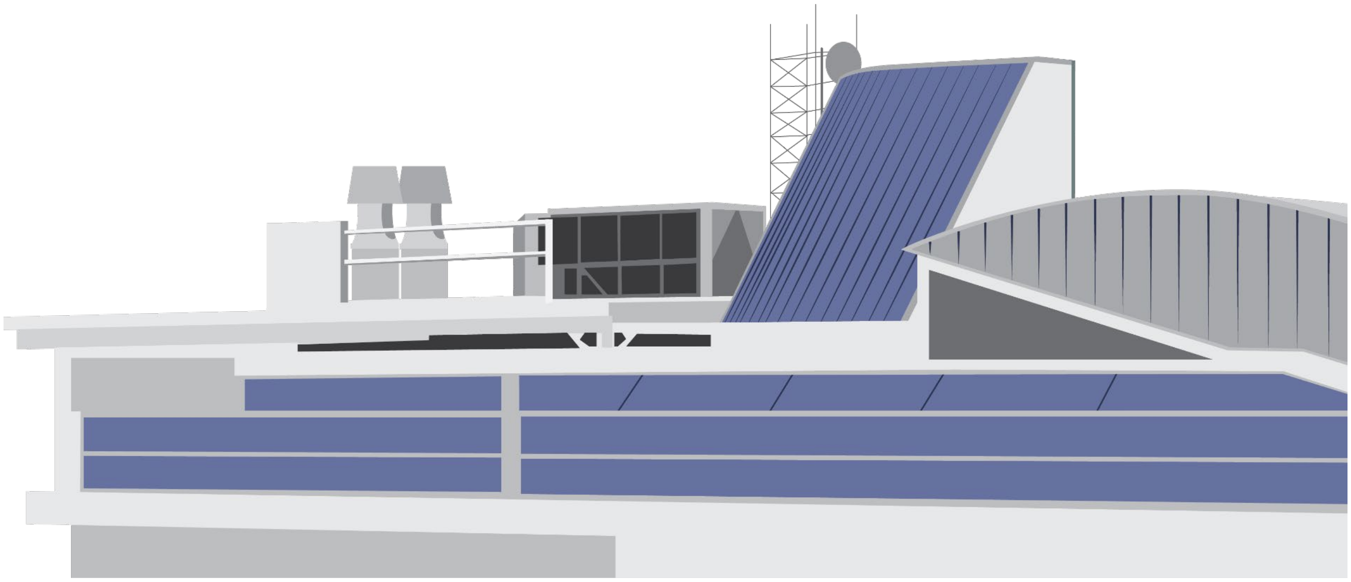
Long Beach Water

Water Resources Plan



December 2019

Report prepared by:

CDM Smith

Table of Contents

List of Figures

List of Tables

Section 1

Introduction

The Long Beach Water Department (LBWD) was founded in 1911 by combining two private water suppliers, the Long Beach Water Company and the Alamitos Water Company, and serves the City of Long Beach (City). In 1931, the City voted to become one of the original 13 member agencies of the Metropolitan Water District of Southern California (MWD). MWD is the regional wholesale water agency that provides imported water to five counties in Southern California. Another election in 1931 led to the creation of the LBWD Board of Water Commissioners that has since been comprised of five appointed members of the Long Beach community who serve up to two 5-year terms.

The LBWD mission is:

- To deliver an uninterrupted supply of quality water to our customers;
- To effectively dispose of or reclaim sanitary sewage; and
- To operate in an economically efficient and environmentally responsible manner.

1.1 Water Resources Plan Purpose and Development

To help guide future water supply decisions and investments, LBWD embarked on development of its first Water Resources Plan (WRP). The purpose of the WRP is to provide a long-term water resources strategy that meets specified objectives and adapts to changing future conditions such as: (1) threats to local groundwater and imported water; (2) regulatory requirements; and (3) climate change.

1.1.1 Planning Process

The process used to develop the WRP is shown in **Figure 1-1**. The process started by forecasting water demands, assessing water supply availability under droughts and other situations, developing planning scenarios that describe possible future conditions, and establishing a range of future water supply needs for LBWD. Then various regional water supply projects and local supply options available to LBWD were assessed in terms of supply yield, certainty, cost, implementation challenges, environmental impacts, and other attributes. The local supply options available to LBWD were compared and ranked against a set of evaluation criteria. And finally, an adaptive management strategy and set of recommendations were formulated.

During the planning process, public stakeholders participated through four workshops, which are described later in this section.

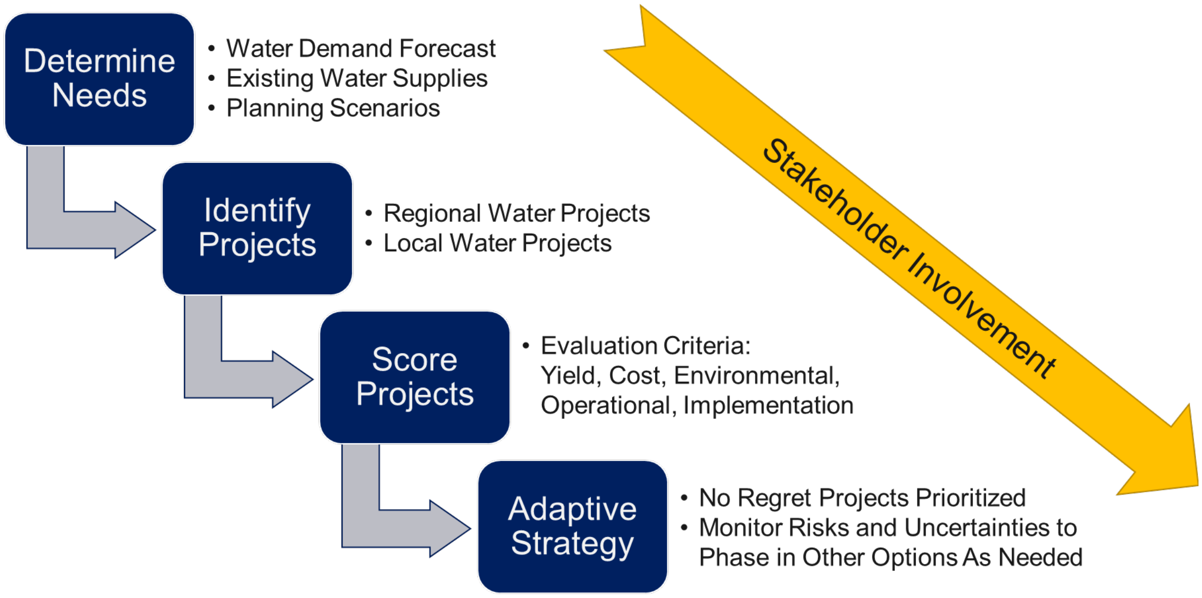


Figure 1-1. LBWD WRP Planning Process

To develop the WRP and its recommendations, the following technical efforts were utilized:

- **Econometric Water Demand Forecasting** – Multivariate statistical regression was used to account for the major factors that influence water use by water billing sector, such as weather, price of water, income, water use efficiency, lot size and employment mix. These factors were then used to forecast water demands through 2050.

- **Water Supply Simulations** – Using a CDM Smith-developed systems model of MWD's imported water and local groundwater, simulations of imported water availability and local groundwater basin levels were performed under historical and climate-changed hydrologic conditions. This resulted in estimates of the probability and potential size of water shortages for LBWD under different assumptions of hydrology and implementation of regional and statewide water projects that could mitigate water shortages for LBWD.

- **Scenario Planning** – Given that the future is uncertain, planning scenarios were used to determine the range of water shortages for LBWD and helped define the need for new local water supply investments. Scenarios represented different assumptions for water demands, implementation of MWD regional water supply projects, and levels of climate change impacts.

- **Ranking LBWD Water Supply Options** – New supply options available to LBWD were characterized based on previous studies. Then multi-criteria decision analysis (MCDA) was used to rank the supply options in terms of reliability of supply, unit cost, system integration, environmental impacts, and implementation challenges.

1.1.2 Adaptive Management

A key feature of the WRP is the development of an adaptive management strategy that provides a flexible roadmap for LBWD in the development of future supply projects and operations. Rather than having a prescriptive plan that lays out the exact timeframe for specified projects to be implemented, the WRP uses uncertainty triggers, which are defined and monitored over time to help identify what future is more likely to occur and which options should be implemented to address that future. Based on the adaptive strategy, recommendations for near-term, mid-term, and long-term actions are developed as guidelines for LBWD that should be re-assessed at least every 10 years, with mid-course adjustments every 5 years (aligned with LBWD's preparation of its Urban Water Management Plan).

1.2 Stakeholder Involvement and WRP Objectives

1.2.1 Public Stakeholder Involvement

To help guide the development of the WRP, LBWD invited key public stakeholders to participate in a series of workshops. The stakeholders represented a broad range of public interests for Long Beach and the greater region of Los Angeles County. **Table 1-1** lists the stakeholders and their affiliation.

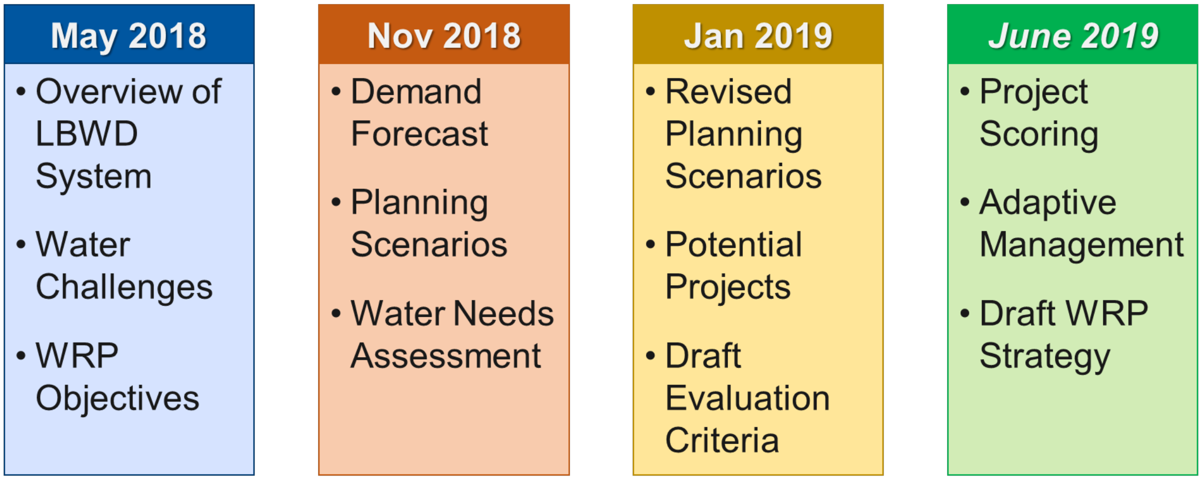
Table 1-1. LBWD WRP Stakeholders

Name	Title	Agency/Affiliation
Richard Cameron	Managing Director, Planning & Environmental Affairs	Port of Long Beach
Kai Craig	Board Member	Surfrider Foundation
Suzanne Dallman	Associate Professor of Geography	California State University, Long Beach and former LBWD Board Commissioner
Sean Gamette	Managing Director, Engineering Services	Port of Long Beach
Terri Shea	Operations Manager	Apartment Association, California Southern Cities
Carolyn Smith-Watts*	Citizen	Long Beach Resident
Dinesa Thomas	Director of Outreach, Advocacy, and Policy	Habitat for Humanity of Greater Los Angeles
Paul Wingco	Interim Director, Facilities Management	California State University, Long Beach
Johanna Woollcott	President	Association of Professional Landscape Designers

* Most unfortunately, Ms. Smith-Watts passed away in May 2019.

The stakeholder workshops set the stage for why the WRP was being developed, provided information on local and imported water, presented future water supply options for consideration, and benefited from input on strategies and recommendations.

Figure 1-2 presents the dates and topics discussed for the four stakeholder workshops held during the development of the WRP. Each workshop was facilitated in order to ensure that topics were presented in a transparent and understandable fashion, and that all stakeholders were provided the opportunity to engage and provide feedback.



May 2018	Nov 2018	Jan 2019	*June 2019*
Overview of LBWD System	Demand Forecast	Revised Planning Scenarios	Project Scoring
Water Challenges	Planning Scenarios	Potential Projects	Adaptive Management
WRP Objectives	Water Needs Assessment	Draft Evaluation Criteria	Draft WRP Strategy

Figure 1-2. LBWD WRP Stakeholder Meetings

The stakeholders were invaluable in providing insight throughout the WRP development. Specifically, the group helped shape the WRP objectives, tailored the planning scenarios used in the supply needs assessment, provided feedback on the proposed water supply options and evaluation criteria, and provided comments on the draft adaptive management strategy.

1.2.2 LBWD Board of Commissioners Participation

In addition to the public stakeholder workshops, two half-day LBWD Board workshops were held to present findings to date and solicit input from the Board. The first Board workshop, held on November 1, 2018, presented the assumptions, methodology and results of the comprehensive water demand forecast. The second Board workshop, held on May 23, 2019, presented the planning scenarios, summarized the availability of local and imported water under a wide range of future conditions, and presented potential supply options available for LBWD. In addition, during the second workshop Board members participated in: (1) a discussion of evaluation criteria that were used to rank potential supply options; and (2) a weighting exercise where Board members provided input on the relative importance of each of the evaluation criteria.

1.2.3 WRP Objectives

To guide the development of the WRP, a set of planning objectives were defined. These objectives were developed in coordination with LBWD and public stakeholders and presented to the LBWD Board for input. The resulting WRP objectives are defined as:

- Provide reliable water supply service to customers
- Increase resiliency of the water system during droughts and unexpected disruptions
- Meet all primary drinking water regulations (health) and secondary water quality goals (taste/odor/color)
- Deliver water services in an equitable and cost-effective manner
- Protect and enhance the local and regional environment
- Maximize success of WRP implementation
- Through public outreach and education, increase public awareness of the WRP

1.3 Report Organization

The WRP Report is organized as follows:

- Section 1 – Introduction
- Section 2 – Long Beach Water Department Service Area
- Section 3 – Water Demand Forecast
- Section 4 – Water Source Reliability
- Section 5 – Water Supply Needs Assessment
- Section 6 – Supply Project Options
- Section 7 – Ranking Water Supply Options
- Section 8 – Strategy and Recommendations
- Section 9 – References
- Appendix A – Water Demand Forecast Methodology and Detailed Analysis

This page intentionally left blank.

Section 2

Long Beach Water Department Service Area

2.1 Service Area Overview

2.1.1 Potable Water Supply Service Area

LBWD’s potable water service area, located in southwest Los Angeles County, covers roughly 52 square miles, identical to the boundary of the City of Long Beach (see **Figure 2-1**).

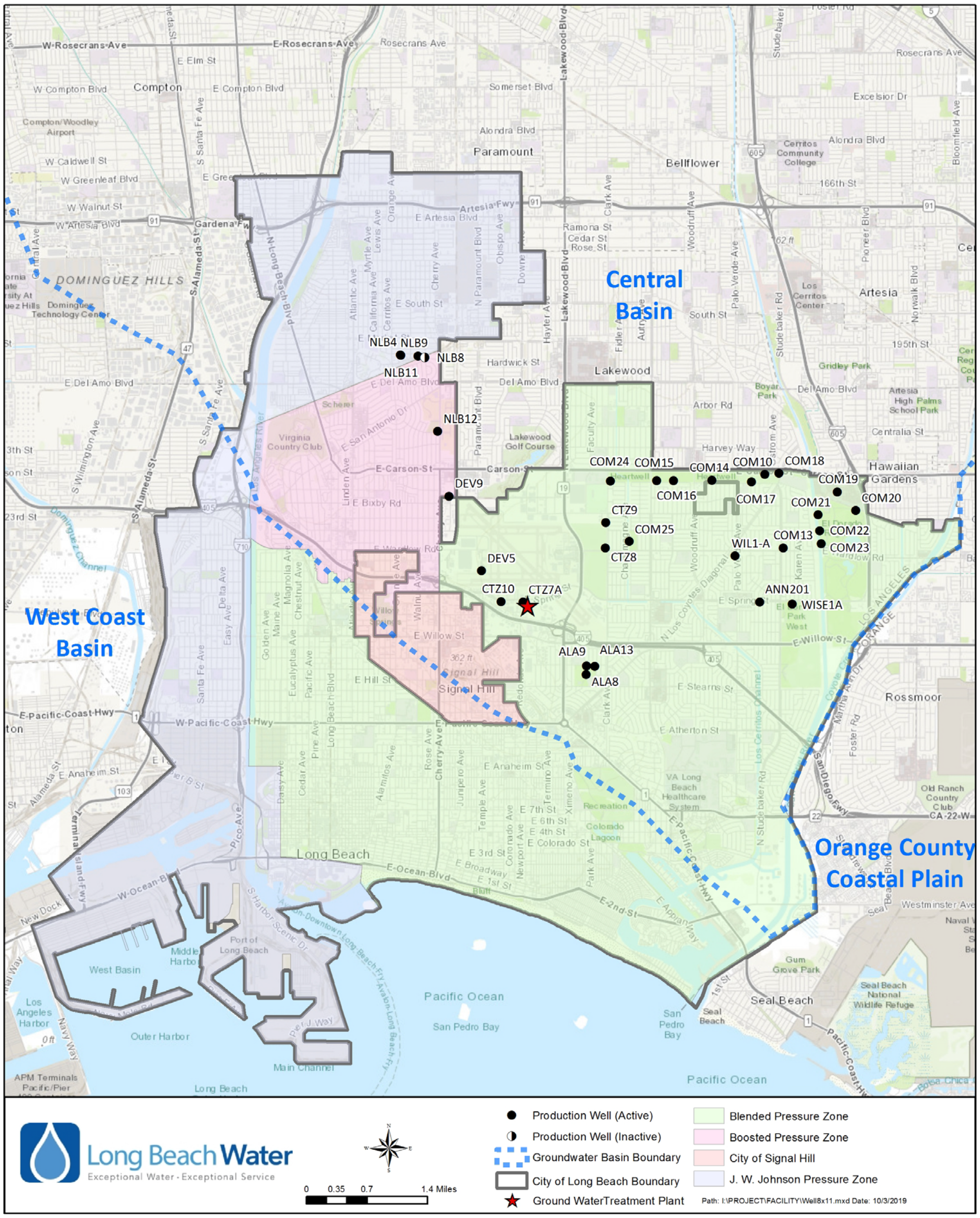


Figure 2-1. LBWD Potable Water Service Area

Figure 2-1 also shows the three pressure zones for LBWD's water system (as shown in green, pink and blue). Note that the City of Signal Hill (shown in orange) is a separate water system that is not served by LBWD. The Blended Pressure Zone (green) and Boosted Pressure Zone (pink) are served with a mix of local groundwater and purchased treated imported water from MWD. The J.W. Johnson Pressure Zone (blue), which is west of the Los Angeles River, only receives treated imported water from MWD due to its distance from the groundwater wells and LBWD's recycled water system. Active groundwater production wells are shown as full black circles on the map. All wells are networked to a centralized water treatment plant, that undergoes a multi-stage treatment process and rigorous testing to ensure it meets strict federal and state standards.

2.1.2 Service Area Population and Water Demands

The current population in the LBWD service area is approximately 490,000. The Southern California Association of Governments (SCAG) forecasts the service-area population to reach approximately 577,000 by 2050. As the City of Long Beach is built-out with fairly dense development around a core downtown center, this growth will mostly be re-development in expansion of multi-family housing.

Current potable water demands are roughly 50,000 acre-feet per year (AFY), down substantially from the historical peak demand of 70,000 AFY in 2007. This decrease in water demands is due to increases in water use efficiency and densification of urban development. Increases in water efficiency are a result of state plumbing codes, local landscape ordinances, and LBWD's water conservation program that provides education and incentives to replace older water-using fixtures with more efficient ones and replacement of turf with California-Friendly landscaping.

The current per capita water demand for LBWD is about 109 gallons per capita per day (GPCD), significantly lower than the California state average of 200 GPCD.

2.1.3 Water Supply Sources Overview

Approximately 30,000 to 35,000 AFY of water, close to 60% of LBWD's total potable demand, can be supplied from local groundwater. The remaining 40% of potable water demand is supplied by purchases of imported water from MWD. Non-potable water demands in the LBWD service area range from 6,000 to 7,000 AFY and are served by treated effluent from the Long Beach Water Reclamation Plant (LBWRP). The LBWRP is operated by the Los Angeles County Sanitation Districts (LACSD). However, all the effluent collected in the LBWRP sewershed belongs to LBWD for use or to sell.

Figure 2-2 presents the sources of potable and recycled water supply for LBWD, showing the conveyance of the imported water from the State Water Project and Colorado River that MWD provides to Southern California.

Figure 2-2. LBWD Water Supply Sources

2.2 Local Groundwater Supply

Two groundwater basins underlie the LBWD service area; the Central Basin spans the northeastern area while the West Coast Basin is located in the southwest portion of the City.

Impermeable layers of clay and silt confine the Central and West Coast Basins in the vicinity of Long Beach and prevent rainfall from percolating into the groundwater aquifer, so basin replenishment occurs north of Long Beach in the Whittier Narrows area through percolation basins at the Rio Hondo and San Gabriel spreading grounds in the Montebello Forebay. Replenishment at the spreading grounds uses a combination of local stormwater runoff, purchased imported water, and recycled water.

The Water Replenishment District of Southern California (WRD) manages the groundwater in both the Central and West Coast Basins. WRD protects the basins through artificial groundwater replenishment, ensuring that aquifers maintain healthy levels, and routinely monitors water quality of groundwater to ensure it meets all health standards. **Figure 2-3** shows the groundwater basins and recharge locations relative to the City.

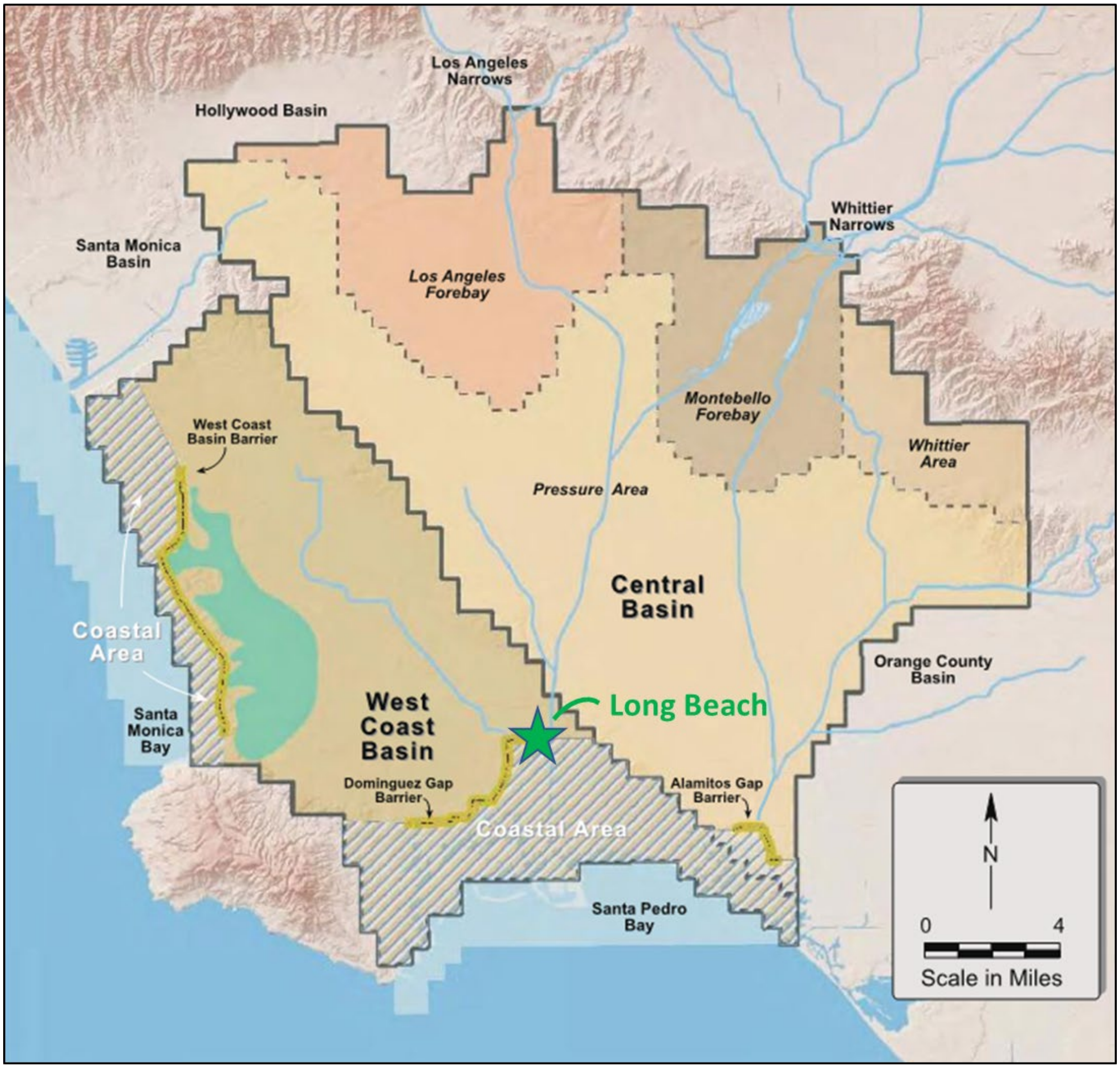


Figure 2-3. Groundwater Basins Relative to City of Long Beach

2.2.1 Central Basin

LBWD has an Allowable Pumping Allocation (APA) of 32,692 AFY from the Central Basin and currently pumps all its groundwater supply from this source. Most of the recharge of the Central Basin occurs at the Montebello Forebay and is comprised of four sources as described in **Table 2-1**.

Table 2-1. Central Basin Recharge Sources

Source	Description
Stormwater and River Baseflow	Mountain front recharge and incidental precipitation contribute to storm and base flows of the Rio Hondo and San Gabriel Rivers.
Makeup Water	According to the 1964 Long Beach Judgement, the Upper Area of the San Gabriel River system must provide an average useable supply of 98,415 acre-feet of water to the Lower Area Parties. The 98,415 acre-feet is the average of tabulated deliveries dependent on a 10-year period of rainfall for San Gabriel Valley.
Imported Water	WRD purchases untreated imported water from MWD for groundwater replenishment in spreading grounds in Montebello Forebay.
Recycled Water	WRD buys recycled water from LACSD's water reclamation plants for groundwater recharge at the Montebello Forebay. These treatment plants include the Whittier Narrows Water Reclamation Plant (WNWRP), the San Jose Creek Water Reclamation Plant (SJCWRP), and the Pomona Water Reclamation Plant (PWRP).

WRD plans to replace the imported water for groundwater replenishment with advanced-treated recycled water generated by the Albert Robles Center for Water Recycling & Environmental Learning (Albert Robles Center), which was formally known as the Groundwater Reliability Improvement Project (GRIP). This facility will produce 10,000 AFY of purified water from the San Jose Creek Water Reclamation Plant (SJCWRP) and convey it to the Central Basin spreading grounds at the Montebello Forebay. The purified water will be blended with another 11,000 AFY of recycled water (also from a SJCWRP connection) to deliver 21,000 AFY of water to the San Gabriel Coastal Spreading Grounds.

Alamitos Barrier

The Alamitos Barrier protects groundwater in the Central Basin from coastal seawater intrusion. The barrier injects recycled water supplied by LBWD and imported potable water purchased from MWD to prevent saltwater from contaminating the fresh water aquifer.

Reclaimed water for the Alamitos Barrier is supplied from the Leo J. Van der Lans Advanced Water Treatment Facility (LVL AWTF), owned by WRD. WRD purchases Title 22 tertiary treated reclaimed water from LBWD as influent supply. LVL AWTF has the capacity to supply 100% of the Alamitos Barrier's needs.

Storage Accounts

Water recharged at the Montebello Forebay takes several decades to travel to the LBWD groundwater wells, resulting in a complicated basin storage and overdraft calculation. The concept of "Average Annual Groundwater Deficiency" (AAGD) is used to determine necessary pumping restrictions. The average annual groundwater deficiency is the long-term average of natural inflows minus total outflows.

The annual overdraft is calculated based on the differences between the current water year and average water year values for natural recharge and groundwater extractions. The AAGD indicates that on average, WRD needs to replenish about 105,385 AFY for groundwater levels to remain relatively constant.

2.2.2 West Coast Basin

Natural replenishment of the West Coast Basin's groundwater supply is largely limited to underflow from the Central Basin through and over the Newport-Inglewood fault zone. There is also artificial recharge associated with the operation of seawater intrusion barriers. Long Beach has an 0.7 AFY APA in this basin.

Dominguez Gap Barrier

The Dominguez Gap Barrier, located in the southern portion of the West Coast Basin, is supplied approximately 50% by imported water from MWD and 50% recycled water from the City of Los Angeles Department of Public Works - Bureau of Sanitation Terminal Island Water Reclamation Plant/Advanced Water Purification Facilities (TIWRP/AWPF).

West Coast Barrier

The West Coast Barrier is supplied with imported water from MWD and reclaimed water from West Basin Municipal Water District (WBMWD) Edward C. Little Water Recycling Facility (ECLWRF).

The amount of recycled water injected into the West Coast Barrier has increased from 50% to 75%. WBMWD is working with WRD to increase the amount of recycled water injected into the Barrier to 100%.

2.2.3 LBWD Groundwater Facilities

Figure 2-4 portrays the boundary between the Central and West Coast Basins and indicates that LBWD has 27 operational pumping wells located in the north eastern portion of their service area in the Central Basin, while there are not currently any operational production wells in the West Coast Basin.

The LBWD central groundwater treatment facility is the second largest groundwater treatment plant in the United States. An individual pump at each Central Basin well conveys water to the 62.5 MGD treatment plant near Long Beach Airport. The plant has sufficient area to expand another 12.5 MGD if further groundwater development occurs. The treated groundwater is mixed with MWD water, then lifted to the Alamitos Reservoir to be stored and distributed to customers.

2.3 Imported Water Supply from MWD

MWD is the regional wholesale water provider for much of the Southern California region, serving 26 public member agencies in five counties, with a service area population of over 19 million people. MWD's wholesale water deliveries supplement local water supplies that many of its member agencies and sub-agencies have access to, including groundwater, surface water, recycled water, and desalinated seawater.

MWD imports water from the Colorado River via its Colorado River Aqueduct (CRA), and the Sacramento-San Joaquin Delta (Delta) via the State Water Project (SWP) which carries water to Southern California via large canals, pipes, tunnels and pump/lift stations. Large SWP and MWD surface reservoirs are used to store imported water when it is plentiful for later use during dry years. In addition, MWD has developed and participates in a number of groundwater storage/banking programs and water transfers/exchanges/fallowing programs from agricultural water districts to supplement its imported water. Over the last 25 years, MWD has also provided millions of dollars to support water conservation and help develop local resource projects implemented by retail water agencies in order to increase regional water supply reliability. This interdependence between MWD and its member agencies has been the foundation of MWD's Regional Integrated Resources Plan (IRP), which was first developed in 1996 and updated several times in subsequent years.

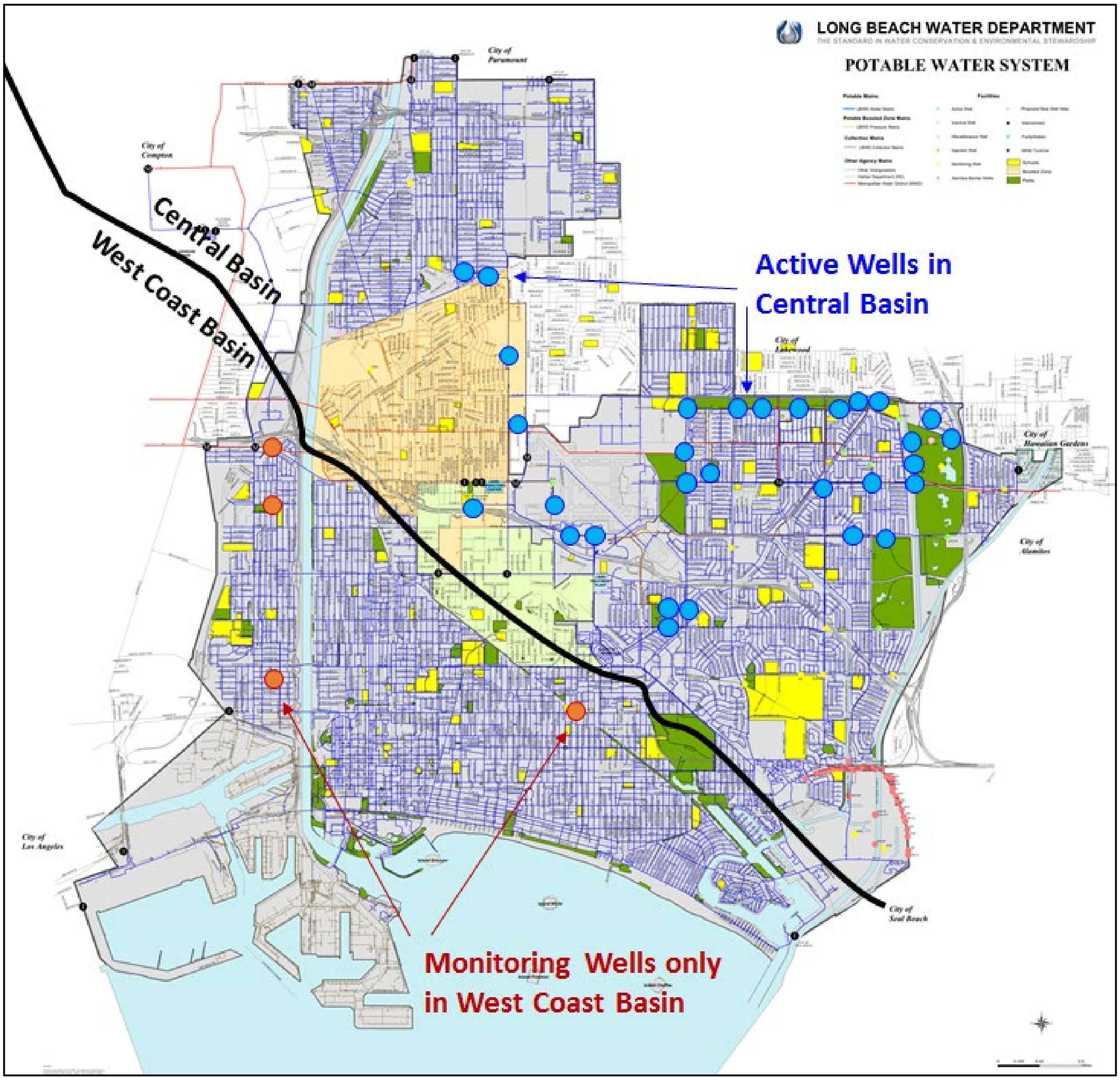


Figure 2-4. LBWD Groundwater Wells

When MWD's total storage that is allocated to drought protection decreases to certain thresholds, and MWD operations staff believe that its wholesale deliveries will not be able to fully meet the water demands of its member agencies, MWD enacts its Water Supply Allocation Plan (WSAP). Using formulas to adjust for member agency local water supplies, conservation and other considerations, MWD allocates its firm water to each member agency for the coming year when the WSAP is enacted. If a member agency's purchase of MWD water goes above this allocation it is subject to a penalty water rate that is currently $1,480/acre-foot (AF), which is charged above MWD's treated water rate (currently at $1,050/AF for 2019). Thus, the total MWD treated water cost for the portion of MWD purchased water above a member agency's allocation would be: $2,530/AF.

