Long Beach Climate Resiliency Study: Impacts on Water Supply and Demand

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Acronyms

AF	Acre-Feet
CMD	Center of Mass Date
CRB	Colorado River Basin
DWR	California Department of Water Resources
ESRI ArcGIS	Environmental Systems Research Institute's Geographic Information System
GCM	Global Climate Model
GEV	Generalized Extreme Value Distribution
GPCD	Gallons per Capita per Day
GHG	Greenhouse Gasses
HM	Hydrological Model
IPCC	Intergovernmental Panel on Climate Change
IRWP	Integrated Water Resources Plan
LA	City of Los Angeles
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
LBWD	Long Beach Water Department
MAF	Million Acre-Feet
MK test	Mann Kendall Statistical Test
ML-OVB	Mono Lake and Owens Valley Basin
MLC	Mono Lake Committee
MWDSC	Metropolitan Water District of Southern California
ppmv	Parts per million by volume
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RUWMP	Regional Urban Water Management Plan
SJR-TLB	San Joaquin River and Tulare Lake Basin
SRB	Sacramento River Basin
SWC	Storm Water Capture
SWE	Snow Water Equivalent
SWP	State Water Project
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
WSAP	Metropolitan Water District's Water Supply Allocation Plan
WUS	Western United States

Figures and Tables

Executive Summary

The City of Long Beach is located in a semi-arid region with finite natural water supplies. Long Beach has established itself as a leader in conservation, achieving a 31% reduction in gallons per capita per day (GPCD) from the 1980's to today. However, due to the arid climate of the Southwest, specifically Southern California with its large population, there is not enough naturally occurring water to meet demands without importing water from other regions. Long Beach is no exception and obtains 39% of water supply from imported sources. Additionally, the 54% originating from groundwater is partially dependent upon imported sources for recharge. Recycled water makes up just 7% of the water supply portfolio. Plans to expand the recycled water system have not yet been realized. Currently, purchasing imported water is more cost effective for Long Beach than expanding the recycled water system or constructing a desalination facility. However, stress on imported water supplies from climate change could drive up prices and make expansions of local supplies more economically attractive.

Southern California's reliance on imported supplies revolves around snowpack and the timing of snowmelt from the Upper Colorado basin and Northern California regions. In the Western United States (WUS), approximately 75% of water discharge comes from spring snowmelt and is primarily controlled by precipitation and temperature (Cayan, 1996). Recent projections of climate change due to increases in anthropogenic greenhouse gases suggest the WUS and Southwest are particularly vulnerable due to this heavy reliance of temperature sensitive snowpack (Christensen & Lettenmaier, 2007; Diffenbaugh et al., 2005; IPCC, 2007; Rauscher et al., 2008). Lack of local supply expansion coupled with potential decreases in imported water supply availability could leave Long Beach in shortage conditions. Here we take a comprehensive approach to examine near term climate change impacts on all sources of water supply to Southern California and specific impacts to Long Beach.

A 10-member ensemble of coupled global climate models is dynamically downscaled forcing one regional and one hydrological model resulting in a high-resolution 4-km output to assess climate change impacts on the hydrologic cycle for all imported water to Southern California including the San-Joaquin River, Tulare Lake, Sacramento River, Owens Valley, Mono Lake and Colorado River basins. Greenhouse gas concentrations are prescribed according to the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP 8.5) using a baseline period of 1966-2005 and future period of 2011-2050.

Surface temperatures are projected to rise by 0.5-1.7°C by 2030 and 1.2-2.5°C by 2050 over the WUS. Accelerated warming is observed in mountain ranges like the Sierra Nevada and Colorado Rocky Mountains as a result of the snow-albedo positive feedback. Average winter albedo decreases upwards

of 20% by 2030 and 25% by 2050 in higher elevations. Timing of peak runoff timing shifts one to two weeks earlier in the year due to warmer temperatures and a much reduced snowpack. The ensemble of models predicted a range of changes in annual average precipitation and runoff amounts by 2050. However, the intensity and frequency of daily annual maximum runoff and precipitation events increases throughout the region. For example the current 100-year runoff even becomes approximately nine times more likely in the Colorado River Basin and twice as likely in other basins of Long Beach's imported water supply. Cumulative annual runoff has an increased probability of being significantly greater or less than historical amounts. The increased frequency of abnormally low annual runoff increases the regions susceptibility to droughts. Regardless of positive or negative changes in annual runoff or precipitation, the region's imported water supply is projected to diminish by mid-century due to lack of reservoir storage capacity to capture the increased proportion of rainfall derived runoff, more extreme winter runoff events and earlier snowmelt timing as projected by climate change.

Long Beach populations are expected to increase at a fairly slow rate. This together with extensive conservation efforts over the past 30 years will make it increasingly difficult for Long Beach to further reduce its gallons per capita per day (GPCD) water usage. Even if the target 100 GPCD is met, increases in population by 2050 will result in a net increase of water demand. Locally, temperatures are projected to rise 1-1.25°C by 2030 and 1.25-1.5°C by 2050; however, annual precipitation is also projected to increase 15-25% by 2030 and 2.5-10% by 2050 however precipitation events are expected to be less frequent, greater in magnitude, and concentrated during the winter months when outdoor demand is low. Without citywide storm water capture efforts, any additional precipitation projected with climate change will not significantly offset demand. Substantially warmer summer temperatures will increase evapotranspiration and outdoor irrigation demand. Drought tolerant conversion efforts could reduce outdoor irrigation requirements by 10-24% and reduce the impacts of increased temperatures. While Long Beach has established itself as a leader in water conservation, further efforts to increase capture and utilization of local storm runoff and expansion of recycled water use must be made in order for the city to withstand future water supply reduction caused by climate change.

1.0 Introduction

The Long Beach Water Department (LBWD) is the retail agency that distributes water to the nearly 500,000 residents of Long Beach. LBWD is required by the California Department of Water Resources (DWR) to submit an Urban Water Management Plan (UWMP) every five years. Addressing climate change is currently an optional section to include in an agency's UWMP. LBWD's 2010 UWMP included a short section on the topic stating, "The effects of climate change will have on water supply and demand are unknown as this time, given the uncertainty with respect to local impacts, intensity, duration and timeliness…LBWD does not expect climate change to have a major impact on its local sources of water, such as groundwater and recycled water" (LBWD, 2010). The paragraph continues to state that climate change impacts on imported supplies were addressed in Metropolitan Water District of Southern California (MWDSC) 2010 Regional UWMP. Long Beach is one of 26 member agencies that purchase imported water from MWDSC which holds fourth and fifth priority rights to water from the Colorado River. Additionally, MWDSC is a contractor for the State Water Project, which is fed by the Sierra Nevada. Although MWDSC has addressed climate change to some extent, it is vital for retail agencies to understand and plan in conjunction with regional and wholesale agencies since climate change will not only affect imported supplied but local supplies as well. Both will impact local Southern California agencies. This report provides a comprehensive overview of potential impacts that climate change may have on Long Beach's water supply and demand. All imported sources of water to Southern California are evaluated along with local sources including groundwater, recycled water, stormwater capture, desalination, graywater use and conservation efforts (Figure 1).

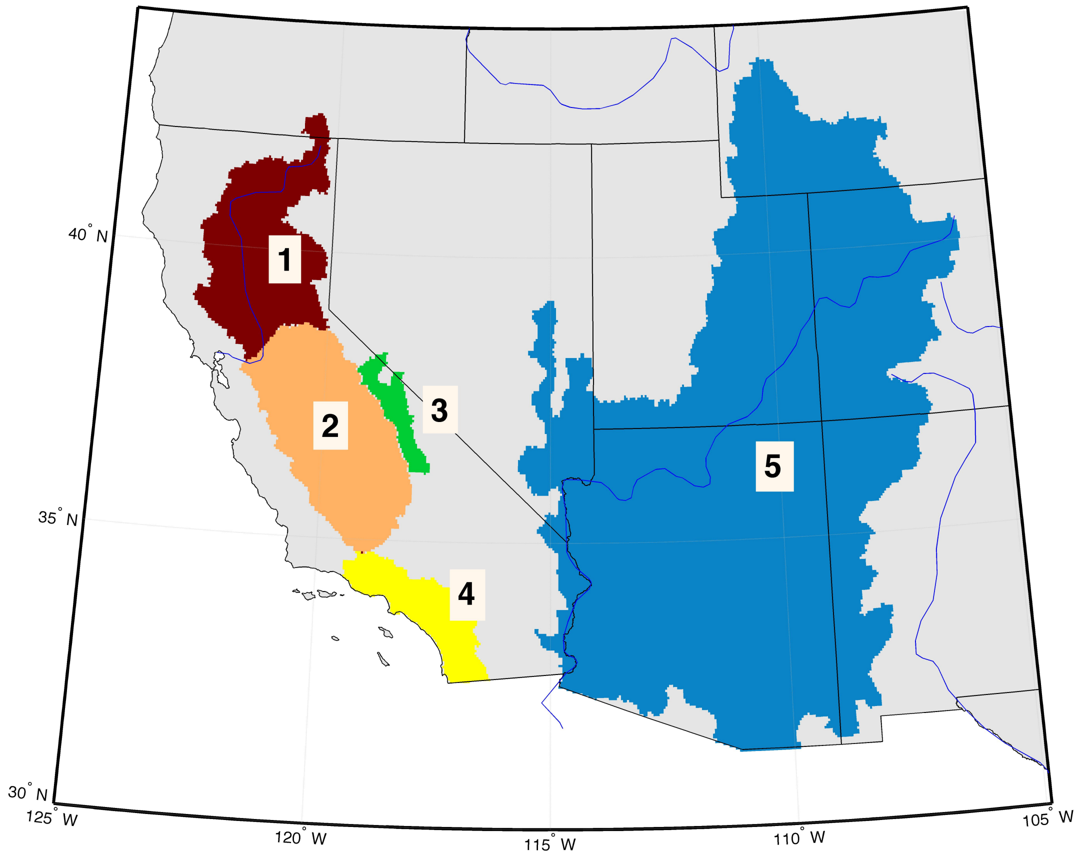


Figure 1: Map of all sources of water supply to Southern California and study basins including 1) Sacramento River (SRB), 2) San Joaquin-Tulare Lake (SJRB-TLB), 3) Mono Lake and Owens Valley (ML-OVB), 4) Southern Hydrologic Region and 5) Colorado River (CRB).

1.1 Current Imported Supply Limitations and Previous Study's Projections

During the past century, 1°-2° C of warming has been observed over the Western United States (Barnett et al., 2004). Temperatures are projected to rise by 3° to 5° C by the end of the century, greater than the global average. These temperature increases are estimated to shift snowmelt and snowmelt-driven runoff up to two months earlier over much of the Western United States (Rauscher et al., 2008) and the San Joaquin-Sacramento River basin (He et al., 2013). With less snowpack, runoff timing is expected to shift earlier in the year when reservoirs are kept at lower levels for flood control purposes when winter precipitation occurs. The reservoirs will fill earlier due to rainfall runoff and may not have spare capacity to hold the snowmelt runoff, even though it is somewhat reduced due to climate change. Because the reservoirs are also required to provide flood control, the dam operating rules will likely require releasing this captured water to maintain their flood control capacity. This released water could be "lost" unless there are systems to move this water to other reservoirs or groundwater recharge facilities where it can be stored and used. Lack of timely local water resource expansion coupled with climate change may leave the area in extended periods of shortages. The following section provides a brief overview of current supply limitations from each imported supply source including 1) the Colorado River Aqueduct, 2) State Water Project and 3) Los Angeles Aqueduct.

