 shows the results of model estimation.

The estimated weather parameters are used to estimate the potential change in water use that would occur under the driest 24-month, 36-month, 48-month, and 60-month period over the historical record, assuming the warmest 12-month period estimated over the historical record.

Table 7-3 Water Authority-Wide Model for Estimating Consecutive Dry Year Scaling Factors

Variable[a,b]	Coefficient	Std. Error	t-Statistic	Prob.
Intercept	10.7753	0.00664	1623.24	0.000
LOG(PRCP24)	-0.0406	0.00859	-4.73	0.000
LOG(PRCP36)	-0.0430	0.01378	-3.12	0.002
LOG(PRCP48)	-0.0942	0.01823	-5.16	0.000
LOG(PRCP60)	-0.0759	0.01879	-4.04	0.000
DECRI - Linearly Detrended LOG(ECRI Index)	1.0159	0.03551	28.61	0.000
LOG(MAXT12)	1.6587	0.13661	12.14	0.000
TREND	0.0001	0.00002	4.54	0.000
Adjusted R-squared	0.90			
Observations	331			

[a] Dependent Variable LOG(USE12)

[b] Sample Period: 1984M12-1990M12, 1993M01-2014M06

Consecutive dry-year scaling factors are derived using the historical minimums of the precipitation and historical maximum of the temperature variable from the historical weather data set:

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[26] Note that a simple average of weather data assigned to each member agency is used to represent regional weather conditions.

2nd consecutive dry year scaling factor =

$$(\mathrm{MAXT12}^{1.6587})*(\mathrm{PRCP24}^{-0.0406}) =$$

$$(1.0428^{1.6587})*(0.4519^{-0.0406}) \approx 1.11$$

3rd consecutive dry year scaling factor =

$$(\mathrm{MAXT12}^{1.6587})*(\mathrm{PRCP24}^{-0.0406})*(\mathrm{PRCP36}^{-0.0430}) =$$

$$(1.0428^{1.6587})*(0.4519^{-0.0406})*(0.5211^{-0.0444}) \approx 1.14$$

4th consecutive dry year scaling factor =

$$(\mathrm{MAXT12}^{1.6587})*(\mathrm{PRCP24}^{-0.0406})*(\mathrm{PRCP36}^{-0.0430})*(\mathrm{PRCP48}^{-0.0942}) =$$

$$(1.0428^{1.6587})*(0.4519^{-0.0406})*(0.5211^{-0.0444})*(0.5798^{-0.0942}) \approx 1.20$$

5th consecutive dry year scaling factor =

$$(\mathrm{MAXT12}^{1.6587})*(\mathrm{PRCP24}^{-0.0406})*(\mathrm{PRCP36}^{-0.0430})*(\mathrm{PRCP48}^{-0.0942})*(\mathrm{PRCP60}^{-0.0759}) =$$

$$(1.0428^{1.6587})*(0.4519^{-0.0406})*(0.5211^{-0.0444})*(0.5798^{-0.0942})*(0.6493^{-0.0759}) \approx 1.24$$

These scaling factors are used to supplement the results of the single hot/dry year scenario. As a result, there is a 5-year sequence for any year in the forecast: single hot/dry year, followed by the second dry year, followed by the third consecutive dry year, and so on.

Under these assumptions, the second consecutive dry year would result in water use that is about 11 percent higher than under normal precipitation conditions. The estimate of water use for the third consecutive dry year would be incrementally higher, or about 14 percent greater than normal. By the end of the fifth consecutive dry year the estimated potential would grow to about 24 percent higher than the normal year baseline.

Scenario values were calculated for each forecast year in order to characterize demands as if each year represented the 2nd, 3rd, 4th, or 5th consecutive dry year. The results of consecutive hot/dry scenarios are presented in Table 7-4. The consecutive dry year scenarios are calculated off of the total baseline forecast, and thus implicitly account for differences in growth occurring among the Water Authority's water use sectors and member agencies. As indicated by the magnitudes of the scaling factors described above, the implication is increasingly higher demands as conditions become drier. It is possible that demands would be restricted through demand management actions prior to reaching these levels if such conditions were to occur.

Table 7-4 Single and Consecutive Year Dry Year Total Baseline Production Demand Forecast Scenarios (Acre-Feet)

Year	Baseline, Normal Weather	Single Hot/Dry Year	2nd Hot/Dry Year	3rd Hot/Dry Year	4th Hot/Dry Year	5th Hot/Dry Year
2025	601,404	649,808	675,851	695,571	720,476	754,178
2026	606,156	654,894	681,191	701,067	726,169	760,138
2027	610,908	659,979	686,532	706,563	731,862	766,097
2028	615,660	665,065	691,872	712,060	737,555	772,057
2029	620,413	670,151	697,213	717,556	743,248	778,016
2030	625,165	675,237	702,553	723,053	748,942	783,976
2031	630,119	680,574	708,120	728,782	754,876	790,188
2032	635,072	685,911	713,687	734,511	760,811	796,400
2033	640,026	691,248	719,254	740,241	766,745	802,612
2034	644,980	696,585	724,821	745,970	772,679	808,824
2035	649,933	701,922	730,388	751,699	778,614	815,036
2036	654,471	706,812	735,487	756,947	784,050	820,726
2037	659,009	711,702	740,587	762,196	789,486	826,417
2038	663,546	716,593	745,686	767,444	794,922	832,107
2039	668,084	721,483	750,785	772,692	800,358	837,798
2040	672,622	726,373	755,885	777,940	805,795	843,488
2041	676,408	730,456	760,140	782,319	810,330	848,236
2042	680,194	734,540	764,394	786,698	814,866	852,984
2043	683,980	738,624	768,649	791,077	819,401	857,731
2044	687,766	742,707	772,904	795,456	823,937	862,479
2045	691,552	746,791	777,158	799,834	828,473	867,227

8. Derivation of Climate Change Forecast Scenarios

Evaluation of potential climate change impacts on water demand represents a prudent water resources planning exercise. However, definitive projections on the timing and magnitude of climate change–initiated variations to local temperature and precipitation patterns are still forthcoming. The body of work currently available from national and international research contains a wide spectrum of possible outcomes based on numerous climate forcing scenarios run through an assortment of General Circulation Models (GCMs). In the absence of research consensus, this analysis adopted a qualitative evaluation approach that uses a manageable number of climate change scenarios to develop a range of potential demands.

8.1 Approach

A number of advances in climate modeling have occurred since past climate change modeling efforts, including fine-scale precipitation and temperature projections based on GCM forecasts. These projections, known as Localized Constructed Analog (LOCA) climate projections, are made available by the World Climate Research Programme's Coupled Model Intercomparison Project phase 5 (CMIP5). The CMIP5 LOCA dataset consists of simulations of historical and future (1950-2099) daily precipitation and maximum/minimum temperature in 1/16th-degree latitude and longitude grid cells covering the conterminous United States. Simulations are produced using 32 different GCMs each paired with two different climate forcing scenarios, or representative concentration pathways (RCPs). The RCPs, named RCP 4.5 and RCP 8.5, reflect new projected scenarios of future global greenhouse gas (GHG) emissions. Each RCP is based on an assumed “radiative forcing”, or RF. Radiative forcing is the change in net radiative flux (expressed in watts per square meter) at the upper atmosphere due to a change in an external driver, such as a change in the concentration of carbon dioxide. Thus, RF expresses the change in energy in the atmosphere due to GHG emissions. The following is a brief description of each RCP scenario:

- RCP 8.5 – High emissions scenario is consistent with no policy changes to reduce GHG emissions and rising radiative forcing pathway leading to 8.5 watts per square meter in 2100. It was developed by the International Institute for Applied System Analysis in Austria.
- RCP 4.5 – Intermediate emissions scenario was developed by the Pacific Northwest National Laboratory in the United States, and radiative forcing stabilized shortly after year 2100 at 4.5 watts per square meter.

Surface weather from each GCM simulation is then downscaled from its native spatial resolution, generally 2-degree latitude and longitude grid cells, to the LOCA resolution using constructed analogs, or sampling of historical local weather patterns (at the 1/16th degree scale) that resemble the GCM projection and correcting any bias in the sample relative to the projection. A total of 64 LOCA downscaled climate projections are available from CMIP5 that represent various combinations of GCMs and RCP scenarios.[27]

The development of demand forecasts based on alternative climate scenarios for the Water Authority's service area (excluding Camp Pendleton) began by selecting LOCA scenarios (combinations of GCMs and RCPs) reflecting central tendencies and extremes of climate projections, specifically:

- Relatively large increases in both average temperature and precipitation (Warm/Wet)
- Relatively large increases in average temperature and relatively large decreases in average precipitation (Warm/Dry)
- Relatively small increases in average temperature and relatively large increases in precipitation (Cool/Wet)
- Relatively small increases in average temperature and relatively large decreases in precipitation (Cool/Dry)
- Moderate increases in average temperature and moderate changes in precipitation (Moderate)

Initial scenario selections consisted of all available LOCA series in the grid cells containing each member agency's geographic centroid. Figure 8-1 shows member agency centroids and the corresponding LOCAL cells that contain them. This resulted in 1,408 time series of daily precipitation and maximum daily temperature covering 1950-2099, one for each scenario and Agency.

Using these data, each scenario was summarized regionally by projected changes in annual precipitation and annual average daily high temperature. With each scenario time series in each grid cell, average annual total precipitation and average annual maximum daily temperature were determined over 1981-2020 and climate projection periods 2040-2060 and 2079-2099, then changes in annual average precipitation and temperature were calculated. Projected changes in temperature and precipitation were then averaged within each scenario across selected grid cells, producing 64 pairs of regional average precipitation and temperature change, one for each scenario for each climate projection period (see x-symbols on Figure 8-2).