MWD has imposed water allocations to its member agencies in 1991, 2007 and 2008, and 2015. Modifications to the existing Bay-Delta Biological Opinions that impact exports from the SWP, more frequent and longer droughts affecting both the SWP and Colorado River systems, and new Colorado River Basin drought allocations to the lower basin states (including California) are all threats to imported water reliability. Future climate change could further exacerbate these threats making it more difficult for MWD to provide imported water reliably in the coming decades unless new statewide and regional water conveyance and supply projects are implemented.

2.3.1 Storage and Imported Water Facilities Serving LBWD

The Alamitos Reservoir, on Alamitos Hill, is LBWD's main storage system and is comprised of 21 steel water storage tanks each with a capacity of approximately 3.3 million gallons (MG) for a total capacity of 69 MG. The completion of the reservoir shaped the LBWD into a high-pressure zone and a "flow pressure" zone. The Alamitos Reservoir is used to serve a blend of treated MWD water and treated groundwater for distribution to the blended pressure zones.

The J. Will Johnson Reservoir was constructed in 1948 on Dominguez Hill to store MWD Colorado River source water for peak demand periods, as LBWD had only one feeder line to MWD's system at that time and summer demands exceed that feeder capacity. The J.W. Johnson Reservoir has a current capacity of approximately 40 MG comprised of twelve 3.3 MG tanks.

In total, the LBWD imported transmission system has 8 connections to MWD supply lines as presented in **Table 2-2**. **Figure 2-5** shows the location of MWD service connections and LBWD reservoirs.

Table 2-2. MWD Connections

MWD Connection	Location	Feeders & Laterals	MGD
LB 1	223rd & Hesperian	LB Lateral	45.42
LB 2	223rd & Santa Fe	LB Lateral	6.46
LB 3	223rd & Delta	LB Lateral	20.00
LB 4	Wilmington & Victoria	Victoria St. Lateral	51.60
LB 5	70th & Atlantic	Middle Feeder	12.90
LB 6	Greenleaf & LB Blvd.	Middle Feeder	4.85
LB 7	Wardlow & Woodruff	South Coast Feeder	19.35
LB 8	Wardlow & Cherry	2nd Lower Feeder	51.60

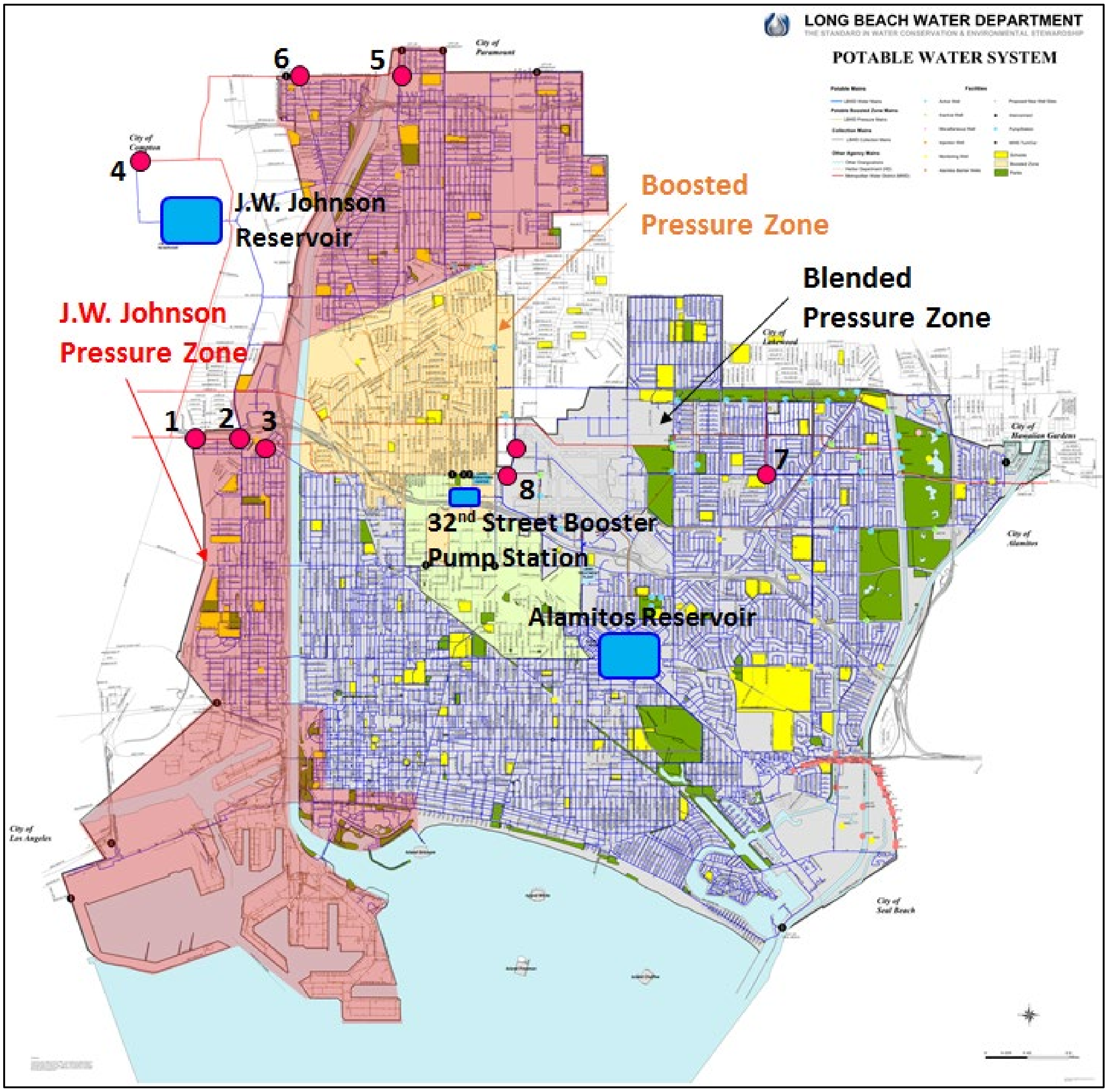


Figure 2-5. LBWD Connections to MWD's Imported Water

2.4 Recycled Water Supply

LACSD owns and operates the LBWRP. The LBWRP treats wastewater collected from the cities of Long Beach, Lakewood, Cerritos, and other parts of LA County. However, LBWD has exclusive rights to the full tertiary effluent from the LBWRP. LBWRP has a maximum treatment capacity of about 25 million gallons per day (MGD). The plant produces an average 17,300 AFY of recycled water.

2.4.1 Recycled Water Customers

Irrigation customers (golf courses and landscape) account for the majority of recycled water service connections within the LBWD service area. Golf courses in the LBWD service area have increased their irrigation efficiency and replaced turf with drought tolerant landscaping. As a result, golf course demand for recycled water is expected to decline into the future. Recycled water demand for irrigation other than golf courses including the City of Long Beach Parks and Recreation Department, as well as schools has increased.

The next largest single user of LBWD recycled water is THUMS Long Beach Company (THUMS), a consortium of oil companies named after the oil property's original shareholders, Texaco, Humble, Union, Mobil and Shell. THUMS extracts oil from the eastern offshore section of California's Wilmington oil field beneath Long Beach Harbor and uses recycled water for groundwater injection to re-pressurize offshore oil-bearing strata to prevent land subsidence. The use of recycled water by THUMS fluctuates with the volume of oil extractions. Over the past fifteen years, there has been a steady downward trend in the recycled water demand from THUMS.

The remainder of recycled water generated within the LBWD service area is projected to be for further treatment and injection into the Alamitos Seawater Barrier to prevent seawater from traveling into and degrading the groundwater in the Central Basin aquifer.

2.4.2 Wastewater Facilities

LBWD delivers over 40 MGD of sanitary sewage to Los Angeles County of Sanitation District (LASAN) facilities. Most of the wastewater is directed to the Joint Water Pollution Control Plant (JWPCP) at Carson to the northwest of the City, while the remaining portion is delivered to LBWRP.

Sewage solids that are removed from the effluent at LBWRP are returned to the trunk sewer and treated at JWPCP. Excess effluent that is not used by LBWD is discharged to Coyote Creek.

2.4.3 Recycled Water Facilities

The LBWD recycled water system consists of three 3.3 MGD tanks at Alamitos Reservoir and two pressure zones: a North Branch System, which flows to Virginia Lake, and a South Branch System which terminates at the intersection of Obispo Avenue and Second Street. Recycled water from Virginia Lake is used to serve the adjacent golf course. **Figure 2-6** shows the recycled water system.

Three booster pump stations distribute the recycled water. El Dorado and THUMS take the treated effluent from LBWRP and drive system distribution. The South Lake Pump Station is used at low pressure conditions to deliver recycled water to customers in Lakewood and Virginia Lake. If needed, the pump station may be used to draw water from the South Lake to meet these demands during periods of low LBWRP effluent. Water is re-supplied to the South Lake Reservoir when flows become available.

A single groundwater well at El Dorado park supplies untreated groundwater to El Dorado Park Lake via a backup booster pump station in case of emergencies and lack of non-potable supplies.

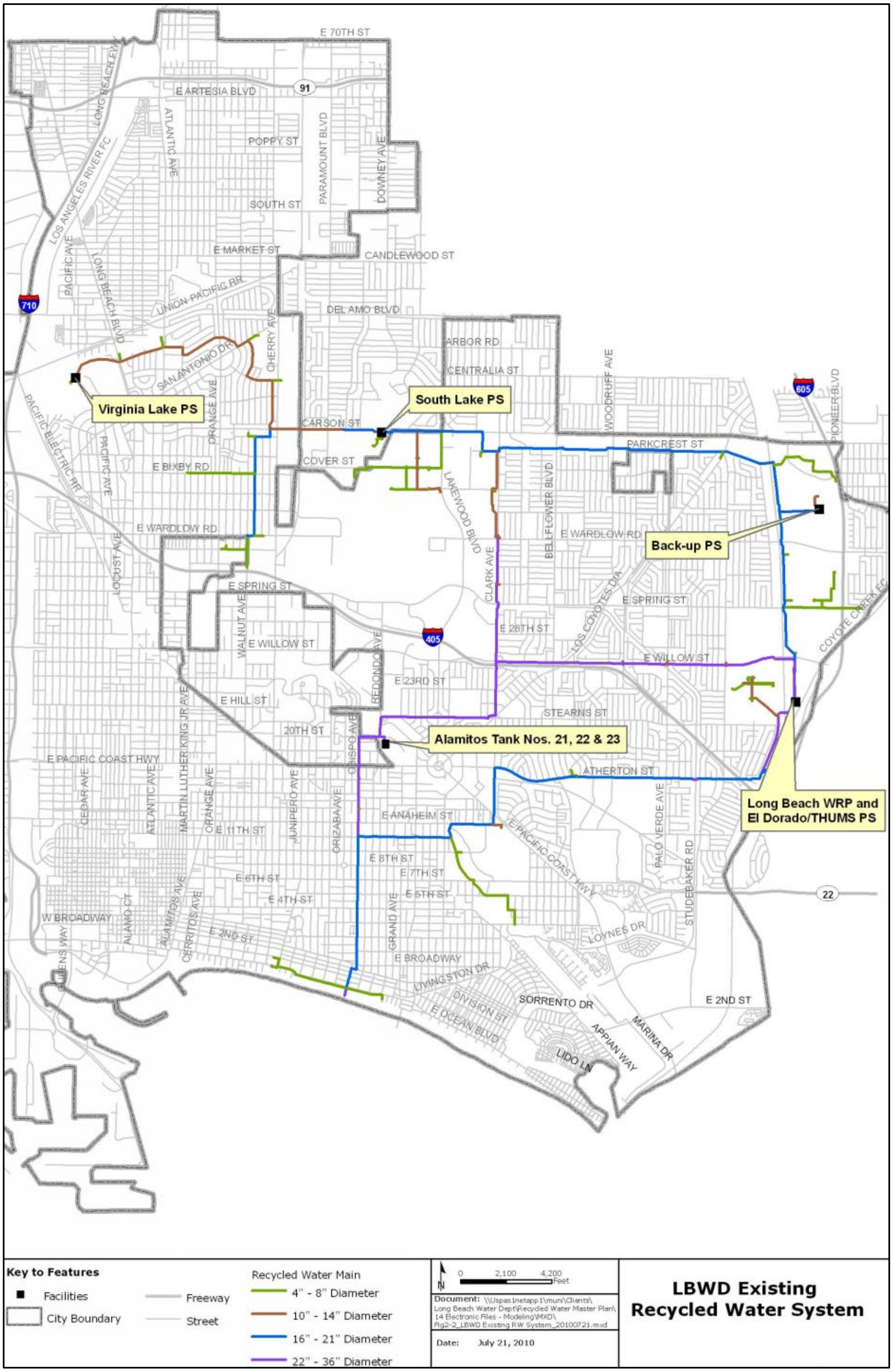


Figure 2-6. LBWD Recycled Water System

This page intentionally left blank.

Section 3

Water Demand Forecast

3.1 LBWD Demand Modeling Approach

A key component of the WRP was the development of a long-range forecast of water demands by customer type. Robust econometric demand models were developed for LBWD's billing customer types, defined as: single-family residential (SFR), multifamily residential (MFR), commercial (COM), industrial (IND) and irrigation (IRR).

An econometric method was selected over a more simplified per capita water use forecast because it allows for examination of the major factors that influence changes in water use over time. Econometric water demand forecasts are becoming the new standard for large water utilities in North America. Industry publications such as the American Water Works Association's Water Resources Planning M50 technical manual suggest the use of this approach for larger utilities with adequate resourcing and data.

Econometric demand models are developed through application of statistical techniques. Specifically, multivariate regression analysis is used to analyze the variation in a dependent variable (y) in relation to the variation in independent variables (x1, x2, … xn) over time. Econometric models, as opposed to standard statistical models, include independent variables such as income, price of water, and employment characteristics based on the theory that these economic variables have significant influence on water use.

The approach used for LBWD is as follows:

1. Estimate historical dependent variables for each customer type (or sector):
    - SFR per unit use (gallons per home per day) = SFR water demand (gal/day from LBWD billing data) ÷ Single-family dwelling units (including duplexes)
    - MFR per unit use (gallons per home per day) = MFR water demand (gal/day from LBWD billing data) ÷ Multi-family dwelling units
    - COM per unit use (gallons per employee per day) = COM sector demand (gal/day from LBWD billing data) ÷ Commercial employment
    - IND per unit use (gallons per employee per day) = IND sector demand (gal/day from LBWD billing data) ÷ Industrial employment
    - IRR per unit use (gallons per account per day) = IRR sector demand (gal/day from LBWD billing data) ÷ Number of irrigation accounts
2. Test independent variables for significance in explaining historical water use by customer sector (i.e., per unit water use), with the most robust variables included in final water demand models.

3. Project independent variables into the future and use demand model coefficients to forecast future per unit water use by customer sector.

4. Project driver variables, such as single-family housing units, multi-family housing units, employment, and irrigation accounts; and multiply drivers by forecasted per unit water use to get forecasted customer sector demands in AFY.

5. A factor for non-revenue (which includes fire protection, unaccounted for water, and system losses), based on difference between historical water production and billed water use, is added to the total of all customer sector demands in order to get total water demand.

3.2 LBWD Demand Model Variables

The variables incorporated into the final sector econometric demand function models for LBWD are described below. The variables fall into one of five general data categories: demographic, water use, weather, economic, and conservation.

3.2.1 Demographic Data

Historical demographic data were provided by LBWD based on the California Department of Finance (DOF) and the Southern California Association of Governments (SCAG) estimates from January 1990 to December 2018. Future forecasts were developed based on a 25-year linear trend extrapolated from the historical data. **Table 3-1** provides the historical and future demographic data for Long Beach. Historical demographic data was used to estimate historical per unit water use, which is used as the dependent variable in the econometric modeling; while projected demographic data was used as driver variables for the water demand forecast.

Table 3-1. Demographic Forecasts for Long Beach Based on 25-Year Trend Analysis

	1990	2000	2010	2020	2030	2040	2050
Population	423,845	460,325	471,205	496,616	517,822	539,027	560,232
Total Occupied Households	160,515	162,562	165,959	177,522	182,446	190,697	198,058
Single-Family Occupied Housing Units[1]	71,775	75,157	78,431	81,255	81,586	84,565	86,778
Multifamily Occupied Housing Units	88,740	87,405	87,528	96,267	100,860	106,132	111,280
Median Household Income (2000$)	$41,137	$36,434	$34,690	$43,669	$43,801	$43,874	$43,948
Employment, Total	231,926	193,532	164,759	175,357	177,431	183,486	191,375
Construction	6,041	4,900	2,929	4,299	4,299	4,435	4,600
Manufacturing	65,163	30,199	9,693	9,931	9,637	9,310	9,194
Transportation, Utilities & Communications	13,064	15,320	10,022	10,765	10,711	11,083	11,519
Wholesale Trade	5,993	8,692	5,953	6,725	6,974	7,284	7,803
Retail Trade	28,132	24,750	24,797	26,591	26,565	26,988	27,778
Finance, Insurance & Real Estate	10,424	6,713	6,403	7,467	7,550	7,793	8,116
Services	74,381	72,942	72,451	77,040	79,366	82,761	87,989
Public Administration	28,728	30,016	32,511	32,537	32,331	33,833	34,375

[1] The definition of single-family housing units represents both detached homes as well as attached duplexes.

Population is projected to grow by nearly 65,000 over the next 30 years, or about 13%. The number of households is projected to increase by more than 20,000, with two-thirds of that growth being multi-family housing. Employment is projected to grow at 9%, but with a decline in manufacturing employment.

To assess changes in the historical average single-family lot size, which impacts the water use per household, the county assessor databases were collected for 2006 and 2016. Using data on lot size and building footprint, irrigable lot size was calculated. Interpolation and extrapolation between 2006 and 2016 were used to generate annual values from 2004 to 2018 as shown in

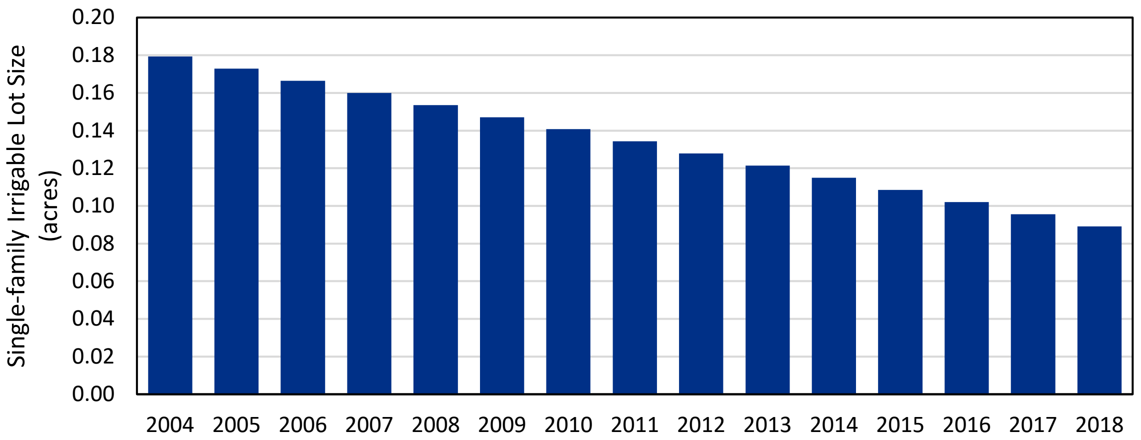


Figure 3-1. Single-family Irrigable Lot Size

3.2.2 Historical Water Use

Historical water use data by customer sector was acquired on a monthly basis from December 2004 to December 2017 from LBWD billing data. Average monthly demand for each type was converted to gallons per unit (or *driver)* per day. The driver is unique for each customer type and represents the primary demographic unit associated with the water use (e.g., for SFR water use the driver is single-family dwelling units, while for COM water use the driver is commercial employment).

Figure 3-2 presents the historical SFR water use, expressed in average gallons per occupied single-family household per day (SFR GHPD). Total SFR water use declined around 2008 and then again in 2015 despite increases in households. SFR GPHD declined from a high of 368 in the summer of 2006 to a low of 149 in 2017 likely in response to gains in water efficiency and increased densification in growth.

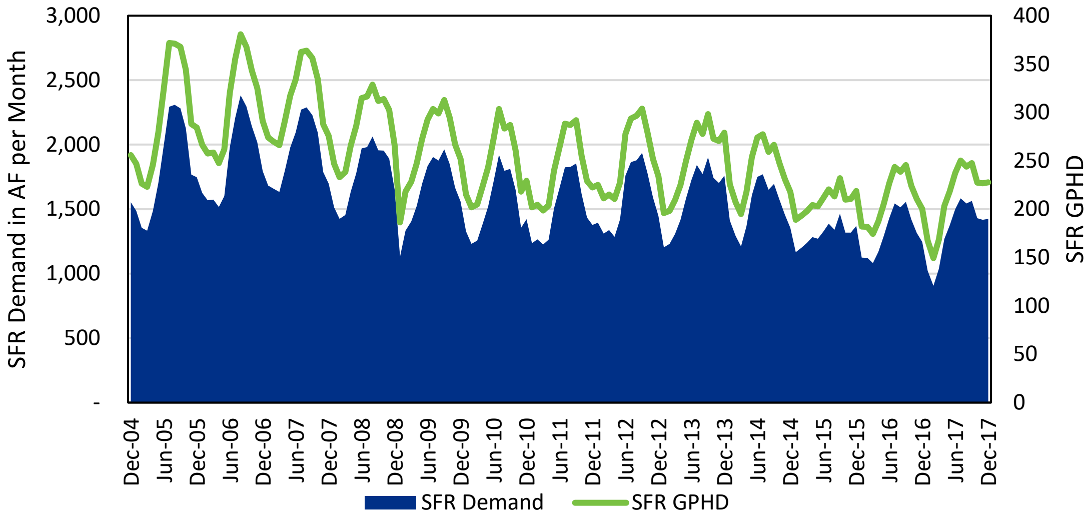


Figure 3-2. Single-family Historical Water Use

Figure 3-3 presents the historical MFR water use. MFR demand is expressed in average gallons per occupied multifamily household per day (MFR GHPD). Similar to SFR, total MFR water use declined around 2008 and then again in 2015. MFR GPHD has declined from a high of 215 in the summer of 2005 to a low of 130 in 2017 likely in response to gains in water use efficiency and increased densification of growth.

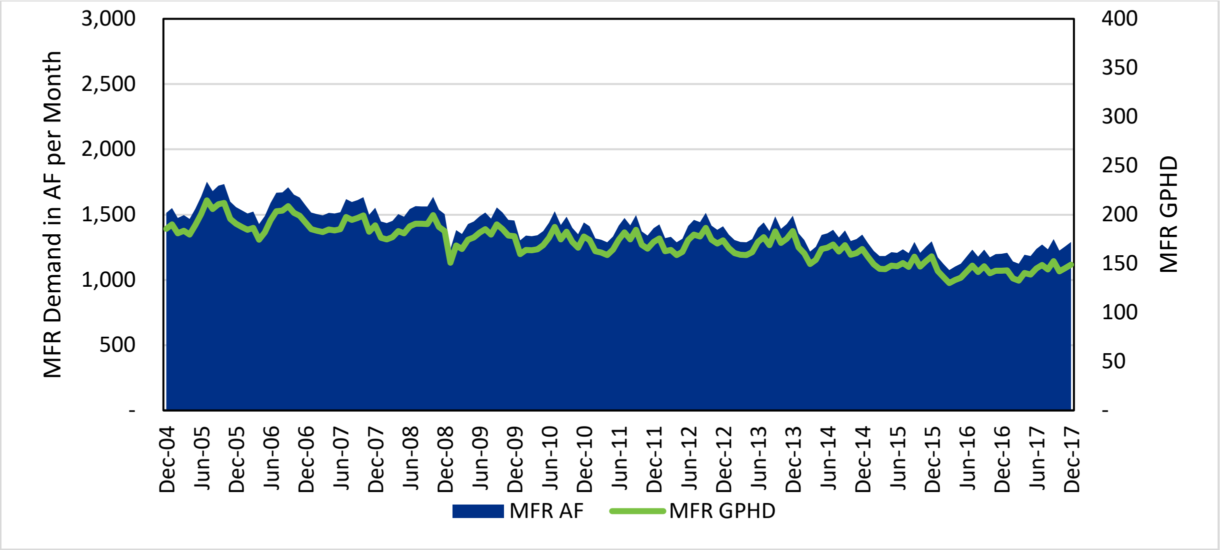


Figure 3-3. Multi-family Historical Water Use

Figure 3-4 presents the historical COM water use. COM demand is expressed in average gallons per COM employee per day (COM GPED). COM employment represents total employment less manufacturing employment, which is used for the IND customer demand category. Total COM water use declined around 2008 and then again in 2015. COM GPED has declined from a high of 211 in the summer of 2005 to a low of 130 in 2016 in response to water use efficiency gains and likely to some shifting of employment to lower water use intensive businesses and establishments.

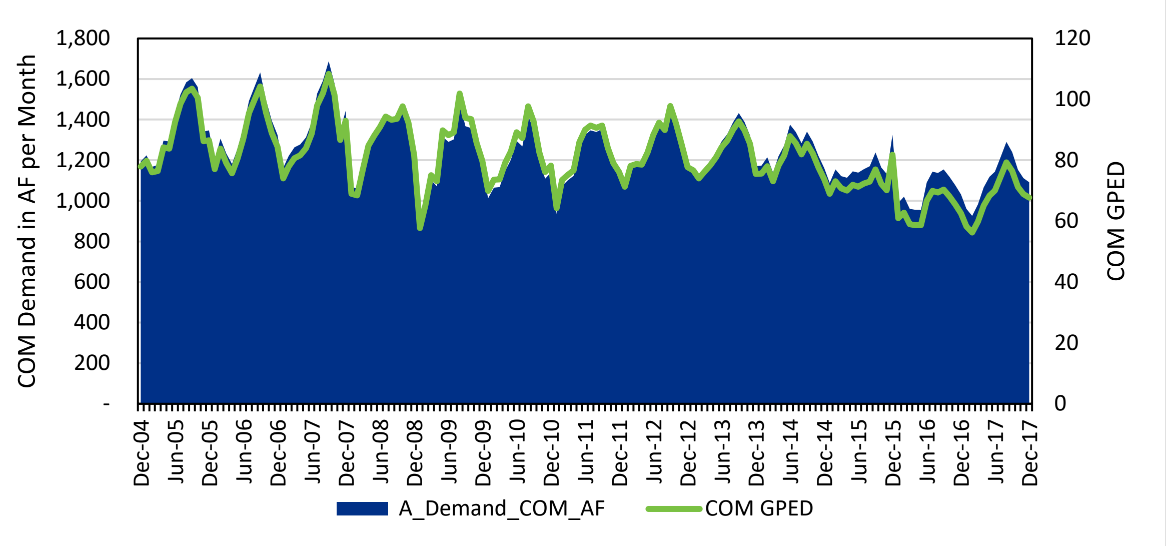


Figure 3-4. Commercial Historical Water Use

Figure 3-5 presents the historical IND water use. IND demand is expressed in average gallons per manufacturing employee per day (IND GPED). IND demand and manufacturing employment both declined drastically following the recession in 2008 and long-term shifts in the manufacturing sector (i.e., loss of aerospace businesses in Southern California).

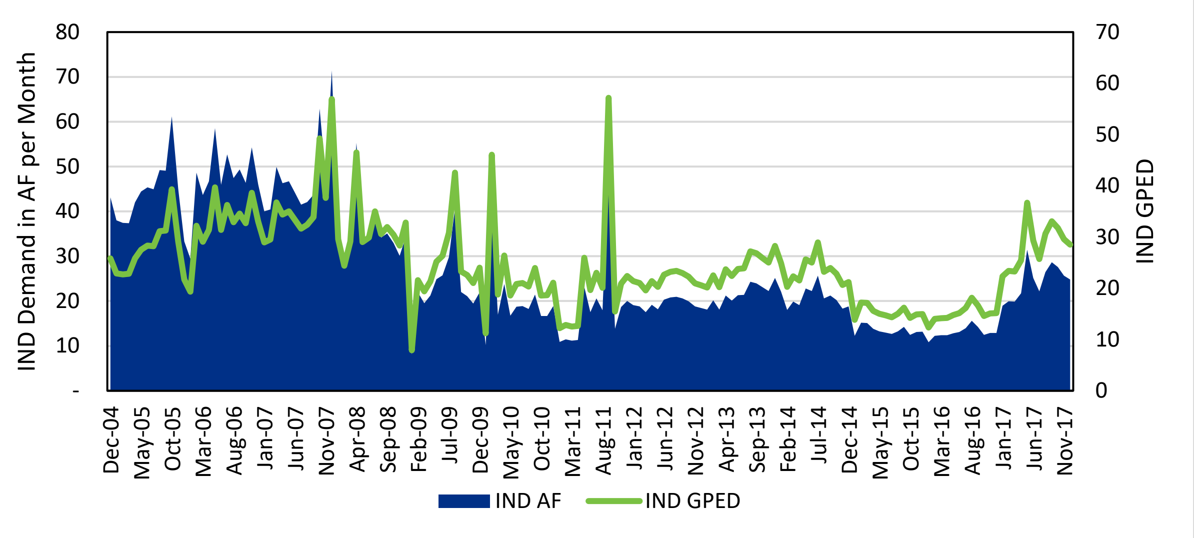


Figure 3-5. Industrial Historical Water Use

Figure 3-6 presents the historical IRR water use that is supplied by potable water. IRR demand is expressed in average gallons per irrigation account per day (IRR GPAD). IRR demand represents dedicated irrigation only meters in use throughout the City. IRR total water use and GPAD both declined in 2015 and 2016 in response to outdoor water restrictions being imposed by LBWD.

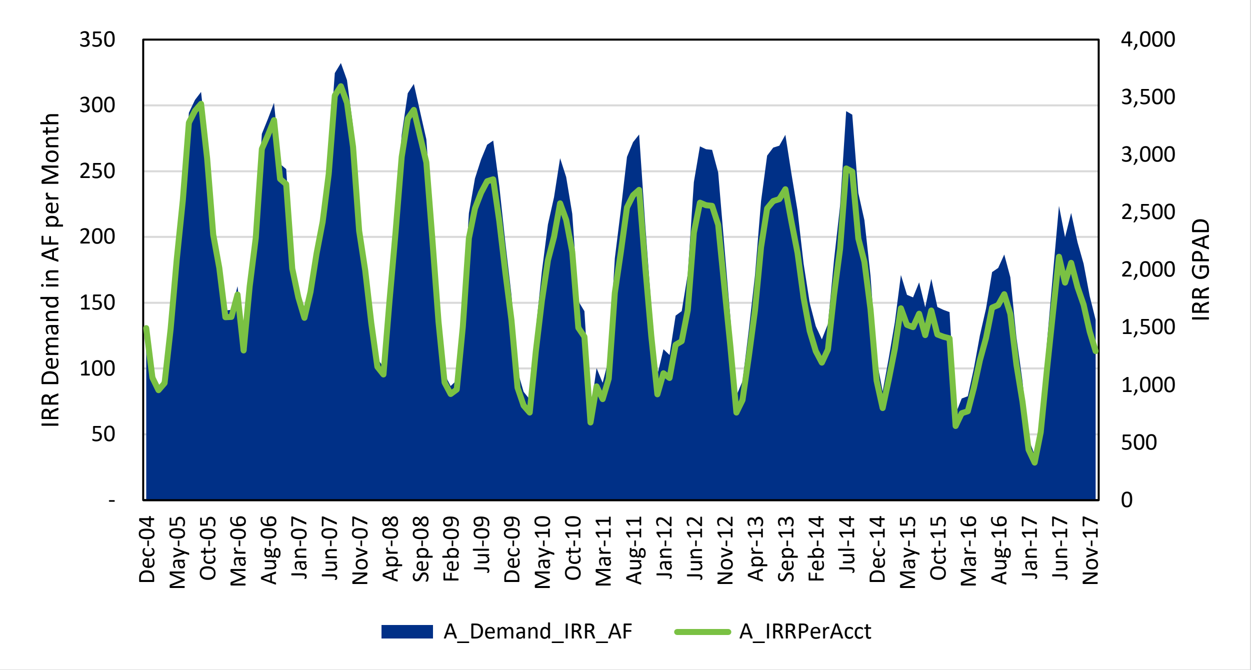


Figure 3-6. Irrigation Historical Water Use

3.2.3 Climate Data

The relationship between climate and water use is well known. As temperature increases, more water is used for outdoor irrigation and indoor cooling. This relationship is represented by a positive coefficient or elasticity. Conversely, as precipitation increases, less water is used for irrigation, and the relationship is represented by a negative coefficient or elasticity.

For this analysis, daily precipitation (TPRCP) and maximum daily temperature (MMXT) data were collected from the Long Beach Daugherty Airport for the period of January 1, 1980 to February 28, 2018. In addition, the number of days with no precipitation for each month was collected.

On average, monthly precipitation is highest in the winter months, with February having the highest average total precipitation at almost three inches. The lowest average monthly precipitation occurs in June, July, and August, with all three months averaging less than 0.01 inches of precipitation. These trends can be seen in **Figure 3-7** for December 2004 to December 2017. Notably, some winter months have significant spikes in total monthly precipitation.