1.1.1 Colorado River Aqueduct

The 630,000 km^2 Colorado River Basin provides water to over 30 million people across Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada, California and Mexico (Christensen et al., 2004; Ficklin, Stewart, & Maurer, 2013). Approximately 70-80% of the water from the CRB is used for agricultural lands, both within the basin and exported to other regions of the WUS (USBR, 2011). The 1922 Colorado River Compact divided the basin into two sections: upper and lower. Each section was apportioned 7.5 million acre-ft (MAF). The Boulder Canyon Project Act of 1928 and the Upper Colorado River Basin Compact of 1948 divided the 7.5 MAF from both the upper and lower regions to state specific allotments. It was not until 1944 with the installment of the Mexican Water Treaty that 1.5 MAF of the CRB's water was promised to Mexico. The early 20th century was a particularly wet period in the CRB. Average annual flows were approximately 16.1 MAF in the 1920's when the compact was first signed. Therefore, calculations used to determine allocation amounts across the region in the aforementioned compacts and treaty were skewed (USGS, 2004). Since the mid 20th century, the CRB has experienced much drier periods more typical for the semi-arid and arid WUS-Mexico region with annual flows reaching as low as 3.8 MAF in 2002 (USGS, 2004).

In the CRB, snowfall in the winter months accumulates until the spring when warmer temperatures melt the snow. The snowmelt is captured by the large reservoir systems of Lake Powell and Lake Mead until summer months when the Colorado River Aqueduct, altering the natural water cycle, redistributes the water. The state of California has an allotment of 4.4 MAF surplus CRB water every year. Agricultural entities possess the first three priority rights totaling 3.85 MAF. MWDSC, the primary wholesaler of water to the Southern California coastal hydrologic region, holds the fourth and fifth priority rights at 0.55 MAF and 0.662 MAF. MWDSC is also entitled to 0.18 MAF of any surplus originating from the first three priority right holders (MWDSC, 2010). Arizona and Nevada's increasing populations have resulted in lower water availability for California. If population and demands continue to increase, MWDSC could be left with just the 0.55 MAF fourth priority right water.

On the Colorado River, reservoir levels are projected to diminish up to 30% by 2050 (Barnett et al., 2004). Storage is expected to decline up to 40% by 2100 due to decreased runoff (Christensen et al., 2004), reducing water available for the Southwest. Minimal changes in precipitation are anticipated by 2040; however studies have shown the potential for both increases and decreases (Christensen & Lettenmaier, 2007). Any potential increase in precipitation can potentially be offset by greater rates of evaporation and evapotranspiration due to warmer temperatures, resulting in decreased streamflow. Total system demand in such a scenario would exceed reservoir inflows for the CRB (Christensen et al., 2004). Incorporating population growth estimates would further increase the system demand. These changes have the potential to adversely affect already scarce water supplies for Southern California.

1.1.2 State Water Project

The San Joaquin River Basin including the Tulare Lake Basin covers 82,000 km^2 of central California while the Sacramento River Basin extends from central to northern California at 71,000 km^2 (USGS, 2014). Combined, the basins provide over 80 percent of the runoff in California supporting 25 million people and the $36 billion dollar agricultural industry(Cloern et al., 2011; Gleick & Chalecki, 1999). In 1960, the California Water Resources Development Bond Act passed providing 1.75 billion dollars to construct the State Water Project (SWP). Runoff from both basins into the Sacramento-San Joaquin Delta where it is then pumped more than 700 miles to central and southern areas of the state through the California aqueduct (SWP) and the federal Central Valley Project (CVP). California and federal policy makers have grappled with numerous issues surrounding the Delta stemming from limited water resources and the challenge of dividing these limited sources between urban, agricultural and environmental users. The Delta is the largest estuary in the Western United States making it a critical ecosystem (Kibel, 2011). Endangered species such as the delta smelt can become entrapped in the SWP and CVP pumps at the south side of the Delta. During drought periods water quality becomes an issue as seawater is drawn in from San Francisco Bay into the Delta, which impacts the aquatic species and adds minerals to the Delta water. In order to protect these species, water pumping at the Delta pumping facilities must be reduced or completely halted. The MWDSC is one of the largest SWP users at 1.9 MAF; however this allocation is highly variable. During the 2014 drought, MWDSC received just 5% of their SWP allocation water due to pumping restrictions. Studies by DWR indicate that the probability of receiving 1.9 MAF in any one year is only about 64% (DWR, 2012).

Between 30-40 km^3 of rain and snowfall flows to the Sacramento-San Joaquin watershed (Knowles & Cayan, 2002). Snowpack accumulated from December to March delays 40% of the water delivered past April 1st, resulting in a system heavily reliant on snowfall timing and reservoirs to store the melt water (Roos, 1989). The timing allows the reservoirs to maintain their flood storage capacity during the fall and early winter months, capture rainfall derived runoff later in the winter and early spring gradually filling the flood control "pool" and then capture the snowmelt when the flood danger is minimal. This reliance makes these systems high vulnerable to climate changes. Previous studies on the SJTLB and SRB have shown large uncertainties in precipitation changes over the basins. The potential impact on runoff ranges from reductions of annual flow to the Delta by 41% to increases by 16% (He et al., 2013). By 2060, April snowpack is projected to be just 66% of baseline normal conditions (Knowles & Cayan, 2002).

1.1.3 Los Angeles Aqueduct

The Los Angeles Aqueduct (LAA) was constructed in 1913 with the purpose of providing water to the growing city of Los Angeles. Initially obtaining water from the Owens River, a second aqueduct was completed in 1970 that extended the aqueduct to the Mono Lake Basin (LADWP, 2013). The LAA conveys both surface water and groundwater as the city of Los Angeles purchased groundwater rights along the LAA route to pump into the aqueduct. Due to excessive pumping of the Owens River Valley and surface diversions, the Owens Lake is now considered a dry lakebed posing a health risk to locals as dust particles can cause respiratory problems. The USGS has stated that the Owens Valley is likely the largest source of PM-10 (particles smaller than 10 microns in diameter) in the U.S. (Reheis, 1997). Mitigation due to human and environmental health concerns has resulted in LADWP being required to provide 40 TAF of water per year for dust control (LADWP, 2013). Environmental degradation from the LAA was not limited to Owens Valley. Mono Lake's unique tufa formations serve as nesting sites for migratory birds. Once LADWP began exporting water the lake's elevation dropped from the historical average of 6,417 feet above sea level to 6,372 feet (MLC, 2015). Air and water quality issues ensued with increased exposure of the lakebed. Furthermore, predators were more easily able to access the nesting migratory birds as water levels declined. As a result the Mono Lake Committee was formed (MLC) which fought alongside organizations like the Sierra Club and the Audubon Society to halt LADWP diversions. After 20 years of challenges, the State Water Resources Control Board of California released decision 1631 (D1631) which restricted LADWP's ability to export based on the water level of Mono Lake further reducing water supply to Los Angeles (LA). From 2006-2010, the city of Los Angeles obtained 36% of its water supply from the LAA, equivalent to 0.22 MAF (LADWP, 2010).

Previous studies have examined the impacts of climate change on the Mono and Owens Valley basins on a global climate model resolution (Costa-Cabral et al., 2013; Ficklin, Stewart, & Maurer, 2013). By the end of the 21st century, temperatures are predicted to increase from 2-5°C while changes in annual precipitation are highly variable, ranging from -24 to 56% (Costa-Cabral et al., 2013). Although the LAA strictly serves the city of Los Angeles (LA), LA is the largest user of MWDSC water and possesses the most preferential rights to MWDSC water. Therefore, if LAA water supply greatly decreases, LA would have to increase purchases from MWDSC, which could leave other member agencies of MWDSC more prone to shortage conditions.

2.0 Methodology and Data

Ten coupled atmosphere-ocean global climate models (GCMs) are used as the driving force for the Regional Climate Model system (RegCM4) at 18-km^2 to form an ensemble of simulations (Giorgi et al., 2012) (Table 1).The output from the GCM simulations is part of the Coupled Model Intercomparison Project Phase 5 (CMIP5), which was used for the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2013). GHG concentrations for the present day period (1966-2005) are specified by observations. Minimum temperature, maximum temperature and precipitation are bias corrected following a modified version of the Wood et al. (2002,2004) approach outlined in Ashfaq et al (2010) (Ashfaq et al., 2010; Wood et al., 2004; Wood et al., 2002). Observed monthly mean 1-km PRISM data is regridded at 4-km and compared with modeled monthly means for temperature and precipitation. Each grid point is adjusted to the PRISM dataset and monthly mean values are redistributed on a daily timescale. Future period (2011-2050) GHGs are specified by the IPCC's Representative Concentration Pathway (RCP) 8.5. While RCP 8.5 GHG concentrations are considered to be relatively high, there is little difference between other RCP scenario concentrations in the early and mid 21st century. The output from each ensemble member is dynamically downscaled and used to drive the Variable Infiltration Capacity (VIC) hydrologic model at 4 km^2 over the entire U.S (Liang et al., 1994). All model processing was completed at Oak Ridge National Laboratory (ORNL). For the purposes of this study, two 20-year timeframes are considered, one which represents impacts to 2030 and the other to 2050.

Extensive efforts are being made to improve modeling techniques in order to obtain higher resolution datasets. The Climate Sensitivity Group at UCLA has created a hybrid dynamical and statistical downscaling approach to create a 2-km dataset over the Los Angeles Basin (Sun, Walton, & Hall, 2015; Walton et al., 2015). Recently the group broadened their research area and applied this technique to the Sierra Nevada at a 3-km resolution and 9-km solution over the rest of California. This study looks at all sources of imported water supply to California, including the Colorado River Basin, which has not been analyzed using the hybrid downscaling approach. To have comparable results across all basins, this study solely uses the ORNL 4-km dataset.

Table 1: Global climate models utilized in this study.

Model	**Modeling Group, Country**	**Resolution (lat x lon)**
ACCESS1-0	Center for Australian Weather and Climate Research, Australia	1.24° x 1.88°
BCC-CSM1-1	Beijing Climate Center and China Meteorological Administration, China	2.81° x 2.81°
CCSM4	National Center for Atmospheric Research (NCAR), United States of America	0.94° x 1.25°
CMCC-CM	Euro-Mediterranean Center for Climate Change, Italy	2.0° x 2.0°
FGOALS-g2	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, China	2.8° x 2.8°
IPSL-CM5A-LR	Institute Pierre Simon Laplace, France	1.89° x 3.75°
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	1.41° x 1.41°
MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	1.88° x 1.88°
MRI-CGCM3	Meteorological Research Institute, Japan	1.13° x 1.13°
NorESM1-M	UNI Bjerknes Center for Climate Research, University of Bergen, Center for Intern Climate and Environmental Research, The Norwegian Meteorological Institute, University of Oslo, Norwegian Computing Center, Norwegian Institute for Air Research and the Norwegian Polar Institute, Norway	1.88° x 2.5°

Parameters evaluated to determine any potential hydrological changes include precipitation, evaporation, baseflow, runoff, snow water equivalent (SWE), soil moisture, temperature and albedo. The Mann-Kendall statistical test (MK test) is used to identify any trends in the data specifically runoff timing (Kendall, 1948; Mann, 1945). Commonly used for hydrologic applications, the MK test is non-parametric and evaluates data sets for upward or downward trends. Two-sample unpaired two-tailed Student t-tests are used to determine statistical significance across all parameters (Gosset, 1908). The Generalized Extreme Value (GEV) distribution is fitted to maximum annual one-day precipitation and runoff events as well as cumulative annual runoff to evaluate return period changes (Jenkinson, 1955, 1969).