Next, the distribution of temperature and precipitation summaries was characterized. The 95th, 5th, and 50th percentile values were calculated for each variable. Then, the approximate joint range of scenario weather was specified as combinations of percentile values of temperature and precipitation values; 95th percentile temperature and 95th precipitation values (wet/warm), 5th percentile temperature and

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[27] LOCA is the downscaling method used by CMIP5. Its predecessor, the Bias-Corrected Constructed Analog (BCCA), worked in a similar manner but downscaled at a 1/8th latitude-longitude resolution using historical samples of contemporaneous weather data across the entire nation-wide grid at once. This earlier method was applied to 20 GCMs using four RCPs, including the two listed above plus RCPs 2.6 (less severe than RCP 4.5) and 6.0 (between 4.5 and 8.5 in severity). LOCA does not provide results for RCPs 2.6 and 6.0. The prior BCCA method was found to create dry biases in arid regions due to its non-localized sampling approach. Both products are available from CMIP5, in addition to even earlier results from the predecessor program (CMIP3).

precipitation values (dry/cool), 95th percentile temperature and 5th percentile precipitation values (dry/warm), 5th percentile temperature and 95th percentile precipitation values (wet/cool), and 50th percentile temperature and 50th percentile precipitation values (moderate). These pairings are called "ideal" scenarios; they express the joint extents of scenarios but generally they involve values from two different scenarios (black dots at intersections of horizontal and vertical lines on Figure 8-2) for the 2040-2060 projection period.

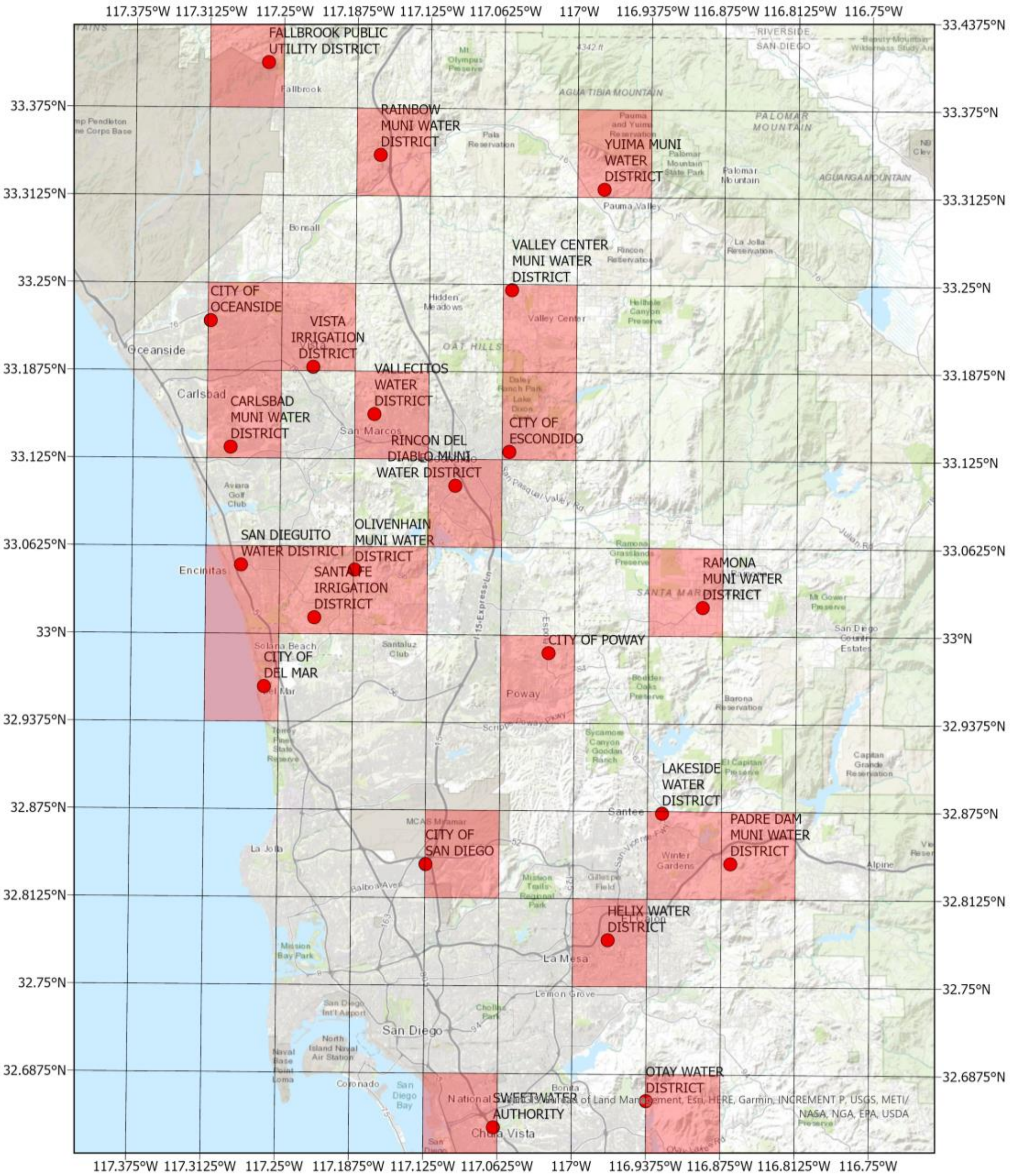


Figure 8-1 LOCA Grid Cells Were Selected for Each Member Agency According to That Agency's Centroid.

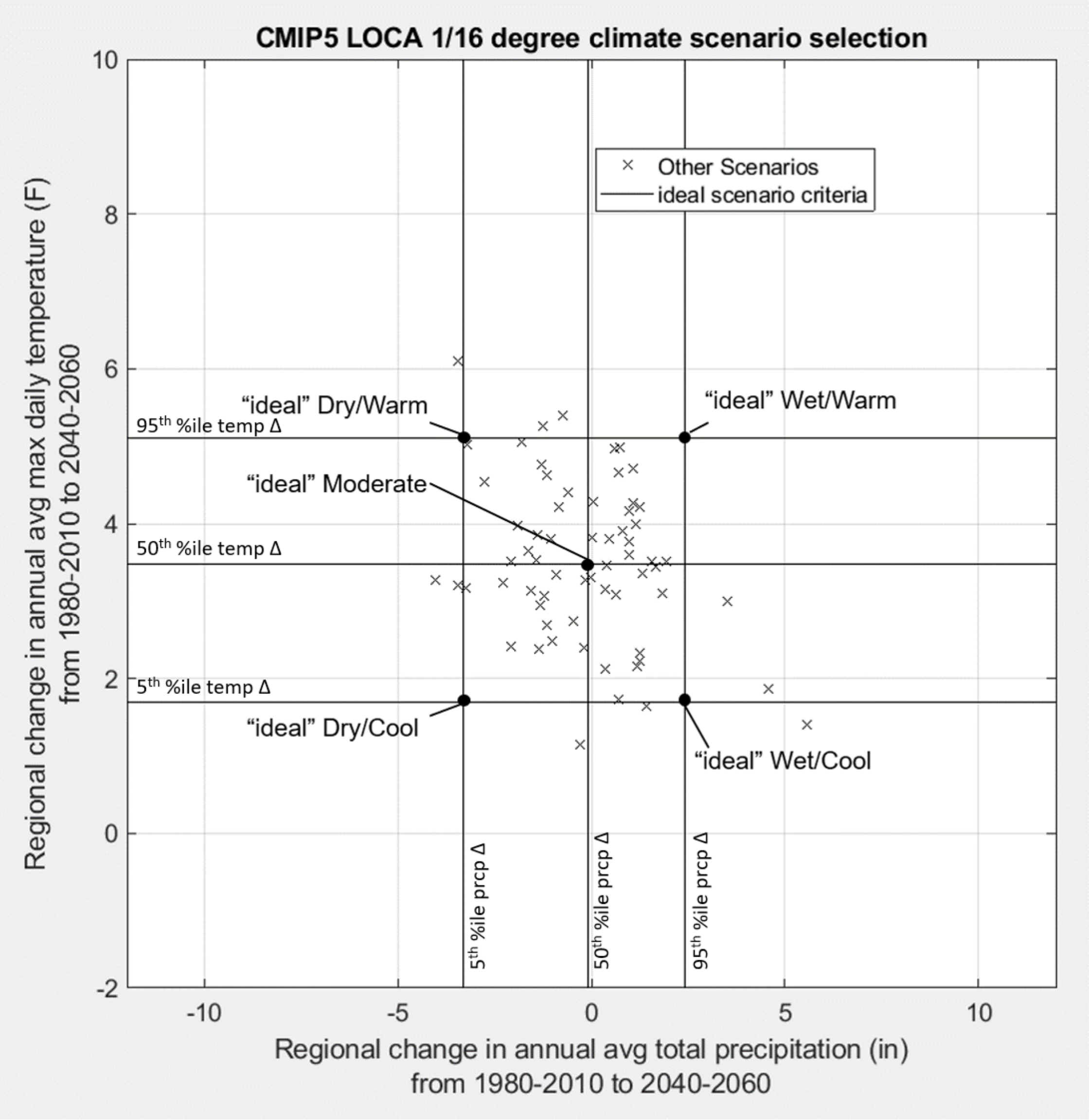


Figure 8-2 Scenario Climate Change Summaries for 2040-2060 and "Ideal" Climate Scenarios

8.2 Selected Model Projections

The final step of the scenario selection process involved the identification of individual model projections that have temperature and precipitation projections that were closest in values to the “ideal” scenario description (for example, the model projection that had a pairing of temperature and precipitation nearest to the “ideal” 95th percentile temperature change and 5th percentile precipitation change). Model projections that were closest to “ideal” conditions were chosen as the representative climate change scenarios (for example, the colored circles on Figure 8-3 for the 2040-2060 climate projection period). The five climate change scenarios selected for each climate project period are shown in Table 8-1.