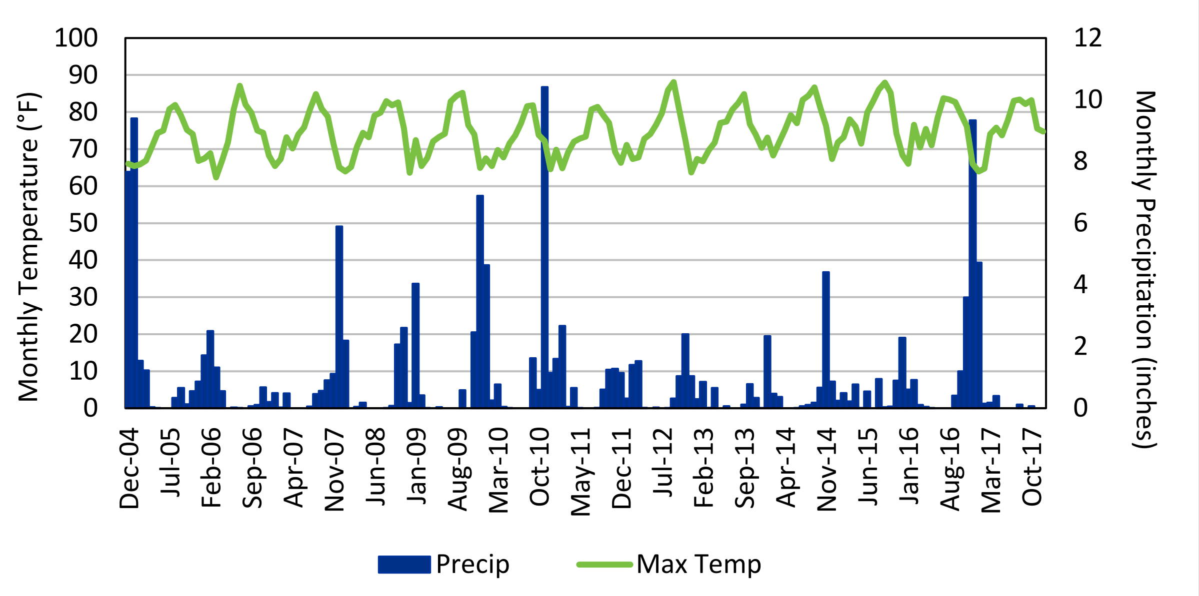


Figure 3-7. Monthly Temperature and Precipitation in Long Beach from 2004 to 2017

3.2.4 Economic Data

Economic conditions can impact water use. Variables such as total employment and median household income are positively correlated with water demand, meaning an increase in these variables results in an increase in water demand. Variables such as the unemployment rate, when high, can result in decreased water demand. The economic downturn occurred from July 2008 to December 2014 when the unemployment rate exceeded 7.5 percent. Median household income has increased in Long Beach, with an estimated value of $35,781 in 2004 growing to $40,461 in 2018 (expressed in constant 2000 $).

Properly structured water rates can be effective in promoting water conservation. LBWD has had conservation-focused water rates with implementation of an inclining block rate structure for residential customers—meaning the more water that is used, the higher the rate is paid for each additional unit of water. Commercial, institutional, industrial, and irrigation customers are charged a flat per unit rate. The second-tier water rate for the SFR, MFR, and flat rate for the COM sectors are shown in **Figure 3-8** (in constant 2018 $).

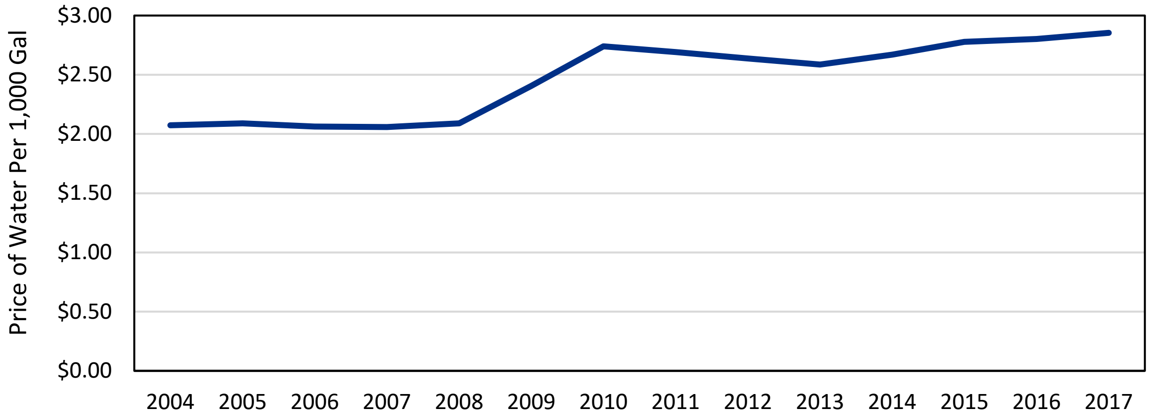


Figure 3-8. Historical Water Rates

3.2.5 Water Conservation

Water conservation and water use efficiency reduces the demand for water. Water conservation can occur from adherence to state plumbing codes that dictate fixture efficiency for new and remodeled properties and landscape ordinances (referred to as passive savings) or through direct water conservation efforts driven by a water utility (referred to as active savings). Active conservation can be achieved through reduction in system losses, fixture rebate programs, turf replacement, and public education. Water savings can also be achieved over time through changes in public attitudes and general tendencies to conserve resources, regardless of utility-driven education programs, or as a call or requirement to reduce water use. These behavioral changes often occur after long periods of droughts when water use restrictions are in place, but sometimes remain after restrictions are lifted.

LBWD has had an extensive and successful water conservation program for decades. They offer residential and commercial customers rebates to replace inefficient toilets, showerheads, washing machines, and to install water saving devices such as rain barrels, irrigation controllers, and flow restrictors. Through LBWD's Lawn-to-Garden incentives, 3.3 million square feet of turf grass has been replaced with lower-water using landscapes.

Statistically calculating water savings from these programs over time can be a difficult challenge, because of intercorrelations with other variables such as weather, housing mix and economic recessions. For LBWD, index variables were created that estimates indoor water use efficiency for the SFR, MFR, and COM sectors, as shown in **Figure 3-9**. The variables are based on general historical water fixture standards (plumbing codes) which have changed since 1992, estimates of housing and commercial establishment stock by year, and an assumption for fixture replacement rates in older homes which incorporates periods of high indoor fixture replacements. The index goes from 0 to 1, with an index of 1.0 indicating maximum efficiency (based on a WaterWise home use rate of 37 GPCD).

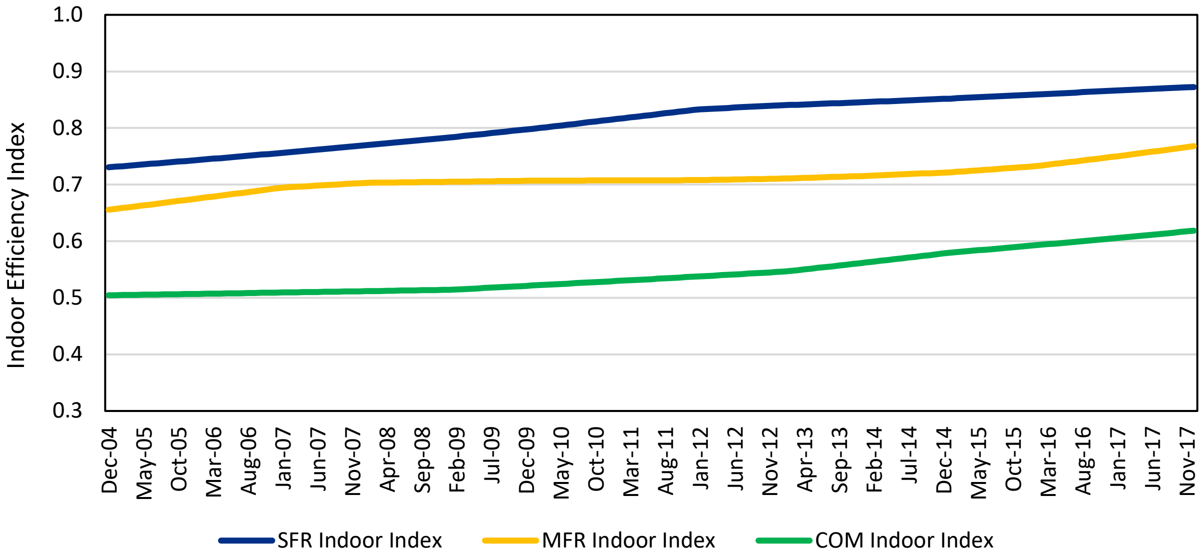


Figure 3-9. Indoor Efficiency Index

In addition, there have been several periods where water use restrictions were in place or when Californians were asked to reduce water use. **Figure 3-10** presents the three stages of LBWD restrictions since 2005 as well as the period where an Executive Order was enacted asking for a 25 percent reduction in water use. **Table 3-2** presents the associated prohibited landscape irrigation times for each of the LBW drought stages.

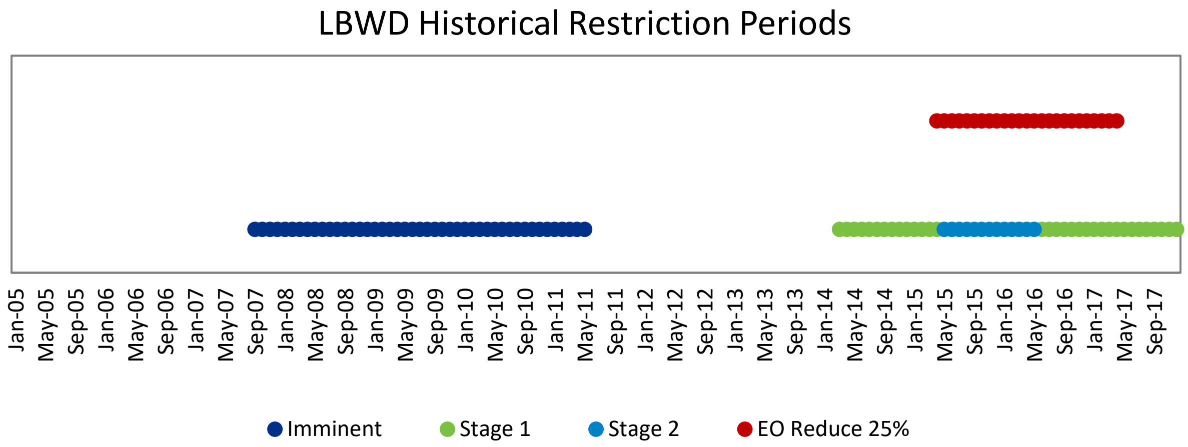


Figure 3-10. Historical Water Restriction Periods

Table 3-2. LBWD Drought Restriction Stages

Stage	Prohibited Landscape Irrigation Times
All Times	All months: 9a - 4p, all days
Imminent	All months: 9a - 4p for 3 days and all times 4 days per week
Stage 1	Summer: 9a - 4p for 3 days and all times 4 days per week
	Winter (Oct-Mar): 9a - 4p for 2 days and all times 5 days per week
Stage 2	All Months: 9a - 4p for 2 days and all times 5 days per week

3.3 LBWD Econometric Demand Models

The LBWD econometric demand models are by LBWD billing sector to allow for single-family, multifamily, commercial, industrial, and institutional water use to be independently forecasted. A number of discrete and binary variables were identified and quantified that represent the data described above. These variables represented various weather, economic and conservation factors (explanatory variables). Over 100 combinations of explanatory variables were tested to identify the most robust statistical model for each sector. Additionally, a mathematical procedure was applied to give more “weight” to variables representing summer demand, when responses to weather and conservation are more pronounced. **Table 3-3** provides a summary of the variables captured in each sector demand model. Detailed statistics for the demand models by customer sector, as well as an analysis of the impacts of climate change on demands, are presented in **Appendix A**.

Table 3-3. LBWD Demand Model Variables

Explanatory Variable	Single Family Residential	Multifamily Residential	Commercial	Industrial	Large Irrigation
Temperature	X	X	X	X	X
Rainfall	X	X	X	X	X
Indoor Water Efficiency	X	X	X		
Price of Water	X	X	X		X
Water Use Restrictions	X	X	X	X	X
Irrigable Lot Size	X				
Employment Mix			X		
Economic Recession				X	
Regression Model R^2 – Measure of Predictive Model Fit to Historical Data (> 0.8 is very good fit)	0.92	0.92	0.80	0.40	0.90

3.3.1 Single-family Residential Model

The multiple regression model explanatory variables for SFR included temperature, rainfall, indoor water efficiency, the price of water, water use restrictions, and irrigable lot size. The adjusted R^2 of 0.92 indicates that about 92 percent of the variability of the explanatory variables is correlated with, or “explains” the variation of single-family water use over time indicating that the model is robust and the "goodness of fit", or the extent to which observed data match the modeled values, is strong.

Figure 3-11 shows a comparison of SFR GPHD actual water demand to predicted demand from the model. To get the predicted values, historical explanatory variables are input into the model equations. As shown, the model's predicted demand matches actual demand very well, both in monthly variability and long-term trends, which indicates a robust statistical model that can be used for forecasting.

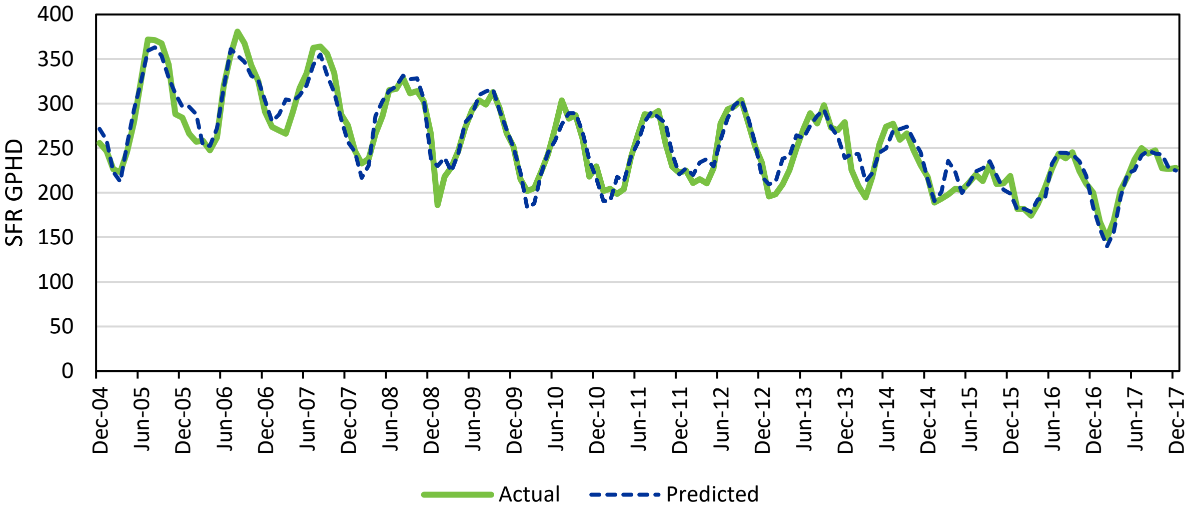


Figure 3-11. LBWD Single-Family Household Demand Model Verification

3.3.2 Multifamily Residential Model

The multiple regression model explanatory variables for MFR included temperature, rainfall, indoor water efficiency, the price of water, and water use restrictions. The adjusted R^2 of 0.92 indicates that, similar to the SFR model, the MFR model is robust and the "goodness of fit" is strong.

Figure 3-12 shows a comparison of MFR GPHD actual water demand to predicted demand from the model. To get the predicted values, historical explanatory variables are input into the model equations. As shown, the model's predicted demand matches actual demand very well capturing long-term trend, but less so in capturing monthly variability. However, for annual demand forecasting this model is considered robust.

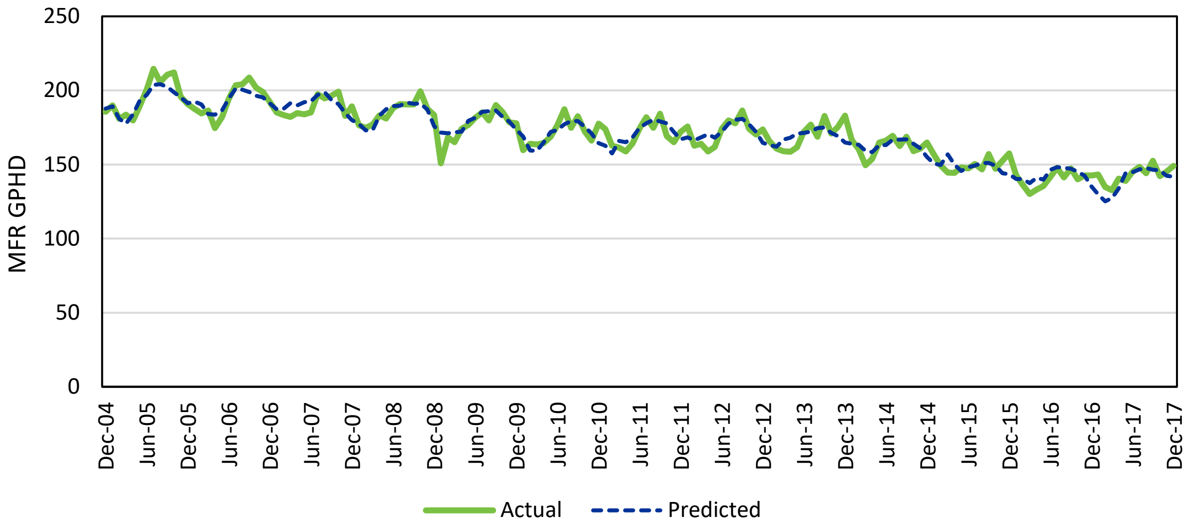


Figure 3-12. LBWD Multifamily Residential Demand Model Verification

3.3.3 Commercial Model

The multiple regression model explanatory variables for COM included temperature, rainfall, indoor water efficiency, the price of water, water use restrictions, and employment mix. The adjusted R^2 of 0.80, although lower than the SFR and MFR model, still indicates a strong "goodness of fit".

Figure 3-13 shows a comparison of COM GPED actual water demand to predicted demand from the model. To get the predicted values, historical explanatory variables are input into the model equations. As shown, the model's predicted demand matches actual demand well capturing both long-term trend and monthly variation. However, some extreme monthly variations were not captured. Given that the COM sector has dozens of non-similar businesses and institutions, the selected explanatory variables are considered robust for forecasting.

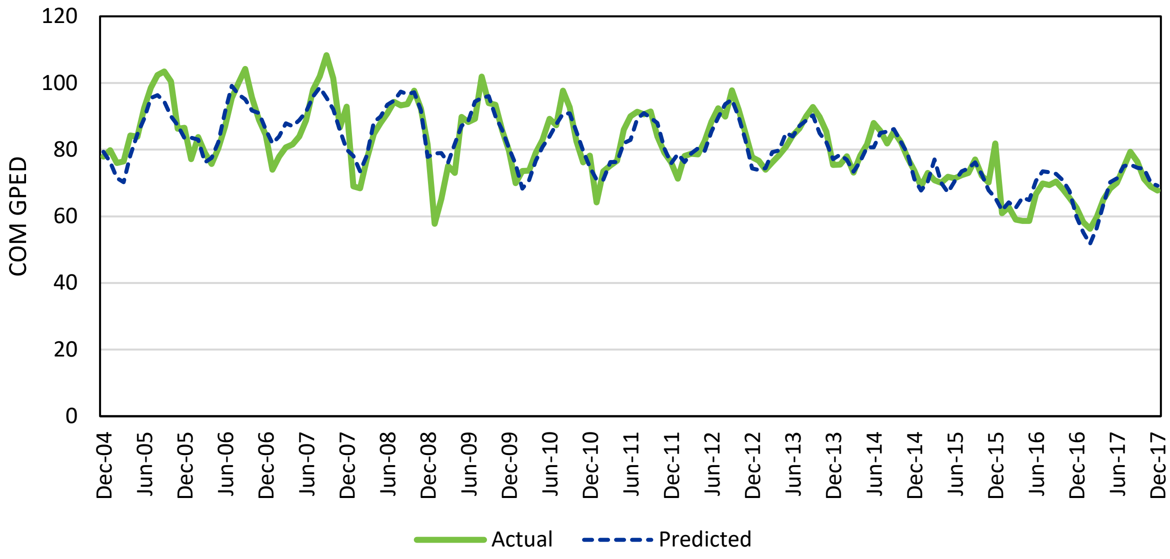


Figure 3-13. LBWD Commercial Demand Model Verification

3.3.4 Industrial Model

The multiple regression model explanatory variables for IND included temperature, rainfall, water use restrictions, and economic recession. The adjusted R^2 of 0.40, indicates a moderate "goodness of fit".

Figure 3-14 shows a comparison of IND GPED actual water demand to estimated demand from the model. The results show that the model has a difficult time reproducing the high variability in demands that were experienced from 2008 to 2011. This is likely due to changes in the type of industrial customers or specific industrial processes over time, perhaps associated with the overall economic downturn that happened during that period, that the model cannot take into account. The magnitude of this demand is also much lower than the other sectors so these relatively small changes could have a significant impact on demands. The general trend of demands over time is captured by the demand model.

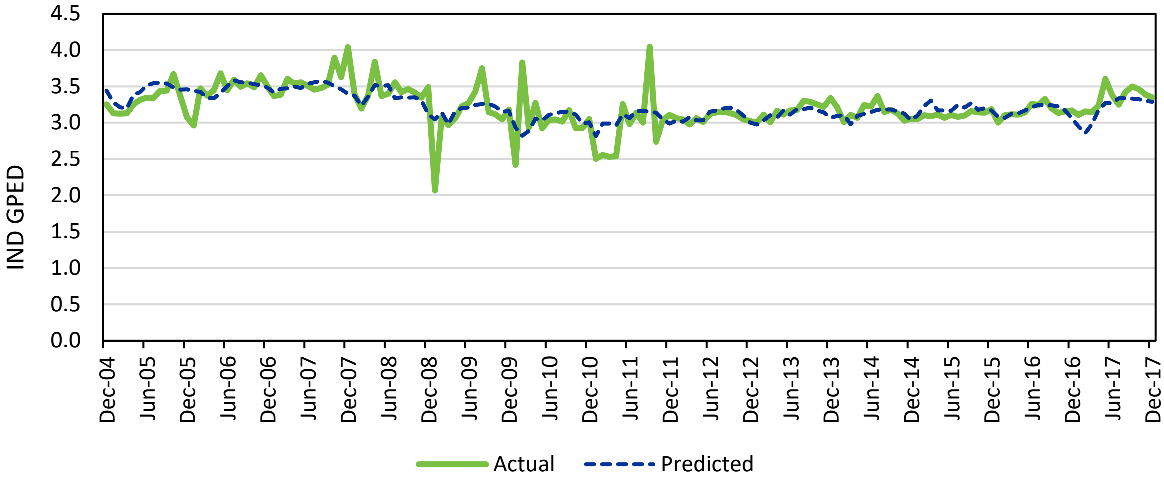


Figure 3-14. LBWD Industrial Demand Model Verification

3.3.5 Irrigation Account Model

The multiple regression model explanatory variables for IRR included temperature, rainfall, price of water, and water use restrictions. The adjusted R^2 of 0.90 indicates an excellent "goodness of fit".

Figure 3-15 shows a comparison of irrigation GPAD actual water demand to estimated demand from the IRR model. The similarity between the predicted and actual per irrigation account water use provides verification that the model performs well in representing factors that influence monthly total GPAD water demand.

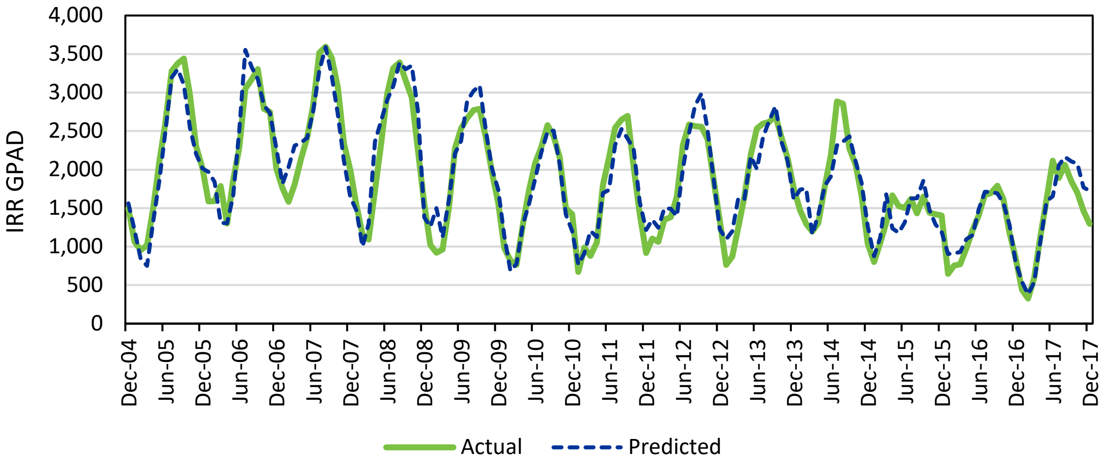


Figure 3-15. LBWD Irrigation Account Demand Model Verification

3.3.6 Impact of Explanatory Variables on Aggregate LBWD Water Demands

The demand models can also be used to explain past water use by examining the elasticity coefficients for each of the explanatory variables. **Figure 3-16** summarizes the changes in water use that would be expected based on the changes in a number of key explanatory variables. For variables that impact multiple customer user sectors a range is shown for the impact. The overall demand impact is also shown, based on percent of each customer use sector to total use.

10% increase in **Temperature** →
1.9% to **18.9%** increase in sector water use, or aggregate City increase of **5.7%**

Periods of **Water Use Restrictions** →
10.0% to **25.2%** decrease in sector water use, or aggregate City decrease of **14.1%**

10% decrease in **Precipitation** →
0.5% to **4.8%** increase in sector water use, or aggregate City increase of **1.2%**

10% decrease in **Irrigation Lot Size** →
1.5% decrease in SFR sector water use, or aggregate City decrease of **0.6%**

10% increase in **Indoor Use Efficiency** →
9.8% to **15.9%** decrease in sector water use, or aggregate City decrease of **12.3%**

10% increase in **Services Employment** →
17.4% increase in COM sector water use, or aggregate City increase of **4.4%**

10% increase in real **Price of Water** →
1.9% to **10.1%** decrease in sector water use, or aggregate City decrease of **2.7%**

Periods of **Economic Recession** →
21.0% decrease in IND sector water use, or aggregate City decrease of **0.2%**

Figure 3-16. Impacts of Explanatory Variables on Water Use

3.4 LBWD Water Demand Forecast

3.4.1 Baseline Water Demand Forecast

Using the econometric models described in Section 3.3 and estimates of future conditions for each variable, water demand forecasts were developed for the per unit water use factors representing baseline conditions. These per unit water use factors are multiplied by forecasts of future households, employment and irrigation accounts to derive a baseline water demand forecast. The specific assumptions for the baseline water demand forecast are:

- Demographic forecasts based on historical trends (lower growth assumption)
- Historical average climate (defined as the average from 1980 to 2017)
- No future increases to the price of water beyond inflation adjustments
- Indoor efficiency improvements based on current plumbing codes and natural replacement rates for plumbing fixtures between 4 and 4.2 percent annually
- MWELO[1] outdoor water savings for the SFR and COM sector of -8 and -4.5 gallons per unit per day as measured from current water use, respectively, by 2050
- LBWD will remain in drought restrictions equivalent to Stage 1

Figure 3-17 presents the per unit water use rates project to year 2050 for the baseline demand forecast. Under this forecast, SFR unit water use is forecasted to decline from 213 to 186 gallons per home per day, a 13 percent decrease. MFR unit water use declines at the roughly the same rate from 141 to 123 gallons per home per day. COM unit water use is forecasted to decline from percent from 58 to 50 gallons per employee per day to 2040, then holding steady through 2050. IND unit water use is forecasted to remain relatively steady through year 2050.

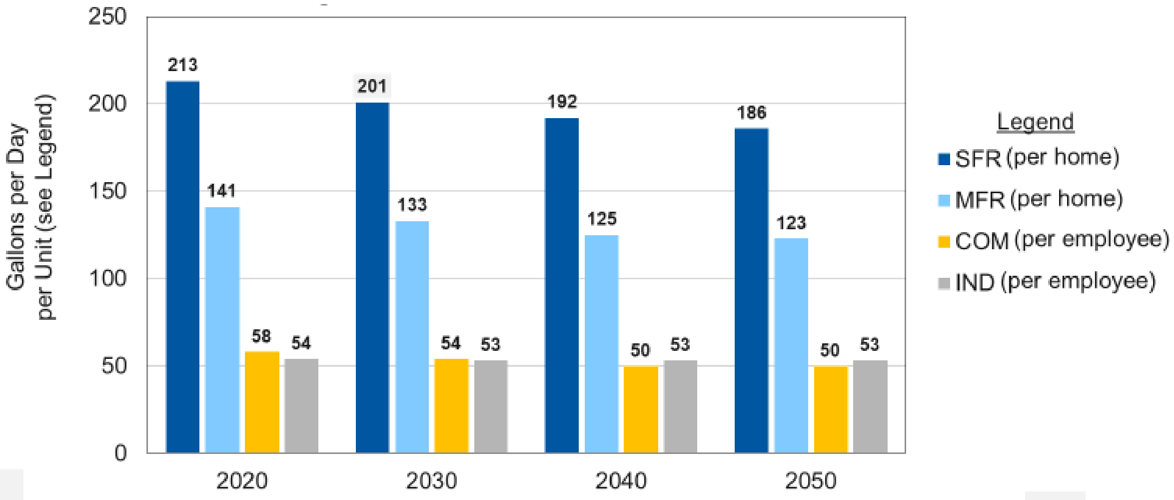


Figure 3-17. Per Unit Water Use Factors - Baseline Forecast

---

[1] CA AB 325 Water Conservation in Landscaping Act passed in 1990 requiring California Department of Water Resources to develop a Model Water Efficient Landscape Ordinance (MWELO). The code was revised in 2010 and again in 2015. MWELO defines the maximum amount of irrigation water that can be applied to a lot or landscape.

The water demand forecast, presented in **Figure 3-18,** is the product of the per unit water use factors combined with the demographic forecasts presented in Section 3.2.1 and an assumption that non-revenue water (NRW) remain at 4%. NRW is water that has been produced and is "lost" before it reaches the customer. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses (for example through theft or metering inaccuracies). Under these baseline conditions, water demand is projected to continue to decline through 2030 as water efficiency continues to increase. Water demand is then projected to hold steady through 2040 as water demand increases from population and economic growth are cancelled out by reductions from conservation. In 2040, water demand is projected to begin increasing to approximately 44,000 AFY by 2050 as population and economic growth surpasses the reductions in demand from conservation. Per capita water use is projected to decline to 70 GPCD by 2050, as shown in **Figure 3-19.** The detailed water demand forecast by each customer sector is presented in **Tables 3-4** through **3-8.**

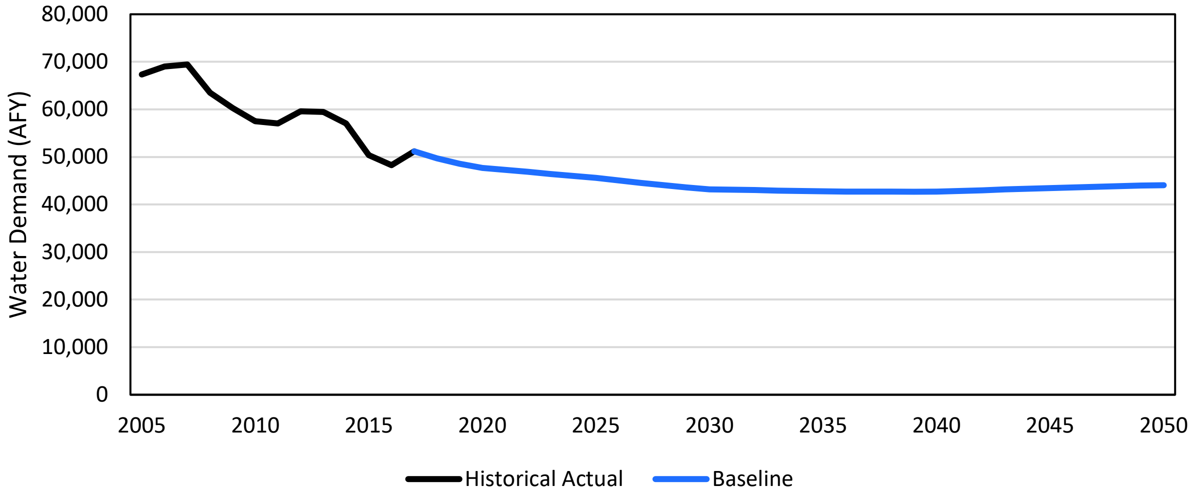


Figure 3-18. LBWD Water Demands (Including System Losses) - Baseline Forecast

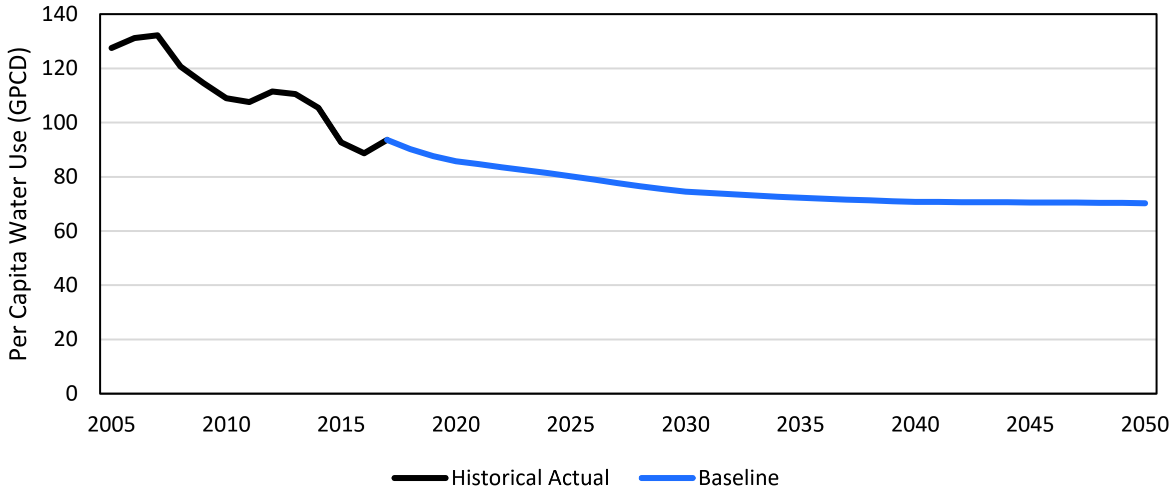


Figure 3-19. LBWD Per Capita Water Use (Including System Losses) - Baseline Forecast

Table 3-4. Water Demands by Customer Use Sector – Baseline Forecast*

Year	SFR AFY	MFR AFY	COM AFY	IND AFY	IRR AFY	Total Billed AFY	NRW LOSS %	Total w/Losses AFY
2020	18,136	14,160	11,084	594	1,820	45,794	4.0%	47,702
2030	16,307	12,987	9,718	574	1,898	41,483	4.0%	43,211
2040	15,916	13,281	9,283	556	1,975	41,012	4.0%	42,721
2050	16,082	13,894	9,735	549	2,049	42,309	4.0%	44,072

* Does not include recycled water demands

Table 3-5. SFR Water Demands and Unit Use Rates - Baseline Forecast

Year	AFY			GPHD		
	INDOOR	OUTDOOR	TOTAL	INDOOR	OUTDOOR	TOTAL
2020	13,840	4,296	18,136	152	47	199
2030	12,599	3,708	16,307	138	40	178
2040	12,614	3,303	15,916	133	35	168
2050	12,918	3,164	16,082	133	33	165

GPHD = gallons per household per day

Table 3-6. MFR Water Demands and Unit Use Rates - Baseline Forecast

Year	AFY			GPHD		
	INDOOR	OUTDOOR	TOTAL	INDOOR	OUTDOOR	TOTAL
2020	13,001	1,159	14,160	120	11	131
2030	12,472	515	12,987	110	5	115
2040	12,849	433	13,281	108	4	111
2050	13,442	452	13,894	108	4	111

GPHD = gallons per household per day

Table 3-7. COM Water Demands and Unit Use Rates - Baseline Forecast *

Year	AFY			GPED		
	INDOOR	OUTDOOR	TOTAL	INDOOR	OUTDOOR	TOTAL
2020	8,736	2,348	11,084	47	13	60
2030	8,022	1,696	9,718	43	9	52
2040	7,974	1,310	9,283	41	7	48
2050	8,326	1,409	9,735	41	7	48

*Does not include recycled water demands
GPED = gallons per employee per day

Table 3-8. IND and IRR Water Demands and Unit Use Rates - Baseline Forecast*

Year	IND		IRR	
	AFY	GPED	AFY	GPAD
	TOTAL (INDOOR)	TOTAL (INDOOR)	TOTAL (OUTDOOR)	TOTAL (OUTDOOR)
2020	594	53	1,820	1,416
2030	574	53	1,898	1,416
2040	556	53	1,975	1,416
2050	549	53	2,049	1,416

*Does not include recycled water demands
GPED = gallons per employee per day
GPAD = gallons per irrigation account per day

3.4.2 Water Demand Forecast Sensitivity

Using the econometric models, different assumptions for demographic growth, future climate, and future water conservation can be tested as a sensitivity to the baseline demand forecast. **Figure 3-20** presents the total potable water demand for the year 2050 under this sensitivity.