Population and historical demand information for Long Beach was obtained from LBWD's 2010 UWMP. In order to analyze potential residential outdoor irrigation demand changes, historical evapotranspiration (ETo) data is obtained from DWR's California Irrigation Management Information System (CIMIS) from weather station 174 located at El Dorado Park in Long Beach for 1990-2005. Average residential single-family (RSF) lot size was provided by LBWD using a sample of 200 homes throughout Long Beach. A duplicate approach is taken utilizing Geographic Information System (GIS) map estimates for 110 residential duplex (R-DUPLX) and multi-family (RMF) buildings. The proportion of irrigated landscape area to total lot size for each customer class is calculated and applied to all customers for that category. All GIS mapping datasets originate from the City of Long Beach's online GIS data catalog. VIC provides data regarding evaporation changes, but not ETo, which is critical in understanding plant water needs. ETo is calculated using the Blaney-Criddle method (FAO, 1998):

$$ET_O = p\left(0.46T_{mean} + 8\right)$$

Where T_{mean} is the mean daily temperature in degrees Celsius and p is mean daily percentage of annual daytime hours for a given latitude and time of a year. The change in ETo using the Blaney-Criddle method is calculated on a monthly basis for each Period and model. Model bias is calculated by subtracting monthly simulated ETo from observed CIMIS ETo. The bias is then subtracted from baseline and RCP 8.5 ETo. Only a fraction of precipitation which falls will be available for plants to utilize, also known as effective rainfall (P_e) where:

$$P_e = \textit{Total rainfall - runoff – evaporation - minus deep percolation}$$

Following the Food and Agriculture Organization (FAO) method for calculating P_e when slope maximum is 4-5%:

$$Pe = (0.8 * P) - 25 \quad \textit{if } P > 75\ mm$$

$$Pe = (0.6 * P) - 10 \quad \textit{if } P < 75\ mm$$

Where P is monthly average precipitation in mm. VIC precipitation is already bias corrected therefore additional correcting was not necessary. Plant watering needs will differ based on the plant type and stage of growth by a factor called the crop coefficient (Kc). For the purposes of this study, it was assumed 90% of properties did not already have drought friendly landscapes, i.e. turf grass lawns. Cool season grasses have a Kc of 0.8 while warm seasons have a Kc of 0.6. An averaged Kc of 0.7 is used to represent grass lawns. Drought tolerant plants can have a Kc as low as 0.2-0.3. Assuming that 90% of existing landscapes were grass and 10% drought tolerant, an average Kc is applied to all landscapes of 0.66. ETo must be corrected by incorporating varying Kc values with irrigation equipment and management efficiency:

$$ETAF=Kc/IE$$

$$IE=DU*IME$$

Where ETAF is the evapotranspiration adjustment factor IE is the efficiency of irrigation equipment, DU is the distribution uniformity of irrigation equipment and IME is the irrigation management efficiency. DU and IME values are obtained from DWR's white paper on Evapotranspiration

Adjustment Factor. Average DU for a landscape is 0.79, representing a mix of irrigation equipment (i.e. spray/rotor heads and drip irrigation). IME can vary between type of customer. Homeowners are less likely to be as efficient as large commercial customers with full time landscape staff. However, to be conservative on watering need estimates and to follow DWR's protocol, an IME of 0.90 is used. IE is therefore 0.7.

Water demands are calculated using:

$$ID=ETAF-Pe$$

Where ID is irrigation demand in mm. Given average irrigated area sizes by customer class, ID is converted into acre-feet.

Using assessor parcel information and GIS, total rooftop area by each customer class is derived in order to determine potential storm water capture. Historical ID assumes residents do not have rain capture devices. To evaluate the potential offset in demand of rain barrels, we optimistically assume every single family, multi-family and duplex customer in the future will have two standard 55-gallon (7.35 ft^3) rain barrels that can be filled up and used twice a month. Rainfall typical occurs in concentrated events in Long Beach and due to soil saturation, the water in a rain barrel may not be needed for outdoor irrigation for weeks. Therefore, rain barrels used twice a month when enough rainfall is available is again an optimistic assumption. Potential storm water capture on a monthly basis is calculated by:

$$SWC=Pe \times RTA$$

$$PSWC= \text{number of rooftops} * 29.4\, ft^3$$

Where SWC is storm water capture, RTA is rooftop area by customer class, PSWC is potential storm water capture and 7.35 ft^3 is rain barrel storage capacity assuming two rain barrels at each property are filled up twice a month.

Therefore, adjusted ID with storm water capture is determined by:

$$ID\_SWC= \begin{cases} ID-PSWC & \text{if } SWC > PWC \\ ID & \text{if } SWC<PWC \end{cases}$$

3.0 Results: Imported Supplies

Results are broken down into two categories: imported and local sources of water supply. Primary hydrological variables which influence imported supplies are evaluated comparing Period 1, baseline (1966-1985) to projected RCP 8.5 (2011-2030) and Period 2, baseline (1986-2005) to RCP 8.5 (2031-2050) potential changes. The impacts on Long Beach water supply resulting from possible alterations to each variable are discussed. Alterations to aforementioned hydrologic parameters are evaluated over the entire WUS study region and each imported supply basin on an annual and monthly basis. Frequencies of extreme runoff and precipitation events are evaluated. Shifts in annual and monthly snowmelt driven runoff amounts are also assessed.

3.1 Temperature Impacts on Snowpack

Daily maximum and minimum surface temperatures are derived from the ensemble of simulations at each grid point. The average between the maximum and minimum datasets is calculated to represent average daily surface temperatures. A comparison of potential changes in temperatures is achieved by subtracting RCP 8.5's averaged ensemble daily surface temperatures from the baseline. Surface temperatures are projected to rise by 0.5-1.5°C under RCP 8.5 by 2030 and 1.24-2.5°C by 2050 (Figure 2a). Changes in temperatures are statistically significant at a 95% confidence level for each grid point across the WUS using the two-sample two-tail Student's t-test. Average January through April (JFMA) daily albedo greatly decreases up to 20% by 2030 and 25% by 2050 for the majority of the WUS (Figure 2b). Notably the major mountain ranges including the Sierra Nevada and Colorado Rocky Mountains experienced greater increases in temperatures than lower elevations. With rising temperatures, a smaller proportion of precipitation will fall as snow resulting in decreasing snowpack. Less snowpack can lower the region's albedo, a measurement of the reflectivity of incoming solar radiation. Lower albedo causes solar insolation to become trapped in Earth's atmosphere further warming the WUS, exacerbating the rate of snow melting. Albedo decreases most significantly during winter and spring months also indicating a loss of snowpack. Temperatures increase closer to 1°C along the Pacific coastline in contrast to the arid inland regions of Southeast California and Southwest Arizona which project slightly higher temperature changes of 1.5°C. Coastal cities like Long Beach typically experience a lower range of temperature variations as a result of their proximity to the ocean. Under RCP 8.5 the ocean continues to act as a buffer for the WUS coastline resulting in a lower magnitude of temperature increases. Across all basins, RCP 8.5 summer months from June through September exhibits the greatest change in temperature. With the exception of very high elevations, snow depth decreases through the WUS. For Period 1, ensemble average JFMA snow depth diminishes by -17% for

CRB, -14% for ML-OVB, -42% for SRB and -21% for SJRB-TLB. For Period 2, snow depth decreases by -22% for CRB, -27% for ML-OVB, -46% for SRB and -28% for SJRB-TLB (Figure 2c). While models MIROC5, MPI-ESM-MR and MRI-CGCM3 show snow depth increases for a few basins, the overwhelming model agreement is towards decreasing snow cover over the WUS (Figure 3). Greatest snowpack changes occur in the State Water Project basins of SRB and SJRB-TLB.