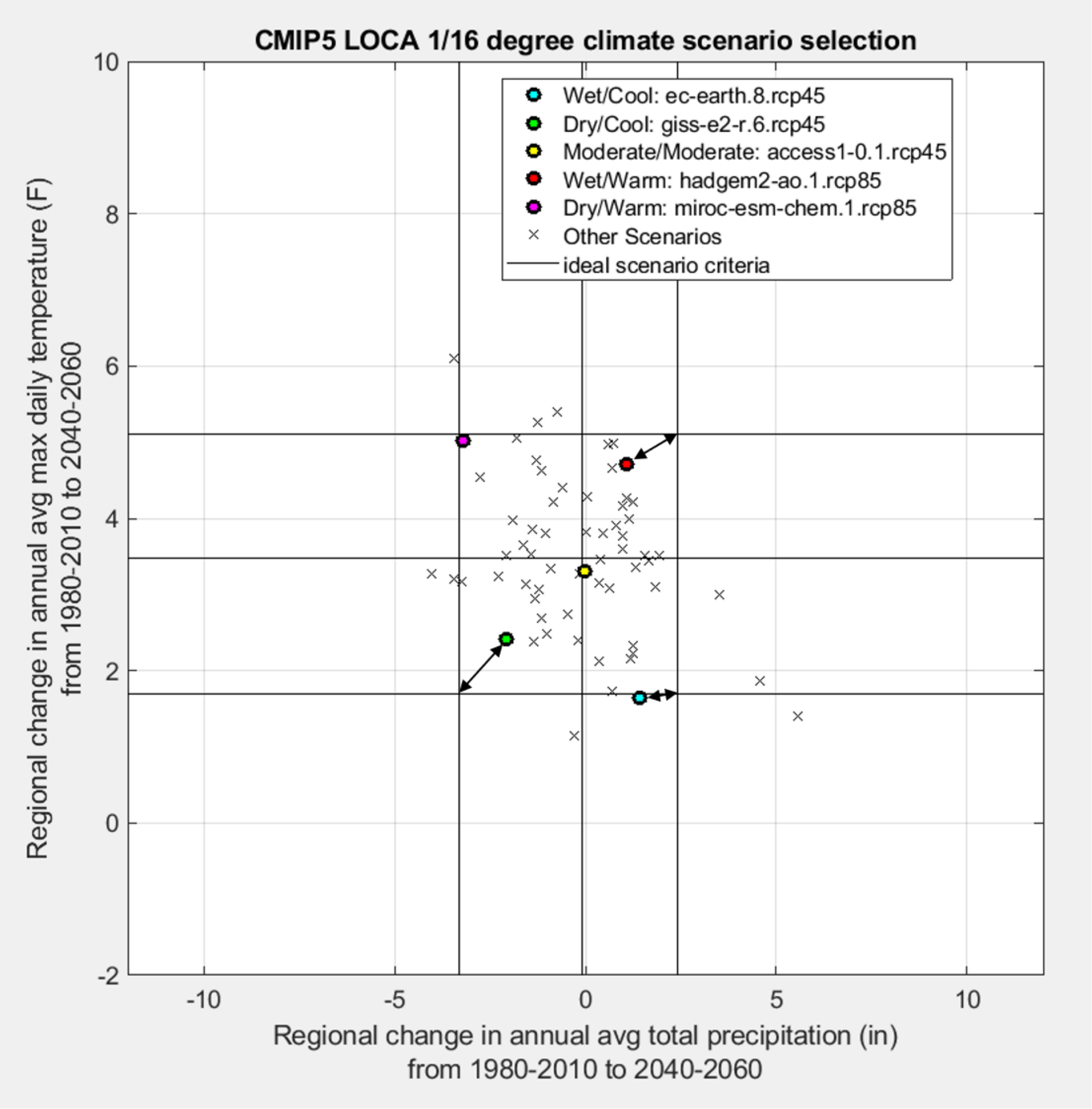


Figure 8-3 Selection of Climate Change Scenarios for 2040-2060

Table 8-1 Climate Change Scenarios for 2040-2060 and 2079-2099 Climate Projection Periods

Climate Projection Period	Scenario	GCM	RCP
2040-2060	Wet/Cool	ec-earth.8	RCP 4.5
	Dry/Cool	giss-e2-r.6	RCP 4.5
	Moderate	access1-0.1	RCP 4.5
	Wet/Warm	hadgem2-ao.1	RCP 8.5
	Dry/Warm	miroc-esm-chem.1	RCP 8.5
2079-2099	Wet/Cool	ec-earth.8	RCP 4.5
	Dry/Cool	gfdl-esm2g.1	RCP 4.5
	Moderate	ccsm4.6	RCP 8.5
	Wet/Warm	canesm2.1	RCP 8.5
	Dry/Warm	miroc-esm.1	RCP 8.5

8.3 Characterization of 2040-2060 Climate Projections

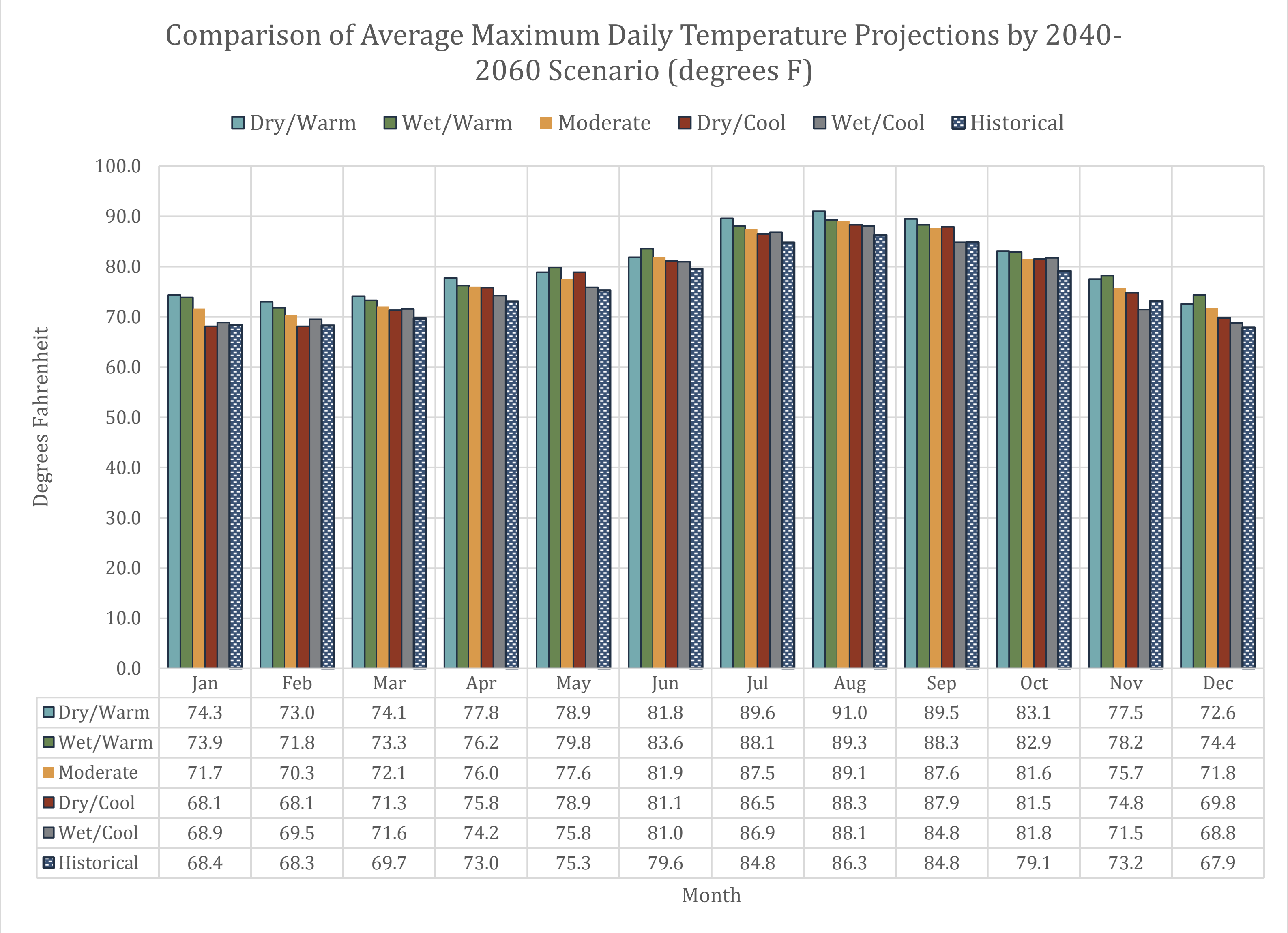
No dramatic shifts in seasonal patterns of mean precipitation and average maximum daily temperature for the San Diego region were observed under any of the five scenarios for the 2040-2060 projection period (see Figure 8-4 and Figure 8-5). Two of the climate scenarios resulted in average annual precipitation estimates for 2040-2060 that can be considered considerably lower than the 1980-2010 historic average (Figure 8-6). As mentioned above, all selected scenarios indicate warming on average relative to historical climate conditions. This is borne out at the monthly level except for only 3 model runs (Figure 8-7).

8.4 Characterization of 2079-2099 Climate Projections

For the five scenarios, the 2079-2099 climate projection period shows additional warming relative to historical normals than shown for the 2040-2060 period (Figure 8-8). There is also more spread in the precipitation projections, but the seasonal patterns of precipitation are consistent with the historical pattern (Figure 8-9). The monthly proportional differences in average maximum daily temperatures are quite a bit larger than in the 2040-2060 period (Figure 8-10). Similar to the 2040-2060 period, only 2 of the scenarios generate considerably less annual precipitation for the 2079-2099 period (Figure 8-11). The Dry/Warm scenario results in annual precipitation levels that are close to half of historical normals.