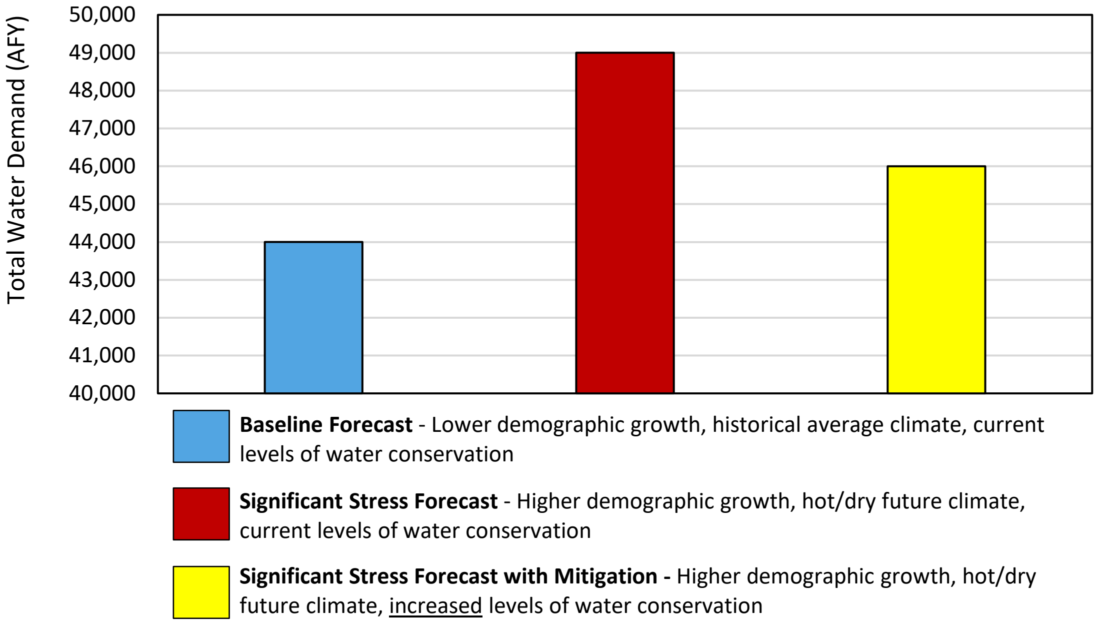


Figure 3-20. Sensitivity in LBWD Water Demand Forecast for Year 2050

When higher demographic forecasts are used along with a future climate that is hotter and drier than historical, forecasted water demands for LBWD are about 5,000 AFY (11%) greater in year 2050 over the baseline forecast of 44,000 AFY. Under these same stressed conditions, but with increased levels of water conservation, the potable demand forecast drops by 3,000 AFY in 2050, but still 4.5% greater than the baseline forecast.

Section 4

Water Source Reliability

LBWD meets its demands through local groundwater, recycled water, and imported water from MWD. **Figure 4-1** depicts past water supplies to LBWD; the total service area supply has decreased over time and imported MWD supplies have been replaced with higher groundwater pumping volumes.

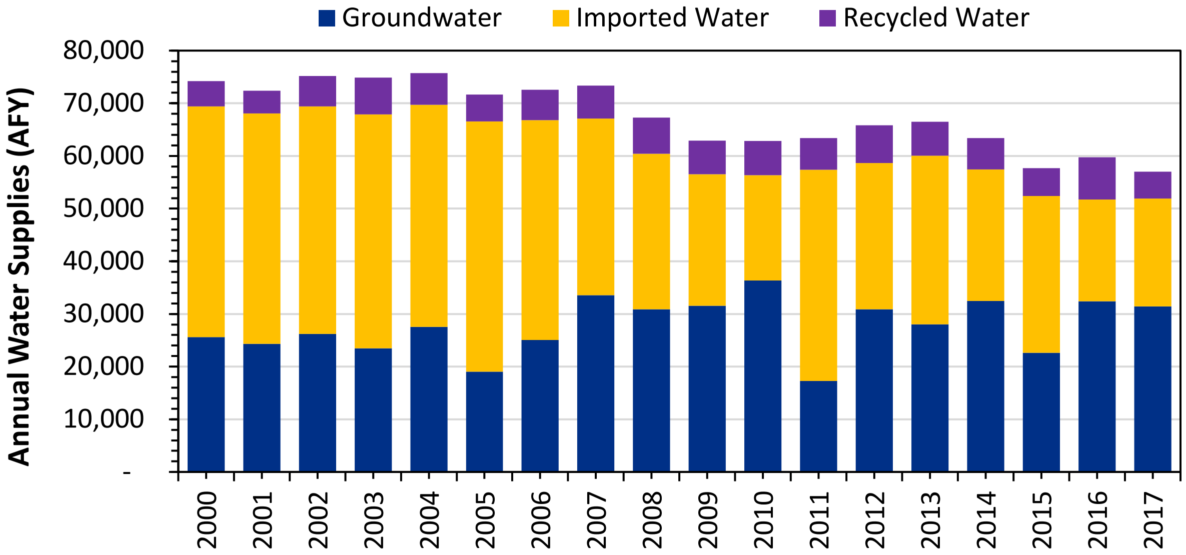


Figure 4-1. LBWD Water Supplies (Calendar Year)

The Central and West Coast groundwater basins (CBWCB) underlie the LBWD service area. The WRD manages pumping and recharge in both basins.

A portion of the wastewater collected from LBWD is delivered to the JWPCP in Carson, and the remainder is delivered to the LACSD LBWRP. Although LBWRP receives wastewater from Long Beach, Lakewood, Cerritos, and other parts of LA County, LBWD has exclusive rights to the full tertiary effluent. LBWRP has a maximum treatment capacity of about 25 MGD, but typically operates at a peak of 19 MGD.

LBWD purchases imported water from MWD, which manages, stores, and allocates water deliveries from the Colorado River via the CRA and the Delta via the SWP. Regulatory or hydrologic-based shortages on either of these two sources may cause MWD to reduce deliveries to member agencies. New drought allocations on the Colorado River, modifications to existing Bay-Delta Biological Opinions, and unprecedented climate change may further reduce water to MWD and challenge LBWD's imported supply.

4.1 Groundwater Supply

Low groundwater levels in the early 1960's compelled WRD to set pumping limitations in the CBWCB. A judgement adjudicated pumping in the West Coast Basin to 64,468.25 AFY and limited pumping in the Central Basin to 217,367 AFY (80 percent of the adjudicated volume.) The total allowable pumping in both basins combined is 281,835 AFY.

The Board of Directors of WRD may declare an emergency and enact measures to encourage reduced pumping if CBWCB water resources risk degradation. WRD considers many factors prior to declaration of emergency, including prior year hydrology, potential reductions in MWD replenishment water, low water elevations in the Montebello Forebay, and a high accumulated overdraft (AOD). Accumulated overdraft increases when groundwater use exceeds the amount of recharge (natural and artificial) into the CBWCB. The AOD is calculated by adding the annual change in storage to the optimum basin AOD of 611,900 AF observed in water year 2000.

A 1999 USGS MODFLOW model of the CBWCB determine overall CBWCB storage based on measured water levels throughout the WRD service area as well as up-to-date records of groundwater users' storage programs. However, prior to model development, WRD calculated storage based only on water levels in the Montebello and Los Angeles Forebays, and AOD values preceding 2000 should be regarded with caution.

During past emergencies, WRD has encouraged voluntary reductions among basin users by increasing annual limits on allowable carryover storage (the amount of water in aquifer storage accounts that users are able to leave in between years.) WRD allowed parties to carryover 10% of their APA during an emergency declaration of 1977 and allowed a 35% APA carryover during a 2010 emergency. **Figure 4-2** plots the CBWCB overdraft and groundwater production (based on water year.)

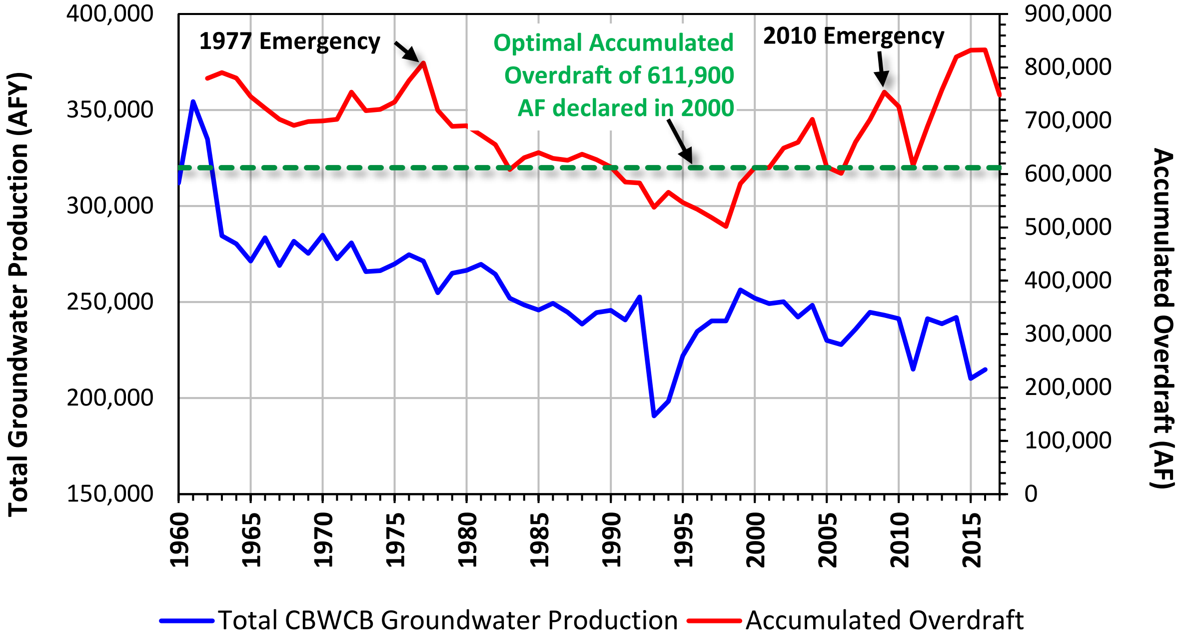


Figure 4-2. Groundwater Overdraft

AOD has trended upwards since 2000 despite relatively constant groundwater pumping. The suspension of MWD's in-lieu program in 2007 has partially contributed to recent high AOD. Reduced natural recharge has also contributed to the decline in basin storage; stormwater and base flow infiltrated at the Montebello Forebay averaged 44,610 AFY from water years 2001 to 2017, almost 14,000 AFY less than the 1960 to 2000 average of 58,500 AFY.

Total CBWCB pumping dips immediately following the 1977 and 2010 emergencies, as well as after a 1991 amendment that increased non-drought carryover from 10 to 20% of users' APA. **Figure 4-3** plots the same total water year groundwater production (which includes LBWD) and demonstrates that LBWD-specific pumping trends mimic those of all basin water users.

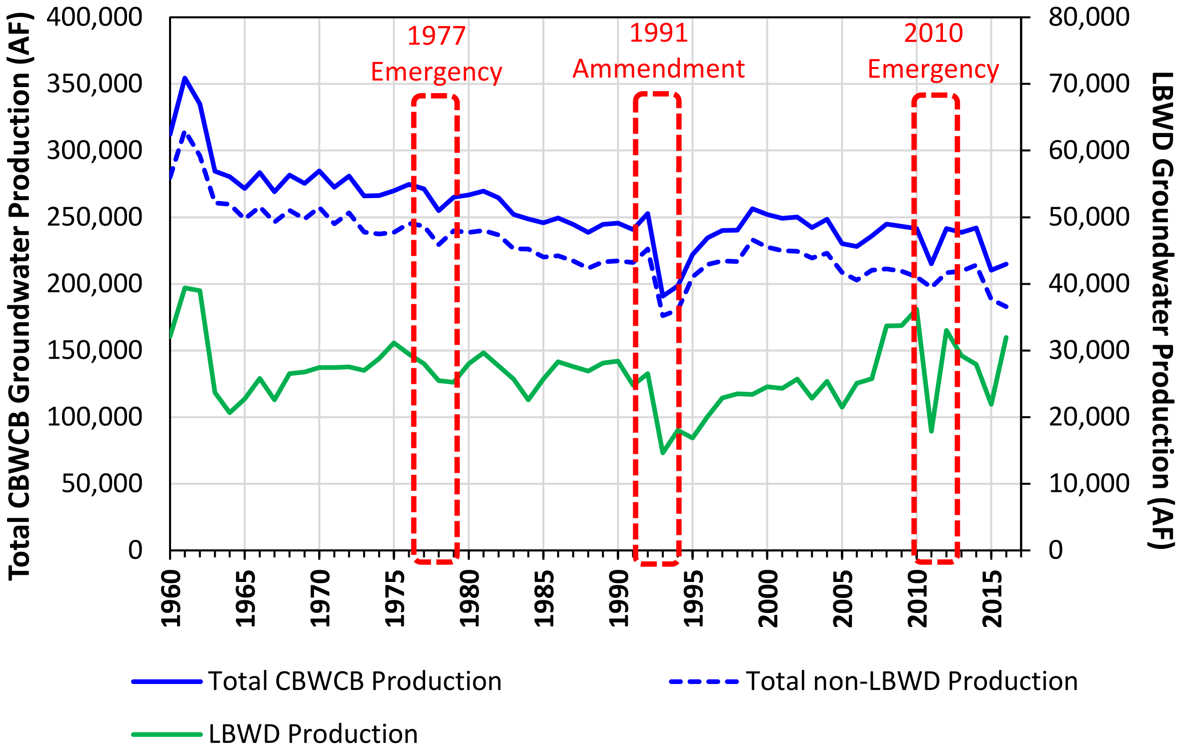


Figure 4-3. Groundwater Production

4.2 Recycled Water

A portion of the wastewater collected from LBWD is delivered to the JWPCP in Carson, and the remainder is delivered to the LACSD LBWRP. Most water treated at LBWRP is wastewater collected from the City sewer system. LBWRP has a maximum treatment capacity of about 25 MGD. **Figure 4-4** plots the inflow to LBWRP for water years 2011 through 2017 (provided by LBWD.) The LBWRP inflow has decreased by 15% over that 7-year span.

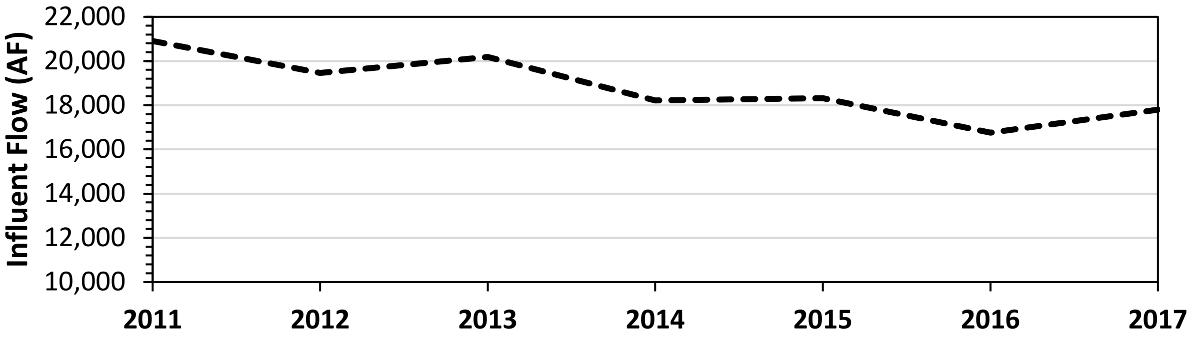


Figure 4-4. LBWRP Influent

The decline in total inflows to LBWRP is attributed to indoor water use efficiencies from plumbing codes and active conservation programs from LBWD.

The pie chart in **Figure 4-5** averages LBWRP outflows for water years 2011 to 2017. Almost 50% of the LBWRP effluent is directed to Coyote Creek, while 6,600 AFY, or 35%, of the effluent is directed to LBWD non-potable demands. WRD Engineering Survey and Report data record 1,541 AFY injected at the Alamitos Barrier through the LVL AWTF facility; this volume includes sales to both WRD and the Orange County Water District (OCWD). The remaining 1,527 AFY counted as a loss is the difference between the average plant influent (18,807 AFY) and the sum of the other three volumes.

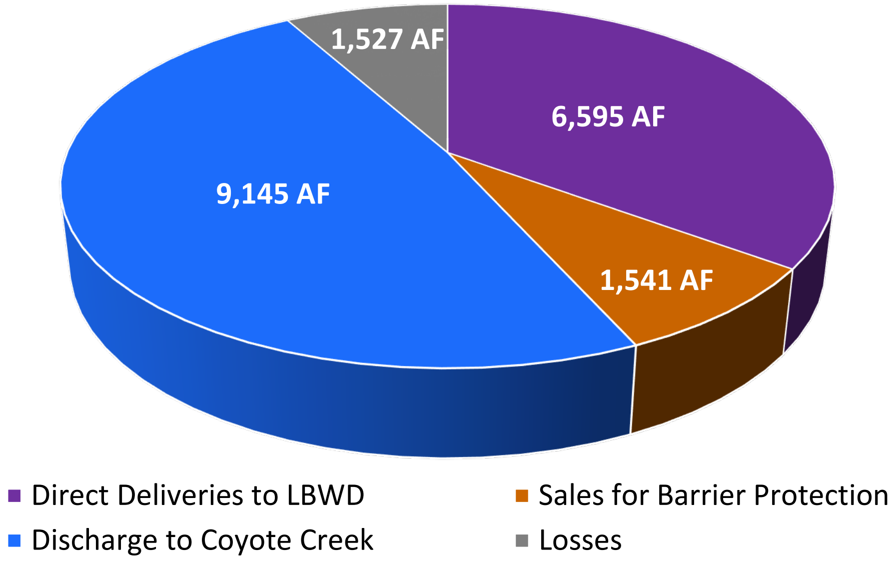


Figure 4-5. LBWRP Effluent

Not considering the impact of flow variation (time of use impact) and available storage capacity, **Figure 4-5** indicates that even if the sales to Alamitos Barrier injection increased to the LVL AWTF full capacity of 8,962 AFY, effluent water would still be discharged to Coyote Creek. The surplus discharges could be utilized for additional LBWD non-potable uses or treated and used for non-barrier groundwater augmentation in the LBWD service area.

4.3 Imported Water from MWD

MWD provides imported water to its 26 member agencies, which consists of SWP water from the Delta and Colorado River via MWD's CRA. **Figure 4-6** plots MWD imported water supplies from calendar years 1976 to 2015, based on data from the MWD's IRP (2015).

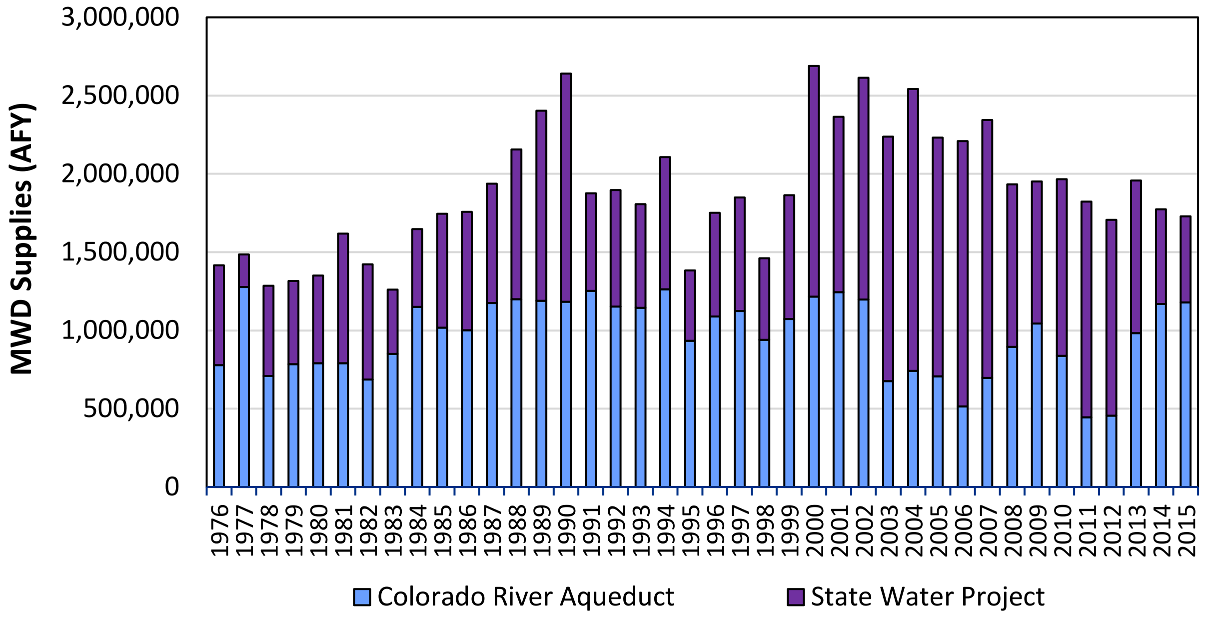


Figure 4-6. MWD Supplies

When CRA and SWP sources cannot meet MWD demands, MWD augments these supplies with withdrawals from storage (reservoir and groundwater banking programs) and water transfers. In hydrologic years in which direct deliveries of SWP and CRA exceed MWD demands, then that water is used to replenish storage.

4.3.1 SWP Deliveries

The availability of SWP deliveries is highly dependent on the hydrology of the watersheds in Northern California that feed the project. The Sacramento and San Joaquin River Watershed are the primary contributors to the Delta. Runoff volumes from these two watersheds are used to create an index to measure the amount of water available in the watersheds. The "Eight River Index" shown in **Figure 4-7**, which is the sum of Sacramento River Runoff and San Joaquin River Runoff, is used to set flow objectives as implemented in State Water Resources Control Board (SWRCB) Decision 1641. The Eight River Index illustrates the variability of runoff feeding the Delta. When runoff is low for one or more years, the availability of imported water would be reduced.

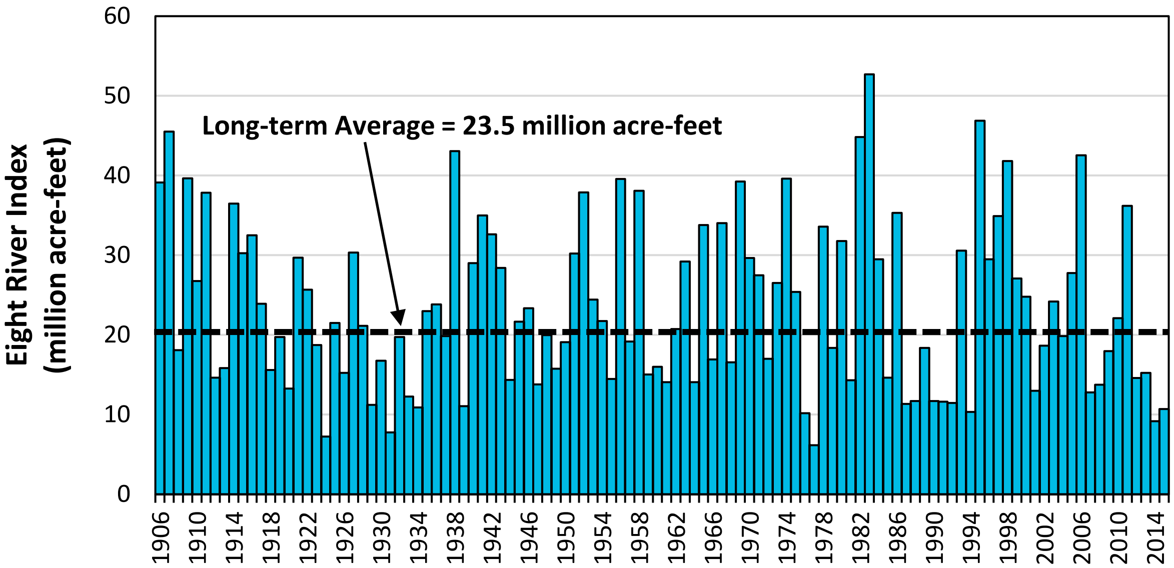


Figure 4-7. Eight River Index – Sacramento and San Joaquin Valley Runoff

Another factor that impacts the availability of imported water is the environmental restrictions on the Delta. Delta Export restrictions include Net Delta Outflow Index (NDOI) requirements set by the SWRCB Decision 1641 and Old and Middle River (OMR) flow restrictions as a result of Biological Opinions (BiOps).

The NDOI requirements limit the combined Central Valley Project (CVP) and SWP export rate to 35% of total Delta inflow from February through June, and 65% of inflow from July through January. The minimum monthly average NDOI ranges from 3,000 to 8,000 cubic feet per second. The NDOI requirements also specify an X2 location; X2 is the upstream distance from the Golden Gate Bridge at which the tidally averaged near-bottom electrical conductivity level is 2 parts per thousand. The location of X2 shifts depending on precipitation and the amount of Delta outflow.

The biological opinions issued by U.S. Fish and Wildlife Service (USFWS, 2008) and the National Marine Fisheries Service (2009) resulted in flow-based environmental standards for SWP operations. Combined CVP and SWP pumping from the south Delta can create reverse, or negative, flows in OMR. USFWS enforces the required OMR flow target by limiting exports during particular months of the year to reduce the magnitude of negative OMR flows and reduce the risk of entrainment of smelt and salmon in the Delta pumps.

SWP deliveries consist of annual Table A supplies based on pre-determined contractor allocations, supplemental Article 21 supplies proportional to contractors' Table A volumes, and surplus Article 56 deliveries, as well as the hydrologic and environmental factors described above. Table A allocations are initially set in December of the prior year but may change due to current year hydrology. The California Department of Water Resources allocates shortages in proportion to Table A contracts. Contractors may carryover their Table A supplies from one year to the next in San Luis reservoir, transferring these supplies to Article 56 Carryover Storage.

Additional Article 21 water deliveries are proportional to Table A amounts and are triggered when San Luis Reservoir is projected to be full, Table A deliveries are fully met, and Banks pumping plant has additional capacity. Article 21 supplies may be reclassified as Table A depending on final allocations.

Urban water users in Southern California have experienced a decline in SWP deliveries in the last decade (see **Figure 4-8**) as a result of regulatory actions to protect several endangered and threatened fish species, including the Delta smelt and winter-run Chinook salmon.

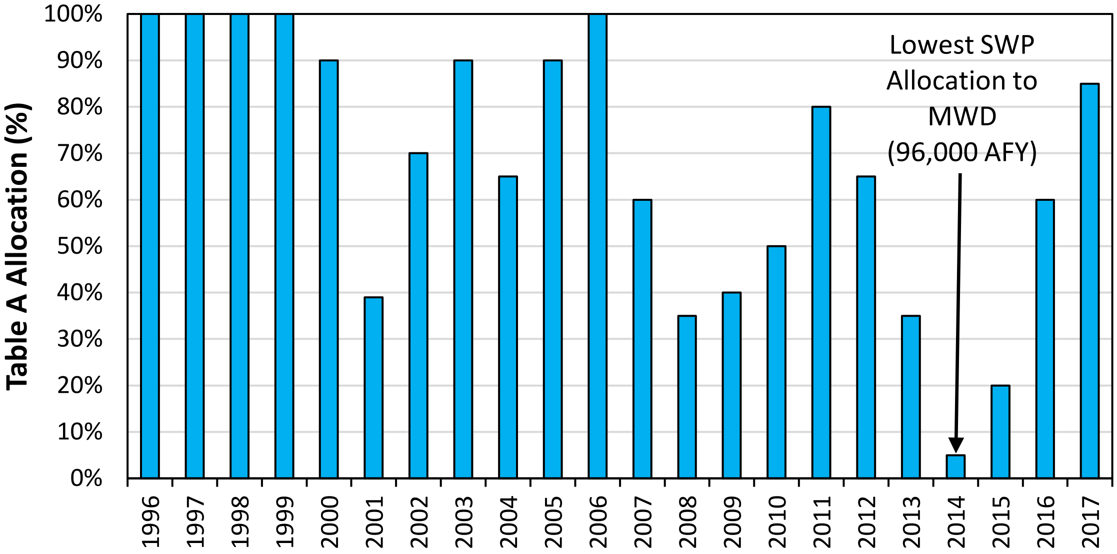


Figure 4-8. SWP Table A Allocations

4.3.2 CRA Deliveries

The U.S. Bureau of Reclamation (BOR) manages the water supply from the Colorado River, which is allocated to Upper Basin and Lower Basin states. Lower Basin states include Arizona, California, and Nevada, as well as treaty water for Mexico. Within California's 4.4 million acre-foot (MAF) apportionment of the Colorado River, senior water rights belong to Native American tribes and irrigation districts in Riverside and Imperial Counties. MWD has a base allocation of 550,000 AFY minus a reduction for California on-River priority 1, 2, and 3b users when their combined use exceeds 420,000 AFY. Prior to 2000, MWD and California irrigation districts also benefited from unused Colorado River apportionment of the Upper Basin States. As a result of Upper Basin states perfecting their river water rights, the 2003 Quantification Settlement Agreement (QSA) spelled out how California's apportionment of Colorado River water would be allocated to MWD and California irrigation districts in order to stay within its 4.4 MAF apportionment. The QSA also settled how current conservation agreements from canal lining projects and water transfers would be accounted for between MWD, Imperial Irrigation District, San Diego County Water Authority, Coachella Water District, and Palo Verde Irrigation District. In total, these water conservation agreements and water transfers provide up to 514,000 AFY of additional water supply from California irrigation districts to MWD and SDCWA.

In response to a decade long drought in the Colorado River Basin, BOR and Lower Basin states established Interim Shortage Guidelines in 2007 that specified Lake Mead elevation targets to trigger when Arizona, California and Nevada would begin taking shortages of their apportionment. As a result of the Colorado River Basin drought, Lake Mead elevation declined significantly from 1,230 feet in year 2000 to just below 1,075 feet in 2010. Wet years in 2011 and 2012 resulted in a slight improvement in Lake Mead elevation (peaking at 1,130 feet), but lake elevation then decreased to 1,075 feet in 2014 which is the trigger for when Arizona and Nevada begin to take shortages under the BOR 2007 guidelines (see **Figure 4-9**). And despite major improvements in snow pack in the Upper Colorado River Basin (which from a purely hydrologic perspective ended the drought), Lake Mead elevations continue hovering around 1,075 feet due to Upper and Lower Basin states fully using their apportionment of the river. When Lake Mead elevation drops below 1,000 feet, a federal shortage declaration is made.

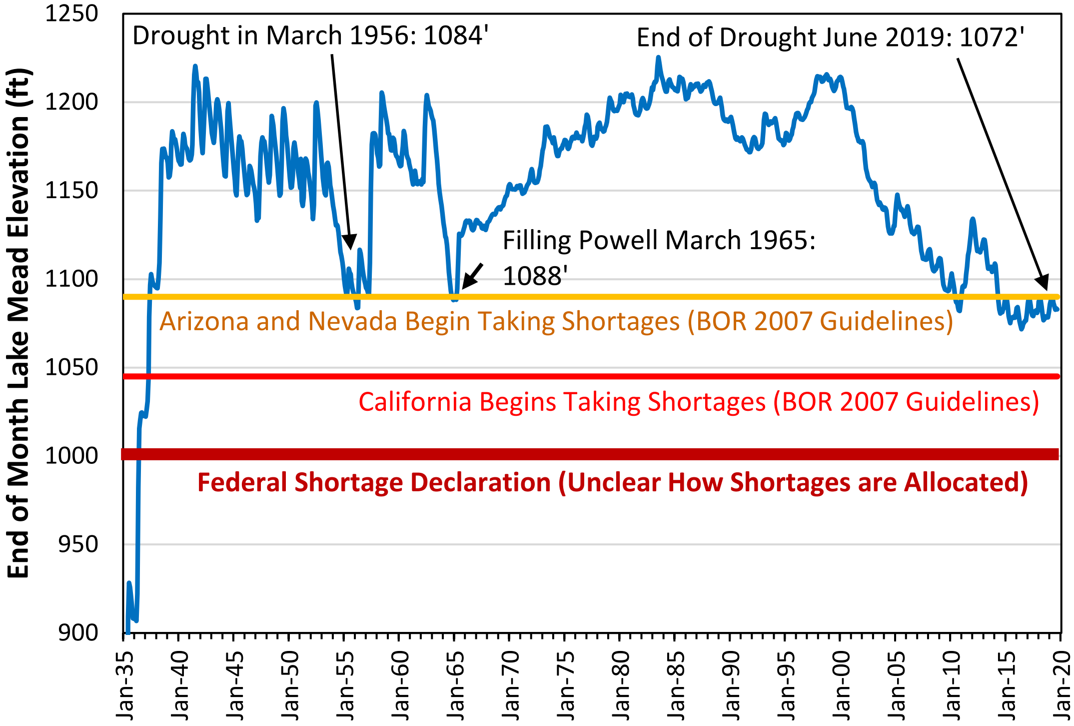


Figure 4-9. Lake Mead Water Elevation

Since the initial filling of Lake Mead, elevations have never gone below 1,000 feet and it is unclear how the Federal Government will formally allocate water among the Lower Basin states when this occurs. Based on BOR studies of water demands and future hydrology of the river, it is estimated that it is likely that Lake Mead elevation could fall below 1,000 feet within the next 10 years. Recognizing the direr situation if this occurs, the Lower Basin States developed a Drought Contingency Plan (DCP) as a replacement to the 2007 Interim Shortage Guidelines in the hopes of delaying Lake Mead elevation from falling below 1,000 feet. In April 2019, U.S. Congress passed a finalized Drought DCP agreed upon and produced by the three Lower Basin States and Mexico. **Table 4-1** presents a comparison of the shorted apportionment volumes between the 200 Interim Shortage Guidelines and the 2019 DCP.