Projected Changes in Temperature, Albedo and Snow Depth

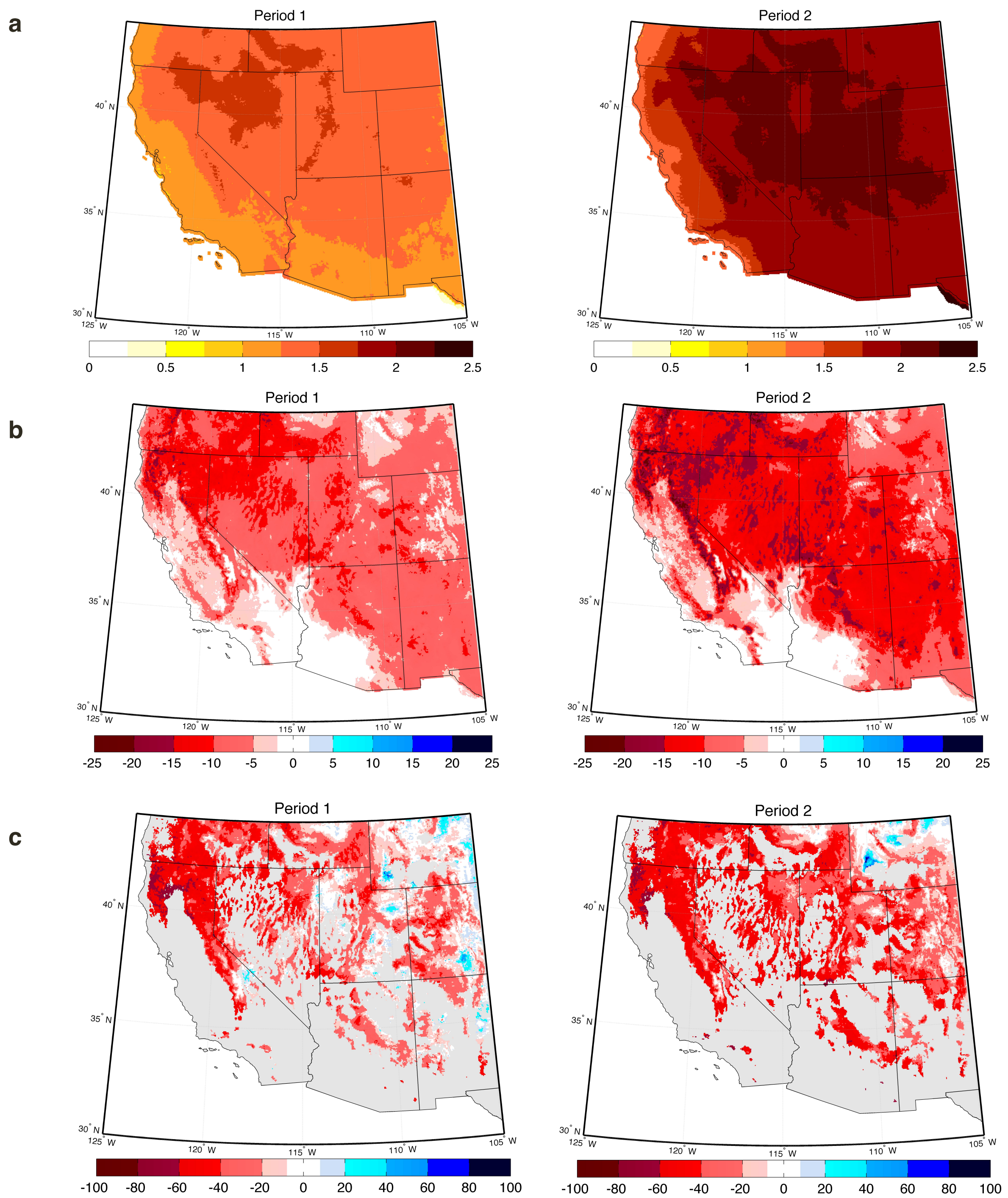
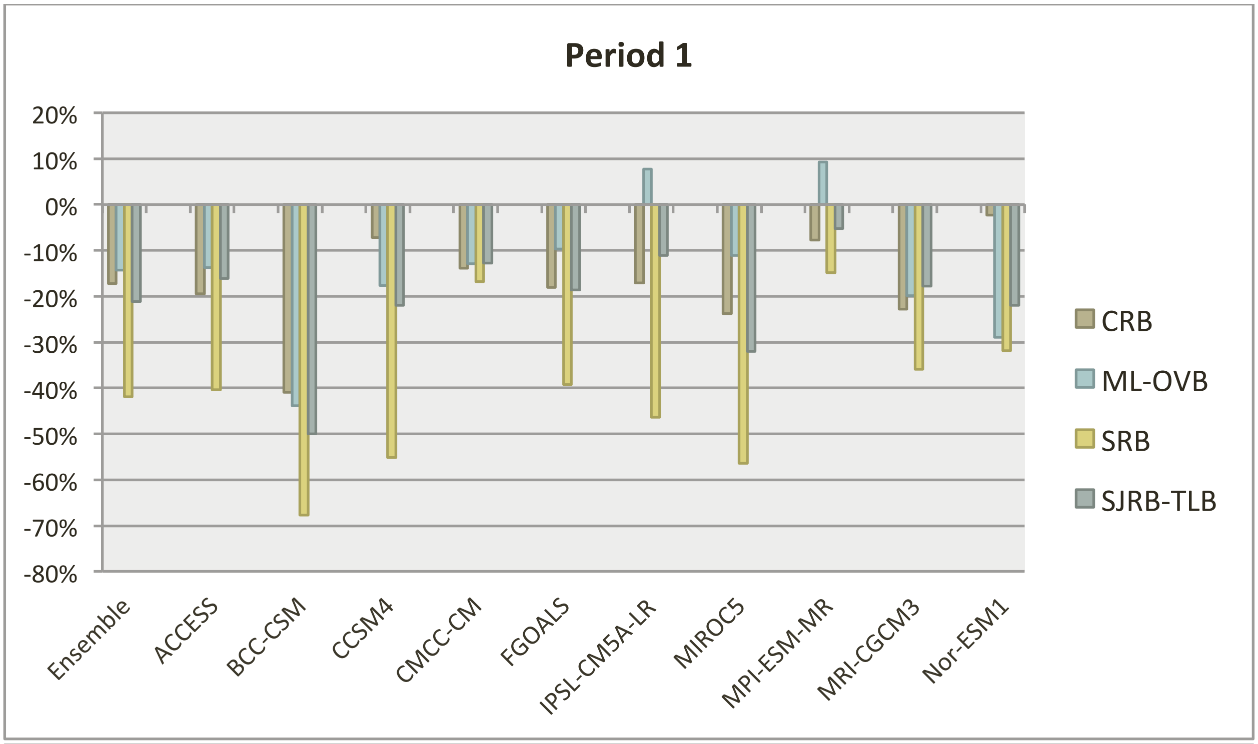


Figure 2: Ensemble average daily a) temperature change (°C), b) JFMA albedo percent change and c) snow depth JFMA percent change by Period 1 (2030) and Period 2 (2050) from baseline to RCP 8.5. Greatest changes are projected to occur in mid to high elevations as a result of the snow-albedo positive feedback.

Individual Model Changes in Snow Depth



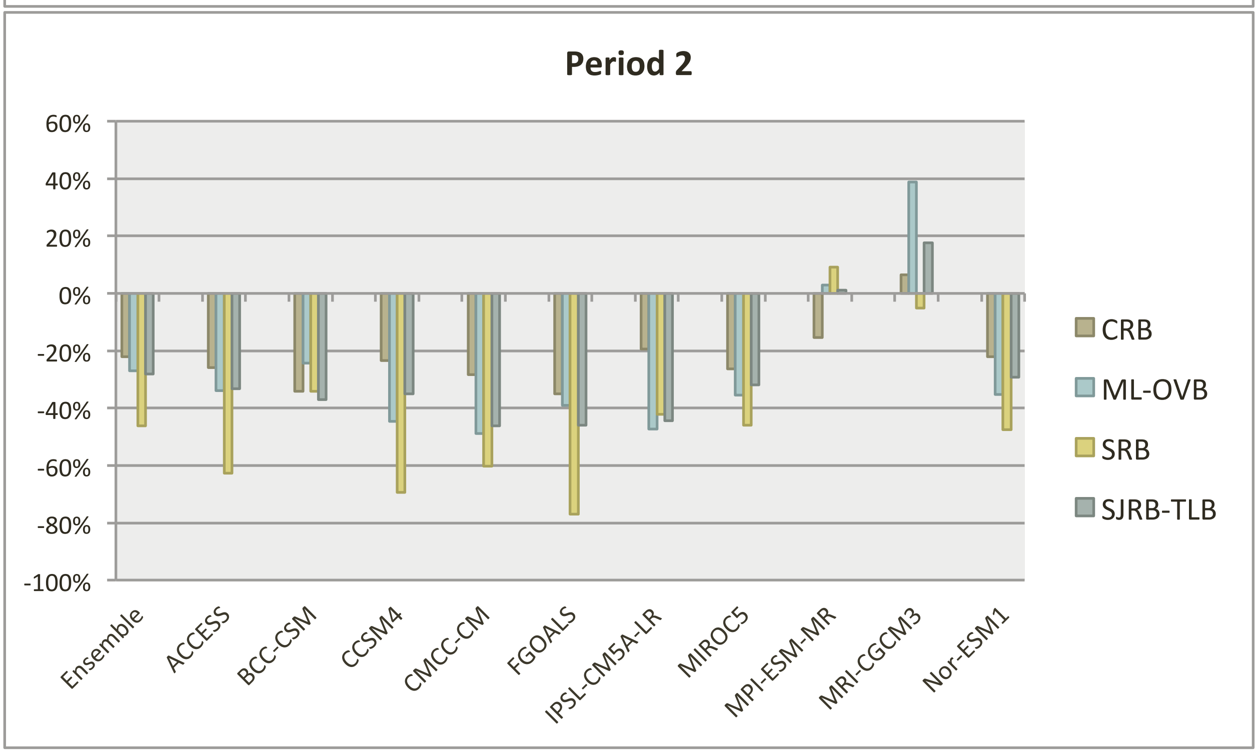


Figure 3: Ensemble and individual model average daily JFMA snow depth percent changes for each basin from baseline to 2030 and 2050.

3.2 Precipitation

Projections for changes in total annual precipitation greatly varied by model, basin and Period. Among the ten models responses to precipitation on a basin level for Period 1 ranges from -7 to 25% for CRB, -12 to 26% for ML-OVB, -14 to 17% for SRB and -14 to 21% for SJR-TLB. For Period 2, precipitation ranges from -7 to 17% for CRB, -16 to 24% for ML-OVB, -21 to 14% for SRB and -20 to 21% for SJR-TLB (Figure 4). This supports previous studies that have found varying precipitation changes for the first half of the 21st century (Christensen & Lettenmaier, 2007; Costa-Cabral et al., 2013). Rising GHG concentrations force increasing temperatures, driving higher evaporation rates which cause more water available for precipitation. Latest GCM projections predict increases in precipitation in mid and high latitudes towards the end of the century (IPCC, 2013). With the exception of the SRB in Period 1 and ML-OVB in Period 2, ensemble average annual precipitation slightly increases over the region.

Baseline vs. RCP 8.5 Precipitation Changes

Figure 4: Ensemble and individual model average annual precipitation percent changes for each basin from baseline to 2030 and 2050.

3.2.1 Precipitation Extreme Events

Annual one day maximum precipitation events are calculated for each year and model. The GEV distribution is fit on a basin and gridpoint level to determine the 10, 25, 50 and 100-year return periods for baseline and RCP 8.5 using a 30-year time series of the data set (1976-2005 versus RCP 8.5 2021-2050). Basin wide peak one-day precipitation amounts increase for each return period by 19-68% for CRB, 8-16% for ML-OVB, 7% for SRB, and 13-16% for SJRB-TLB. The probability of experiencing the extreme 50 and 100-year events approximately doubles throughout the basins, except for the CRB where the 50-year is six times more likely to occur and 100-year nine times (Figure 5; Table 2).