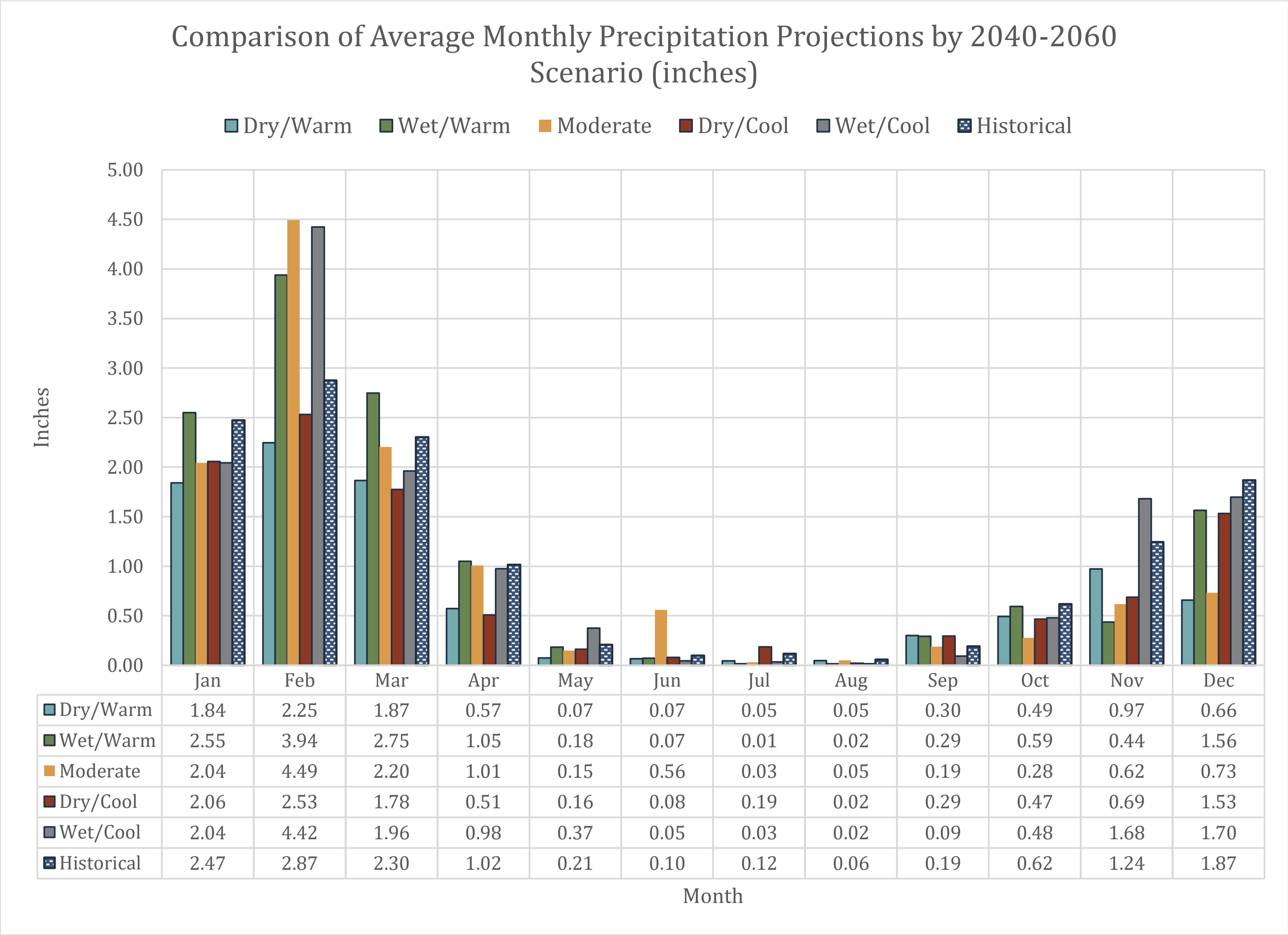
8.5 Climate Change Demand Forecast Scenarios

The range of climate change impacts on Water Authority demands was calculated by substituting the five climate scenarios for each climate projection period into sectoral water use equations. While the scenarios were identified using region-average temperature and precipitation, demand for each member agency was forecasted using the selected scenario’s precipitation and temperature data for the individual member agency’s grid cell. This assured that demand forecasts for various members were derived for a consistent scenario, would better represent real contemporaneous weather regionally, and could be sensibly aggregated to regional totals, while retaining the climatic heterogeneity typical to the region.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry/Warm	74.3	73.0	74.1	77.8	78.9	81.8	89.6	91.0	89.5	83.1	77.5	72.6
Wet/Warm	73.9	71.8	73.3	76.2	79.8	83.6	88.1	89.3	88.3	82.9	78.2	74.4
Moderate	71.7	70.3	72.1	76.0	77.6	81.9	87.5	89.1	87.6	81.6	75.7	71.8
Dry/Cool	68.1	68.1	71.3	75.8	78.9	81.1	86.5	88.3	87.9	81.5	74.8	69.8
Wet/Cool	68.9	69.5	71.6	74.2	75.8	81.0	86.9	88.1	84.8	81.8	71.5	68.8
Historical	68.4	68.3	69.7	73.0	75.3	79.6	84.8	86.3	84.8	79.1	73.2	67.9

Figure 8-4 Comparison of Average Maximum Daily Temperature Projections by 2040-2060 Scenario (degrees F)



Comparison of Average Monthly Precipitation Projections by 2040-2060 Scenario (inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry/Warm	1.84	2.25	1.87	0.57	0.07	0.07	0.05	0.05	0.30	0.49	0.97	0.66
Wet/Warm	2.55	3.94	2.75	1.05	0.18	0.07	0.01	0.02	0.29	0.59	0.44	1.56
Moderate	2.04	4.49	2.20	1.01	0.15	0.56	0.03	0.05	0.19	0.28	0.62	0.73
Dry/Cool	2.06	2.53	1.78	0.51	0.16	0.08	0.19	0.02	0.29	0.47	0.69	1.53
Wet/Cool	2.04	4.42	1.96	0.98	0.37	0.05	0.03	0.02	0.09	0.48	1.68	1.70
Historical	2.47	2.87	2.30	1.02	0.21	0.10	0.12	0.06	0.19	0.62	1.24	1.87

Figure 8-5 Comparison of Average Monthly Precipitation Projections by 2040-2060 Scenario (inches)