Table 4-1. Colorado River Shorted Apportionment for Lower Basin States

Lake Mead Trigger Elevation (feet)	Shorted Apportionment Volumes Under 2007 Interim Guidelines (KAFY)			Shorted Apportionment Volumes Under 2019 Drought Contingency Plan (KAFY)		
	Arizona	Nevada	California	Arizona	Nevada	California
1,090	0	0	0	192	8	0
1,075	320	13	0	192	8	0
1,050	400	17	0	192	8	0
1,045	400	17	0	240	10	200
1,040	400	17	0	240	10	250
1,035	400	17	0	240	10	300
1,030	400	17	0	240	10	350
1,025	480	20	0	240	10	350

Under the 2019 DCP, the total Lower Basin states combined will be shorted by 450,000 AF when Lake Mead elevation hits 1,045 vs. 417,000 AF in the 2007 Guidelines, and California will take 200,000 AF of that shortage (whereas California did not take any shortages in the 2007 Guidelines through elevation 1,025 feet). When Lake Mead elevation hits 1,025 feet, the Lower Basin states combined will be shorted by 600,000 AF vs. 500,000 AF in the 2007 Guidelines, and California will take 350,000 AF of that shortage.

Within California, the Imperial Irrigation District has withdrawn from participation in the DCP until the Federal Government has addressed Salton Sea mitigation, and the portion of the California-specific shortage that MWD may take is uncertain at this time.

4.3.3 MWD Imported Water Allocation

Regulatory or hydrologic-based shortages on either the Colorado River or Delta may cause MWD to pass potential supply shortages on to its member agencies. Reduced MWD deliveries, or allocations, are determined based on reservoir storage levels recorded in the MWD Water Supply Allocation Plan (WSAP). The most current version of the WSAP was finalized in 2015, and **Table 4-2** lists all past MWD delivery reductions.

Table 4-2. Reductions in MWD Deliveries

Year of Reduction	Percent Reduction
1977	10%
1991	17%
2009	10%
2010	10%
2015	15%

Calendar years 1991 and 2015 have MWD allocations larger than 10%, while in 1977, 2009 and 2010 MWD deliveries were reduced by 10%.

4.4 Summary of LBWD Water Source Reliability

LBWD has faced a number of challenges that impact the reliability of the water sources they rely on for supply. Variations in hydrology and the evolving environmental and regulatory issues surrounding the Delta affect the availability of imported water. Similarly, variable hydrology, especially long-term droughts, and climate change are impacting the availability of groundwater supplies. Finally, the increase in water efficiency through continued progress with water conservation has reduced wastewater flows and availability of drought-proof supply of recycled water. These challenges and impacts to LBWD's water reliability are discussed in Section 5.

Section 5

Water Supply Needs Assessment

To evaluate future water supply options, a water supply needs assessment (sometimes referred to as supply gap analysis) is required. This assessment involves subtracting forecasted water demands for LBWD (as described in Section 3) from total existing water supplies available to LBWD (as described in Section 4). If forecasted water demands exceeds available existing water supplies, then shortages exist. If these shortages are large and/or occur often, then new water supply options are recommended.

However, because of the uncertainties associated with future water demands and existing supplies, the water supply needs assessment becomes more challenging. **Figure 5-1** presents the existing water supply sources available to meet LBWD's water demands, as well as new supply options. Uncertainties for existing water supply and demand are also shown in the figure.

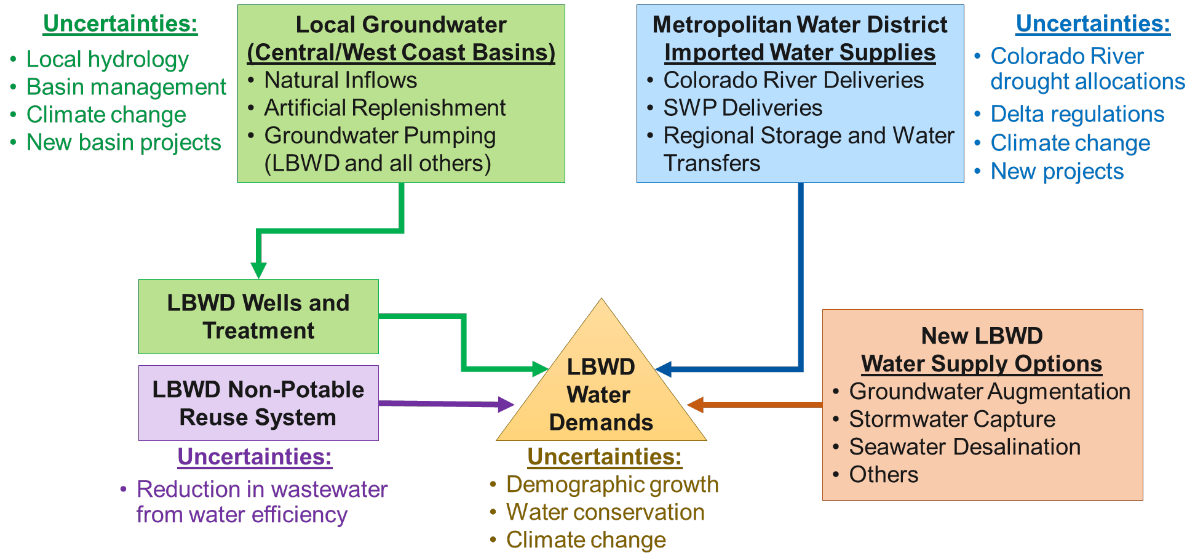


Figure 5-1. Sources of Water Supplies Available to Meet LBWD Water Demands

5.1 Planning Scenarios

As the future is uncertain, a technique called scenario planning was used for the water supply needs assessment. As applied for WRP, scenario planning had the following three steps:

1) Identify the major uncertainty elements (or scenario building blocks) to be included in each planning scenario, with the goal on focusing those elements that have the most individual impact on LBWD;

2) Combine uncertainty elements into various scenario narratives that are plausible, have internal consistency[2] , and span a reasonable range of future conditions; and

3) Evaluate the impact that each planning scenario has on future water supply needs for LBWD.

The planning scenarios used for the WRP had the following uncertainty elements: (1) future climate; (2) future water demands; (3) implementation of local, regional and statewide water supply projects.

5.1.1 Uncertainty in Future Climate

In late 2014, the Coupled Model Intercomparison Project Phase 5 (CMIP5) climate forecasts were released and are now being used to evaluate water supply impacts by water agencies around the globe. The global climate models (GCMs) for CMIP5 utilize Representative Concentration Pathways (RCPs) to show a range in climate forecasts based on radiative forcing (the difference between the incoming energy from sunlight and the energy radiated back into space) which are impacted by greenhouse gas emissions. **Table 5-1** presents the four different RCP assumptions used in the CMIP5 GCMs.

Table 5-1. CMIP5 Representative Concentration Pathways

RCP	Assumption
RCP 2.6	Radiative forcing equal to 2.6 Watts per square meter (W/m^2) Annual GHG* emissions peak between 2010-2020 and decline substantially afterward
RCP 4.5	Radiative forcing equal to 4.5 W/m^2 Annual GHG emissions peak near 2040 then decline
RCP 6.0	Radiative forcing equal to 6 W/m^2 Annual GHG emissions peak near 2080 then decline
RCP 8.5	Radiative forcing equal to 8.5 W/m^2 Annual GHG emissions increase throughout 21st century

* GHG = greenhouse gases

For the WRP, it was decided that the RCP8.5 would be used as the base assumption for future climate models for two reasons: (1) while the GCMs using RCP8.5 show the greatest increases in global temperatures, many climate policy experts categorize RCP8.5 as being a good "business-as-usual" assumption for future greenhouse gas emissions; and (2) because our planning period for the WRP ends at year 2050, the difference in future greenhouse gas emissions and rising temperatures between RCP8.5 and RCP6.0 are negligible from now until year 2080.

Within RCP8.5 there are about a dozen or so GCMs that forecast future temperature and precipitation. To span a reasonable range of potential climate impacts on water supply needs, three CGMs for RCP8.5 were used for the WRP. **Table 5-2** presents these three GCMs and the relative impacts they have on future water demand and supply sources.

---

[2] Internal consistency refers to several things. First when using global climate models (GCMs) for scenarios, each GCM used is downscaled to the appropriate geographical area (Long Beach for local demands and groundwater, Colorado River basin for MWD's Colorado River supplies, and Sierra Nevada watershed for MWD's State Water Project supplies. Second, if future climate change results in significant impacts to imported water supply, it is assumed that more local water supplies funded under MWD's Local Resources Program would likely occur as partial offset or mitigation to the climate change impacts.

Table 5-2. RCP8.5 Global Climate Models Used for WRP and Relative Impacts

GCM Name	LBWD Demand	Local Groundwater	State Water Project	Colorado River	Overall Impact on Supply Need
GFDL	Minimal Impact	Minimal Impact	Minimal Impact	Minimal Impact	Minimal
CNRM	Moderate Impact	Minimal Impact	Minimal Impact	Moderate Impact	Moderate
CSIRO	Significant Impact	Moderate Impact	Moderate Impact	Significant Impact	Significant

5.1.2 Uncertainty in LBWD Water Demand

LBWD water demand is primarily driven by growth in demographics, future climate and water conservation. A baseline potable water demand forecast was prepared (as discussed in Section 3) that assumed that demographic growth for the City would continue at historical trends through 2050, with historical average climate and with current water conservation levels. Sensitivities were performed on key drivers of water demand, such as higher levels of demographic growth (developed by SCAG) future climate with hotter temperatures and drier precipitation, and increased levels of water conservation. These sensitivities were the basis for developing planning scenario elements presented in this section of the report.

5.1.3 Uncertainty in Local, Regional and State Supply Projects

There are several large water supply projects and programs in various levels of implementation that can have significant impact on future water supply needs for LBWD. These projects include:

- **Albert Robles Center (ARC):** This WRD project will purify 10,000 AFY of tertiary treated reclaimed water annually to near-distilled levels through an advanced water treatment facility. Together, with another 11,000 AFY of recycled water, WRD will in total deliver 21,000 AFY of reclaimed water to the San Gabriel Spreading Grounds which would provide firm replenishment source of supply to the Central Basin. Source water for ARC will come from the San Jose Treatment Plant. The ARC project is in the final stages of construction and it is expected that the project will be delivering purified water by 2020. As such, this project is included in every planning scenario for the WRP.

- **MWD Regional Recycled Water Program (RRWP):** In partnership with LACSD, MWD is proposing a phased RRWP to improve regional water supply reliability. Wastewater from LACSD's Carson JWPCP will be purified at an advanced water treatment plant owned and operated by MWD located on the same property as the Carson plant. The purified water will be delivered to several groundwater basins in Los Angeles County (and possibly Orange County) and two of MWD's regional water treatment plants (pending the outcome of state regulations for potable reuse). Ultimately, 150 MGD or 168,000 AFY could be delivered from the RRWP, providing increased reliability during droughts and seismic events. Once permitted and approved by MWD's Board, the full project would take approximately 11 years to design and construct, but an accelerated phased approach could see initial water deliveries sooner. Main issues with this project being implemented center around the pricing of water and ensuring that benefits from the program are spread among all MWD's member agencies.

- **MWD Local Resources Program (LRP):** MWD provides funding for local recycled water, groundwater and seawater desalination, and stormwater capture projects under LRP. Potential member agency projects are summarized in the appendix to the 2015 Update of MWD's IRP. The IRP organizes these member agency projects into six categories in order of decreasing certainty: Existing and Planned; Under Construction; Full Design & Appropriated Funds; Advanced Planning (EIR/EIS Certified); Feasibility; Conceptual. MWD's IRP, only assumed that projects in the *Existing and Planned* and *Under Construction* categories are included MWD's local water supplies. For the WRP, it was assumed that four additional potable reuse projects would be implemented that were not included in MWD's IRP, these being: City of San Diego Pure Water Program Phase 1, Los Angeles Department of Water and Power Groundwater Replenishment at Tillman, Upper San Gabriel Municipal Water District Indirect Reuse Replenishment, and Eastern Municipal Water District Indirect Potable Reuse. It is expected that these four projects would produce approximately 88,000 AFY of new water supply by 2023, and thus this amount is included in every planning scenario for the WRP.

- **MWD Water Transfers:** MWD has been successful in developing water transfer programs where water from agricultural irrigation districts are transferred to MWD on either a permanent (as a result of agricultural water conservation, or permanent transfer of water rights) or on a temporary or call basis during drought periods (as a result of fallowing agricultural lands when called upon by MWD). These water transfers have been implemented in the Central Valley and in Riverside and Imperial Counties. For the WRP, it was assumed that additional water transfers could likely be developed by MWD, with a range from 80,000 to 130,000 AFY, in response to climate change and regulatory restrictions in the Delta.

- **Delta Conveyance:** This potential project aims at stabilizing SWP water deliveries, protecting habitats and fish populations in the Delta, and increasing Delta levee resiliency from seismic and flooding events. The Delta Conveyance project is a modification to the previous California WaterFix project, in which Governor Gavin Newsome altered that project from a two-tunnel solution to a one-tunnel solution in 2019 to by-pass water flows through the environmentally-sensitive Delta. This change in project configuration requires a new environmental review/permitting process before design of the project can be started. It is expected this environmental review/permitting will be completed over the next two years. Furthermore, the full implementation of this project is still uncertain as there are many organizations that still oppose it. In addition, it is unclear at this time what the capacity of this new project will be and how it will change the economics of the project in the eyes of water agencies that make up the Delta Conveyance Design and Construction Authority—which is partnering with the California DWR in the implementation of the project. For the purposes of the WRP, it is assumed (based on previous modeling for the WaterFix one-tunnel option that was studied before its environmental documentation was completed) that the Delta Conveyance project would provide MWD with an average of 400,000 AFY of lost SWP supplies.

5.1.4 Development of Planning Scenarios

The uncertainty elements described earlier were combined in different ways to develop a narrative of possible future conditions. Initially four planning scenarios were developed spanning a plausible range of outcomes, defined as: (1) current conditions, reflecting conditions and projects as they are right now; (2) ideal conditions, reflecting minimal climate change impacts and partial implementation of regional and statewide water projects; (3) moderate conditions, reflecting moderate climate change impacts and partial implementation of regional and statewide water projects; and (4) stressed conditions, reflecting significant climate change impacts and full implementation of regional and statewide water projects.

These initial planning scenarios were presented at the November 2018 stakeholder workshop along with impacts on water supply needs for LBWD. After much discussion at that workshop, consensus was reached among both stakeholders and LBWD staff that three additional scenarios should be added. These three additional scenarios, all built from the original stressed conditions scenario, had one or both of the MWD RRWP and Delta Conveyance projects not being implemented. All seven planning scenarios are presented in **Table 5-3**. For the water supply projects and programs uncertainty elements of the scenarios, the supply yields in AFY are shown in the table with indication of likely operational year, shown in parenthesis.

5.2 Methodology for Water Supply Needs Assessment

To appropriately deal with water supply and demand uncertainties, a *systems model* was used to conduct the water supply needs assessment for the WRP. Systems models are comprehensive tools that simulate water demands and supplies under multiple hydrologic and climatic assumptions and can integrate: (1) water demand forecasts; (2) different sources of water supplies from different watersheds (e.g., surface water, local groundwater, and imported water); and (3) storage operations. Systems models use output and relationships from more detailed hydrologic modeling but tie these together using a common set of hydrologic years. As a result, these types of models can simulate demands and all sources of water supply within a single model, instead of having to run multiple models. Systems models are better suited for development of future water resources strategies as they can quickly answer "what-if" scenarios and rapidly evaluate future alternatives. These types of models are also well-suited for public stakeholder involvement as they can more easily show complex interrelationships between multiple water supply sources.

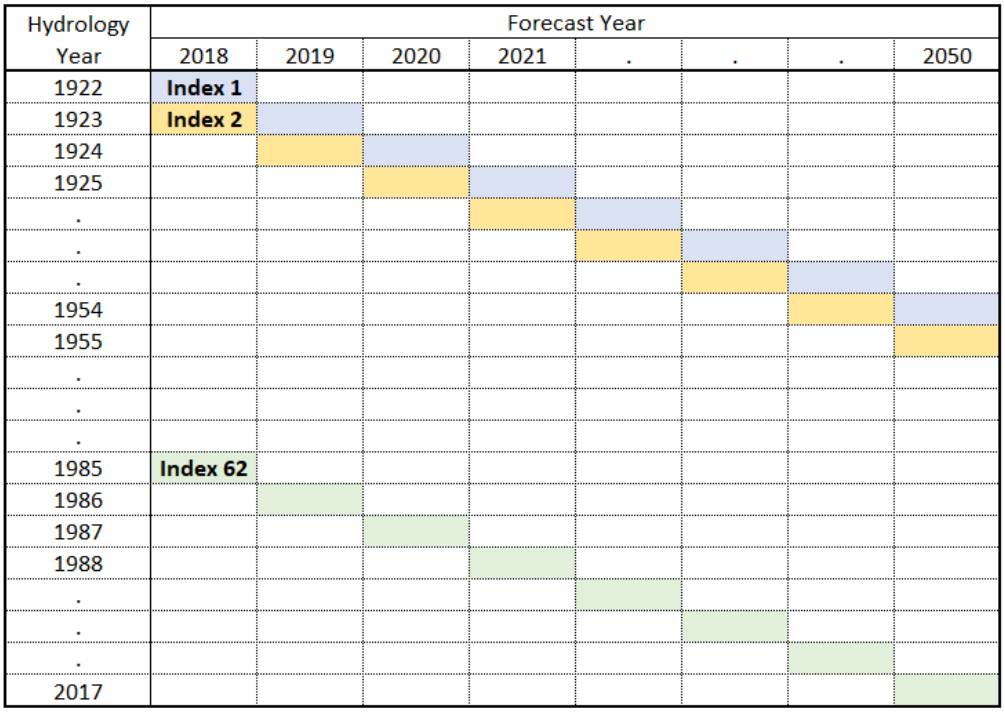
CDM Smith developed a regional water supply systems model for planning studies in MWD's service area for several water agencies (Municipal Water District of Orange County, Upper San Gabriel Valley Municipal Water District and the City of San Diego) using the Water Evaluation and Planning (WEAP) simulation software. WEAP is maintained by the Stockholm Environment Institute (http://www.sei-us.org/weap) and used by water agencies around the globe for water supply planning. CDM Smith's WEAP model simulates all of MWD's regional water demands, imported water sources, water transfers and groundwater banking programs, and reservoir storage operations. It can also be expanded to include local water demands and local water supplies for any MWD member agency or retail water agency. MWD's drought allocation formulas for its member agencies can be used in the WEAP model to estimate the expected imported water deliveries that are available to any member agency under different stages of drought.

Table 5-3. Planning Scenarios for WRP

Planning Scenario	Uncertainty Elements						
	Future Climate Change Impacts	LBWD Water Demands	ARC Project	MWD RRWP Project	Additional MWD LRP	Additional MWD Water Transfers	California Delta Conveyance
Current Conditions	None	Lower Population Growth	21,000 AF (2018)	Not Implemented	Not Implemented	Not Implemented	Not Implemented
Ideal Conditions	Minimal Impacts	Lower Population Growth	21,000 AF (2018)	112,000 AF (2030)	88,000 AF (2025)	80,000 AF (2020)	400,000 AF (2035)
Moderate Conditions	Moderate Impacts	Higher Population Growth	21,000 AF (2018)	112,000 AF (2030)	88,000 AF (2025)	80,000 AF (2020)	400,000 AF (2035)
Stressed Conditions A	Significant Impacts	Higher Growth with Increased Conservation	21,000 AF (2018)	168,000 AF (2040)	88,000 AF (2025)	130,000 AF (2020-2030)	400,000 AF (2035)
Stressed Conditions B	Significant Impacts	Higher Growth with Increased Conservation	21,000 AF (2018)	Not Implemented	88,000 AF (2025)	130,000 AF (2020-2030)	400,000 AF (2035)
Stressed Conditions C	Significant Impacts	Higher Growth with Increased Conservation	21,000 AF (2018)	168,000 AF (2040)	88,000 AF (2025)	130,000 AF (2020-2030)	Not Implemented
Stressed Conditions D	Significant Impacts	Higher Growth with Increased Conservation	21,000 AF (2018)	Not Implemented	88,000 AF (2025)	130,000 AF (2020-2030)	Not Implemented

CDM Smith's WEAP model utilizes indexed-sequential simulation to compare water demands and supplies under historical hydrologic conditions that are mapped to future years. The sequence of the historical hydrology years is maintained in this method. The WEAP model has a 33-year planning horizon from 2018 to 2050, and the model uses a historical hydrological period of 1922 to 2017 (96 years). The water demands and supplies are simulated in sequence, with the first index being historical hydrology year 1922 mapped to forecast year 2018, 1923 mapped to 2019, and so forth until the hydrology year 1954 is mapped to 2050. The second index of model simulation shifts the historical hydrologic period one year forward so hydrology year 1923 is mapped to 2018, 1924 is mapped to 2019 … and 1955 mapped to 2050. This indexing process continues until all sequences of historical hydrology years are mapped to all forecast years (see below for example).

Example of indexed-sequential simulation



Hydrology Year	Forecast Year							
	2018	2019	2020	2021	.	.	.	2050
1922	**Index 1**							
1923	**Index 2**	🟦						
1924		🟨	🟦					
1925			🟨	🟦				
.				🟨	🟦			
.					🟨	🟦		
.						🟨	🟦	
1954							🟨	🟦
1955								🟨
.								
.								
.								
1985	**Index 62**							
1986		🟩						
1987			🟩					
1988				🟩				
.					🟩			
.						🟩		
.							🟩	
2017								🟩

Thus, for any given forecast year, a probability of potential water shortages for LBWD is generated with 96 possible outcomes. The benefit of index-sequential simulation is that regional MWD and local groundwater storage (inflows, outflows, and ending period storage levels) can be accurately calculated at the beginning and end of each simulation. This also allows the WEAP model to maintain the complex water rights and storage assumptions used to model the State Water Project and Colorado River systems.

In addition to portraying historic hydrology through the index-sequential method, the WEAP model can test the impact of climate change scenarios on water supplies. The climate change scenarios are assumed to alter the historical hydrology (1922 to 2017) using the hybrid-delta approach that the US Bureau of Reclamation (USBR) uses for its basin studies across the western United States.

For the WRP, CDM Smith customized its WEAP model to include LBWD's water demand and all the water supply sources depicted in Figure 5-1 and described in Section 4.

To estimate future water supply needs for LBWD, the following logic is reflected in the WEAP model

1. LBWD prioritizes groundwater, as it is lower in cost;
2. Groundwater is limited to LBWD's well capacity, pumping rights, and condition of accumulated overdraft in the groundwater basin; and
3. LBWD's remaining water supply need for MWD imported water (i.e., total LBWD less local groundwater, less local recycled water) is a function of whether or not MWD is in drought allocation and how much imported water is allocated to LBWD during different stages of drought.

5.2.1 Groundwater Accumulated Overdraft Assumptions

Accumulated overdraft of the Central/West Coast Basins is tracked by WRD and compared to a target AOD level as discussed in Section 4. During times in which AOD has greatly exceeded the target, WRD has declared emergency conditions and called for voluntary reductions in pumping. Because the LBWD is looking out to year 2050 and its WRP is simulating future groundwater and imported water supply under various climate change impacts, a conservative assumption was made that these voluntary reductions in pumping during extended drought periods would essentially become mandatory restrictions. This is because even if WRD wanted to purchase MWD replenishment water under these severe conditions, MWD would not be able to provide deliveries. As point proven, this did occur in the last drought when MWD did not provide replenishment water (even at full cost) to groundwater agencies that requested such water.

As such, for the purposes of the WRP it was assumed that LBWD would need to reduce its groundwater pumping in accordance with different levels of AOD above WRD's AOD target (see **Table 5-4**). It should be noted again that WRD does not currently impose mandatory groundwater reductions during emergency declarations, but it is not implausible to assume this would need to change if future climate change caused more frequent and severe droughts.

Table 5-4. Assumed Reduction in LBWD Groundwater Pumping Under Different Basin AOD Conditions

Increase in Basin AOD	Reduction in LBWD Groundwater Pumping
0 to 5%	0%
6 to 10%	5%
11 to 15%	10%
16 to 20%	12%
>20%	15%

Note: The assumed reductions in groundwater pumping shown in this table do not reflect existing WRD policies.

5.2.2 MWD Imported Water Allocations

During drought periods, MWD allocates its imported water using its WSAP. The allocation involves several types of adjustments in order to balance historical purchases of imported water with: retail water needs, amounts of local water supplies, and per capita water use. Currently, the WSAP has a provision that if a member agency has a total per capita water use under 100 GPCD it will receive all MWD imported water needed by that agency—meaning there will be no shortage for that agency even during a severe drought. This provision was originally made in order to encourage water use efficiency and it reflects that agencies that have achieved this level of efficiency would have a more difficulty in restricting water use during droughts. However, with increased levels of statewide water-efficient plumbing codes and landscape ordinances, coupled with aggressive statewide per capita water use targets, it is likely that more of MWD's member agencies will approach this 100 GPCD target. And as that happens in the future, MWD would will likely have to eliminate this per capita water use provision in its allocation formula.

Thus, for the purposes of the WRP, it is assumed that the MWD's future WSAP will only have adjustments for retail water needs and amounts of local water supplies. **Table 5-5** shows the allocation of MWD imported water to LBWD under different stages of drought based on a revised assumption of WSAP.

Table 5-5. Assumed Allocation of MWD Imported Water to LBWD Under Specified Water Demand

Regional Shortage Level	Regional MWD Shortage Percentage	Total MWD Supplies Allocated to LBWD (AFY) [1]	LBWD Total Water Shortage (AFY) [1]
1	5%	27,920	1,850
2	10%	26,070	3,700
3	15%	24,220	5,550
4	20%	22,400	7,370
5	25%	20,500	9,270
6	30%	19,060	10,710
7	35%	17,210	12,560
8	40%	14,980	14,790
9	45%	13,130	16,640
10	50%	11,280	18,490

[1] Assumes total LBWD water demand is 58,000 AFY, groundwater pumping is 22,600 AFY (restricted level assumed during a local severe drought), and recycled water supplies are 5,300 AFY.

5.3 Water Supply Needs

Future water supply needs for LBWD using the WEAP model can be shown under historical and climate changed hydrologic conditions in the form of probabilities. This is useful because not only can the maximum water supply need be estimated, but so can the probability of that need.

5.3.1 Future Groundwater Availability

As discussed previously, AOD in the CBWCB is a function of inflows to the basins (which are impacted by local hydrology, basin management, climate change, and new basin projects) and groundwater pumping. This is modeled in WEAP for 96 hydrologic years and under different scenarios of climate change and future groundwater augmentation projects. **Figure 5-2** presents the results of the WEAP simulation of AOD for the Ideal Conditions scenario (minimal climate change impacts with MWD's RRWP implemented by 2030. The dotted black line in the figure is the WRD AOD target. As shown in the figure, there is a 40% probability that the AOD exceeds the

WRD target in the year 2020, with the maximum AOD exceedance over the target being 110,000 AF. With the operations of WRD's ARC groundwater augmentation project fully kicking in by 2030, the probability that the AOD exceeds the target drops to 10%. After MWD's RRWP is operational, both the probability of AOD exceeding the target drops further in 2040 and 2050. Because climate change impacts in this scenario are minimal the AOD is simulated to generally be lower in subsequent forecast years with the exception of year 2050 as future demands grow.

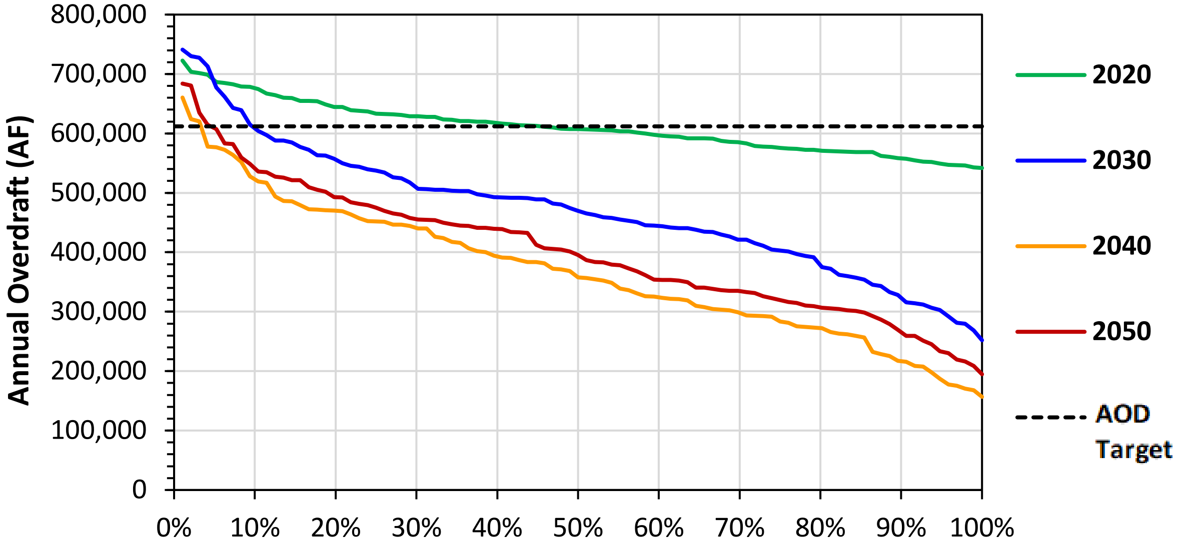


Figure 5-2. Probability of Basin AOD Levels for Ideal Conditions Scenario

Figure 5-3 shows the same analysis of AOD under the Stressed Conditions A scenario (significant climate change impacts with MWD's RRWP implemented by 2030). Under this scenario, climate change impacts are more significant in reducing natural inflows to the basin. Even with WRD's ARC project fully operational and MWD's RRWP implemented by 2030, AOD is projected to increase and the probability that AOD exceeds WRD's target is greater. In this scenario, as climate change impacts grow over time, AOD is also expected to increase. By year 2050, the probability that AOD exceeds the target is 83%, with the maximum AOD exceedance over the target being 295,000 AF.

5.3.2 Future Imported Water Availability

MWD regional water demands and water supplies are simulated in the WEAP model to reflect historical hydrology from 1922 to 2017. Utilizing past hydrologic years illustrates the impacts of wet years, normal years, dry years and multi-year droughts. These representations of historical hydrology are used to model 96 possible conditions that span the forecast period 2018 to 2050. When climate change impacts are imposed, the model alters the historical hydrologies using the hybrid-delta method. **Figure 5-4** shows the probability of MWD water shortages simulated for the Ideal Conditions scenario.

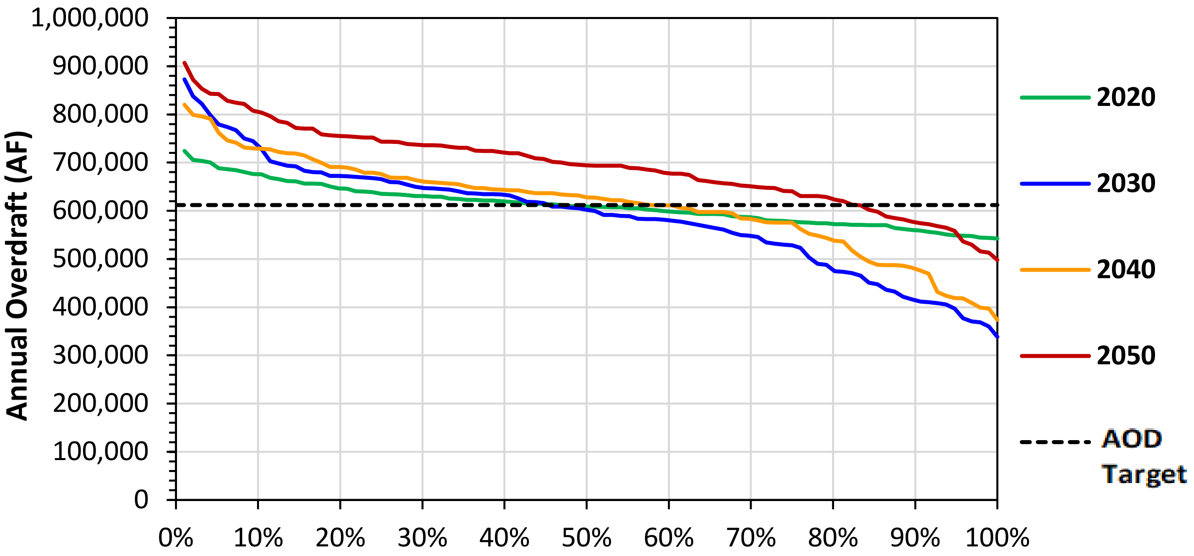


Figure 5-3. Probability of Basin AOD Levels for Stressed Conditions A Scenario

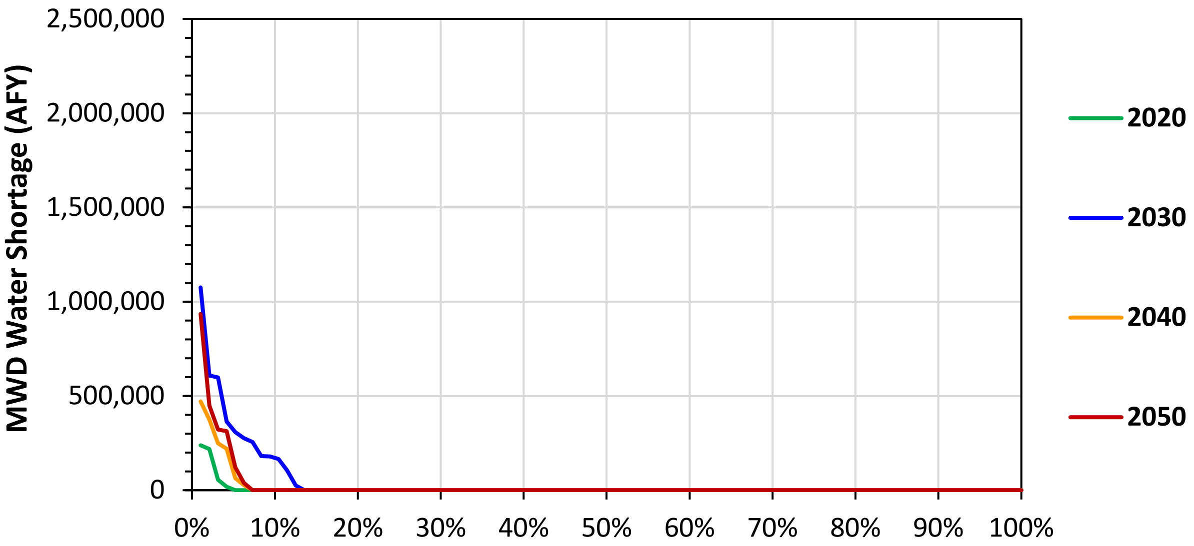


Figure 5-4. MWD Water Shortages Under Ideal Conditions Scenario

Under the Ideal Conditions scenario, the probability of MWD water shortages are very low (less than 10% of the time after 2040), although in very rare critical drought years the size of the shortage can be large (approaching 1.0 million AFY).