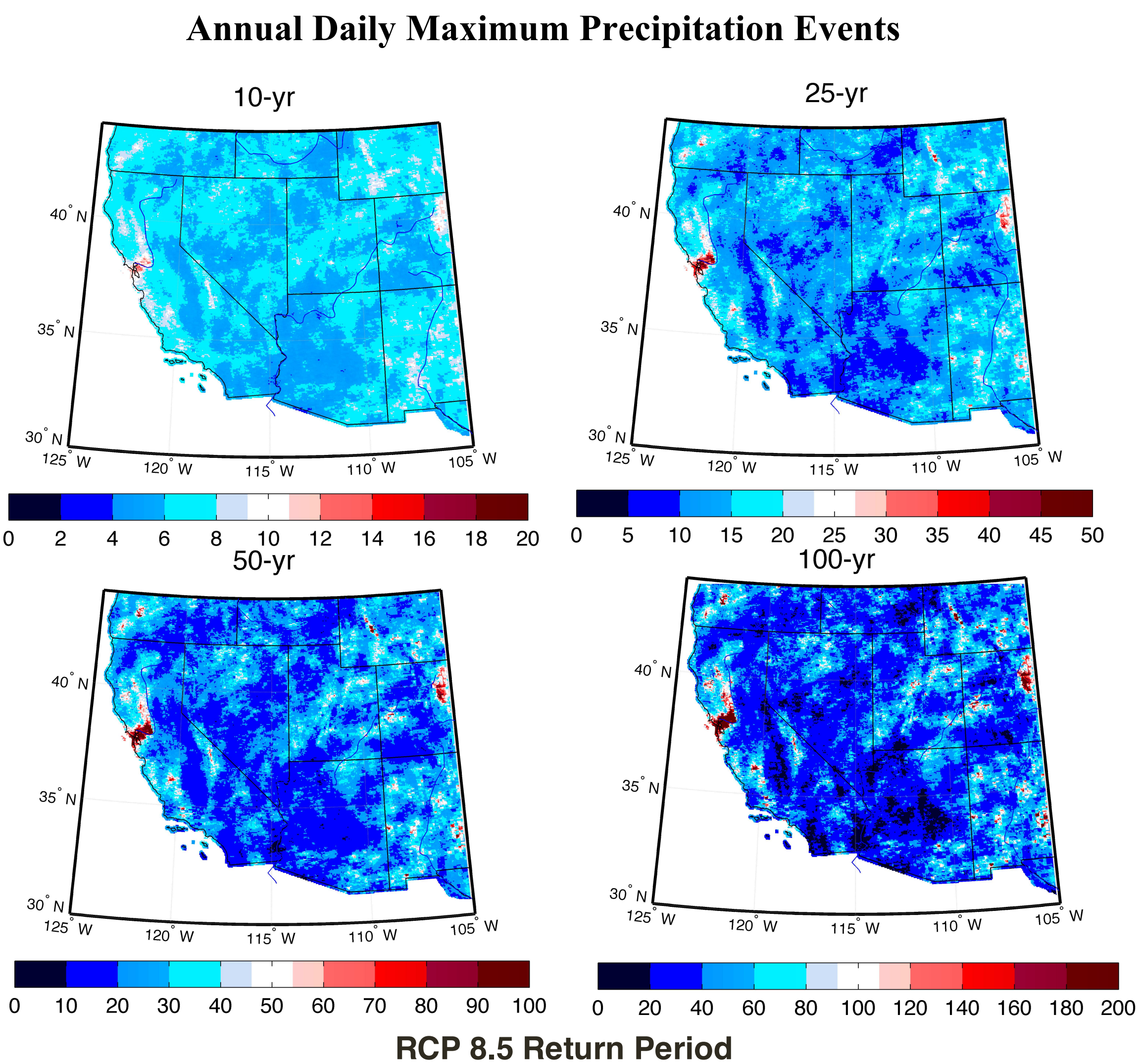


Figure 5: RCP 8.5 projected return periods for baseline's 10, 25, 50, and 100-year annual daily maximum precipitation events. The Sierra Nevada, Colorado moutains and Southern Coastal hydrologic regions have a higher probability of experiencing concentrated high volume precipitation events which can result in flooding.

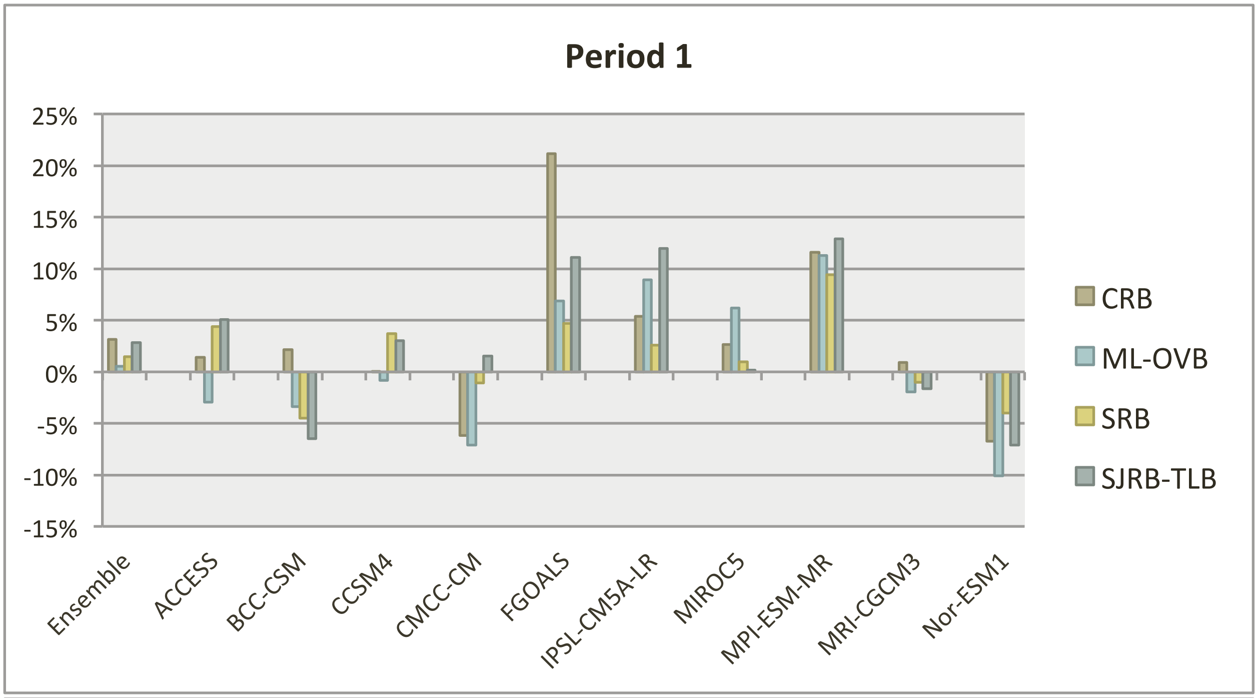
Table 2: Comparison of baseline to RCP 8.5 10, 25, 50 and 100-year a) annual maximum one-day precipitation amounts (m^3/s) over the area of each basin and cooresponding RCP 8.5 return period for precipitation amounts for each baseline return period.

	Base Return Period (yr)	Base (m^3/s)	RCP 8.5 (m^3/s)	Base Return Period Now RCP 8.5 Return Period (yr)
CRB	10	115,500	149,200	4
	25	131,500	188,000	6
	50	142,400	220,500	8
	100	152,500	256,500	11
ML-OVB	10	3,700	4,000	7
	25	4,400	4,900	15
	50	5,000	5,600	27
	100	5,500	6,400	45
SRB	10	56,300	60,000	7
	25	64,200	68,700	16
	50	69,700	74,700	28
	100	74,900	80,400	51
SJRB-TLB	10	44,300	49,900	5
	25	50,400	57,600	11
	50	54,700	63,000	18
	100	58,700	68,200	29

3.3 Evaporation

Evaporation changes between each model for Period 1 range from -7 to 21% for the CRB, -10 to 11% for LAA, -4 to 9% for SRB and -7 to 13% for SJR-TLB. Period 2 evaporation changes range from -8 to 15% for the CRB, -12 to 8% for LAA, -5 to 8% for SRB and -9 to 11% for SJR-TLB (Figure 6). With the exception of ML-OVB for Period 2, all basins project minor increases in evaporation. The persistent increase of temperatures and slight potential increase of precipitation likely drives the increases in evaporation.

Baseline vs. RCP 8.5 Evaporation Changes



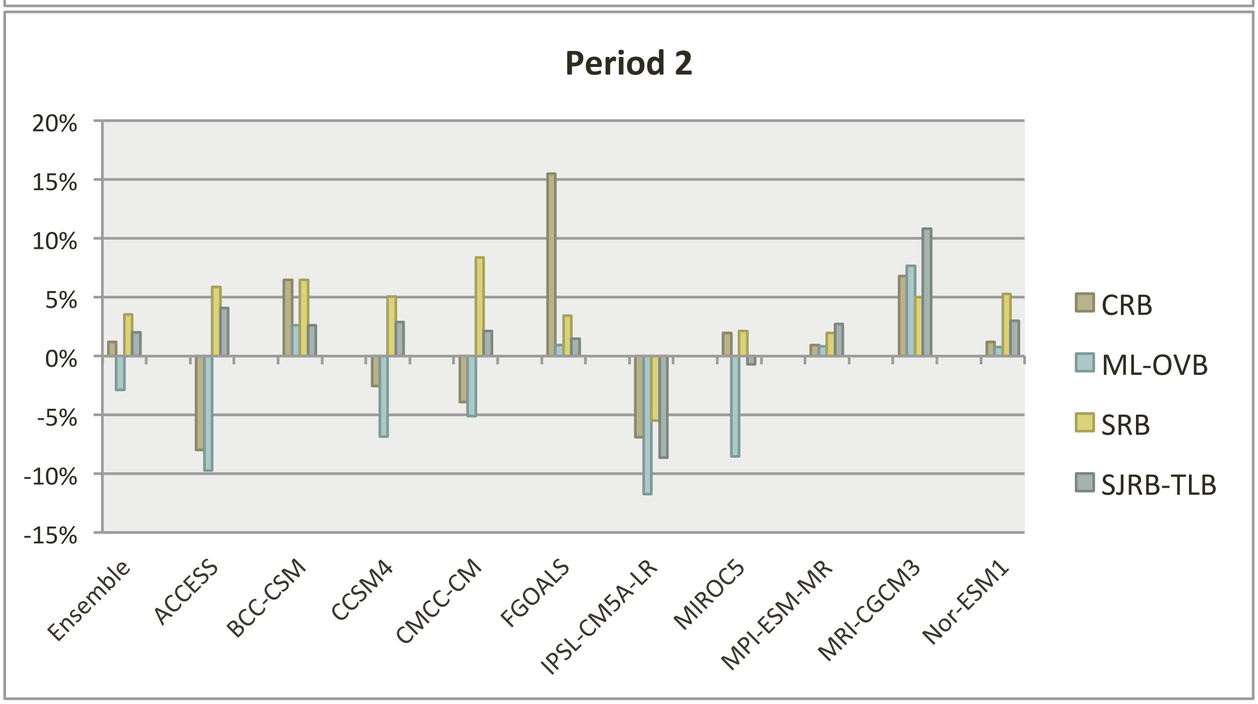


Figure 6: Ensemble and individual model average annual evaporation percent changes for each basin from baseline to 2030 and 2050.

3.4 Runoff

Alterations to average annual runoff varies by basin and is dependent upon changes in precipitation and evaporation in corresponding periods. Total 20-year average annual runoff changes between each model for Period 1 range from -21 to 64% for the CRB, -22 to 54% for LAA, -48 to 26% for SRB and -39 to 39% for SJR-TLB. Period 2 runoff changes range from -7 to 21% for the CRB, -10 to 11% for LAA, -4 to 9% for SRB and -7 to 13% for SJR-TLB. For Period 1, ensemble average runoff increases for CRB and ML-OVB and decreases for SRB and SJRB-TLB. For Period 2, all basins except SJRB-TLB project greater runoff amounts (Figure 7).