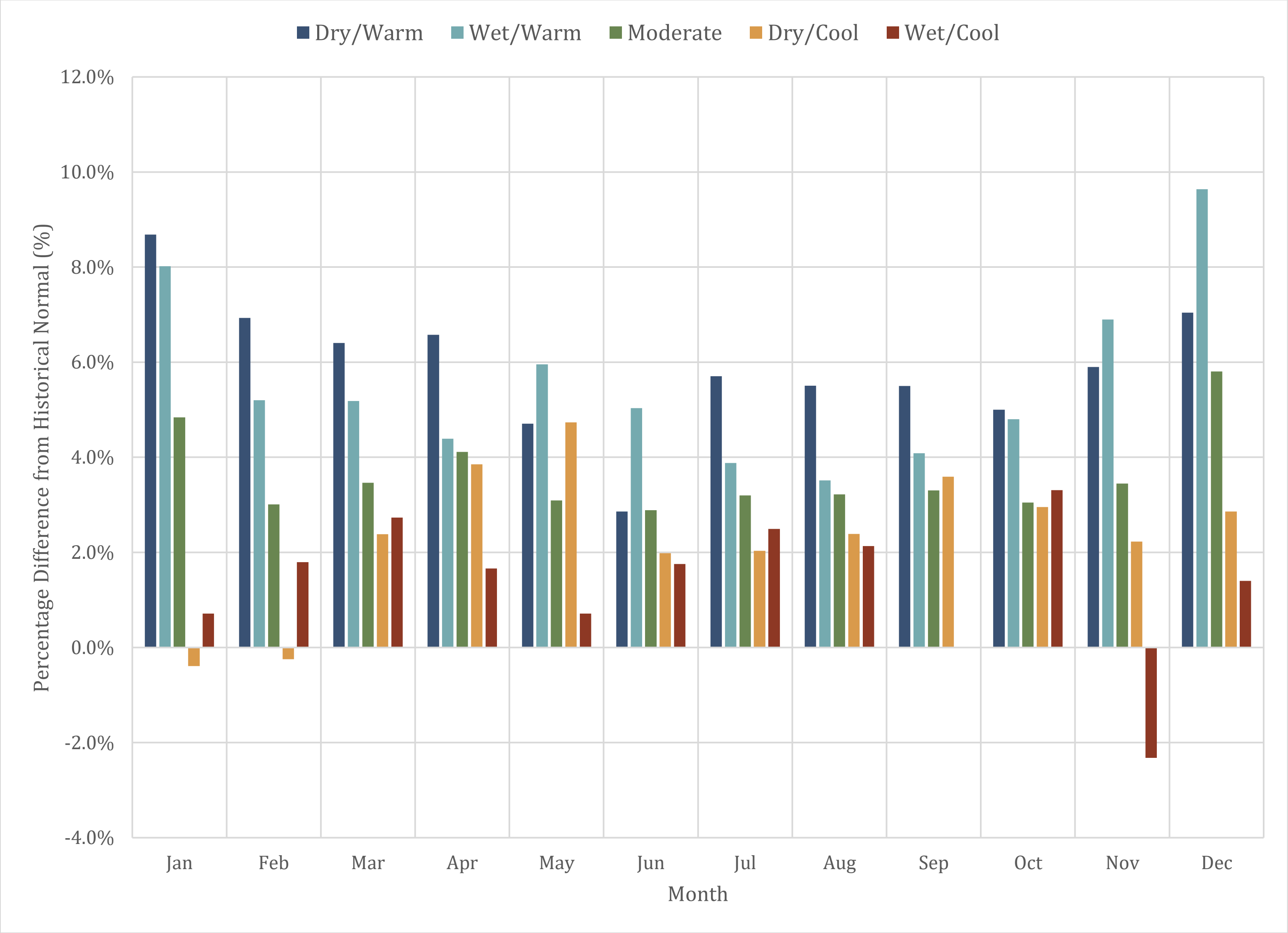
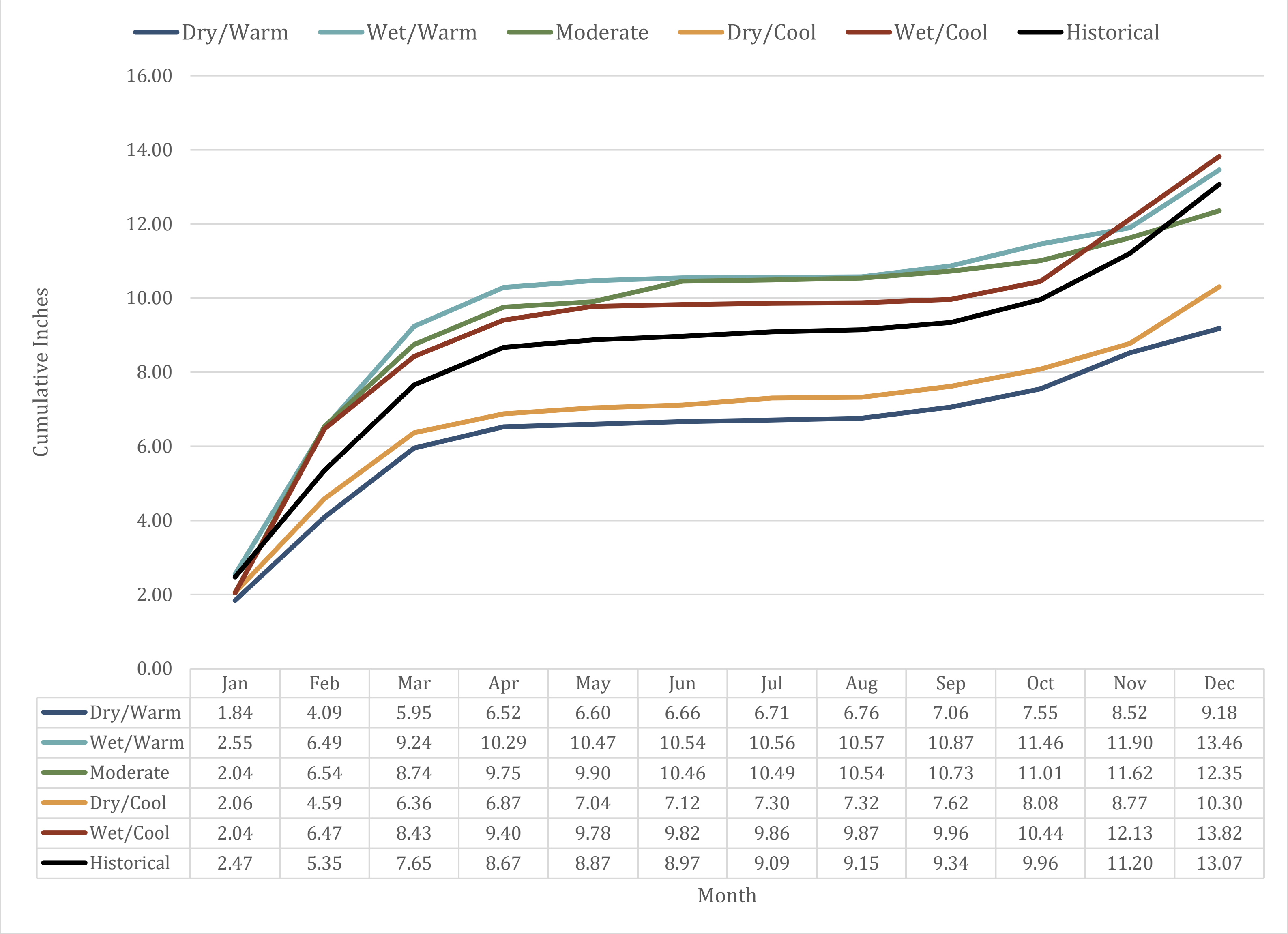
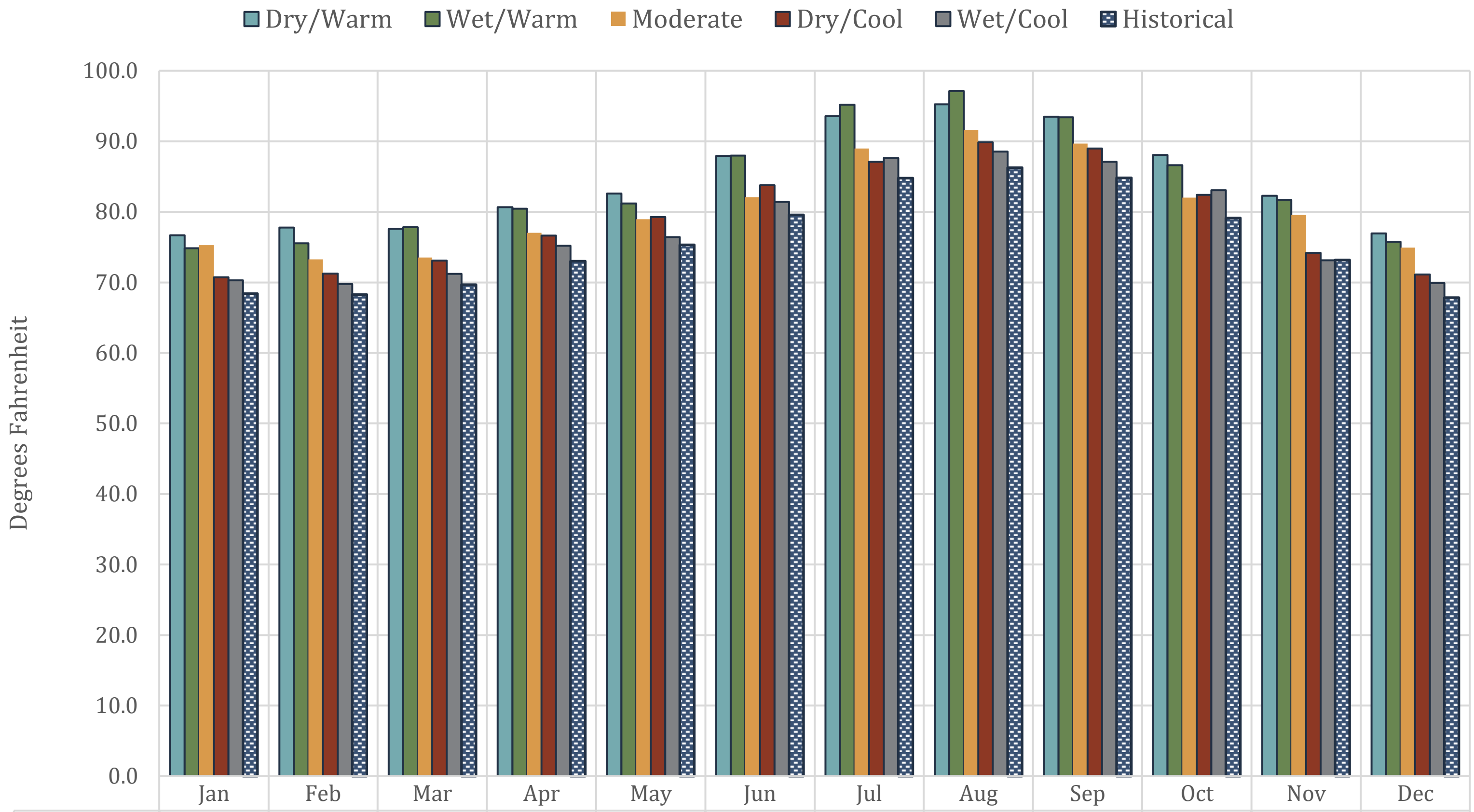


Figure 8-6 Comparison of Average Maximum Daily Temperature Projections by 2040-2060 Scenario (% Change from Historical Normal)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry/Warm	1.84	4.09	5.95	6.52	6.60	6.66	6.71	6.76	7.06	7.55	8.52	9.18
Wet/Warm	2.55	6.49	9.24	10.29	10.47	10.54	10.56	10.57	10.87	11.46	11.90	13.46
Moderate	2.04	6.54	8.74	9.75	9.90	10.46	10.49	10.54	10.73	11.01	11.62	12.35
Dry/Cool	2.06	4.59	6.36	6.87	7.04	7.12	7.30	7.32	7.62	8.08	8.77	10.30
Wet/Cool	2.04	6.47	8.43	9.40	9.78	9.82	9.86	9.87	9.96	10.44	12.13	13.82
Historical	2.47	5.35	7.65	8.67	8.87	8.97	9.09	9.15	9.34	9.96	11.20	13.07