Figure 5-5 presents the simulated MWD water shortages under Stressed Conditions A scenario. Under this scenario, which assumes significant climate change impacts, the probability of MWD water shortages by 2050 is 50%, while the maximum shortage in that same year is 1.9 million AFY.

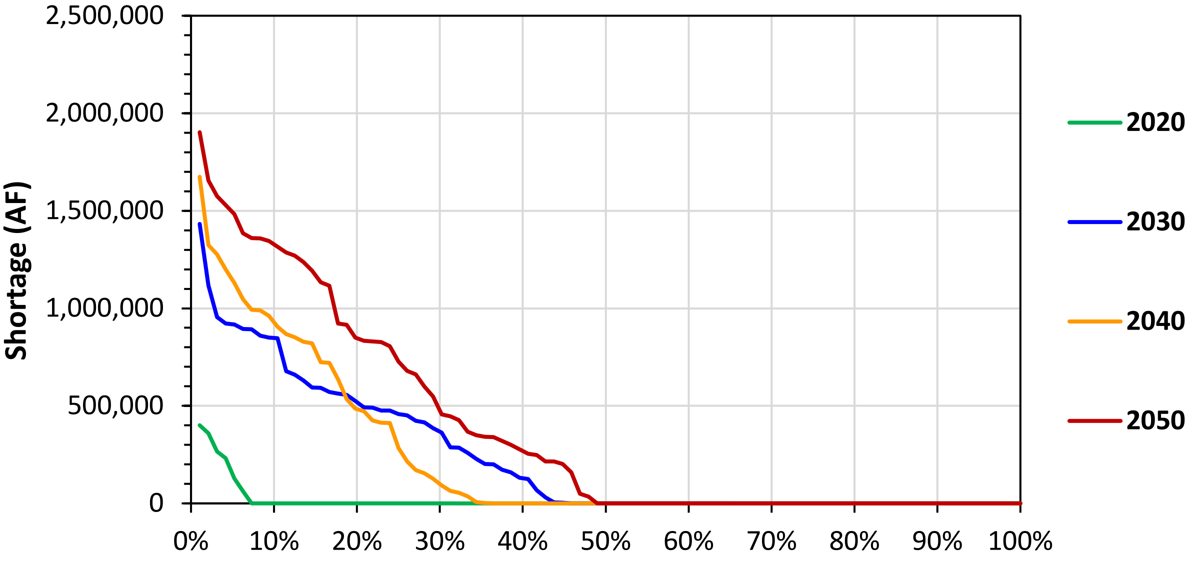


Figure 5-5. MWD Water Shortages Under Stressed Conditions A Scenario

5.3.3 Water Supply Needs for LBWD

When local groundwater and imported water from MWD are simulated together to meet water demands, the WEAP model can assess the need for new water supplies for LBWD. **Figure 5-6** presents LBWD water demands, local groundwater, and imported water for the Ideal Conditions scenario. Local groundwater (shown in green color in the figure) includes WRD's ARC groundwater augmentation and is simulated for historical hydrologic years 1922-2017. After year 2030, when the ARC project is fully operational and stabilizing the groundwater levels in the Central Basin, there are only a few years in which groundwater pumping is restricted. Imported water from MWD (shown in blue color in the figure) includes MWD's RRWP (online in 2030) and Delta Conveyance (online in 2040) allocated to LBWD. The white color area under the water demand line (in black) indicates a water shortage for LBWD, with the probability of shortage shown in the vertical axis of the figure. Water shortages for this scenario are relatively small with low probability in year 2020 and grow slightly in 2030. After 2040, the water shortages decrease as MWD's RRWP project is operational and Delta Conveyance is implemented.

For the Stressed Conditions A scenario, the same simulations are shown in **Figure 5-7**. Under this scenario which includes significant climate change impacts on both local groundwater and MWD imported water, there are many more times that groundwater pumping is restricted and more times that MWD is in allocation—leading to larger and more frequent water shortages for LBWD.

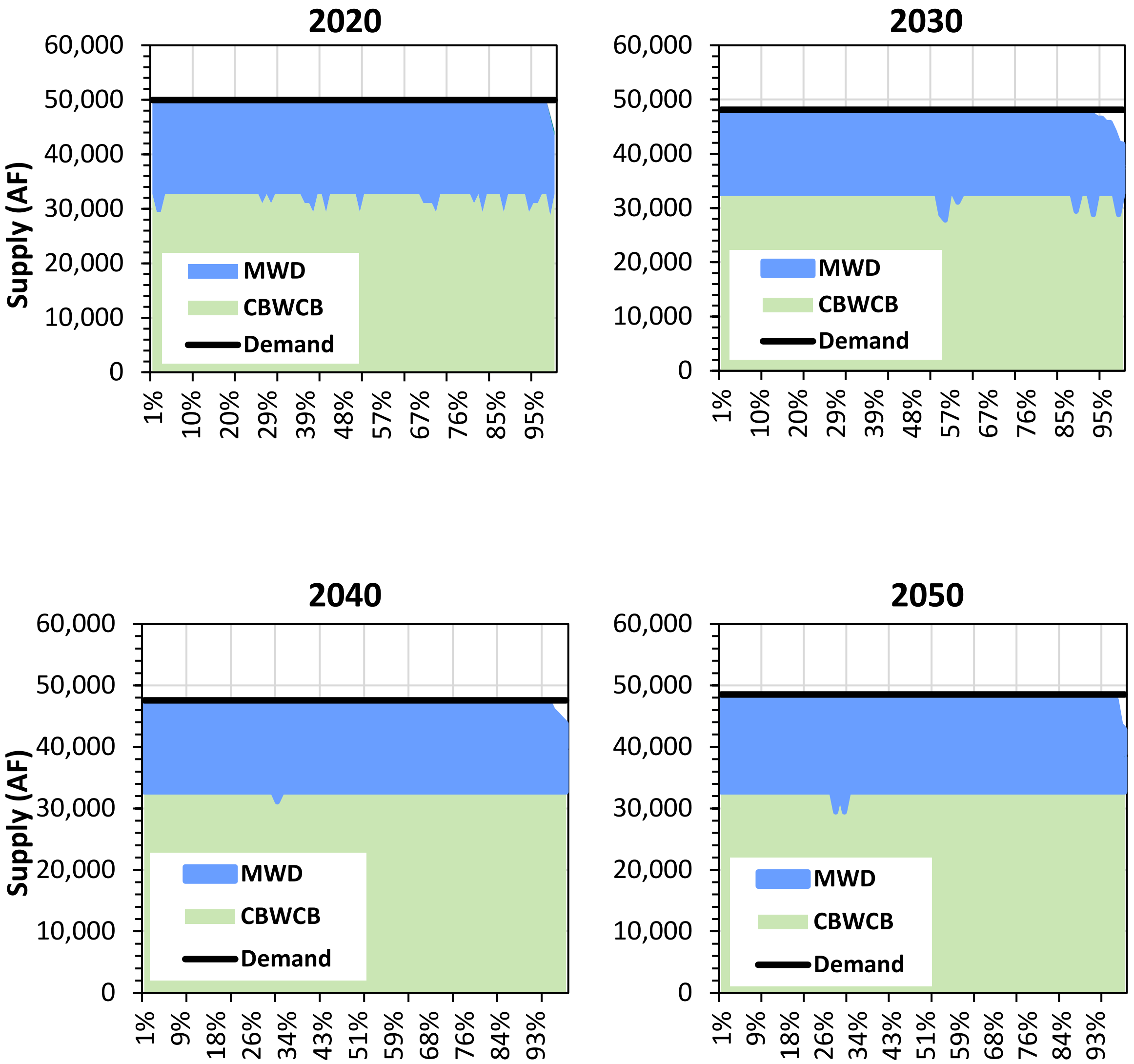


Figure 5-6. LBWD Water Demand and Supply Simulated for Ideal Conditions Scenario

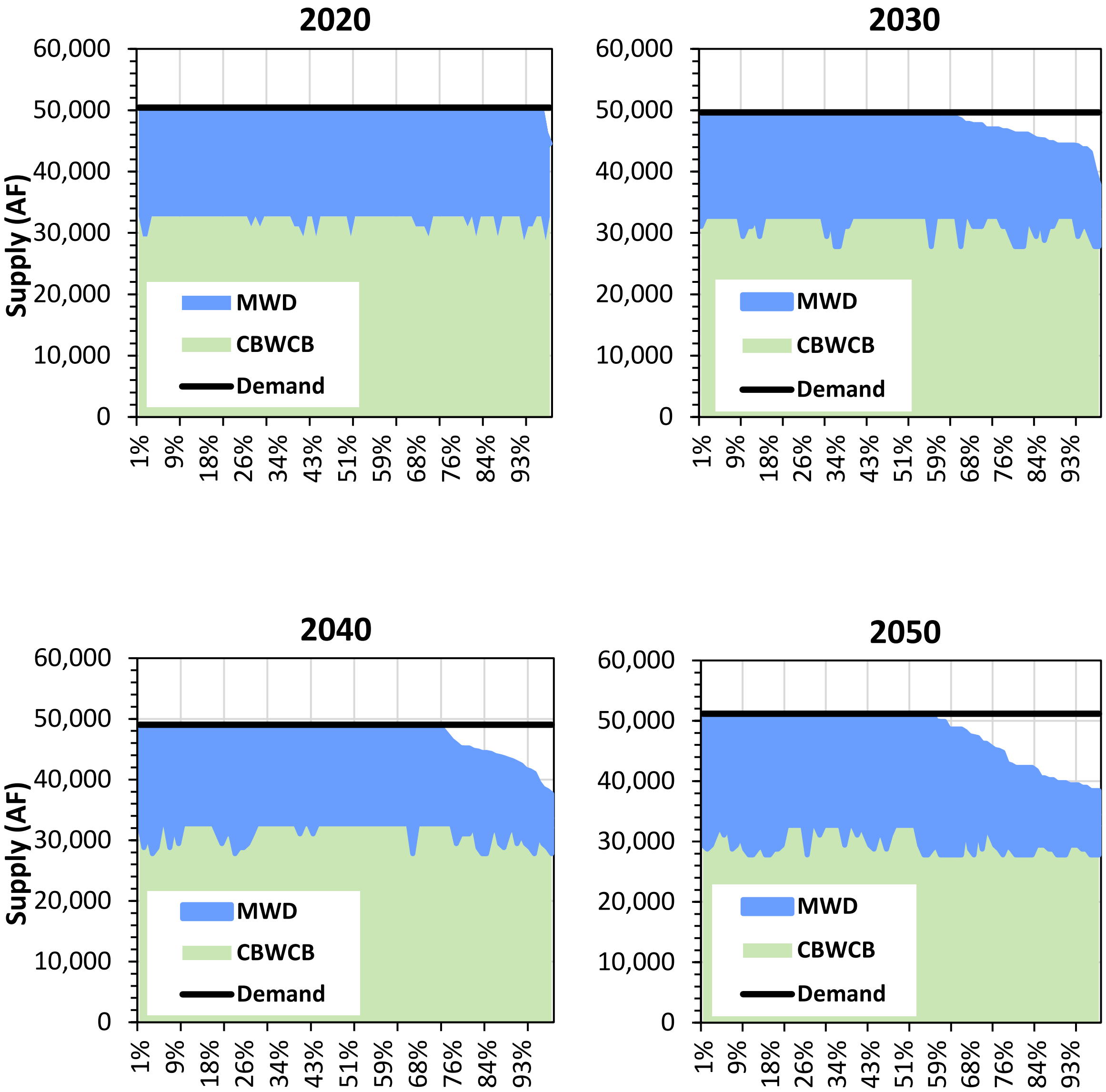


Figure 5-7. LBWD Water Demand and Supply Simulated for Stressed Conditions A Scenario

The maximum water shortage for LBWD for all planning scenarios and the probability that any-sized shortage occurs is shown in **Table 5-6**. For the maximum water shortage (shown in AFY), the percent shortage relative to LBWD water demand is also shown in parenthesis. Maximum shortages and probability of shortages occurring both increase from 2020 to 2030 for all planning scenarios. For the Current Conditions scenario which does not include any future MWD projects or Delta Conveyance, shortages continue to increase from 2030 to 2050. For the Ideal Conditions scenario, which includes only minimal climate change impacts and implementation of MWD's RRWP and Delta Conveyance, shortages decrease in 2040, but slightly increase again in 2050 due to growing demands in the region. For the Moderate Conditions scenario, which includes moderate climate change impacts, shortages decrease significantly from 2030 to 2040 (as a result of implementation of MWD's RRWP) but increase significantly from 2040 to 2050 due to climate change (despite implementation of Delta Conveyance).

For all the Stressed Conditions scenarios (A-D), shortages decrease slightly from 2030 to 2040, but are capped at the maximum shortage level of 11,400 AFY in 2040 due to MWD's WSAP allocation rules for LBWD. Shortages then increase slightly from 2040 to 2050 as climate change impacts increase. Shortages in 2050 are capped at 14,900 AFY due to MWD's WSAP allocation rules for LBWD.

Table 5-6. Water Shortages for LBWD for All Planning Scenarios

Scenario	2020	2030	2040	2050
Maximum Water Shortage in AFY (% Shortage Relative to Water Demand)				
Current Conditions	6,900 (14%)	11,300 (22%)	12,200 (24%)	12,800 (25%)
Ideal Conditions	5,700 (11%)	6,300 (12%)	3,700 (7%)	5,700 (11%)
Moderate Conditions	6,400 (13%)	12,400 (24%)	4,300 (9%)	9,700 (23%)
Stressed Conditions A	5,900 (12%)	11,800 (23%)	11,400 (22%)	12,700 (25%)
Stressed Conditions B	5,900 (12%)	14,000 (28%)	11,400 (22%)	14,900 (30%)
Stressed Conditions C	5,900 (12%)	11,800 (23%)	11,400 (22%)	12,700 (25%)
Stressed Conditions D	5,900 (12%)	14,000 (28%)	11,400 (22%)	14,900 (30%)
Probability that Any-Sized Water Shortage Occurs (%)				
Current Conditions	4%	31%	64%	74%
Ideal Conditions	3%	11%	5%	4%
Moderate Conditions	3%	15%	8%	14%
Stressed Conditions A	3%	42%	28%	43%
Stressed Conditions B	3%	46%	40%	55%
Stressed Conditions C	3%	42%	71%	82%
Stressed Conditions D	3%	46%	84%	93%

Current Conditions = no climate change, no new MWD programs and no Delta Conveyance
Ideal Conditions = minimal climate change impacts, implementation of both new MWD programs and Delta Conveyance
Moderate Conditions = same as Ideal Conditions but with moderate climate change impacts
Stressed Conditions A = same as Moderate Conditions but with significant climate change impacts
Stressed Conditions B = same as Stressed Conditions A, but without MWD's RRWP implemented
Stressed Conditions C = same as Stressed Conditions A, but without Delta Conveyance
Stressed Conditions D = same as Stressed Conditions A, but without both MWD's RRWP and Delta Conveyance

Despite the maximum shortages being capped in 2040 and 2050, the probabilities that water shortages occur is not capped. These probabilities of shortages, shown in Table 5-6, reveal an additional challenge for LBWD. Even if water shortages are small in size, if they occur very often LBWD would likely need to implement new projects to avoid erosion in water customer service. The probability of water shortages increases when moving from Ideal to Moderate to Stressed Conditions A – D scenarios.

The water shortages in Table 5-6 can be used to assess future water supply needs for LBWD. Available water supply options for LBWD to mitigate these potential shortages are discussed in discussed in Section 6.

This page intentionally left blank.

Section 6

Supply Project Options

A key objective of the WRP was to identify and evaluate water supply options that could be developed to meet the forecasted supply shortages through 2050, identified in Section 5. A range of potential water projects and programs were initially considered and evaluated as part of this effort. Initial supply options included those that were identified from previous LBWD studies, as well as options not previously studied. This section summarizes the 10 supply options considered in the WRP. For each supply option, information on a consistent set of elements was compiled, including costs, benefits, implementation approach, and risk. This allows each option to be evaluated objectively against a set of criteria in Section 7.

6.1 West Coast Basin Groundwater Well

This project option involves the construction of a new groundwater production well in the West Coast Basin, which underlies the southwestern portion of Long Beach. This well would enable LBWD to utilize their 0.7 AFY APA. LBWD would have to purchase or lease water rights that are currently unused in order to fully utilize the new well's production capacity of 2,400 GPM (assumed long-term average of 3,000 AFY). The West Coast Basin well would offset imported water uses on the west side of LBWD's service area.

KEY FACTS AT A GLANCE	
Capital Cost ▪ Baseline Construction Work ▪ Materials ▪ Design	**$3.4 M**
Annual O&M Costs ▪ Well Maintenance ▪ Pump Replacement ▪ Energy Cost ▪ Disinfection ▪ Leased Water Rights ▪ WRD Replenishment Assessment	**$1.9 M**
Total Supply	**3,100 AFY**
Total unit Cost ($/AF)	**$700**

6.1.1 Project Implementation

The West Coast Basin Groundwater Well has already been drilled, so remaining capital expenditures are limited to pump and disinfection equipment installation and connections to the current water distribution system.

Adjudicated pumping in the West Coast Basin is set to 64,468 AFY but recent pumping has reached only 30,000 AFY, indicating that excess water rights may be available to support this project.

6.1.2 Project Risks

Purchasing or leasing water rights differs strategically from historical LBWD operations and the time and level of effort to acquire additional supplies is undetermined.

6.2 LBMUST Advanced Treatment Expansion

The City of Long Beach Public Works Department is designing the Long Beach Municipal Urban Stormwater Treatment System, LBMUST, to capture and treat dry weather flows to comply with the Los Angeles Regional Water Board municipal separate storm sewer systems (MS4) permits issued by the National Pollutant Discharge Elimination System (NPDES) Program.

The treated water that leaves the LBMUST facility would be discharged to the Los Angeles River. LBMUST will result in a treatment facility with a 2 MGD (2,240 AFY) capacity to treat dry weather runoff to a quality that would meet NPDES discharge requirements but not to a quality that would be suitable for reuse. The expansion of LBMUST includes additional advanced treatment equipment to further treat the effluent from the Public Works LBMUST treatment facility to a quality that would be suitable for non-potable irrigation use.

KEY FACTS AT A GLANCE	
Capital Cost - Long Beach Civic Center and nearby users (188 AFY of demand) - Convention Center, Aquarium, and Shoreline Parks (127 AFY of demand) - Booster pump station and storage tank	**$22 M**
Annual O&M Costs - Volume-based portion of LBMUST Operations (LASAN, 2018 reports $421/AF for LBWRP)	**$0.4 M**
Total Supply	**300 AFY**
Total unit Cost ($/AF)	**$4,700**

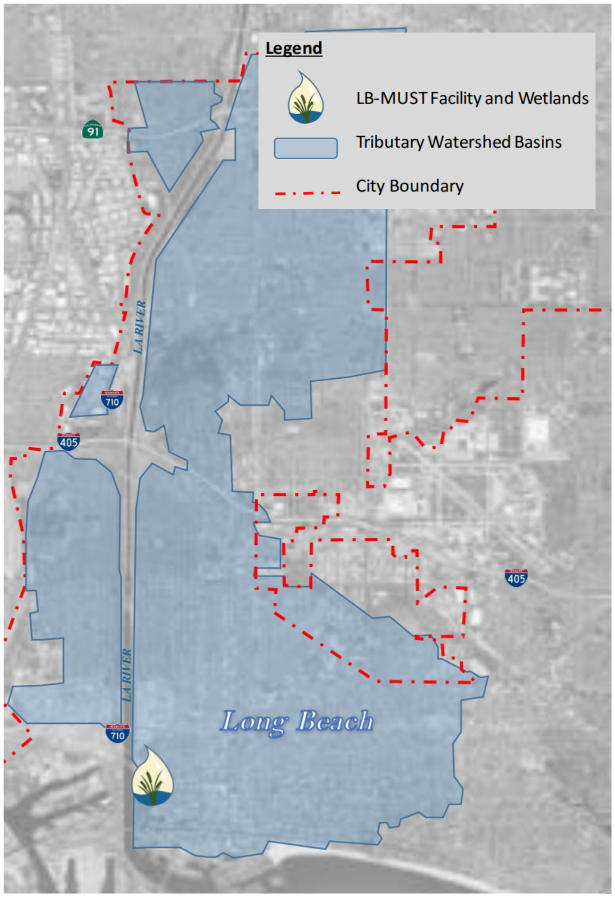


Figure 6-1. LBMUST Facility Location and Contributing Watershed

6.2.1 Project Implementation

Two potential areas that would be able to use the advanced treated non potable water from LBMUST for irrigation are the Long Beach Civic Center area and the Shoreline Parks area (**Figure 6-1**). The Civic Center is estimated to have approximately 188 AFY of irrigation demand, and the Shoreline Parks area has an estimated irrigation demand of 127 AFY. Total estimated irrigation demand is ~300 AFY.

6.2.2 Project Risks

LBMUST supply will not be connected to the existing LBWD recycled water system, and a new recycled water infrastructure will have to be constructed. Additionally, LBWD participation in the LBMUST construction cost is not included in this cost estimate at this time, only operations and maintenance costs are included, so costs per acre-foot may be higher depending on LBWD's contribution towards capital costs.

6.3 Industrial Reuse at Port of LB - LADWP Source

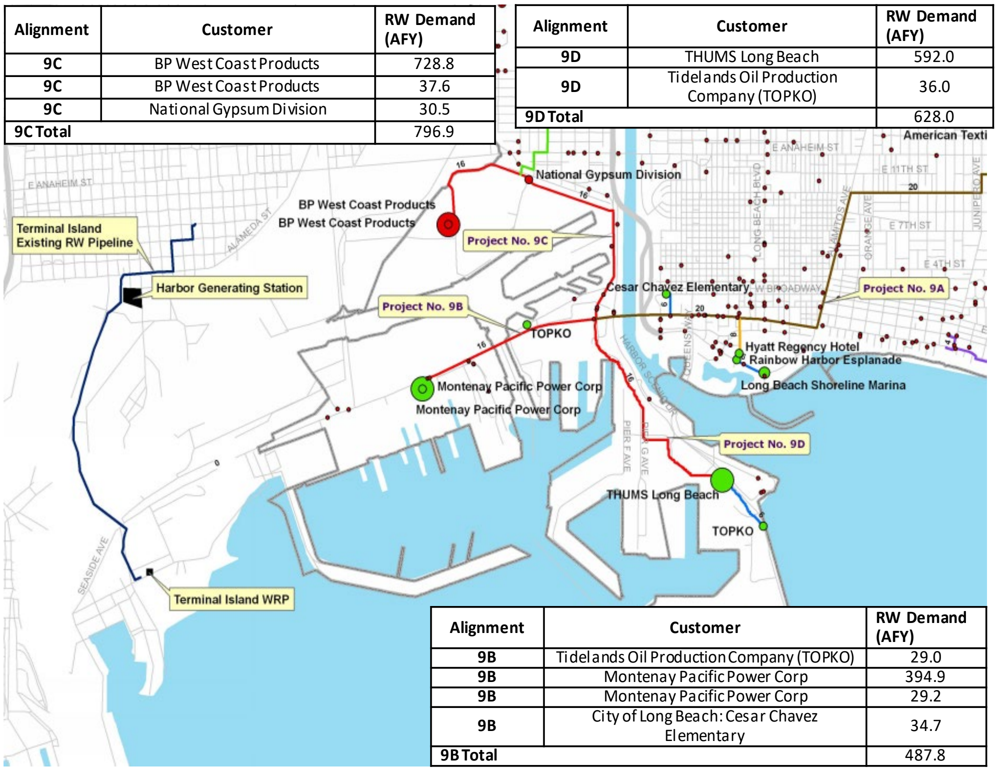
Many of LBWD's largest commercial and industrial water users, including the Port of Long Beach and several oil refineries, are located in west Long Beach and do not have access to recycled water. The 2010 LBWD Recycled Water Master Plan identified potential pipeline alignments and recycled water customers (**Figure 6-2**) associated with expanding the existing recycled water system.

Pipeline routes 9B, 9C, and 9D could serve potential west Long Beach industrial demands.

The LBWD study identified a potential demand of 1,913 AFY, however an ongoing study by the Port of Long Beach (to be completed by November 2019) estimates the potential advanced treated recycled water demands to be closer to 1,000 AFY.

KEY FACTS AT A GLANCE	
Capital Cost - Based on pipeline alignments in Recycled Water Plan; despite a slightly smaller proposed recycled water demand	**$21.2 M**
Annual O&M Costs - Annual O&M costs assumed per inch of diameter (CDM Smith, 2012) - Labor costs assumed based on crew size and visits per year (CDM Smith, 2012) - LADWP water purchase rate ($7.20 per hundred cubic feet)	**$75k**
Total Supply	**1,000 AFY**
Total unit Cost ($/AF)	**$1,200**

The advanced treated product water could be sourced from LADWP via the Terminal Island Advanced Water Purification Facility (TIAWPF) which was constructed and expanded under a partnership between LADWP and LASAN. LADWP is continuing to work with LASAN to identify additional sources of recycled water supplies for the Los Angeles Harbor area, including treated water from Hyperion Water Reclamation Plant. Because the Hyperion Advanced Water Purification Facility (HAWPF) has not yet been constructed, supplying advanced treated water needs in the Port of Long Beach from Hyperion source water would require waiting until construction or working with industrial customers to accept the secondary treated flows.



Alignment	Customer	RW Demand (AFY)
9C	BP West Coast Products	728.8
9C	BP West Coast Products	37.6
9C	National Gypsum Division	30.5
9C Total		796.9

Alignment	Customer	RW Demand (AFY)
9D	THUMS Long Beach	592.0
9D	Tidelands Oil Production Company (TOPKO)	36.0
9D Total		628.0

Alignment	Customer	RW Demand (AFY)
9B	Tidelands Oil Production Company (TOPKO)	29.0
9B	Montenay Pacific Power Corp	394.9
9B	Montenay Pacific Power Corp	29.2
9B	City of Long Beach: Cesar Chavez Elementary	34.7
9B Total		487.8

Figure 6-2. LBWD Recycled Pipeline Alignments

6.3.1 Project Implementation

Industrial water uses such as cooling and boiler supplies currently require additional processing of LBWD potable water before use, and the advanced treatment of the recycled water could be tailored for these processes and eliminate current potable water treatment.

6.3.2 Project Risks

The demand targeted in this project could also be served by the Industrial Reuse at Port of LB – MWD RRWP Source project discussed in the next subsection.

6.4 Industrial Reuse at Port of LB – MWD RRWP Source

The 1,000 AFY of advanced treated recycled water demands determined for Industrial Reuse at Port of LB – LADWP Source could be served by the MWD/LASAN JWPCP in Carson instead of by LADWP. The proposed RRWP is discussed in MWD's 2019 Regional Recycled Water Program Conceptual Planning Studies Report (MWD, 2019). The RRWP would deliver up to 150 MGD, or 168,000 AFY, of purified water to four regional groundwater basins through a new regional conveyance system. The report identifies 10 MGD (11,000 AFY) of potential refinery demands, of which the 1,000 AFY for LBWD would be a subset (**Figure 6-3**).

KEY FACTS AT A GLANCE	
Capital Cost ▪ MWD builds all infrastructure	**$0**
Annual O&M Costs ▪ Built into MWD rate	**$0**
Total Supply	**1,000 AFY**
Total unit Cost ($/AF)*	**$1,300 to $1,900**

* The unit cost of water to LBWD would depend on the MWD decision to allocate a portion of the cost to all member agencies, or whether project water recipients would contribute to the construction and O&M costs.

6.4.1 Project Implementation

The report presents several phasing alternatives for the RRWP; the most probable implementation includes a 100 MGD Phase 1 Backbone System, and a 50 MGD Phase 2 Orange County IPR option. Approximately 23 MGD of purified water demands within an 8-mile radius of the AWT plant, along the Backbone System, could serve as an early delivery opportunity to test plant and conveyance operations. Member agencies would be responsible for connecting directly to the RRWP conveyance pipeline (at locations to be determined) and for making the delivery of the purified water to the industrial end users. Phase 1 would take 10 years to implement.

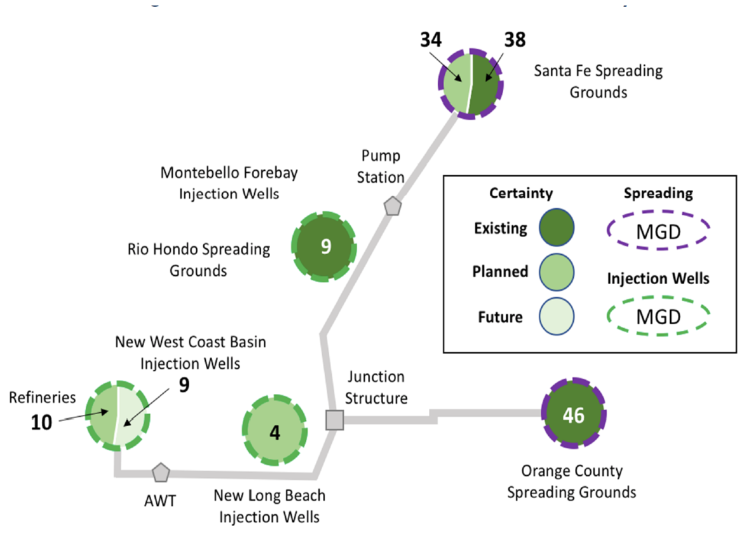


Figure 6-3. RRWP Conveyance Pipeline

6.4.2 Project Risks

MWD is likely to pursue the project, however LBWD must track progress of RRWP planning and design process.

6.5 Groundwater Augmentation – LBWRP/LVL Source

KEY FACTS AT A GLANCE	
Capital Cost - Injection wells, extraction well	**$9.7 M**
Annual O&M Costs - Injection wells, extraction well	**$1.3 M**
Total Supply	**900 AFY**
Total unit Cost ($/AF)	**$1,900**

The LVL AWTF provides advanced treatment to tertiary effluent from the LBWRP. Although historically, LVL AWTF has supplied a maximum of only 2,350 AFY to the Alamitos barrier, the facility has a maximum capacity of 8 million gallons per day (mgd) and is permitted to supply the Alamitos barrier with up to 100% of necessary inflow.

6.5.1 Project Implementation

Figure 6-4 summarizes the seasonal variability of total LVL AWTF commitments (that were supplied from combined LVL AWTF outflows and MWD imports) for CY 2014 – 2015. A small amount of supply is sent to OCWD for the portion of the seawater barrier maintained in Orange County. Figure 6-5 shows that, if LVL AWTF were operated at maximum capacity similar hydrologic years, additional water supply beyond the combined Alamitos barrier requirement could be seasonally available. Going forward, this seasonally varying supply of approximately 900 AFY of LVL AWTF effluent could be made available to LBWD for groundwater injection into the Central Basin in the vicinity of the LVL AWTF facility. **Figure 6-5** illustrates the pipeline alignment and connections needed to implement this project.

This project would require negotiation with WRD to have the LBWD APA increased by 900 AFY and allow LBWD to pump the recharged water.

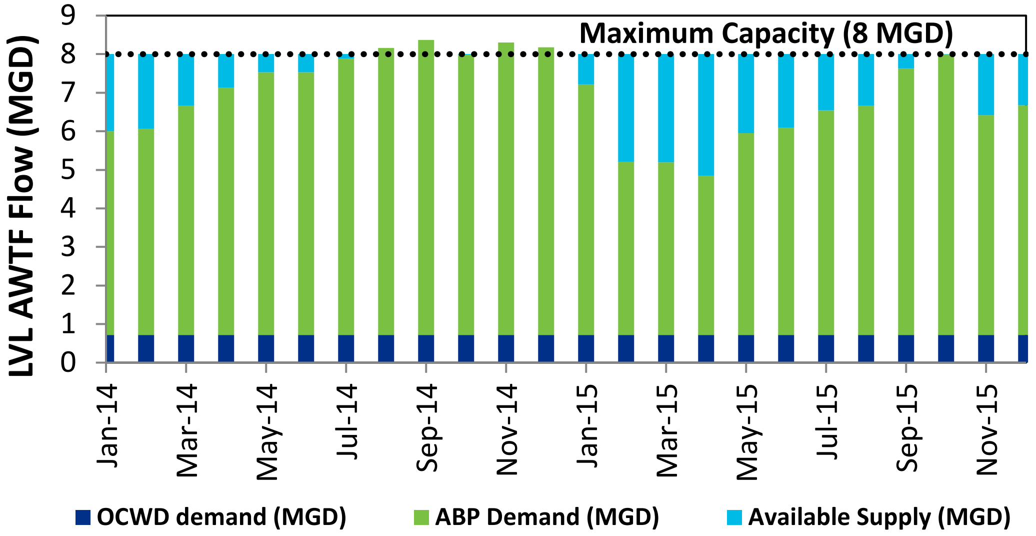


Figure 6-4. LVL AWTF Supply Commitments

6.5.2 Project Risks

Capital and O&M costs are reported in a LBWD Groundwater Augmentation summary and include the pipeline conveyance costs from LVL AWTF to the injection wells (the alignment and cost is provided by LBWD) and the cost of the wells. The cost of constructing an extraction well is added to the capital cost, which assumes that current LBWD groundwater capacity is limited. Water treatment at the LBWD groundwater facility is added to the O&M. Although construction of injection wells is straightforward, excess flows from LVL AWTF are not guaranteed year-round and into the future as wastewater flows may decrease due to additional water conservation. The outcome of negotiations with WRD to increase the LBWD APA are uncertain.

Figure 6-5. Pipeline Alignment for LVL Injection

6.6 Groundwater Augmentation – MWD RRWP Source

The proposed RRWP is being developed by MWD to deliver up to 150 MGD, or 168,000 AFY, of purified water to four regional groundwater basins through a new regional conveyance system. MWD's 2019 Regional Recycled Water Program Conceptual Planning Studies Report (MWD, 2019) identifies 9 MGD (10,000 AFY) of potential injection to the West Coast Basin near the Carson AWT plant in the Harbor Area, and 4 MGD (4,000 AFY) of recharge into the Central Basin in the Long Beach Area. **Figure 6-6** displays the RRWP distribution alignment.

KEY FACTS AT A GLANCE	
Capital Cost ▪ Injection wells, extraction well	**$2 M**
Annual O&M Costs ▪ Injection wells, extraction well	**$8.6 M**
Total Supply	**4,500 AFY**
Total unit Cost ($/AF)	**$2,000 – $2,500**

6.6.1 Project Implementation

The report presents several phasing alternatives for the RRWP; the most probable implementation includes a 100 MGD Phase 1 Backbone System, and a 50 MGD Phase 2 Orange County IPR option. Approximately 23 MGD of purified water demands within an 8-mile radius of the AWT plant, along the Backbone System, could serve as an early delivery opportunity to test plant and conveyance operations. Member agencies would be responsible for connecting directly to the RRWP conveyance pipeline (at locations to be determined) and for making the delivery of the purified water to the industrial end users. Phase 1 would take 10 years to implement.

Discussions with the City indicate that up to 4 MGD of purified water could be injected into the Central Basin Aquifer. MWD would install up to four injection wells to achieve an ongoing replenishment program in this portion of the Central Basin. The extracted water would then be treated at the LBWD Groundwater Treatment Plant prior to introduction into the potable water supply.