Baseline vs. RCP 8.5 Runoff Changes

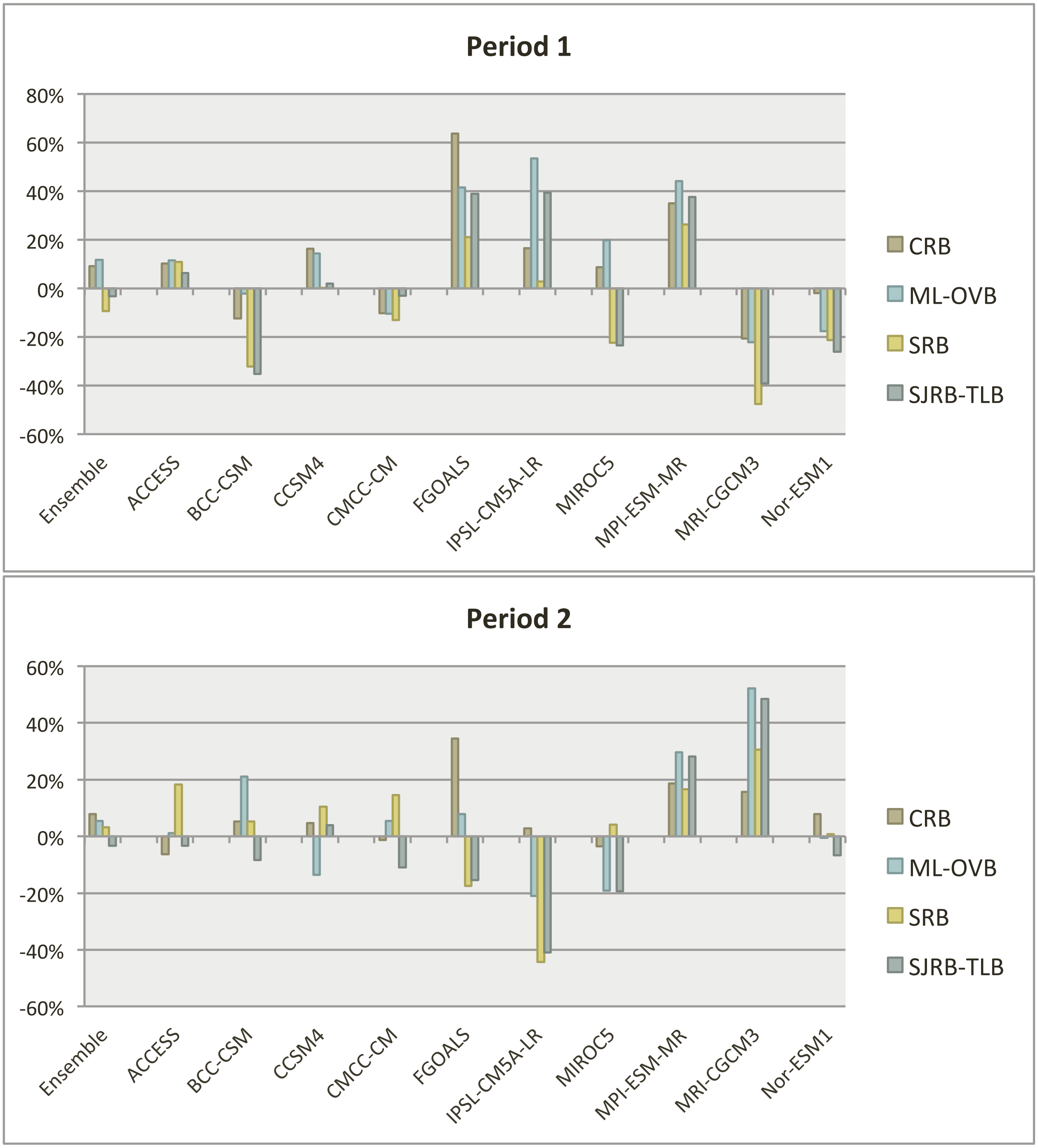


Figure 7: Ensemble and individual model average annual runoff percent changes for each basin from baseline to 2030 and 2050.

3.4.1 Shifts in Runoff Timing

The center of mass date (CMD), defined as the Julian day of the water year when 50% of annual runoff occurs, is crucial in regions like the WUS, which heavily rely on snowmelt for water supply and designed reservoirs on the basis of that timing (McCabe & Clark, 2005; Rauscher et al., 2008). The CMD is calculated for both scenarios at each grid point and basin for a subset of 30-years (1976-2005 compared with 2021-2050). Over most of the WUS (except Arizona), the ensemble average CMD under RCP 8.5 occurs earlier in the season with changes up to 20 days. At the basin scale, the CMD develops 6 to 11 days earlier (11 days for CRB, 7 days for ML-OVB, 6 day for SR, and 8 days for SJR-TLB) (Figure 8). Individual models and years show changes ranging from 50 to 80 days depending on the basin (Figure 9).

The MK test is run for each basin to identify any trends in the ensemble average runoff monthly data at a 95% confidence level. Months that exhibit changing trends have a calculated z-value greater than 1.96 or less than -1.96. Runoff increases during the winter and early spring months across all basins. Only the CRB and ML-OVB exhibit statistically significant increases from December to May. Runoff decreases across all basins during the summer months, but only statistically significant for the SRB and SJR-TLB (Figure 10). Although there were minimal changes in average annual runoff over the forty-year scenarios, the distribution of runoff among months drastically changes. The shift in runoff occurring earlier in the year may represent shifts in snowmelt timing as a result of increasing temperatures. A separate analysis of monthly Colorado River flows at Lee's Ferry, Arizona in the CRB from 1906 to 2010 using the MK test revealed statistically significant decreases in flow from July to September and an increase in January. The flow measured at Lee's Ferry is fed by runoff originating from the upper CRB. Data from the United States Bureau of Reclamation (USBR) is used and considered to be unimpaired, accounting for the construction of the Glen Canyon Dam from 1956 to 1966. The observed trend of decreasing summer flows support a shift in snowmelt timing to earlier in the year.

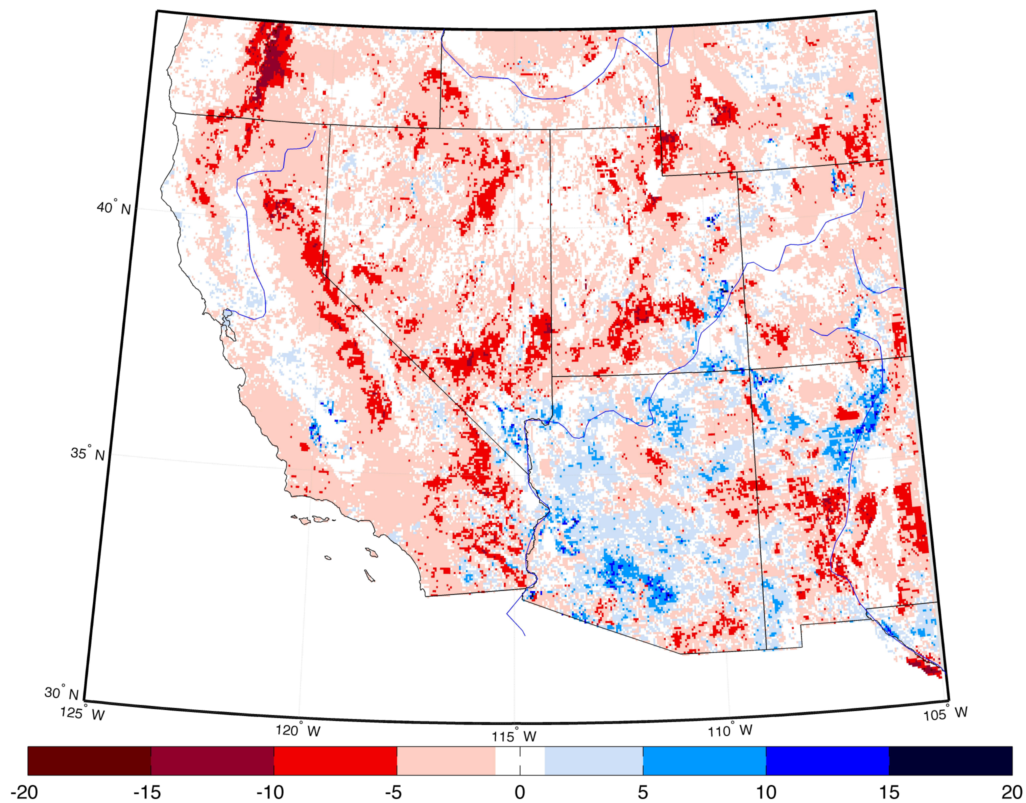


Figure 8: Change in CMD calculated for water years on a grid point basis. Negative values indicate peak runoff occurring earlier in the year as seen throughout the higher mountain ranges and the Sierra Nevada

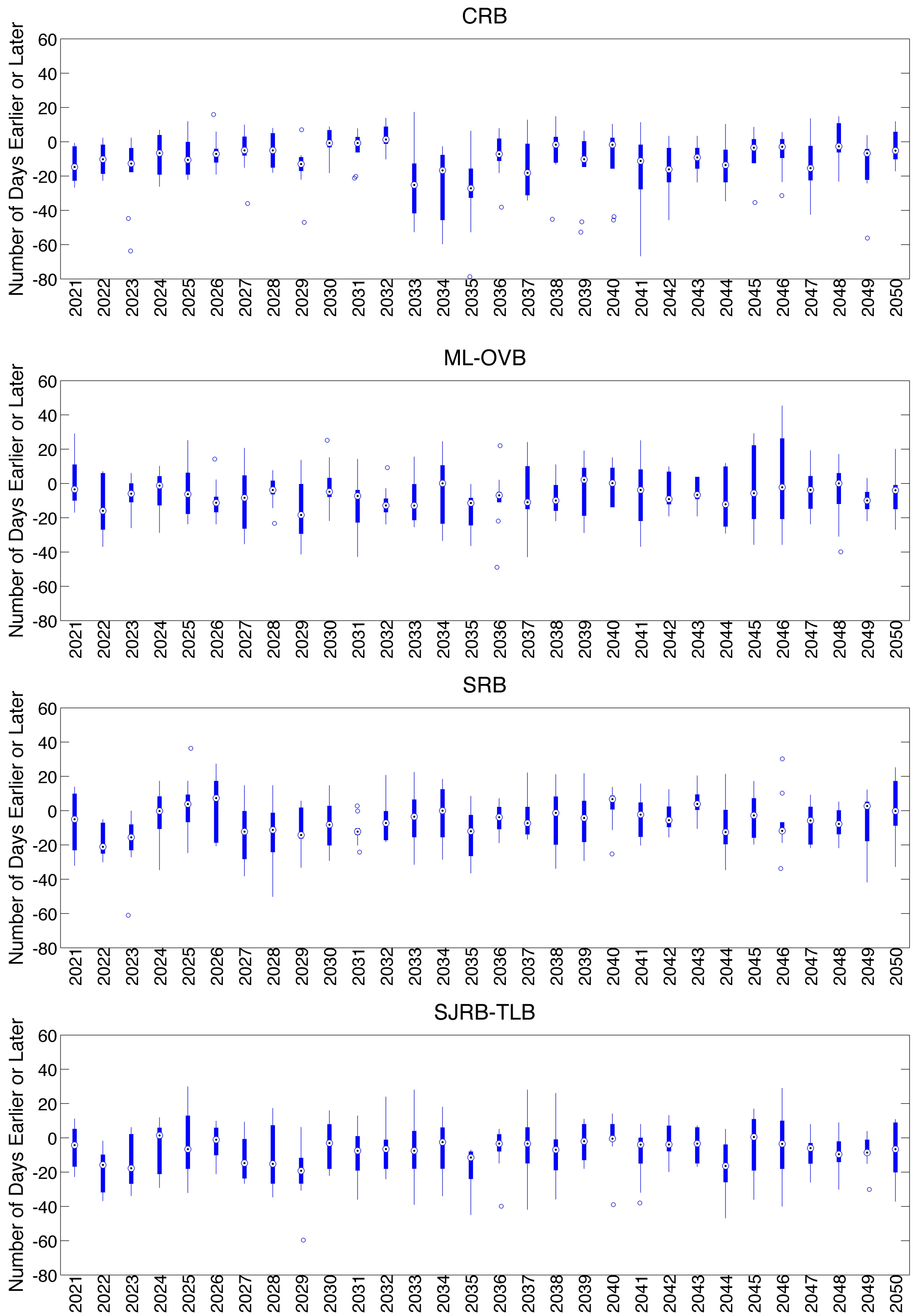


Figure 9: Change in CMD on a basin level for a) CRB, b) ML-OVB, c) SRB and d) SJRB-TLB. Boxplots represent the change of each model (n=10) under RCP 8.5 from baseline average CMDs. Black dots depict ensemble median and outliers are defined as being +/- 2.7 standard deviations from the median.