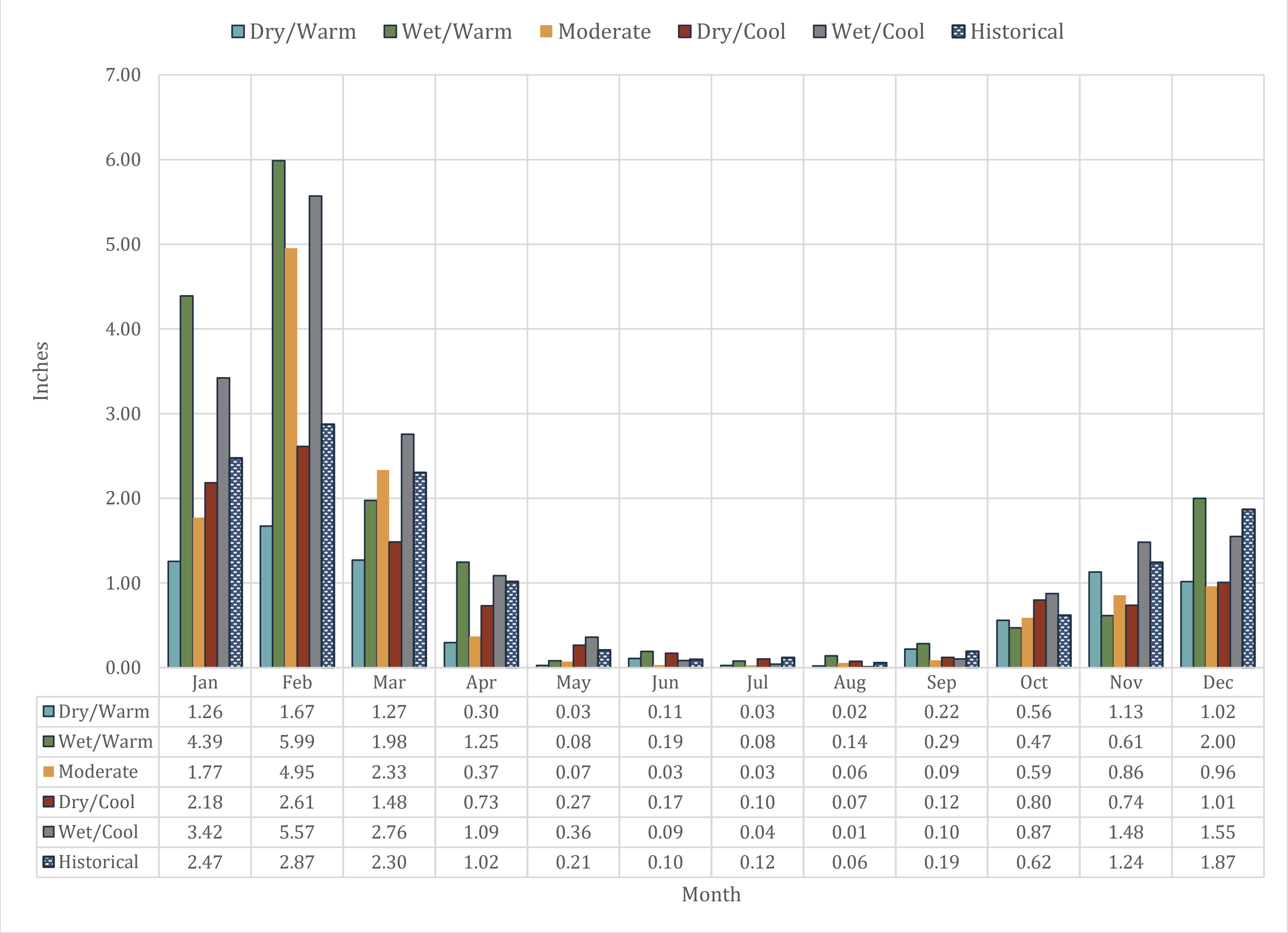
Figure 8-7 Comparison of Cumulative Annual Precipitation Projections by 2040-2060 Scenario (inches)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▨ Dry/Warm	76.7	77.8	77.6	80.7	82.6	87.9	93.6	95.3	93.5	88.1	82.3	77.0
▨ Wet/Warm	74.8	75.5	77.8	80.4	81.2	88.0	95.2	97.1	93.4	86.6	81.7	75.7
▨ Moderate	75.3	73.3	73.5	77.0	78.9	82.1	89.0	91.6	89.7	82.0	79.6	74.9
▨ Dry/Cool	70.7	71.3	73.1	76.6	79.3	83.8	87.1	89.9	89.0	82.4	74.2	71.1
▨ Wet/Cool	70.3	69.7	71.2	75.2	76.4	81.4	87.6	88.5	87.1	83.1	73.2	69.9
▨ Historical	68.4	68.3	69.7	73.0	75.3	79.6	84.8	86.3	84.8	79.1	73.2	67.9

Month

Figure 8-8 Comparison of Average Maximum Daily Temperature Projections by 2079-2099 Scenario (degrees F)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry/Warm	1.26	1.67	1.27	0.30	0.03	0.11	0.03	0.02	0.22	0.56	1.13	1.02
Wet/Warm	4.39	5.99	1.98	1.25	0.08	0.19	0.08	0.14	0.29	0.47	0.61	2.00
Moderate	1.77	4.95	2.33	0.37	0.07	0.03	0.03	0.06	0.09	0.59	0.86	0.96
Dry/Cool	2.18	2.61	1.48	0.73	0.27	0.17	0.10	0.07	0.12	0.80	0.74	1.01
Wet/Cool	3.42	5.57	2.76	1.09	0.36	0.09	0.04	0.01	0.10	0.87	1.48	1.55
Historical	2.47	2.87	2.30	1.02	0.21	0.10	0.12	0.06	0.19	0.62	1.24	1.87

Figure 8-9 Comparison of Average Monthly Precipitation Projections by 2079-2099 Scenario (inches)

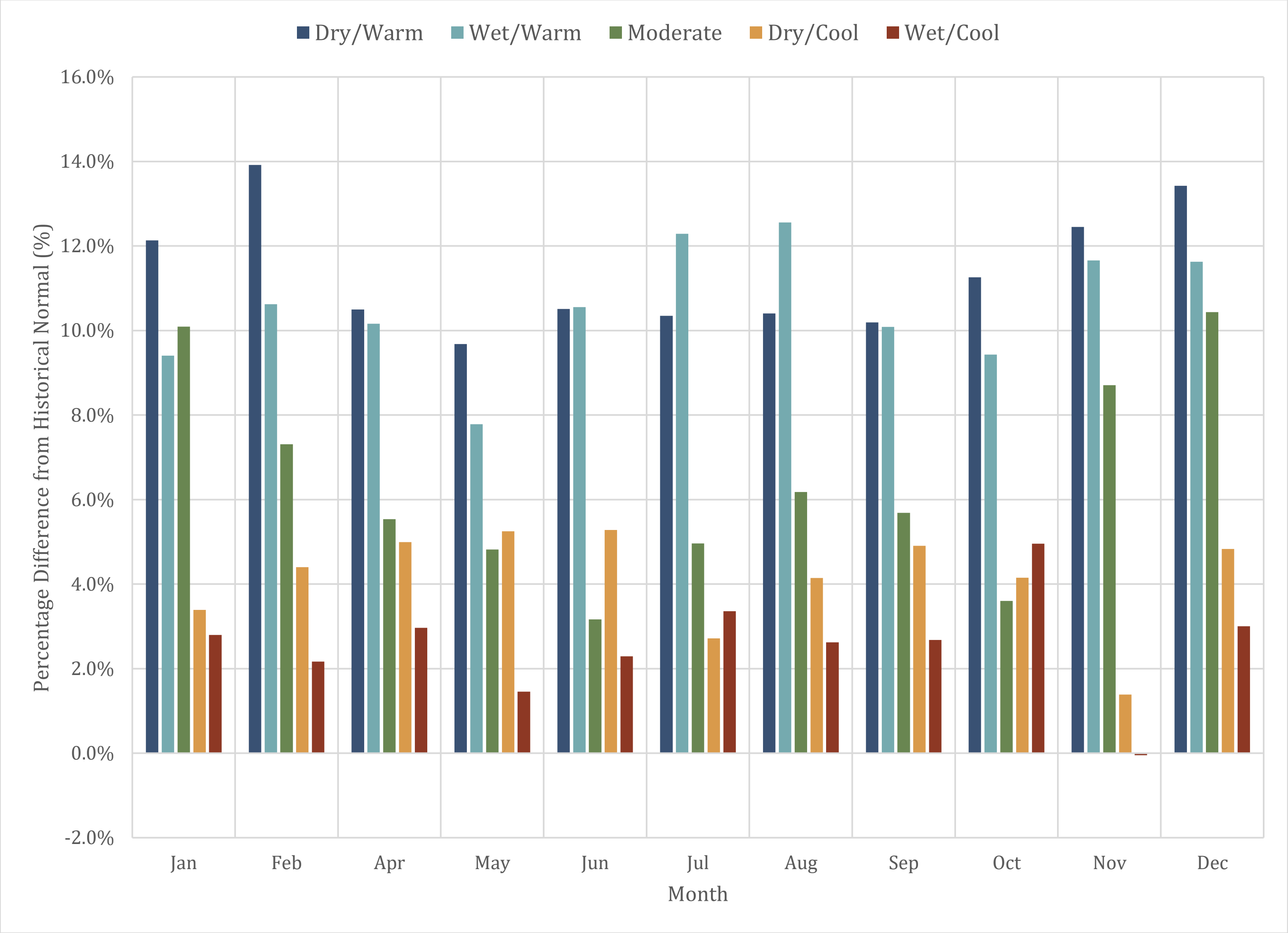
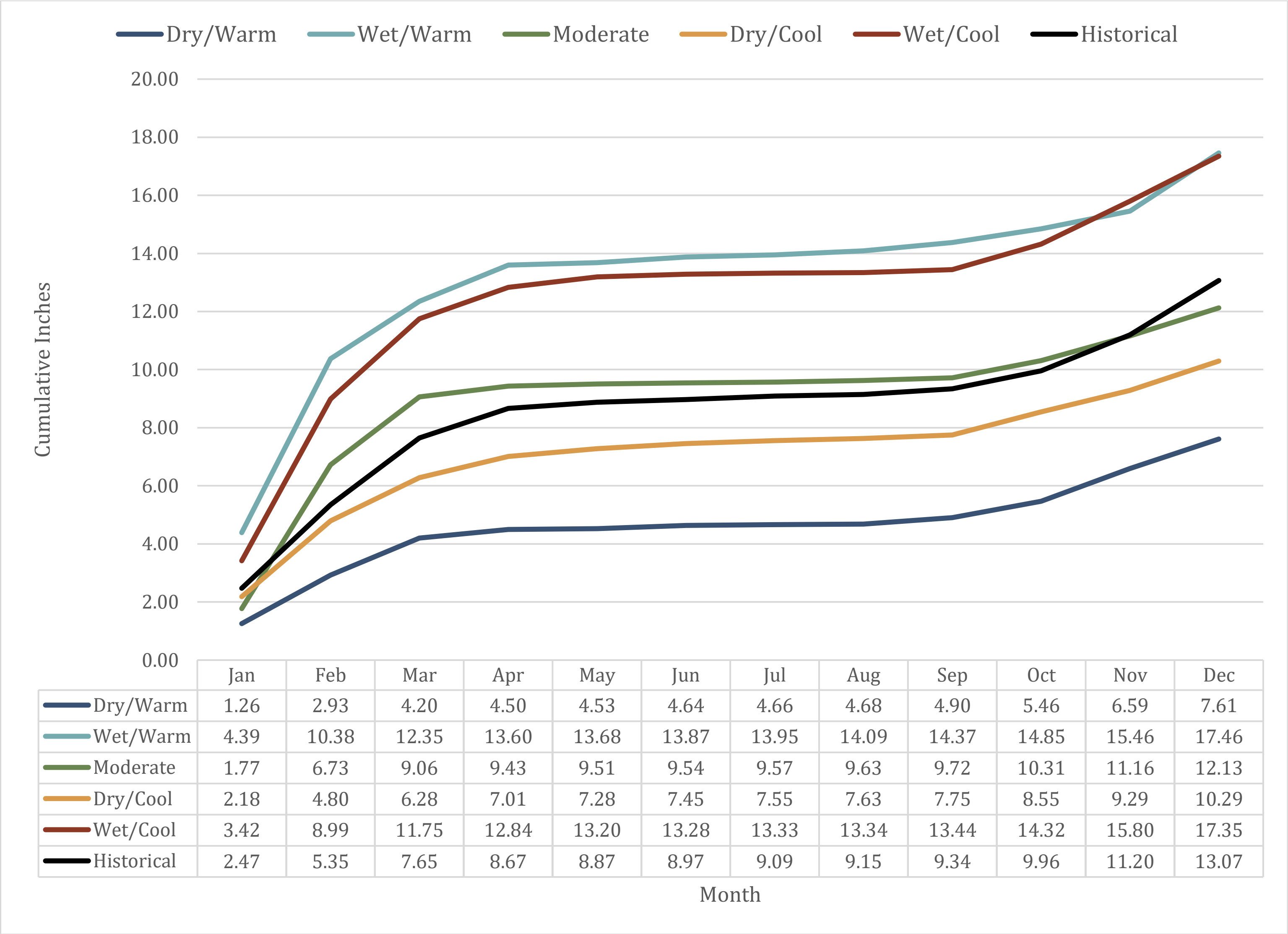