6.6.2 Project Risks

LBWD may have to work with WRD to ensure the additional 4 MGD would fit under their current APA.

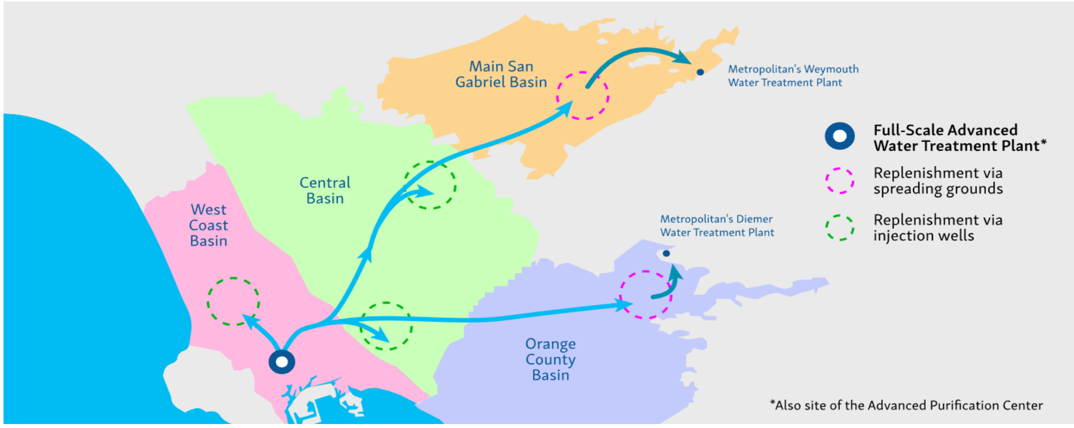


Figure 6-6. RRWP Distribution Alignment

6.7 Groundwater Augmentation – LBWRP/AWTF

KEY FACTS AT A GLANCE	
Capital Cost - Injection wells	**$52.7 M**
Annual O&M Costs - Injection wells	**$5.6 M**
Total Supply	**3,200 AFY**
Total unit Cost ($/AF)	**$2,600 – $4,200**

LBWRP effluent averages over 18,000 AFY and is directed to the LVL AWTF, to LBWD non-potable uses, or discharged to nearby Coyote Creek. LVL AWTF has a maximum capacity of (8 MGD) and is assumed to be operated at full capacity in the future. Historically, between 5,200 AFY and 6,600 AFY has been directed to LBWD recycled water uses. Future LVL AWTF uses summed with historical LBWD non-potable uses indicate that of the 18,000 AFY of effluent, approximately 3,200 AFY could be redirected from the Coyote Creek outfall to additional LBWD uses. LBWD has rights to the effluent leaving LBWRP so would not have to enter additional negotiations to use this supply.

6.7.1 Project Implementation

The yellow bars in **Figure 6-7** show the difference between the total Title 22 water available (black dotted line) and the sum of maximum LVL AWTF flows and LBWD recycled water use. The yellow bars indicate that for calendar year 2014, if LVL AWTF had been operated at maximum capacity, most months would yield water discharged to Coyote Creek that could instead be redirected from the Creek outfall to recycled water tanks at the Alamitos tank farm.

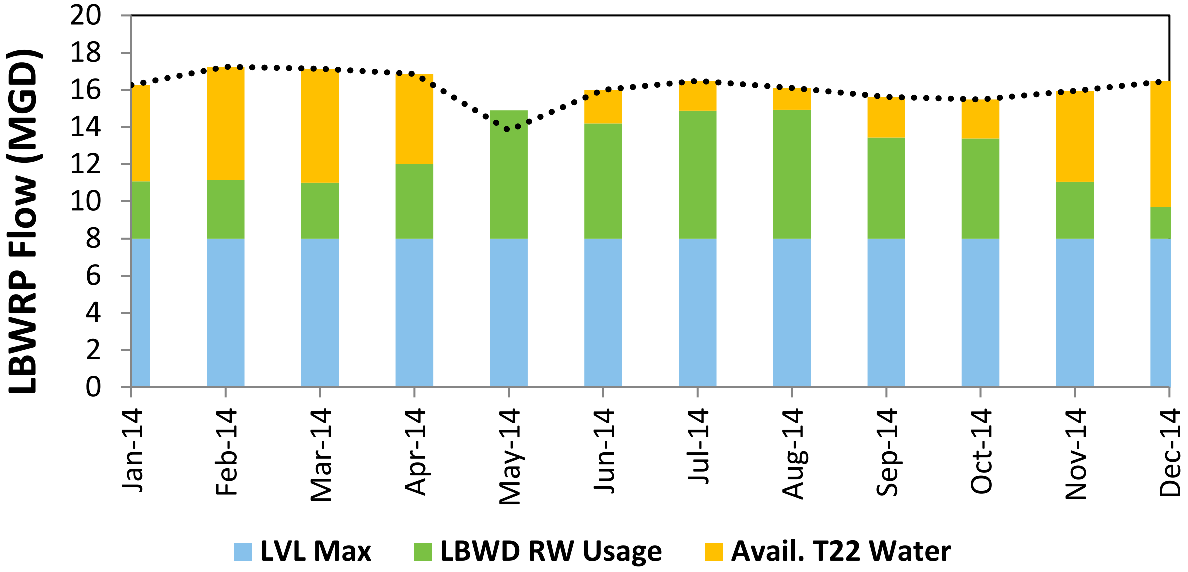


Figure 6-7. LBWRP Effluent Use

As shown in **Figure 6-8**, recycled water from the Alamitos tanks would be sent to a new Advanced Water Treatment Facility (AWTF) constructed at an empty parcel north of the existing LBWD groundwater treatment facility. The advanced treated water would be reinjected into the

Central Basin, and LBWD would work with WRD to increase their APA and be able to pump the additional recharged water.

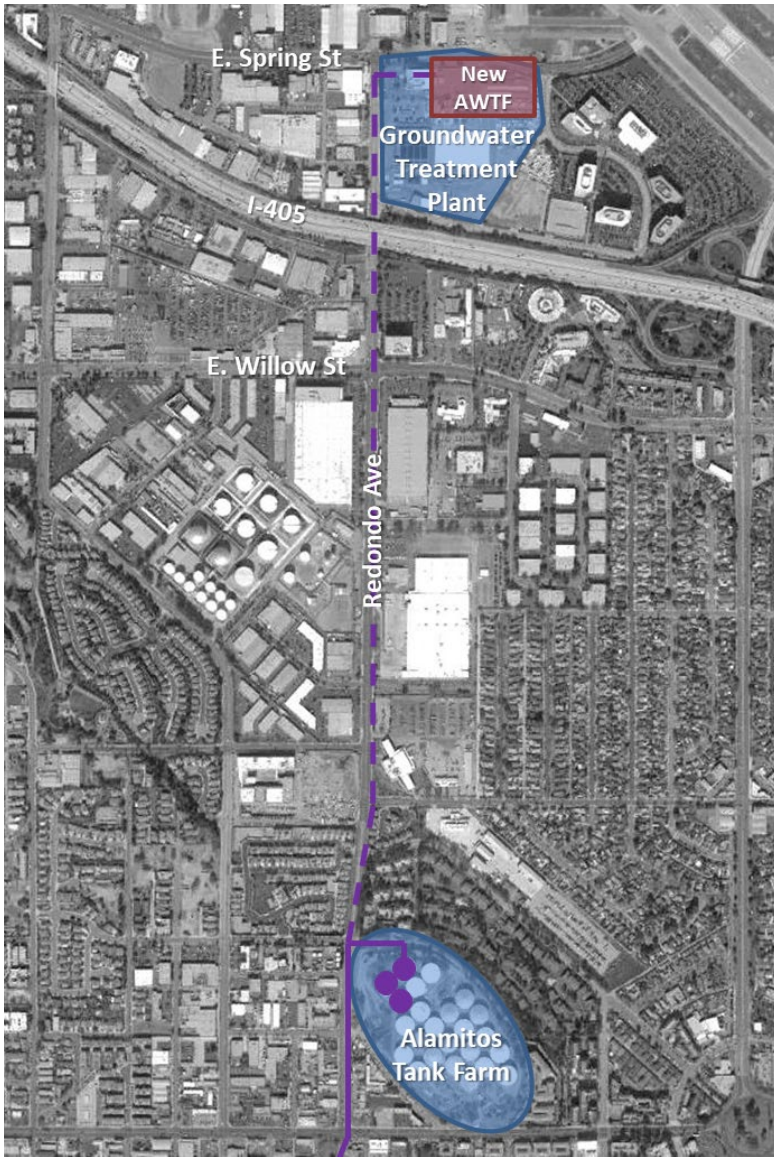


Figure 6-8. Pipeline Alignment for Indirect Potable Reuse – LBWRP/LBWD Treatment Project

6.7.2 Project Risks

Excess flows from LBWRP are not guaranteed year-round and into the future as wastewater flows may decrease due to water conservation. The outcome of negotiations with WRD to increase the LBWD APA are uncertain.

6.8 Rainwater Harvesting – Onsite Irrigation

KEY FACTS AT A GLANCE	
Capital Cost ▪ Rain barrels and large cisterns	**$6.3 M**
Annual O&M Costs ▪ Repair and replacement of barrels	**$126k**
Total Supply	**100 AFY**
Total unit Cost ($/AF)	**$3,700**

Stormwater capture and rainwater harvesting provide local, non-potable supplies, typically for irrigation use. Large centralized facilities traditionally have been used to manage runoff. The deployment of site-scale decentralized rainwater harvesting devices can reduce the need to purchase expensive urban land or use scarce publicly-owned land for centralized facilities. Use of stormwater for groundwater recharge is not feasible for LBWD because the confined portion of the Central and West Coast Groundwater Basins.

6.8.1 Project Implementation

Project yield is based on a combination of factors:

- Targeted area of implementation (# of acres): ½ of the area defined as schools in the general plan and 1/3 of the area defined as single family residences (4,850 acres)
- Amount of rainfall able to be captured: Based on historical rainfall from 2004 to 2016 (average rainfall of 7 in/year), approximately 982 AFY of water could be collected from the target area in the form of rainfall runoff from the various sites.
- Size of storage cistern or barrel: Large storage cisterns (1,300 gallons) would be used at school sites, rain barrels (120 gallons) would be used at single family residence sites
- How often, and at what rate, the stored rainwater can be used: Due to the limitations of the storage volume of the cisterns/barrels and the low frequency of rainfall, only approximately 100 AFY could be stored and used.

6.8.2 Project Risks

To realize the estimated 100 AFY of supply, large cisterns would be installed at 42 school sites and rain barrels (see **Figure 6-9**) would be installed at 27,000 single family residences. This ambitious deployment would need to include an education program to maximize the yield and maintenance of the individual rain barrels and cistern systems.

Figure 6-9. Rain Barrel Installation

6.9 Rainwater Harvesting – Wastewater Augmentation

Stormwater capture and rainwater harvesting could also be used to augment wastewater flows and therefore increase potential recycled water supplies. In addition to on-site storage of collected runoff, these systems would include a connection to the nearest sewer conveyance. Because these connections would have a larger capacity and usage would not be limited to landscaped areas at any particular site, project yields are greater than the onsite irrigation systems.

KEY FACTS AT A GLANCE	
Capital Cost ▪ Large cisterns	**$128 M**
Annual O&M Costs ▪ Repair and maintenance of cisterns	**$0.9 M**
Total Supply	**1,100 AFY**
Total unit Cost ($/AF)	**$6,800**

6.9.1 Project Implementation

Project yield is based on the following assumptions:

- Targeted area of implementation (# of acres): ½ of the area defined as commercial in the general plan and 1/5 of the area defined as multifamily residences (4,700 acres)
- Amount of rainfall able to be captured: Based on historical rainfall from 2004 to 2016 (average rainfall of 7 in/year), approximately 1,100 AFY of water could be collected from the target area in the form of rainfall runoff from the various sites.
- Size of storage cistern or barrel: Large storage cisterns (1,300 gallons) would be used at all targeted sites
- How often, and at what rate, the stored rainwater can be used: Because stored water could be immediately routed to the sewer system, the system yields is close to 100% of captured flow.

6.9.2 Project Risks

This project has a large capital outlay because it involves the installation of large cisterns (see **Figure 6-10**) at 20,000 commercial and multi-family residence sites. Each cistern costs $4,800 and the systems must be properly managed to maintain the initial system yield. Other implementation considerations include the sewer connections required at each of the sites and the managing the additional load at the wastewater treatment plant.

Figure 6-10. Rain Cistern Installation

6.10 Seawater Desalination

LBWD recognizes the need for a diverse water supply portfolio and has developed and patented a two staged nano-filtration (NF2) process, the "Long Beach Method". The NF2 process reduces the overall energy requirement of seawater desalination by 20-30% using a low-pressure process in which the second pass concentrate recycle dilutes the feed water, which allows for lower feed pressures (see **Figure 6-11**).

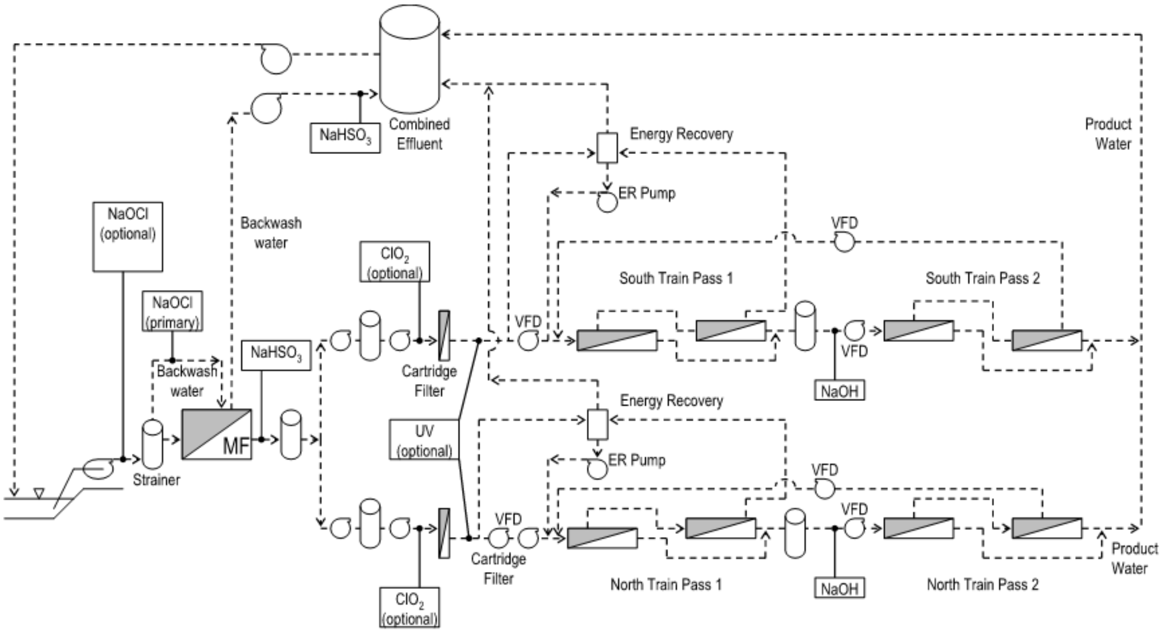


Figure 6-11. Desalination (NF2) Process Diagram

6.10.1 Project Implementation

KEY FACTS AT A GLANCE	
Capital Cost ▪ Filters, Membranes, Pumps, Tanks, Facility	**$500 M**
Annual O&M Costs ▪ Energy, membrane replacement	**$55 M**
Total Supply	**~5,000 AFY**
Total unit Cost ($/AF)	**$2,400**

LBWD partnered with the U.S. Bureau of Reclamation and the Los Angeles Department of Water and Power during two subsequent pilot phases that verified the energy savings when employing full-scale membranes. LBWD tested the hybrid desalination process in a 9,000 gallon per day (GPD) pilot scale unit at its Groundwater Treatment Plant. In 2006, the pilot text at the treatment plant ended and LBWD partnered with the USBR and the Los Angeles Department of Water and Power (LADWP) in the construction of a 300,000 GPD Seawater Desalination Prototype Facility located at the LADWP Haynes Generating Station. The Prototype was operated from October 2006 to January 2010.

Comparison of two parallel membrane trains to test the NF2 and RO process successfully demonstrated the comparable efficiency and reliability of the NF2 process verses RO for seawater desalination. LBWD also developed an alternative to traditional open ocean intake practices through an environmentally sound Under Ocean Floor Intake and Discharge Demonstration System.

6.10.2 Project Risks

At lower production volumes, the economies of scale are not seen and costs per acre-foot may increase. Seawater desalination is difficult to permit in Southern California., although the recently proposed Doheny Desalination plant would utilize advanced slant wells that draw water from beneath the ocean floor and has received less environmental resistance than traditional seawater intake methods.

6.11 Other Projects Considered

Additional projects that are being studied by LBWD for feasibility were not far enough along for characterization for this WRP. However, as the WRP is a flexible plan that is intended be updated as conditions and project concepts evolve, these other projects could prove to be viable and highly-ranked options and will be reconsidered accordingly.

6.11.1 Direct Use of the Los Angeles River

Unlike the river waters in eastern and mid-western US, the Los Angeles River (River) does not have regular storm events or consistent water quality throughout the year. The River runs through urbanized communities and has wide seasonal fluctuation in water quality and flow rates. During dry weather, the River water consists of mostly tertiary treated wastewater effluent from upstream wastewater treatment plants combined with a small percentage of local urban runoff and groundwater seepage. During a storm event, this ratio of tertiary treated wastewater effluent water to runoff and groundwater fluctuates significantly and creates an inconsistent water quality.

The Los Angeles River project supply would not be potable reuse supply project, but rather be an impaired surface water treatment project. The focus of the Los Angeles River project would be to use traditional treatment methods (i.e., coagulation, flocculation, mechanical separation) for unconventional treatment. A membrane-based treatment process similar to the Orange County Water District Groundwater Replenishment System (GWRS) may ultimately be needed to serve as redundancy in the system for risk management and to satisfy log removal credits, but unlike many projects using membrane-based treatment, the Los Angeles River project is envisioned as a surface water treatment project, not a potable reuse project. However, the membrane-based treatment is not the focus of the project.

LBWD performed a 5 GPM pilot study from 2010 to 2018 to determine the treatability of the water in the Los Angeles River, understand the variability of the source water, and identify potential contaminants of concern. LBWD compared the pilot study results to the California Department of Drinking Water (DDW) Maximum Contaminant Levels (MCLs), and the results consistently showed that the water quality parameters were either non-detectable or below DDW standards. The conclusion from the pilot study was that the proof of concept was achieved.

The next step to study the feasibility of this Los Angeles River project would be to construct and operate a 50 – 80 GPM demonstration scale facility. However, at this time, there are several upstream proposed projects that would use the tertiary treated wastewater effluent that currently comprise of a significant portion of the water in the Los Angeles River. Consequently, there are concerns for the environmental impact on fish and wildlife habitat in the Los Angeles River should water flows be diminished. Therefore, it is currently uncertain the amount of future flow that would be available to LBWD in the Los Angeles River, and the immediate action for LBWD will be to remain engaged in any regional stakeholder processes regarding the flows in the Los Angeles River.

6.11.2 Expanded Pumping in the Central and West Coast Basin

There is the opportunity for LBWD to acquire or lease additional groundwater rights in the Central Basin and West Coast Basin. Historically, population growth and over pumping in the Central Basin and West Coast Basin resulted in overdraft and seawater intrusion, which resulted in the adjudication and limitation of pumping in the basins, the construction of seawater barriers, and additional augmentation of natural replenishment with artificial replenishment. However, more recently, water efficiency and conservation efforts have significantly decreased the overall water demand in Long Beach and the rest of Southern California even though the population has continued to grow. As a result, many pumpers in both basins are no longer utilizing their full groundwater rights and may not pump those rights within the 2050 planning timeframe of this Water Resources Plan (as evident by reduced pumping shown in Figure 4-2). LBWD therefore should investigate the potential to lease or purchase additional groundwater rights from those pumpers who are not fully utilizing their groundwater rights in the Central Basin and West Coast Basin.

Groundwater is currently the primary water resource for LBWD, so integrating additional groundwater rights into the LBWD water supply portfolio may likely be more straightforward and cost effective than most other water supply options. The priority for LBWD must be to ensure that the groundwater infrastructure is developed and maintained enough to first allow LBWD to fully draw upon its existing groundwater rights as well as to occasionally produce in excess of existing groundwater rights to flexibly utilize groundwater storage. Assuming those objectives are achieved, the existing well capacity, collection main capacity, treatment capacity, and other factors need to be evaluated to determine the feasibility for LBWD to produce, treat, and distribute additional groundwater.

6.12 Summary of Water Supply Options Considered in WRP

The most feasible water supply options that were ranked in the WRP are summarized in **Table 6-1**.

Table 6-1. Summary of Water Supply Options Considered for the WRP

Supply Option	Supply (AFY)	Unit Cost ($/AF)	Anticipated Partnerships	Source Reliability
West Coast Basin Groundwater Well	3,100	$700	WRD/Other Cities	Semi-Firm
Industrial Reuse at Port of LB - LADWP Source	1,000	$1,200	Port/LADWP	Drought-Proof
Industrial Reuse at Port of LB – MWD RRWP Source	1,000	$1,300	Port/MWD	Drought-Proof
Groundwater Augmentation – LBWRP/LVL Source	900	$1,900	WRD	Drought-Proof
Groundwater Augmentation – MWD RRWP	4,500	$2,000	MWD/WRD	Drought-Proof
Groundwater Augmentation – LBWRP/AWTF	3,200	$4,200	WRD	Drought-Proof
Rainwater Harvesting – Onsite Irrigation	100	$3,700	City Developers	Seasonal
Rainwater Harvesting – Wastewater Augmentation	1,100	$6,800	City Developers	Seasonal
Seawater Desalination	~5,000	$2,400	None	Drought-Proof
LBMUST - Advanced Treatment Expansion	300	$4,700	City Public Works	Intermittent

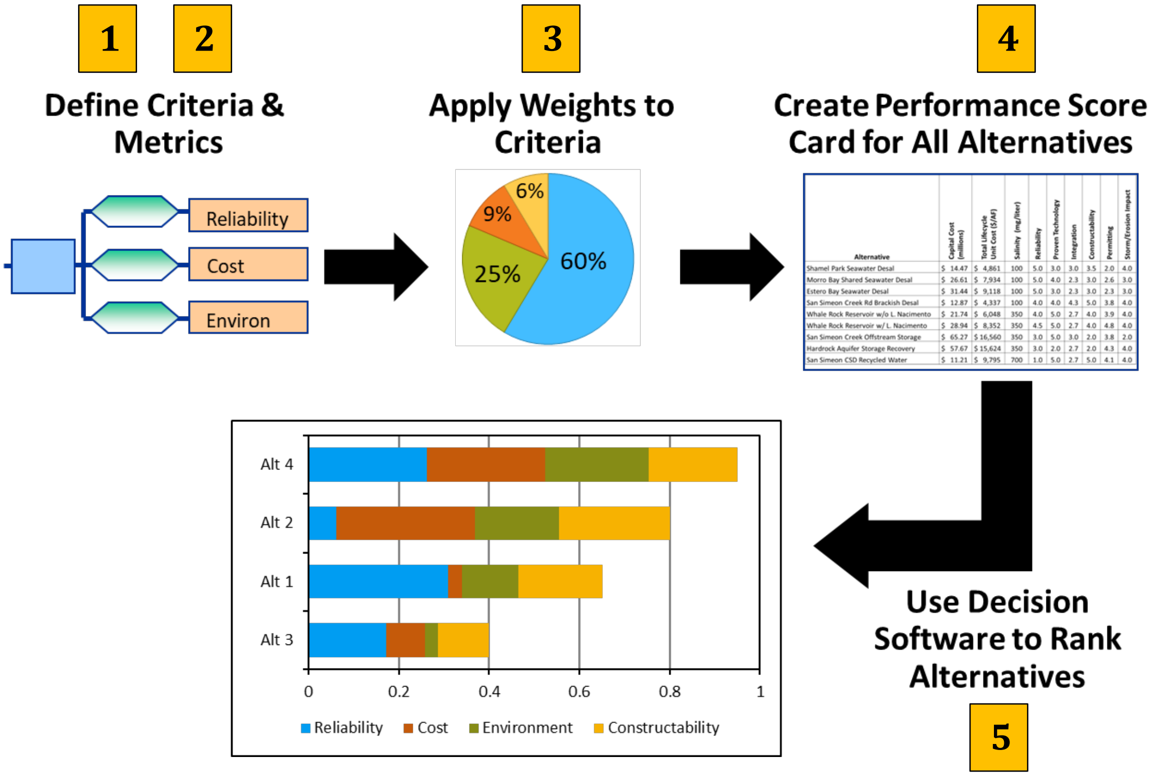
Section 7

Ranking Water Supply Options

A key objective of the WRP was to identify and evaluate water supply options that could be developed to meet potential water supply needs through 2050, as identified in Section 5. Feasible water supply options, presented in Section 6, were ranked against multiple criteria in order to see trade-offs and develop a long-term, adaptable strategy for the WRP.

7.1 Project Ranking Approach

The method for ranking the feasible water supply options utilized the technique known as multi-criteria decision analysis (MCDA). This method involves: (1) defining evaluation criteria by which options will be compared; (2) establishing performance metrics that indicate when criteria are being achieved; (3) assigning weights of relative importance for each criteria; (4) using tools and analyses to assign metric scores to the options; and (5) rank the supply options based on the metrics scores and criteria weighting. The commercial software Criterium Decision Plus (CDP), developed by Infoharvest Inc., was used to rank the feasible water supply options because of its sophistication, ease of understanding and use, and its ability to conduct sensitivity analyses. **Figure 7-1** illustrates the project ranking approach through the numbered sequence above.



Alternative	Capital Cost (millions)	Total Lifecycle Unit Cost ($/AF)	Salinity (mg/liter)	Reliability	Proven Technology	Integration	Constructability	Permitting	Storm/Erosion Impact
Shamel Park Seawater Desal	$ 14.47	$ 4,861	100	5.0	3.0	3.0	3.5	2.0	4.0
Morro Bay Shared Seawater Desal	$ 26.61	$ 7,934	100	5.0	4.0	2.3	3.0	2.6	3.0
Estero Bay Seawater Desal	$ 31.44	$ 9,118	100	5.0	3.0	2.3	3.0	2.3	3.0
San Simeon Creek Rd Brackish Desal	$ 12.87	$ 4,337	100	4.0	4.0	4.3	5.0	3.8	4.0
Whale Rock Reservoir w/o L. Nacimento	$ 21.74	$ 6,048	350	4.0	5.0	2.7	4.0	3.9	4.0
Whale Rock Reservoir w/ L. Nacimento	$ 28.94	$ 8,352	350	4.5	5.0	2.7	4.0	4.8	4.0
San Simeon Creek Offstream Storage	$ 65.27	$ 16,560	350	3.0	5.0	3.0	2.0	3.8	2.0
Hardrock Aquifer Storage Recovery	$ 57.67	$ 15,624	350	3.0	2.0	2.7	2.0	4.3	4.0
San Simeon CSD Recycled Water	$ 11.21	$ 9,795	700	1.0	5.0	2.7	5.0	4.1	4.0

Figure 7-1. Project Ranking Approach Using MDCA Method

7.2 Evaluation Criteria

Supported through the WRP stakeholder process, LBWD developed the major objectives or goals of the WRP. These objectives, presented in Section 1.2, were used by LBWD to define evaluation criteria for the comparison and ranking of water supply options. Because criteria are not typically equal in importance, weights are used to indicate relative comparisons between them. The criteria weights were established with input from LBWD's Board during a special WRP workshop. Metrics were then established to indicate how well the criteria are being achieved. For any given criterion, there might be more than one metric used. Some metrics were measured by engineering cost estimates, considered quantitative measurements, while other metrics were measured by qualitative scoring using insights from hydrological assessments and modeling, and engineering judgement. Use of both quantitative and qualitative metrics for evaluating alternatives is common in planning studies that use multi-attribute rating techniques, such as was used for the WRP.

While the evaluation criteria used for the WRP are similar to those used in other comparable plans and studies across the United States, the criteria weights and specific metrics used for this plan were tailored to reflect local conditions and considerations. **Table 7-1** presents the evaluation criteria, weightings, metrics, and metric measurement.

Table 7-1. Evaluation Criteria for Ranking Supply Options

Criteria	Criteria Weight	Metric	Metric Measurement
Reliability	30%	Source Variability	1 = intermittent; 3 = normal hydrologic variation; 5 = drought proof
Cost	25%	Unit Cost	$/Acre-foot (lower $/AF is best)
		Potential Grant Funding	1 = low likelihood; 3 = moderate likelihood; 5 = high likelihood
Implementation	20%	Permit Score	1 = high degree of complexity; 3 = medium level of complexity; 5 = low level of complexity
		Institutional Score	1 = significant partnerships required; 3 = moderate partnerships; 5 = few partnerships required
Integration	10%	System Score	1 = significant system challenges; 3 = moderate system challenges; 5 = few system challenges
Environmental	10%	Impact Score	1 = significant negative impacts; neutral impacts; 5 = positive impacts
Multi-Benefit	5%	Multi-benefit Score	1 = no other benefits; 3 = some other benefits; 5 = significant other benefits

The project costs presented in Section 6 were used to develop the unit cost metric in $/AF.

The qualitative metrics for source variability, potential grant funding, permit and institutional scores, system integration, environmental impact, and multi-benefit scores were determined using a 1 to 5 scale, where 1 indicates the lowest relative performance and 5 indicates the highest relative performance. **Table 7-1** presents narratives used to guide the qualitative scoring of options.

7.3 Supply Option Metric Scores

Using the qualitative score narratives in **Table 7-1**, LBWD assigned qualitative scores to the supply options. **Tables 7-2** through **7-8** present the quantitative scores for each supply option and justification for the scoring.

Table 7-2. Source Variability Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	4	Subject to hydrologic variability
Industrial Reuse at Port of LB – LADWP Source	5	Drought-proof supply
Industrial Reuse at Port of LB – MWD RRWP Source	5	Drought-proof supply
Groundwater Augmentation – LBWRP/LVL Source	5	Drought-proof supply
Groundwater Augmentation – MWD RRWP	5	Drought-proof supply
Groundwater Augmentation – LBWRP/AWTF	5	Drought-proof supply
Rainwater Harvesting – Onsite Irrigation	2	Limited by local rainfall patterns
Rainwater Harvesting – Wastewater Augmentation	3	Limited by local rainfall patterns
Seawater Desalination	5	Drought-proof supply
LBMUST - Advanced Treatment Expansion	1	Intermittent due to nature of urban runoff

Table 7-3. Grant Funding Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	5	Grant funding for well-head treatment already secured
Industrial Reuse at Port of LB – LADWP Source	5	Potential funding from MWD and state are very high for water reuse projects
Industrial Reuse at Port of LB – MWD RRWP Source	5	Potential funding from MWD and state are very high for water reuse projects
Groundwater Augmentation – LBWRP/LVL Source	5	Potential funding from MWD and state are very high for water reuse projects
Groundwater Augmentation – MWD RRWP	5	Potential funding from MWD and state are very high for water reuse projects
Groundwater Augmentation – LBWRP/AWTF	5	Potential funding from MWD and state are very high for water reuse projects
Rainwater Harvesting – Onsite Irrigation	4	Potential funding from LA County Measure W and state are relatively high
Rainwater Harvesting – Wastewater Augmentation	4	Potential funding from LA County Measure W and state are relatively high
Seawater Desalination	5	Potential from federal, state and MWD funding are high for desalination projects
LBMUST - Advanced Treatment Expansion	4	Potential funding from LA County Measure W and state are relatively high

Table 7-4. Permit Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	5	Permitting well-head treatment has little regulatory complexity
Industrial Reuse at Port of LB – LADWP Source	5	Permitting for industrial reuse has little regulatory complexity
Industrial Reuse at Port of LB – MWD RRWP Source	5	Permitting for industrial reuse has little regulatory complexity
Groundwater Augmentation – LBWRP/LVL Source	3	Permitting for indirect potable reuse can sometimes be more difficult
Groundwater Augmentation – MWD RRWP	3	Permitting for indirect potable reuse can sometimes be more difficult
Groundwater Augmentation – LBWRP/AWTF	3	Permitting for indirect potable reuse can sometimes be more difficult
Rainwater Harvesting – Onsite Irrigation	3	Permitting might be difficult given regulations for Title 22-equivalent water for irrigation
Rainwater Harvesting – Wastewater Augmentation	4	Permitting will likely be easier for rainwater harvesting that is used for wastewater flows
Seawater Desalination	1	Permitting is most challenging due to a myriad of regulations including coastal impacts, brine management, and greenhouse gas generation
LBMUST - Advanced Treatment Expansion	3	Permitting might be difficult given regulations for Title 22-equivalent water for non-potable reuse and generally poor quality of urban runoff

Table 7-5. Institutional Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	4	Securing water rights will involve WRD and other agencies
Industrial Reuse at Port of LB – LADWP Source	2	Will require coordination with Port of LB and LADWP with no current institutional history
Industrial Reuse at Port of LB – MWD RRWP Source	4	Will require coordination with Port of LB and MWD (which LBWD is a member of)
Groundwater Augmentation – LBWRP/LVL Source	4	Will require partnership with WRD
Groundwater Augmentation – MWD RRWP	5	If MWD RRWP moves forward, little coordination is required
Groundwater Augmentation – LBWRP/AWTF	5	No institutional coordination is needed as the AWTF would be operated by LBWD
Rainwater Harvesting – Onsite Irrigation	2	Will require coordination with City Public Works, building codes and developers
Rainwater Harvesting – Wastewater Augmentation	3	Will require coordination with City Public Works and building codes
Seawater Desalination	5	No institutional coordination is required as this project would be owned and operated by LBWD
LBMUST - Advanced Treatment Expansion	4	Will require coordination with City Public Works

Table 7-6. System Integration Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	4	Integrating groundwater in LBWD's western service area will require some changes in operations
Industrial Reuse at Port of LB – LADWP Source	3	Sending advanced-treated recycled water to Port of LB will involve some moderate system challenges
Industrial Reuse at Port of LB – MWD RRWP Source	3	Sending advanced-treated recycled water to Port of LB will involve some moderate system challenges
Groundwater Augmentation – LBWRP/LVL Source	5	Water will be produced in LBWD's groundwater service area with no required system changes
Groundwater Augmentation – MWD RRWP	5	Water will be produced in LBWD's groundwater service area with no required system changes
Groundwater Augmentation – LBWRP/AWTF	5	Water will be produced in LBWD's groundwater service area with no required system changes
Rainwater Harvesting – Onsite Irrigation	5	No system integration issues as water is generated and used onsite
Rainwater Harvesting – Wastewater Augmentation	2	Connecting harvested rainwater to sewer collection system is very challenging
Seawater Desalination	1	Pumping from coastal area and introduction of desalinated water will require significant operational changes and integration issues
LBMUST - Advanced Treatment Expansion	2	Integration challenges likely due to linking new source of water into LBWD's non-potable reuse system

Table 7-7. Environmental Impact Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	3	Groundwater pumping is neutral in terms of environmental impacts
Industrial Reuse at Port of LB – LADWP Source	3	While reuse provides increased sustainability, advanced treatment produces brine that needs to be discharged, producing a neutral score
Industrial Reuse at Port of LB – MWD RRWP Source	3	While reuse provides increased sustainability, advanced treatment produces brine that needs to be discharged, producing a neutral score
Groundwater Augmentation – LBWRP/LVL Source	3	While reuse provides increased sustainability, advanced treatment produces brine that needs to be discharged, producing a neutral score
Groundwater Augmentation – MWD RRWP	3	While reuse provides increased sustainability, advanced treatment produces brine that needs to be discharged, producing a neutral score
Groundwater Augmentation – LBWRP/AWTF	3	While reuse provides increased sustainability, advanced treatment produces brine that needs to be discharged, producing a neutral score
Rainwater Harvesting – Onsite Irrigation	5	Helps meet stormwater goals for TMDLs and is a sustainable practice
Rainwater Harvesting – Wastewater Augmentation	5	Helps meet stormwater goals for TMDLs and is a sustainable practice
Seawater Desalination	1	Results in impacts to marine ecology, and produces significant brine and greenhouse gases
LBMUST - Advanced Treatment Expansion	3	Treating urban runoff for irrigation is neutral in terms of environmental impacts

Table 7-8. Multi-benefit Score and Justification

Supply Option	Score	Score Justification
West Coast Basin Groundwater Well	4	Improves the underutilization of local groundwater
Industrial Reuse at Port of LB – LADWP Source	2	Reduces reliance on potable water for non-potable need
Industrial Reuse at Port of LB – MWD RRWP Source	2	Reduces reliance on potable water for non-potable need
Groundwater Augmentation – LBWRP/LVL Source	2	Helps with groundwater replenishment
Groundwater Augmentation – MWD RRWP	2	Helps with groundwater replenishment
Groundwater Augmentation – LBWRP/AWTF	2	Helps with groundwater replenishment
Rainwater Harvesting – Onsite Irrigation	5	Improves receiving water quality and provides opportunities for more green space in City
Rainwater Harvesting – Wastewater Augmentation	3	Adds more flow to wastewater so recycled water deliveries can be maximized
Seawater Desalination	1	Other than supply benefits, produces no other benefits locally
LBMUST - Advanced Treatment Expansion	5	Improves receiving water quality and provides opportunities for more green space in City

All the metric scores for the supply options are summarized in **Table 7-9** for ranking.