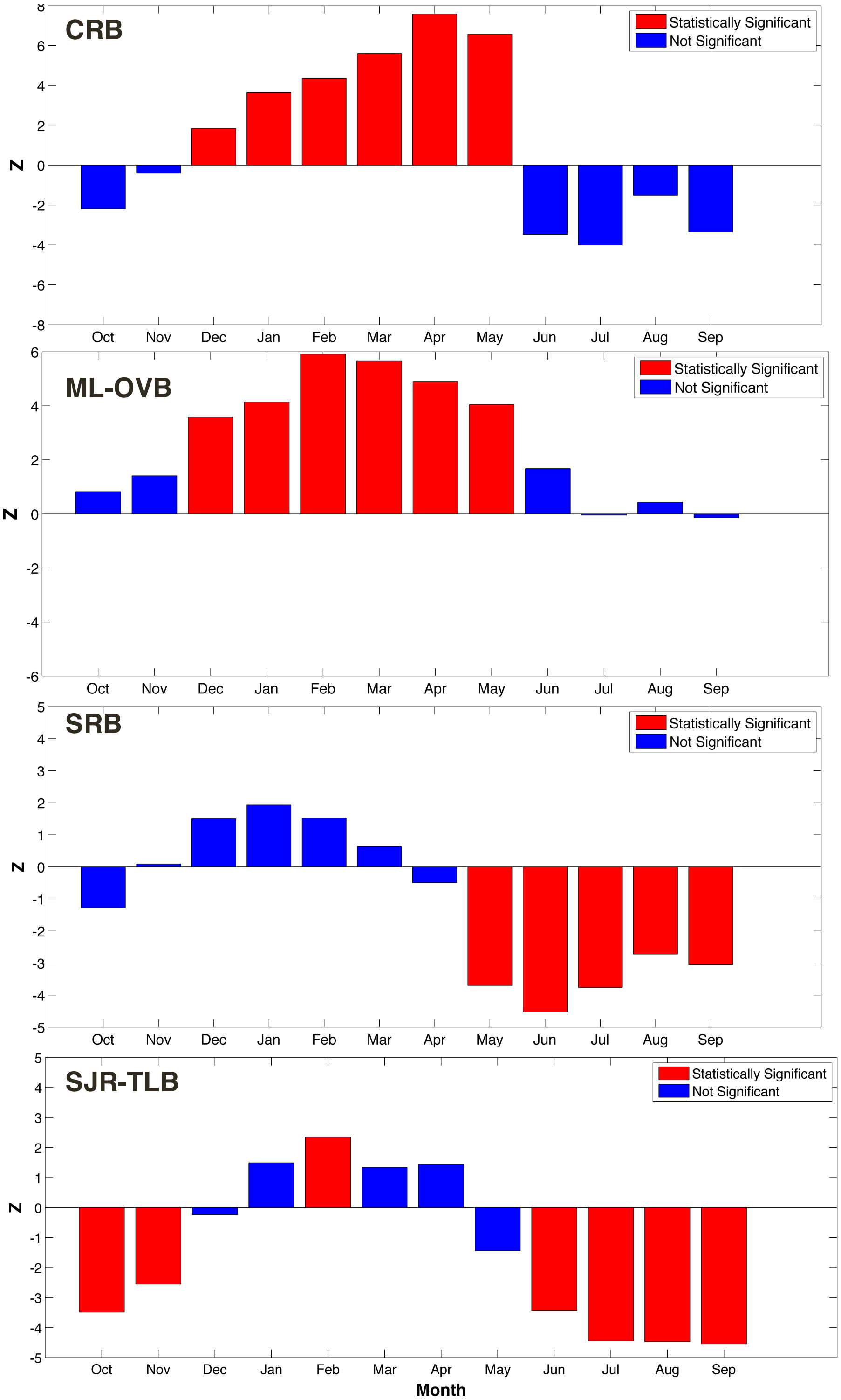


Figure 10: MK test results for monthly runoff trends. Z-values greater than +/- 1.96 are statistically significant. CRB and ML-OVB exhibit positive trends during the winter and spring months. Negative trends in the summer and fall are not statistically significant, resulting in a net increase in runoff for the basins. SRB and SJR-TLB exhibit significant decreases in the summer and early fall months also indicating a shift in snowmelt timing. An annual net decline in total annual runoff can be observed the SRB and SJR-TLB.

3.4.1 Extreme Runoff Events

Annual one day maximum runoff events are calculated for each year and model. The GEV distribution is fit on a basin and gridpoint level to determine the 10, 25, 50 and 100-year return periods for baseline and RCP 8.5 using a 30-year time series of the data set (baseline 1976-2005 versus RCP 8.5 2021-2050). Basin wide peak one-day runoff amounts increase for each return period by 60-151% for CRB, 42-51% for ML-OVB, 12-15% for SRB, and 18-24% for SJRB-TLB. Mirroring extreme precipitation changes, the probability of experiencing the extreme 50 and 100-year events approximately doubles throughout the basins, except for the CRB where the 50-year is six times more likely to occur and 100-year nine times (Figure 11;Table 3)

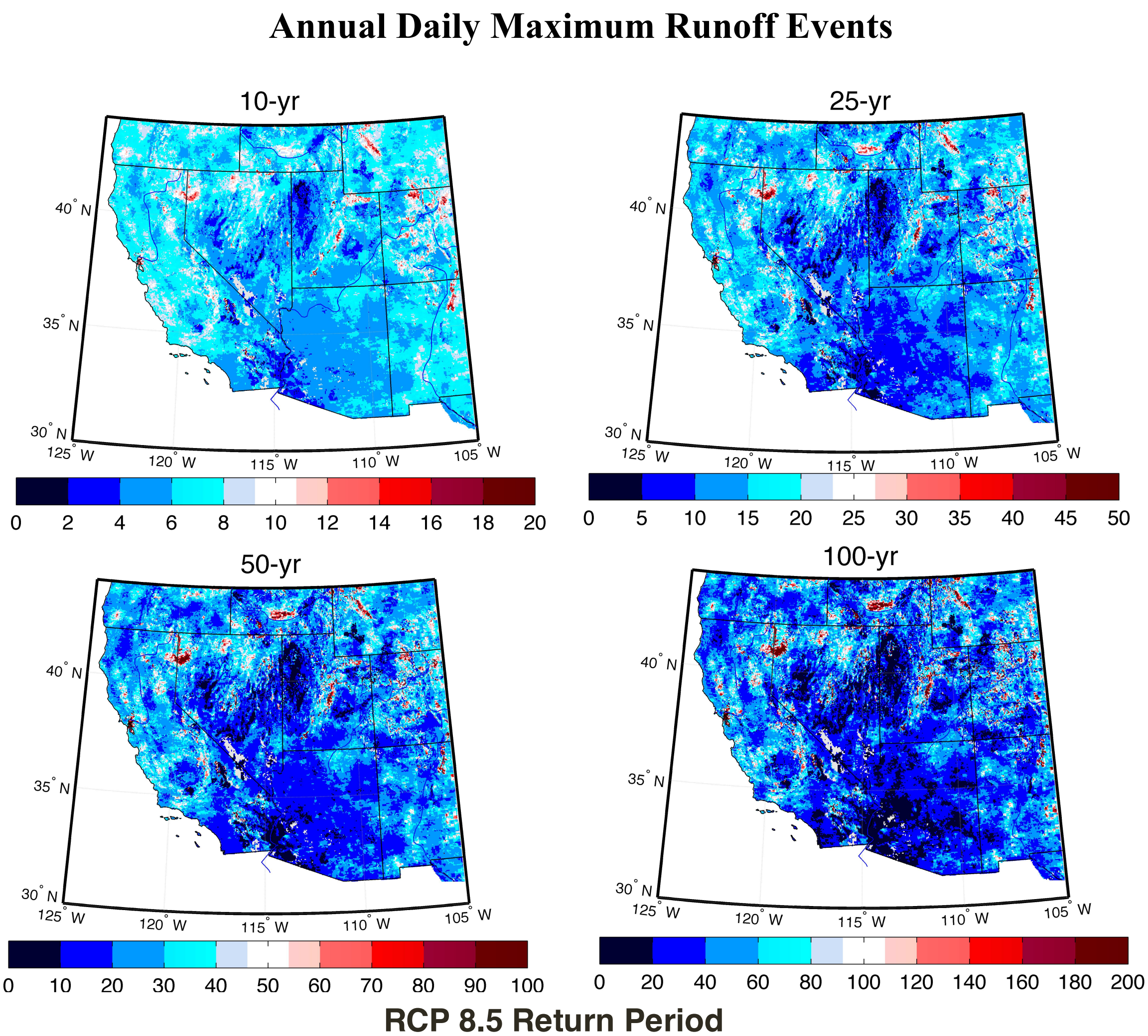


Figure 11: RCP 8.5 projected return periods for baseline's 10, 25, 50, and 100-year annual daily maximum runoff events. The Sierra Nevada, Colorado moutains and Southern Coastal hydrologic regions have a higher probability of experiencing concentrated high volume runoff events which can result in flooding.

Table 3: Comparison of baseline to RCP 8.5 10, 25, 50 and 100-year annual maximum one-day runoff amounts (m^3/s) over the area of each basin and cooresponding RCP 8.5 return period for precipitation amounts for each baseline return period.

	Base Return Period (yr)	Base (m^3/s)	RCP 8.5 (m^3/s)	Base Return Period Now RCP 8.5 Return Period (yr)
CRB	10	4,000	6,500	4
	25	5,000	9,600	6
	50	5,800	12,800	8
	100	6,700	16,900	11
ML-OVB	10	200	300	5
	25	400	500	12
	50	500	800	22
	100	700	1,000	41
SRB	10	14,600	16,800	7
	25	19,400	22,000	16
	50	23,400	26,500	31
	100	28,000	31,500	62
SJRB-TLB	10	4,800	5,600	6
	25	6,400	7,700	14
	50	7,800	9,500	26
	100	9,400	11,700	48

In order to further examine annual shifts, GEV distribution was fit to water year cumulative maximum and mininum runoff amounts for a 30-year comparison (baseline 1976-2005 versus RCP 8.5 2021-2050) for 10, 25, 50 and 100-year return periods. On a basin level, amounts for extremely high annual runoff increases by 14-20% for CRB, 9-11% for ML-OVB, 2-4% for SRB, and 2-8% for SJRB-TLB. However, along the Sierra Nevada mountain range, the probability of greater than average cumulative runoff decreases (Figure 12;Table 4). Abnormally dry annual runoff totals changes by 0 to -4% for CRB, 4 to 5% for ML-OVB, -4 to -17% for SRB, and -7 to -11% for SJRB-TLB (Figure 13; Table 5). The probability of experiencing both extremely high and low cumulative runoff events increases with the exception of ML-OVB for low annual runoff. Therefore, the Northern Sierra Nevada and the Colorado mountain ranges are more susceptible to drought and flooding in the mid-century.