Figure 8-10 Comparison of Average Maximum Daily Temperature Projections by 2070-2099 Scenario (% Change from Historical Normal)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry/Warm	1.26	2.93	4.20	4.50	4.53	4.64	4.66	4.68	4.90	5.46	6.59	7.61
Wet/Warm	4.39	10.38	12.35	13.60	13.68	13.87	13.95	14.09	14.37	14.85	15.46	17.46
Moderate	1.77	6.73	9.06	9.43	9.51	9.54	9.57	9.63	9.72	10.31	11.16	12.13
Dry/Cool	2.18	4.80	6.28	7.01	7.28	7.45	7.55	7.63	7.75	8.55	9.29	10.29
Wet/Cool	3.42	8.99	11.75	12.84	13.20	13.28	13.33	13.34	13.44	14.32	15.80	17.35
Historical	2.47	5.35	7.65	8.67	8.87	8.97	9.09	9.15	9.34	9.96	11.20	13.07

Figure 8-11 Comparison of Cumulative Annual Precipitation Projections by 2079-2099 Scenario (inches)

8.6 Implications for Forecasted Baseline Water Demands

Table 8-2 provides 2045 Water Authority forecasts under the 2040-2060 and 2079-2099 alternative climate change scenarios and presents comparisons of these forecasts to the baseline “normal weather” forecast. Meanwhile Table 8-3 provides alternative estimates based on scaling crop ET requirements based on the projected relative change in average maximum temperature. The alternative estimates are provided since the agricultural model depends only on net watering requirements and projections of ET were not readily available.

For the 2040-2060 climate projection period, the relative change from 2045 projected baseline production demands ranges from about –2 percent to about +3 percent across the scenarios. Using 2079-2099 climate projections, the relative change from 2045 projected baseline production demands ranges from about –3 percent to about +10 percent across the scenarios. This suggests both that climate change impacts are highly uncertain and possibly more pronounced the farther out the forecast horizon. The climate models assuming RCP8.5 generally produce higher demands because of greater warming.

The sector level differences are indicative of the estimated demand response to weather. The agricultural and nonresidential sectors, which comprise higher levels of irrigation and/or meters devoted to irrigation tend to show larger percentage differences relative to baseline that the residential sectors. The multifamily sector is least sensitive to the climate change scenarios. As might be expected, the dry/warm scenarios suggest the higher water use projections. The impact of scaling ET according to projected temperatures is clearly evident in the agricultural projection scenarios (e.g., -8 percent relative change versus about +5 percent relative change under the 2079-2099 warm/wet scenario).

Table 8-2 Comparison of Climate Change Water Demand Scenarios for 2045

				2045 Water Demand (Acre Feet)					Percent Difference from Normal				
Climate Projection Period	Scenario	GCM	RCP	SF	MF	NR	AG	Total Production	SF	MF	NR	AG	Total Production
Historical	NORMAL			238,279	130,331	196,615	37,255	691,552	0.00%	0.00%	0.00%	0.00%	0.00%
2040-2060	Wet/Cool	ec-earth.8	RCP 4.5	233,020	129,339	190,299	35,927	675,386	-2.21%	-0.76%	-3.21%	-3.56%	-2.34%
	Dry/Cool	giss-e2-r.6	RCP 4.5	233,497	129,294	189,647	38,376	678,271	-2.01%	-0.80%	-3.54%	3.01%	-1.92%
	Moderate	access1-0.1	RCP 4.5	234,993	129,597	191,437	36,729	680,330	-1.38%	-0.56%	-2.63%	-1.41%	-1.62%
	Wet/Warm	hadgem2-ao.1	RCP 8.5	242,049	130,120	197,615	36,469	696,089	1.58%	-0.16%	0.51%	-2.11%	0.66%
	Dry/Warm	miroc-esm-chem.1	RCP 8.5	244,524	130,565	200,498	39,151	706,018	2.62%	0.18%	1.97%	5.09%	2.09%
2079-2099	Wet/Cool	ec-earth.8	RCP 4.5	232,082	129,000	188,653	34,081	669,886	-2.60%	-1.02%	-4.05%	-8.52%	-3.13%
	Dry/Cool	gfdl-esm2g.1	RCP 4.5	235,198	129,405	191,153	38,177	681,887	-1.29%	-0.71%	-2.78%	2.48%	-1.40%
	Moderate	ccsm4.6	RCP 8.5	248,359	131,022	204,461	37,650	713,808	4.23%	0.53%	3.99%	1.06%	3.22%
	Wet/Warm	canesm2.1	RCP 8.5	247,910	130,457	202,628	34,233	706,583	4.04%	0.10%	3.06%	-8.11%	2.17%
	Dry/Warm	miroc-esm.1	RCP 8.5	264,703	132,709	221,298	40,470	757,691	11.09%	1.82%	12.55%	8.63%	9.56%

Table 8-3 Comparison of Climate Change Water Demand Scenarios for 2045 with Adjustments to Crop Requirements

Climate Projection Period	Scenario	GCM	RCP	2045 Water Demand (Acre Feet)					Percent Difference from Normal				
				SF	MF	NR	AG	Total Production	SF	MF	NR	AG	Total Production
Historical	NORMAL			238,279	130,331	196,615	37,255	691,552	0.00%	0.00%	0.00%	0.00%	0.00%
2040-2060	Wet/Cool	ec-earth.8	RCP 4.5	233,020	129,339	190,299	36,655	676,333	-2.21%	-0.76%	-3.21%	-1.61%	-2.20%
	Dry/Cool	giss-e2-r.6	RCP 4.5	233,497	129,294	189,647	39,663	679,892	-2.01%	-0.80%	-3.54%	6.47%	-1.69%
	Moderate	access1-0.1	RCP 4.5	234,993	129,597	191,437	38,190	682,157	-1.38%	-0.56%	-2.63%	2.51%	-1.36%
	Wet/Warm	hadgem2-ao.1	RCP 8.5	242,049	130,120	197,615	38,590	698,732	1.58%	-0.16%	0.51%	3.59%	1.04%
	Dry/Warm	miroc-esm-chem.1	RCP 8.5	244,524	130,565	200,498	41,495	708,917	2.62%	0.18%	1.97%	11.38%	2.51%
2079-2099	Wet/Cool	ec-earth.8	RCP 4.5	232,082	129,000	188,653	35,224	671,342	-2.60%	-1.02%	-4.05%	-5.45%	-2.92%
	Dry/Cool	gfdl-esm2g.1	RCP 4.5	235,198	129,405	191,153	40,129	684,310	-1.29%	-0.71%	-2.78%	7.72%	-1.05%
	Moderate	ccsm4.6	RCP 8.5	248,359	131,022	204,461	40,210	716,988	4.23%	0.53%	3.99%	7.93%	3.68%
	Wet/Warm	canesm2.1	RCP 8.5	247,910	130,457	202,628	39,074	712,498	4.04%	0.10%	3.06%	4.88%	3.03%
	Dry/Warm	miroc-esm.1	RCP 8.5	264,703	132,709	221,298	45,654	764,034	11.09%	1.82%	12.55%	22.55%	10.48%

9. Summary and Recommendations

The update of the Water Authority's baseline water demand forecast was initiated in conjunction with the preparation of the Water Authority's 2020 Regional Urban Water Management Plan. A set of econometric equations was developed, which transform projections of socioeconomic, demographic, and other model inputs into forecasts of water use. The estimation of the predictive equations and update of the long-term water demand forecast reflects a periodic and adaptive cycle of improvements undertaken on behalf of the Water Authority to develop and maintain reliable data and methodologies for water demand and supply planning.