Table 7-9. Summary of Scores for Supply Options

Project	Source Variability	Unit Cost	Grant Funding	Permit	Institutional	System Integration	Environmental Impact	Multi-Benefit
West Coast Basin Groundwater Well	4	$700	5	5	4	4	3	4
Industrial Reuse at Port of LB – LADWP Source	5	$1,200	5	5	2	3	3	2
Industrial Reuse at Port of LB – MWD RRWP Source	5	$1,300	5	5	4	3	3	2
Groundwater Augmentation – LBWRP/LVL Source	5	$1,900	5	3	4	5	3	2
Groundwater Augmentation – MWD RRWP	5	$2,000	5	3	5	5	3	2
Groundwater Augmentation – LBWRP/AWTF	5	$4,200	5	3	5	5	3	2
Rainwater Harvesting – Onsite Irrigation	2	$3,700	4	3	2	5	5	5
Rainwater Harvesting – Wastewater Augmentation	3	$6,800	4	4	3	2	5	3
Seawater Desalination	5	$2,400	5	1	5	1	1	1
LBMUST - Advanced Treatment Expansion	1	$4,700	4	3	4	2	3	5

7.4 Project Ranking

The criteria metric scores for the water supply options shown in **Table 7-9**, along with the criteria weights developed by the LBWD Board shown in **Table 7-1**, were input into the decision software CDP to rank the supply options (see **Figure 7-2**).

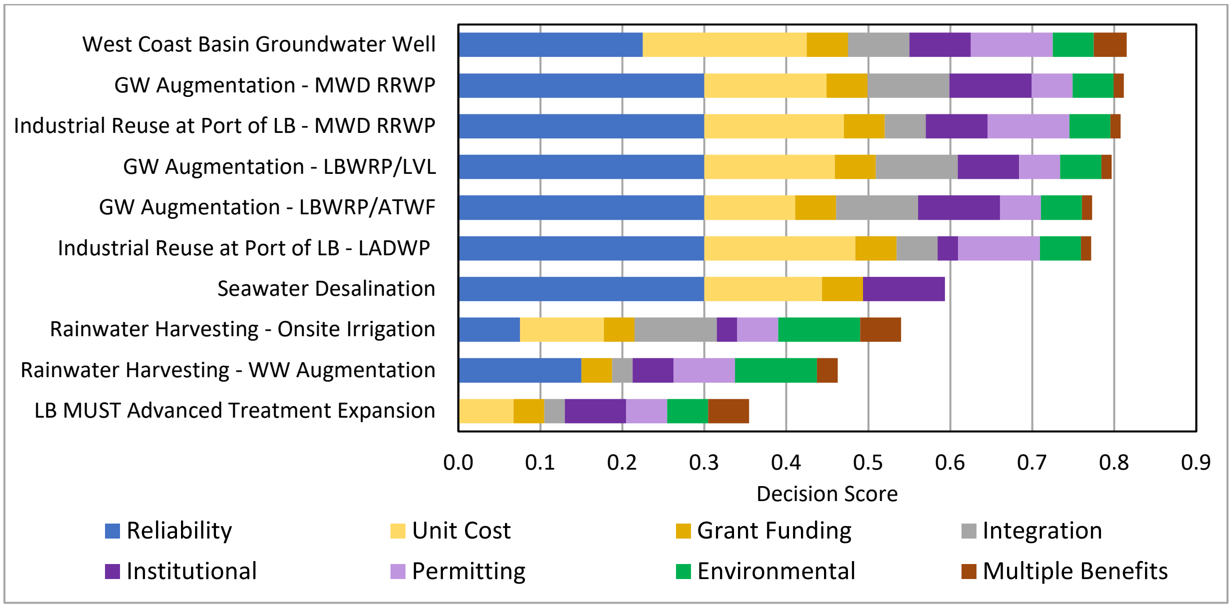


Figure 7-2. Ranking of Supply Options – Board Criteria Weighting

The length of the stacked bar for each supply option represents its aggregated score. The length of each color segment of the bar represents the score for the five main criteria. The longer the bar segment, the better it performs against the given criteria. If a supply option has the worst score for any specific criteria, there is no color contribution (e.g., LBMUST Advanced Treatment Expansion has the worst score for Reliability Criteria and as such there is no blue color bar for this option). This allows for direct comparison of how one option performs compared to others for each of the criteria. For example, one supply option might have a very high score for supply reliability but have a low score for cost effectiveness.

The ranking results are interpreted as follows:

- West Coast Basin Groundwater Well is the highest overall scoring option and ranks 1st.
- The next grouping of options are all very close behind the 1st ranked option in scoring and include: Groundwater Augmentation with MWD RRWP (ranked 2nd), Industrial Reuse at Port of Long Beach with MWD RRWP sourced water (ranked 3rd), and Groundwater Augmentation with LBWRP water treated at LVL AWTF (ranked 4th).
- The next grouping of options have similar scores and include: Groundwater Augmentation with LBWRP water treated at AWTF (ranked 5th) and Industrial Reuse at Port of Long Beach with LADWP sourced water (ranked 6th).

- Seawater Desalination ranks 7th due to its high reliability score but tempered down in rank because of its poor scoring for system integration, permitting, environmental criteria.
- The two rainwater harvesting projects rank 8th and 9th, due to poor to moderate scoring for reliability and their high costs.
- Finally, the LBMUST Advanced Treatment Expansion project is ranked last, due to its low scores across multiple criteria.

7.5 Ranking Sensitivity

A sensitivity analysis was performed to determine how the supply options ranking would change if the evaluation criteria weightings were adjusted to be equal in terms of relative importance. **Figure 7-3** shows the sensitivity ranking results, while **Table 7-10** compares the ranking using the Board criteria weighting vs. equal weighting.

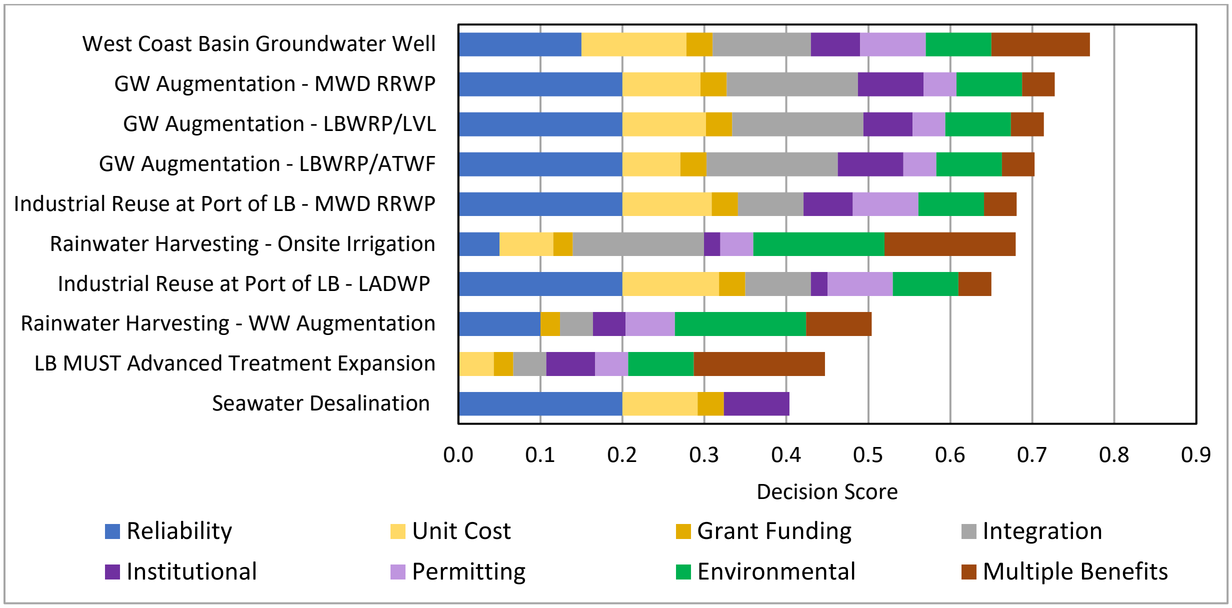


Figure 7-3. Ranking of Supply Options – Equal Criteria Weighting

Table 7-10. Comparison of Option Ranking with Different Criteria Weighting

Supply Option	Ranking with Board Weighting	Ranking with Equal Weighting
West Coast Basin Groundwater Well	1	1
Groundwater Augmentation - MWD RRWP	2	2
Industrial Reuse at Port of LB - MWD RRWP	3	5
Groundwater Augmentation - LBWRP/LVL	4	3
Groundwater Augmentation - LBWRP/ATWF	5	4
Industrial Reuse at Port of LB - LADWP	6	7
Seawater Desalination	7	10
Rainwater Harvesting - Onsite Irrigation	8	6
Rainwater Harvesting - WW Augmentation	9	8
LBMUST Advanced Treatment Expansion	10	9

Under both criteria weightings, the top 5 ranked options remain the same, those being West Coast Basin Groundwater Well, Groundwater Augmentation with MWD RRWP, Industrial Reuse at Port of Long Beach with MWD RRWP sourced water, Groundwater Augmentation with LBWRP water treated at LVL AWTF, and Groundwater Augmentation with LBWRP water treated at AWTF. This means that these five options are generally robust and should be prioritized in implementation over the other options.

But when the criteria are weighted equally, Rainwater Harvesting for Irrigation moves from 8th to 6th in ranking, and seawater desalination moves from 7th to 10th in ranking. LBMUST with Advanced Treatment Expansion, Rainwater Harvesting for Wastewater Augmentation, and Industrial Reuse at Port of Long Beach with LADWP sourced water rank relatively the same under both criteria weightings

This page intentionally left blank.

Section 8

Strategy and Recommendations

8.1 Adaptive Management Approach

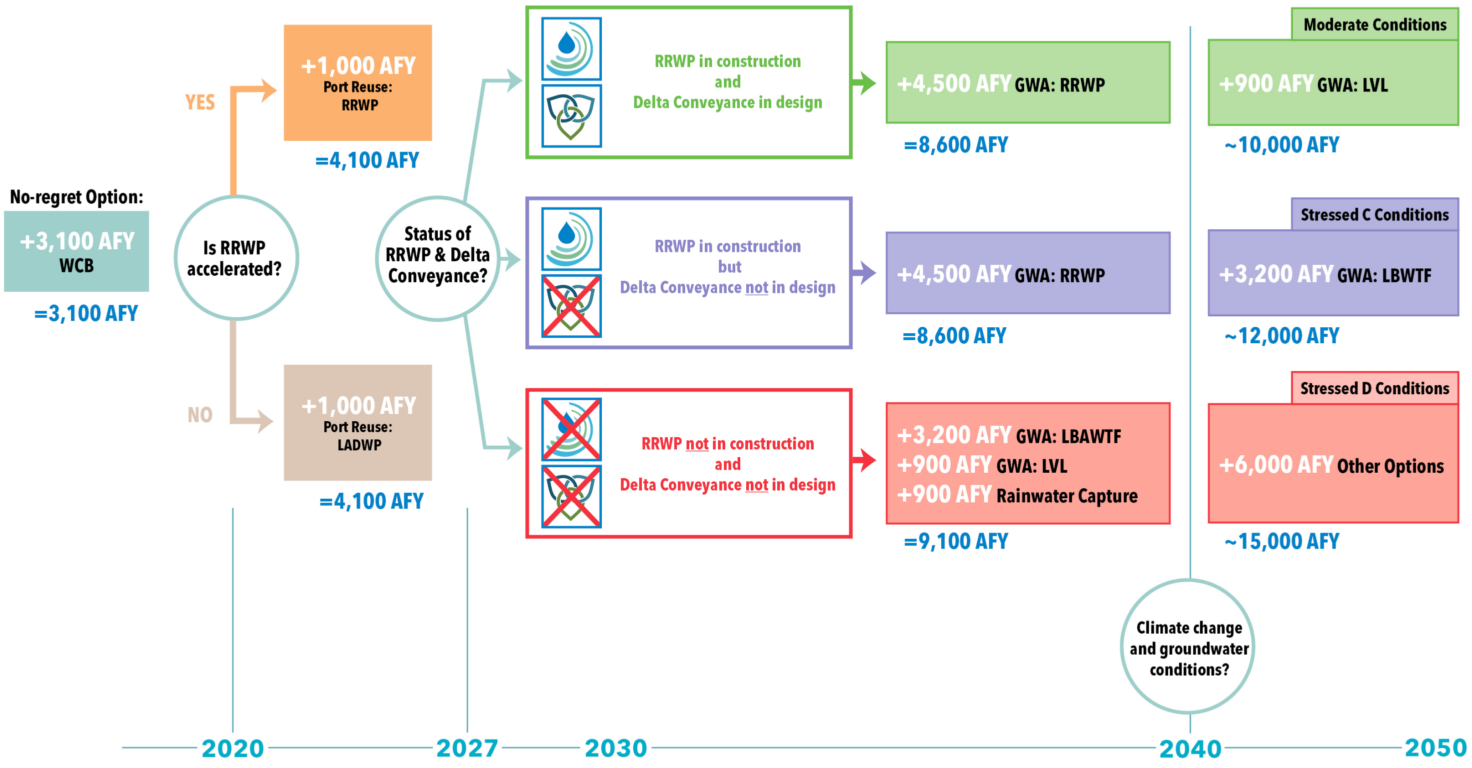
Planning scenarios, as described in Section 5, were used to estimate a plausible range of future water supply needs for LBWD given uncertainties in imported water, climate change and other factors. To meet these potential supply needs, water supply options available to LBWD were characterized and ranked in Sections 6 and 7. However, there are two possible risks that face LBWD in the development of its water resources strategy: (1) not implementing enough local water supply projects to deal with imported water constraints, worsening droughts and climate change (i.e., under-performing); or (2) over-investing in local water supply projects if climate change impacts on water supplies are less severe, and MWD and the State are successful in implementing projects to improve supply reliability.

Adaptive Management is a process by which a strategy can be developed to reduce the risks of under-performing or over-investing for LBWD. Instead of a prescriptive plan that lays out a specific timeline for implementing new projects, adaptive management provides a flexible roadmap for making incremental investments as the future unfolds. *No-Regret Options* are those highly-ranked options that can be implemented within the first several years and provide benefits under a wide range of uncertainties. *Triggers* are defined and monitored over time to that help identify what future is more likely to occur and which options should be implemented to address that future.

For LBWD, the following steps were used to develop the adaptive management approach: (1) establish alternative paths of water supply needs, which are informed by the planning scenarios described in Section 5; (2) determine if there are no-regret options that can be implemented quickly; (3) define triggers that can help determine what path of water supply needs are likely to occur; and (5) match water needs for each path with supply options that are characterized and ranked in Sections 6 and 7, considering the relative ranking of supply options, size of water supply yields produced by options, the development time to implement the options.

8.2 Water Resources Strategy for LBWD

The paths of water supply needs and triggers were identified for developing LBWD's water resources strategy using adaptive management with input from LBWD staff and stakeholders. **Figure 8-1** presents a graphical depiction of the water resources strategy for LBWD using adaptive management.



= X AFY - indicates cumulative acre-feet per year in water supply developed at points in time

LADWP - Los Angeles Department of Water and Power

LBAWTF = Long Beach Water Department Advanced Water Treatment Facility with source water from LBWRP for groundwater augmentation

LBWRP - Long Beach Water Reclamation Plant

LVL - Leo J. Vander Lans Advanced Water Treatment Facility

RRWP - Metropolitan Water District Regional Recycled Water Program

WCB - West Coast Basin well

GWA - Ground water augmentation

Figure 8-1. Water Resources Strategy for LBWD

8.2.1 Paths of Water Supply Needs

In Section 5, seven planning scenarios were evaluated in terms of future water needs for LBWD—with needs ranging from 5,700 to 15,000 AFY by 2050. However, three scenarios were selected as being most relevant for developing the paths of possible water supply needs for LBWD's water resources strategy; these paths are described as follows:

- **Path 1 - Moderate Conditions Scenario**: Moderate climate change impacts on water supplies, with successful implementation of MWD RRWP and State Delta Conveyance water supply projects; leading to projected water needs for LBWD of approximately 10,000 AFY by 2050.
- **Path 2 - Significant Conditions C Scenario**: Significant climate change impacts on water supplies, with partial implementation of MWD and State water supply projects; leading to projected water needs for LBWD of approximately 12,000 AFY by 2050.
- **Path 3 - Significant Conditions D Scenario**: Significant climate change impacts on water supplies, with no implementation of MWD and State water supply projects; leading to projected water needs for LBWD of approximately 15,000 AFY by 2050.

8.2.2 Triggers to Determine Likely Path of Water Supply Needs

Triggers are decision points that lead to outcomes, which can be mitigated by future actions. For LBWD, two near-term triggers were tied to the success of two large water projects being implemented by MWD and the State. The first near-term trigger is whether MWD's Board decides to accelerate construction of its RRWP, which could provide direct deliveries of highly-treated recycled water to the Port of Long Beach for its industrial users by as early as 2027.

The second near-term trigger is the status of MWD's full-scale RRWP. Even if MWD's Board does not accelerate the construction of the RRWP, the full-scale program could still be implemented by MWD's original schedule as presented in its feasibility study, which is by 2029. However, if construction of this program has not begun by 2025-2027, it is assumed that for the purposes of LBWD's strategy that the RRWP will not be implemented in the foreseeable future.

Concurrent with the second near-term trigger is the status of the State's Delta Conveyance project. This project came about from Governor Gavin Newsom's request to alter the WaterFix project from a two-tunnel solution to one tunnel. As a result of this project change, a new environmental documentation is underway and engineering design for the project will be delayed at least two years from the target date that was identified for the WaterFix project. For the purposes of the WRP, it is assumed that if the Delta Conveyance project is not in the final design stage of implementation by 2027 it is unlikely it will be operational by 2040.

In addition, long-term triggers such as climate change and local groundwater health (basin levels), should be monitored by LBWD to further refine future water supply needs. These long-term triggers can impact supply reliability of imported and local groundwater supplies.

8.2.3 Strategy for Local Water Supply Development for LBWD

Based on the adaptive management approach described earlier, **Figure 8-1** summarizes the water resources strategy for LBWD. The strategy can be interpreted as a decision tree, where triggers indicate which branch of outcomes are likely and what actions to take. The strategy starts with the implementation of the WCB Well, which was the only no-regret option available to LBWD. The WCB Well, with the well already constructed and grant money for well-head treatment secured, was the highest-ranked option and can be fully implemented within the next 12-18 months. This project also provides benefits under any of the planning scenarios evaluated.

8.2.4 No-Regrets and First-Trigger Outcomes and Options

Following the implementation of the no-regrets WCB Well option, the next highly-ranked options that can be implemented within the next 7 to 10 years is providing highly-treated recycled water for industrial users at the Port of Long Beach. The source water for these options can come from MWD's RRWP or LADWP's Terminal Island Water Reclamation Plant. Thus, the first near-term trigger (to be assessed in 2022) is the decision of MWD's Board on whether to accelerate construction of the RRWP. If this program is accelerated, it offers the best option for delivery of recycled water to industrial users at the Port of Long Beach by 2027. However, it should be noted that if MWD's RRWP is not accelerated and LBWD cannot secure highly-treated recycled water from LADWP at a reasonable cost and schedule, LBWD could still ultimately chose source water from MWD's RRWP but just not on an accelerated schedule. The cumulative supply generated from the no-regrets and first-trigger options is 4,100 AFY implemented by approximately 2027. Either option for serving industrial users at the Port of Long Beach would then connect to the second trigger, which is the status of MWD's full-scale RRWP and State's Delta Conveyance project.

8.2.5 Second-Trigger Outcomes and Options

Around the year 2027, the second near-term trigger (status of implementation of MWD's full-scale RRWP and the State's Delta Conveyance project) is assessed. Three outcomes for this trigger are shown in Figure 8-1. The **first outcome** assumes both MWD's RRWP and State's Delta Conveyance project will be implemented by 2030 and 2040, respectively. Under this outcome, the next highest-ranked groundwater augmentation option that meets the mid-term supply need would be source water from MWD's RRWP. This advanced-treated recycled water would be injected by MWD into the Central Basin for use by LBWD. The cumulative water supply generated for this outcome, including no-regret and first-triggered options, is **8,600 AFY** implemented by 2035.

The **second outcome** for the second-trigger, in which only MWD's RRWP is assumed to be implemented, would have the same mid-term groundwater augmentation option implemented, that being source water from MWD's RRWP. Thus, the cumulative water supply generated for this outcome, including no-regret and first-triggered options, is **8,600 AFY** implemented by 2035—same as for the first outcome.

The **third outcome** for the second-trigger assumes neither MWD's RRWP or the State's Delta Conveyance projects are implemented. For this outcome, the two groundwater augmentation options would need to be implemented, the first being LBWRP effluent treated at the existing LVL AWTF, and the second being LBWRP effluent being treated at a new AWTF operated by LBWD. However, these two options do not produce enough water supply to meet the mid-term need under this scenario and so some rainwater harvesting would also need to be implemented. By

2040, the cumulative water supply generated for this outcome, including no-regret and first-triggered options, is **9,100 AFY**.

8.2.6 Third-Trigger Outcomes and Options

Around 2040, it is likely that climate change impacts on imported and local water supplies, as well as local groundwater health can be better ascertained. As such, a third trigger should be monitored by LBWD to determine the next level of water supply investments under the strategy. If the **first outcome** for the second trigger (i.e., both MWD's RRWP and the State's Delta Conveyance project are implemented) and climate change impacts are moderate in nature, then LBWD would likely only have to implement a second smaller groundwater augmentation option that treats LBWRP effluent that is currently discharged in certain months at the existing LVL AWTF. This would produce a cumulative water supply (including all previous triggered options) of just under **10,000 AFY** by 2050—representing the water supply need depicted for **Moderate Conditions Scenario**. However, if climate change impacts are more severe and/or groundwater health is declining, then LBWD would likely have to implement additional options in the long-term.

If the **second outcome** for the second trigger (i.e., only MWD's RRWP is implemented) and climate change is more significant, then LBWD would likely have to implement a second larger groundwater augmentation option that treats LBWRP effluent that is currently discharged in certain months at a new AWTF operated by LBWD. This would produce a cumulative water supply (including all previous triggered options) of just under **12,000 AFY** by 2050—representing the water supply need depicted for **Significant Conditions C Scenario**. However, if groundwater health is still declining, then LBWD would likely have to implement additional options in the long-term.

If the **third outcome** for the second trigger (i.e., neither MWD's RRWP or the State's Delta Conveyance project are implemented) and climate change is significant, then LBWD would likely have to implement a combination of other options that may include use of Los Angeles River, increased levels of rainwater harvesting, LBMUST with Advanced Treatment Expansion, additional groundwater by securing new groundwater rights, or seawater desalination. The amount of water needed under this path would be 6,000 AFY. This would produce a cumulative water supply (including all previous triggered options) of just under **15,000 AFY** by 2050—representing the water supply need as depicted for **Significant Conditions D Scenario**. However, if climate change impacts are less severe and/or groundwater health is stabilized or improved, then LBWD might not have to implement as much of these other options.

8.3 Recommended Actions for LBWD

To implement the water resources strategy for LBWD, the following recommendations for the near-, mid- and long-term are presented in **Tables 8-1**, **8-2** and **8-3**. For each recommended action, roles for LBWD, WRD, and other agencies/entities are indicated.

Near-term recommendations focus on design and construction of well-head treatment for the new WCB Well, followed by securing highly-treated recycled water from either MWD's RRWP or LADWP's Terminal Island Water Reclamation Plant for industrial use at the Port of Long Beach.

Other near-term recommendations include assessment of LBWD's groundwater pumping capacity and determining groundwater augmentation options implemented in the mid-term.

Mid-term recommendations focus on engineering designs for subsequent groundwater augmentation projects, and further feasibility and pre-design studies of other options such as use of Los Angeles River with advanced treatment for water supply, rainwater harvesting. If warranted, the potential construction of groundwater augmentation using LBWRP effluent treated at a new LBWD AWTF could occur depending on the outcome of MWD and State projects.

Long-term recommendations focus on monitoring climate change impacts and local groundwater basin health. Design and construction of other groundwater augmentation options would occur; as well as potential implementation of other options such as use of Los Angeles River for water supply with advanced treatment, securing additional groundwater rights in Central Basin, LBMUST Advanced Treatment Expansion or Seawater Desalination (if warranted).

Finally, it is recommended that the LBWD WRP and its adaptive strategy be updated in 10 years, in concurrence with LBWD's preparation of its 2030 Urban Water Management Plan.

Table 8-1. Near Term Actions (2020-2030)

Action	LBWD	WRD	MWD or LADW	Others
Evaluate groundwater pumping capacity for current rights in Central Basin (CB)	Construct new wells and conveyance to ensure adequate capacity to fully utilize groundwater rights.			
Implement well-head treatment at new West Coast Basin (WCB) Well	Design and construct treatment facility. Work with WCB pumpers to secure water rights in WCB.	Process LBWD application for APA lease/purchase in WCB.		WCB pumpers work with LBWD and WRD to lease/sell APA for new WCB well.
Assess MWD's Accelerated Construction of its RRWP	Track progress of MWD's accelerated schedule for its RRWP, especially as it pertains to deliveries to Port of Long Beach.		MWD provides updates to LBWD on RRWP accelerated schedule status.	
Deliver highly-treated recycled water to industrial users at Port of Long Beach (Port of LB)	Work with MWD or LADWP to purchase highly-treated recycled water for industrial users, and work with Port of LB on delivery of water.		Either LADWP or MWD deliver highly-treated recycled water to LBWD service area.	Port of LB works with industrial users and LBWD on delivery of recycled water.
If MWD RRWP is under construction, negotiate terms for groundwater augmentation (GW Aug)	Negotiate with MWD on pricing and delivery terms for GW Aug in CB for LBWD use.	Amend LBWD's groundwater rights in CB to allow for increased pumping.	MWD works with WRD and LBWD on GW Aug deliveries.	
Conduct study on locating LBWD injection wells for GW Aug and design injection wells	Work with WRD to determine optimal location of injection wells for GW Aug, and design injection wells.	Work with LBWD to determine optimal location of injection wells for GW Aug		
Conduct feasibility study on LBWD AWTF for treating LBWRP effluent for GW Aug	Conduct pre-design on a new LBWD AWTF for GW Aug using effluent from LBWRP.	Work with LBWD on treatment requirements for GW Aug.		
Assess State's Delta Conveyance Project	Determines if Delta Conveyance is in construction and on track for operations by 2040.		MWD provides Delta Conveyance project updates to LBWD.	

Table 8-2. Mid Term Actions (2030-2040)

Action	LBWD	WRD	MWD or LADWP	Others
Implement additional GW Aug at a new LBWD AWTF, depending on assessment of Delta Conveyance being implemented by 2040	If Delta Conveyance is not likely to be operational by 2040, construct injection and production wells for GW Design and construct a new LBWD AWTF for unused LBWRP effluent.	Work with LBWD on water quality requirements, and optimal location of injection and production wells.		
Explore acquisition of additional groundwater rights in CB.	Work with WRD and other pumpers on availability and cost of additional groundwater rights. Assess feasibility of new wells and treatment.	Coordinate with LBWD and other pumpers in CB on possible acquisition of groundwater rights.		Other pumpers in CB work with LBWD on availability and price for acquiring new rights in CB.
Further study Rainwater Harvesting potential.	Work to refine estimates of supply yields, potential water customers and costs.			City's Public Works and City's Building Code Departments coordinate with LBWD.
Further study on LBMUST Advanced Treatment Expansion	Work to refine estimates of yields, potential recycled water customers and costs.			City's Public Works Department coordinate with LBWD.
If Delta Conveyance and RRWP is unlikely to be implemented explore Seawater Desalination	Preliminary design of approximately 5 mgd seawater desalination facility and associated distribution.			
If Delta Conveyance is unlikely to be implemented, start implementing rainwater harvesting	Work with City's Public Works and Building Codes Departments, and developers to implement phased rainwater harvesting.			City's Public Works and Building Codes Departments, and developers work with LBWD on phased rainwater harvesting.

Table 8-3. Long Term Actions (2040-2050)

Action	LBWD	WRD	MWD or LADWP	Others
Monitor climate change impacts on water supply	Works with WRD and MWD to monitor impacts of climate change on imported and local groundwater supply.	Works with LBWD to monitor groundwater impacts.	Works with LBWD to monitor imported water impacts.	
Determine long-term water supply needs and remaining options	Based on climate change trends and outcomes of LBWD's efforts to develop other water supply projects, assess the need for lower ranked projects			
Implement new wells if additional groundwater rights in CB are secured	Design and construct new wells and additional treatment if required.	Amend LBWD's groundwater pumping rights.		Other pumpers sell groundwater water rights in CB to LBWD.
Construct LBMUST Advanced Treatment Expansion	If needed, design and construct advanced treatment for LBMUST expansion and deliver water to recycled water customers.			City's Public Works Department to coordinate with LBWD.

This page intentionally left blank.

Section 9

References

Beersma, J., Buishand, A., and van Pelt, S. (2012). Advanced delta change method for time series transformation. Presentation, Workshop “Non-stationary extreme value modelling in climatology.” Technical University of Liberec, February 15-17, 2012.

California Data Exchange Center (2017). Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices. http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

California Department of Finance. Annual population and demographic data.

California Natural Resources Agency (2015). State Water Project Delivery Capability Report. https://cawaterlibrary.net/wp-content/uploads/2017/05/SWP-Delivery-Capability-Report-2015.pdf

Colorado River Drought Contingency Plan Authorization Act of 2019, H.R. 2030, 116th Cong. (2019-2020).

Cox, T., McCluskey, M., and Arthur, K. (2012). Incorporating Climate Change into Water Supply Planning and Yield Studies: A Demonstration and Comparison of Practical Methods. Prepared for Bureau of Reclamation’s 2011 WaterSMART Program Grant No. R10SF80326.

Lenderink, G., Buishand, A., and Van Deursen, W. (2007). Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. Hydrology and Earth System Sciences Discussions, Copernicus Publications, 11(3), 1145-1159.

Long Beach Water Department (2015). Urban Water Management Plan.

Long Beach Water Department (2018). Groundwater Augmentation Projects.pptx (D. Wang, personal communication, March 27, 2018.)

Metropolitan Water District of Southern California (2013). Inland Feeder fact sheet at a glance.

Metropolitan Water District of Southern California (2015). The Regional Urban Water Management Plan.

Metropolitan Water District of Southern California (2015). Operations data http://www.mwdh2o.com/mwdh2o/pages/operations/ops01.html

Metropolitan Water District of Southern California (2015). Integrated Resources Plan.

Metropolitan Water District of Southern California (July 2016). Regional Recycled Water Program: White Paper on Program Implementation and Delivery.

Metropolitan Water District of Southern California (2018). Annual Report for the Fiscal Year July 1, 2017 to June 30, 2018. http://mwdh2o.com/PDF_Who_We_Are/2018_AnnualReport.pdf

Municipal Water District of Orange County (2018). Orange County Water Reliability Study.

National Oceanic and Atmospheric Administration (2015). Climatological Rankings. https://www.ncdc.noaa.gov/monitoring-references/dyk/ranking-definition

United States, Upper Colorado River Commission, Arizona Department of Water Resources, Metropolitan Water District of Southern California, Coachella Valley Water District, Palo Verde Irrigation District, City of Needles, Colorado River Commission of Nevada, Southern Nevada Water Authority. (2019). Agreement Concerning Colorado River Drought Contingency Management And Operations. https://www.usbr.gov/dcp/docs/final/Companion-Agreement-Final.pdf

United States Bureau of Reclamation (2007). Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead: Appendix D, Lower Division States Depletion Schedules. D-3. http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html

United States Bureau of Reclamation (2011). Operation Plan for Colorado River System Reservoirs (24-Month Study). http://www.usbr.gov/lc/region/g4000/24mo/index.html

United States Bureau of Reclamation (2012). Colorado River Basin Water Supply and Demand Study: Appendix G, Analysis & Evaluation. G2-5 to G2-6. http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html

United States Bureau of Reclamation (2013). Climate Change Analysis for the Santa Ana River Watershed, August 2013.

United States Bureau of Reclamation (2013). Hood River Basin Study: Groundwater Modeling. Presentation, August 19th, 2013.

San Diego County Water Authority (2019). Quantification Settlement Agreement. https://www.sdcwa.org/quantification-settlement-agreement

South Coast Water District (2015). Draft Water Supply Allocation Plan, February 12, 2015.

State Water Project (2015). Draft Delivery Capability Report.

Yates, D., Averyt, K., Flores-Lopez, F., Meldrum, J., Sattler, S., Sieber, J., and Young, C. (2013). A water resources model to explore the implications of energy alternatives in the southwestern US. Environ. Res. Lett., 8, 14 pp.