The development of the new water demand forecasts and predictive equations relied on an extensive data collection process, which was facilitated by Water Authority staff and involved the help of member agencies. The equations fundamentally rest upon historical water use data from the Water Authority's member agencies, as well as historical information on weather, the price of water, and socioeconomic factors that influence water use. The updated equations were estimated using multiple regression procedures that are well-suited for pooled, time-series and cross-sectional, data. The estimated equations were shown to have rational parameter estimates and reasonably high predictive power in reproducing water use over a 180-month model estimation period, which includes periods of robust economic growth, the Great Recession, and severe drought. The equations are built not only to capture socioeconomic differences across the Water Authority service area, but also the underlying response of water use to weather and climate, which can vary markedly across the Water Authority's service area.

Using the updated predictive equations, baseline (without future conservation) forecasts were prepared out to 2045 in 5-year increments. Forecasting equations were calibrated over a three fiscal year base period (FY 2013, FY 2014 and FY 2018). Two of the three selected fiscal years come before the most recent drought period and the third selected fiscal year represents the last full fiscal year of member agency water billing data compiled for the model update. The selection of these time periods was intended to balance pre-drought conditions with post-drought conditions that may still be dampened due to the severe water use restrictions. All SANDAG variables were also averaged across the three fiscal year base period. Trends in the baseline forecasts are a direct function of SANDAG's forecast of regional growth and demographics between the three fiscal year base period and 2045.

For the Water Authority as a whole, total baseline production demands are projected to increase at an annual average rate of about 0.7 percent per year to about 691,552 acre feet in 2045 not counting the potential impacts of future water conservation efforts. Water use in the multifamily sector is forecast to grow faster than all other water use sectors over the forecast period (increasing by 31 percent by 2045). Projected growth in the nonresidential sector is forecast to experience a 21 percent change, while single-family water use is forecast to increase by about 7 percent by 2045. Projections of the future number of households are generally the most impactful factor for the projected increases in baseline residential water use. However, variables such as housing density and persons per household influence future demands a well. Meanwhile, growth in total employment and the relative shares of jobs in specific industries are significant factors underlying the projected increase in water demand in the nonresidential sector. Agricultural demands are projected to decrease by about 3.4 percent over the forecast period. The forecast decline in agricultural use is tied directly to projected declines in the amount of acreage devoted to agricultural production in the Water Authority service area.

The update of the Water Authority's long-term water demand forecasts also included the development of a single hot/dry year scenarios, as well as 2-, 3-, 4- and 5-year consecutive dry year scenarios. Using the weather components of the sectoral water demand equations, an indexing procedure was developed to combine observations on temperature and precipitation into a commensurable index for measuring the degree of heat/moisture over any particular time interval. For each member agency, the index procedure was used to select a historically observed sequence of weather conditions that was substituted into the sectoral water use equations for scenario analysis.

Under the single hot/dry year scenario, forecasted Water Authority demands in 2045 are just under 750,000 acre feet, or about 8 percent higher than the forecast under the assumption of normal weather conditions. A two-year dry spell is projected to increase the total baseline forecast by about 11 percent over the normal weather scenario. Additional consecutive dry years result in progressively higher baseline demand projections. However, it is unlikely such a severe dry spell would endure without corresponding demand management measures.

Finally, the weather components of the sectoral equations were used to evaluate the potential impacts on water use for five climate change scenarios over two 20-year projection periods (2040-2060 and 2079-2099). Across all five scenarios, the mean percent difference from the 2045 baseline forecast ranges from -2.34 to +2.09 for 2040-2060 climate projections and from -3.13 to +9.56 for 2079-2099 climate projections. However, if agricultural crop ET requirements are assumed to change similarly to average high temperatures, the ranges change from -2.20 to +2.51 percent for 2040-2060 projected climate and from -2.92 to +10.48 percent for 2079-2099 projected climate.

9.1 Recommendations

It is recommended that the Water Authority continue its periodic updates and refinements of its water demand forecasting procedures. As new SANDAG projections become available, the long-term water demand forecasts should be updated accordingly to reflect new assumptions regarding socioeconomic trends and long-term growth patterns among the Water Authority's member agencies. Furthermore, each update to the water use models and long-term forecast yields the benefits of a longer time series of member agency water sales data, including the ability to re-estimate sectoral water use models in order both to detect and reflect emerging trends in water use.

The following additional recommendations are also offered for consideration:

Verify and validate SANDAG data generation processes for developing demographic and land use projections. SANDAG socioeconomic projections serve as crucial inputs to the demand model. For this update SANDAG changed some of its processes used to generate projections, which affected the integration of projections made in the past and required additional analyses and judgments for both model and forecast development. The Water Authority should work with SANDAG to establish a firmer understanding of how projections are produced and connected to historical data in order to (a) preempt unanticipated changes in projection processes that may influence modeling and (b) collaborate on the availability of additional regional land use data that could be used in the modeling and forecasting process.

Parameterize the effects of passive water savings within the forecast model development process. The forecasts that are presented in this report are baseline forecasts that do not account for the effects of future water conservation programs and on-going increases in the technical efficiency associated with many water end uses. While these estimates were developed using a water end-use model and accounting procedure and accounted for in the 2020 Urban Water Management Plan, this output could be used to parameterize the impacts of passive water efficiency directly within the econometric forecast models. This would permit statistical assessment of uncertainty related to the rate and intensity passive efficiency is expected to occur. It is possible that SANDAG or other local planning departments could provide additional characteristics on the existing housing stock that could lead to the statistical parameterization of passive efficiency trends.

Develop and implement standardized billing data collection mechanisms. As recommended in previous studies, an automated water use reporting mechanism between the member agencies and the Water Authority could also be designed to reduce the cost of data collection and to provide a means through which the Water Authority might encourage standard water use reporting procedures. Such a mechanism might also enable the Water Authority to identify suspicious or outlying records that could be validated in consultation with member agencies. Routine and periodic collection of sector data would present additional opportunities for evaluating water demand patterns in addition to examining total Water Authority deliveries and regional water produced. Furthermore, differences in customer classifications and lack of class disaggregation continue to affect the design and sector disaggregation of the water use models and forecasts. This and prior modeling and forecast updates have relied on a standardized set of sectors. However, it is likely that some member agencies have more detailed classification schemes that may lie behind the data provided for the forecast model updates. A water demand data working group could be established and coordinated by the Water Authority to develop and promulgate guidance and standardization on the customer and land use classification schemes that might improve upon existing practices and broaden the analytical and planning capabilities associated with water use data.

Re-visit probabilistic procedures for incorporating forecast uncertainty. Predictions of future water demand are conditioned on assumed values and assumptions regarding the future values of explanatory variables contained in the sectoral forecasting models. The forecasts derived in this study are deterministic point forecasts in that they implicitly assume 100 percent accuracy of model inputs that are defined by single values in any point in time. By construction, the forecasts do not recognize the likelihood that the key predictive factors are both variable and uncertain in any future time period. Past studies conducted for the Water Authority have demonstrated that it is possible to quantify overall forecast uncertainty in the Water Authority forecast using statistical and mathematical techniques. Measurement and portrayal of the impact of uncertainty on the Water Authority's long-term water demand forecasts may be timely with respect to other water supply planning efforts that may require more future scenarios than a single deterministic baseline projection.

Establish a forecast monitoring and update process. The predictive models that were derived as part of this project are intended for forecasting water use over relatively long-time horizons. Although the models (and associated elasticities) are designed primarily for the purpose of longer-term planning, the models follow a monthly and yearly time step, which provides the capability of predicting water use over shorter intervals. Development of annual forecasts and comparison with observed water use might assist the Water Authority in adapting to changes in water use and related weather and socioeconomic conditions and evolving behavioral aspects related to outdoor use. In particular, the degree of rebound from severe water use restrictions is highly uncertain and should be tracked. The same goes for other unanticipated events such as the COVID-19 pandemic. Establishing an annual process of evaluating the performance of the models in tracking short-term demands would provide a periodic opportunity to address demand trends that may not be detected by the models or by SANDAG socioeconomic projections. Periodic input of recent weather and pricing data could help determine whether model predictions adequately follow observed patterns in water use, and the degree to which prediction errors might be associated with random or unmeasured phenomena versus structural or emerging shortcomings of the models. This monitoring and update process would involve periodic (e.g., annual) collection of member agency sectoral water use and pricing data. Tracking of model performance over time would permit a regular assessment, which would support judgments regarding the need for additional model calibrations and/or the need to revise model parameters. This process would be consistent with the development of new and routinized data collection mechanisms recommended above.