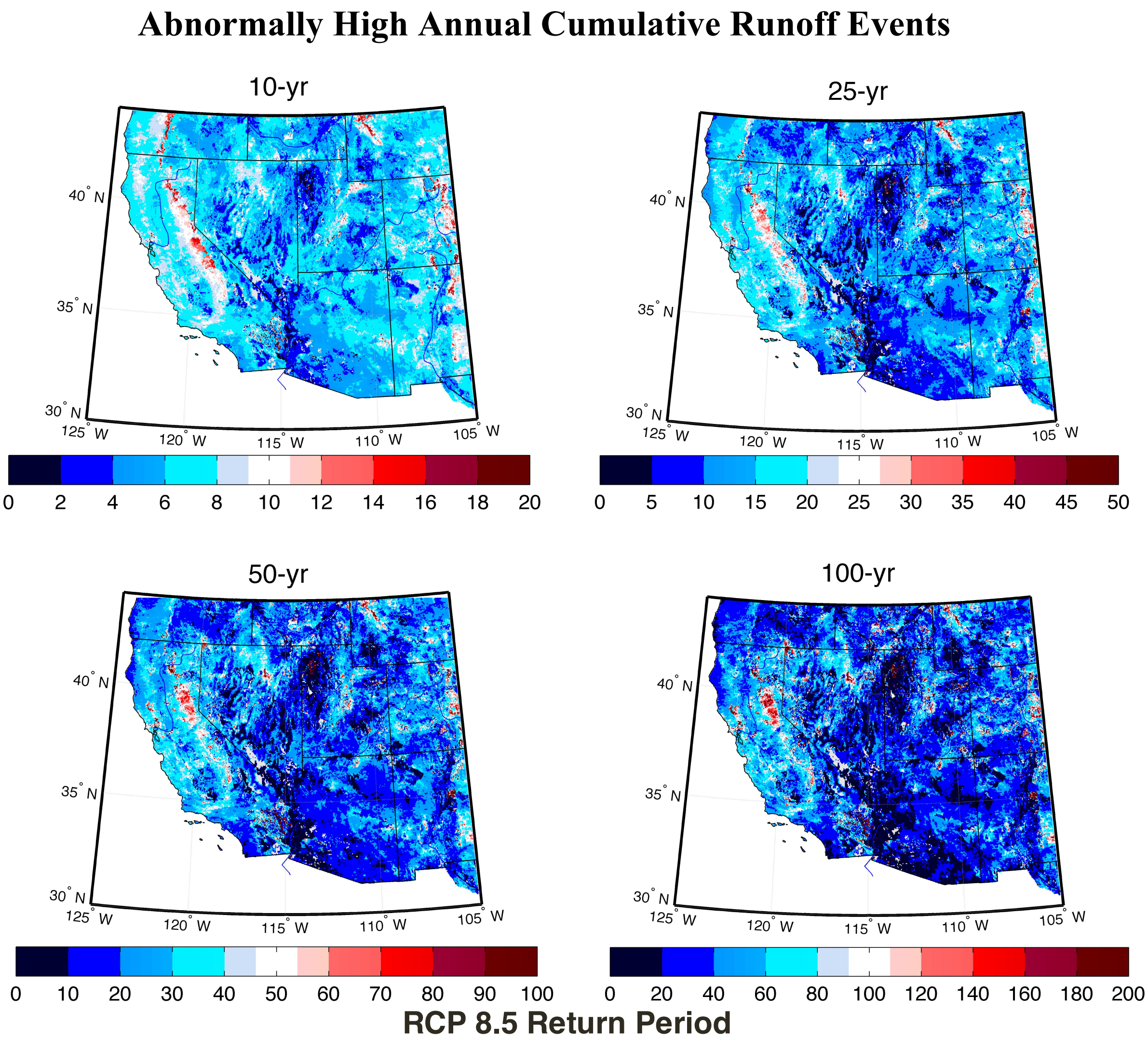


Figure 12: Annual cumulative maximum runoff events highlight increased frequency of above baseline average total runoff over the majority of the WUS which can lead to further flood risk. However, some regions of the Sierra Nevada project lower amounts of maximum annual runoff, resulting in a region more prone to droughts.

Table 4: Comparison of baseline to RCP 8.5 10, 25, 50 and 100-year cumulative maximum runoff amounts (m^3/s) over the area of each basin and cooresponding RCP 8.5 return period for precipitation amounts for each baseline return period.

	Base Return Period (yr)	Base (m^3/s)	RCP 8.5 (m^3/s)	Base Return Period Now RCP 8.5 Return Period (yr)
CRB	10	376,600	437,600	5
	25	430,500	520,800	9
	50	469,900	585,300	14
	100	508,500	651,900	22
ML-OVB	10	24,000	26,300	7
	25	28,300	31,400	14
	50	31,600	35,200	26
	100	34,900	39,200	47
SRB	10	459,200	479,500	8
	25	562,300	583,300	21
	50	643,100	662,000	42
	100	727,100	741,500	88
SJRB-TLB	10	256,500	261,000	9
	25	316,100	329,800	21
	50	361,800	384,500	38
	100	408,300	442,000	67

Abnormally Low Annual Cumulative Runoff Events

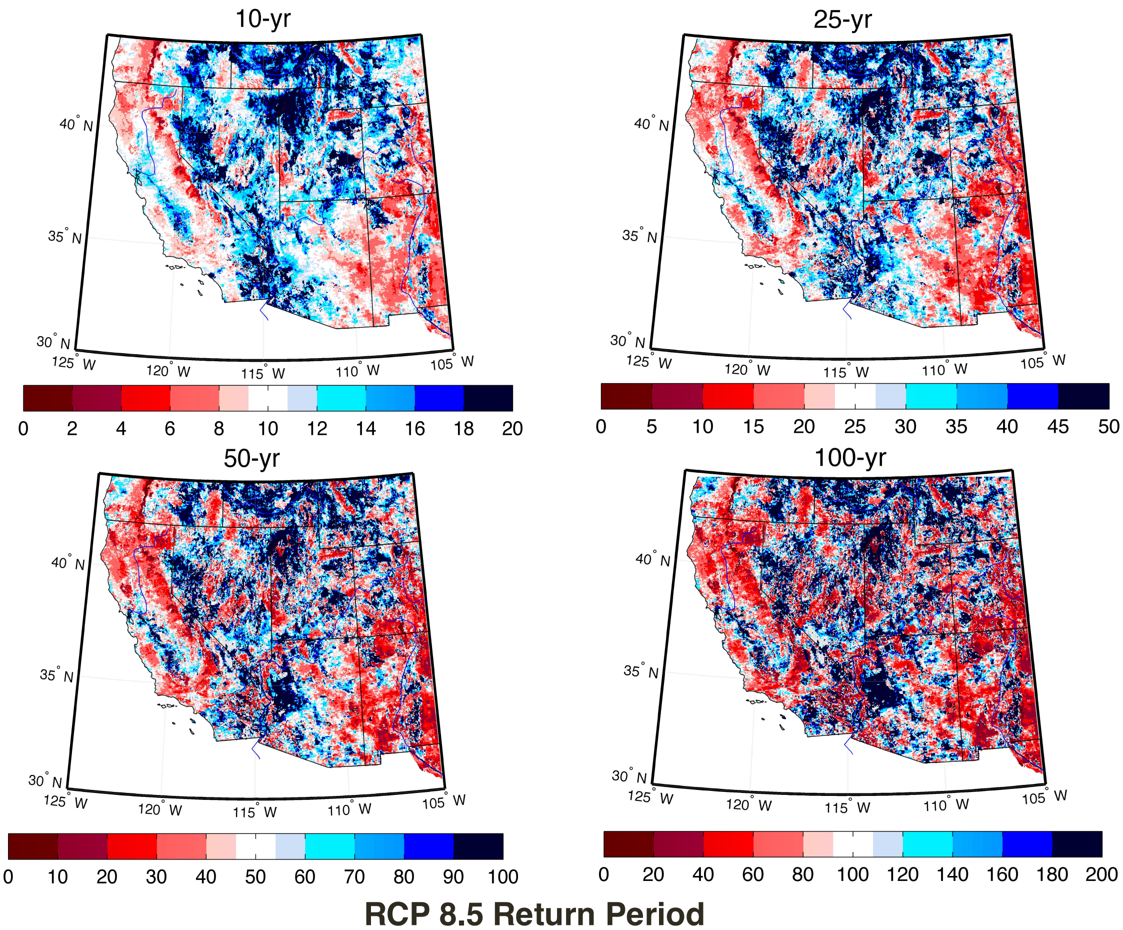


Figure 13: Annual cumulative minimum runoff events highlight increased frequency of below baseline average total runoff over the majority of the Sierra Nevada and CRB.

Table 5: Comparison of baseline to RCP 8.5 10, 25, 50 and 100-year cumulative minimum runoff amounts (m^3/s) over the area of each basin and cooresponding RCP 8.5 return period for precipitation amounts for each baseline return period.

	Base Return Period (yr)	Base (m^3/s)	RCP 8.5 (m^3/s)	Base Return Period Now RCP 8.5 Return Period (yr)
CRB	10	194,300	194,700	10
	25	173,800	170,700	22
	50	161,900	156,900	38
	100	151,900	145,500	67
ML-OVB	10	10,700	11,300	14
	25	9,400	9,800	34
	50	8,600	8,900	69
	100	7,900	8,200	136
SRB	10	165,600	158,400	9
	25	137,200	125,000	17
	50	121,000	105,700	29
	100	107,600	89,700	47
SJRB-TLB	10	76,800	71,300	8
	25	58,500	53,400	19
	50	48,000	43,300	36
	100	39,200	34,900	69

3.5 Potential Impacts from MWDSC Water Shortage Allocation Plan

Long Beach's imported supply is limited when MWDSC enacts the Water Supply Allocation Plan (WSAP). MWDSC has entered into shortage conditions due to lack of precipitation and snowpack as recently as the 2011-2015 drought. In response to a lack of precipitation, minimal snowpack, and diminishing reservoir storage, MWDSC enacted a Regional Shortage Level 2 in 2015. As stated in the previous results section, State Water Project and Colorado River Aqueduct supplies are likely to decrease as a result of warmer temperatures driving less snowfall, more extreme events and shifts in snowmelt timing. Reservoirs, especially in Northern California, will fill earlier in the year and without additional storage water will need to be released for flood control purposes to comply with reservoir operating rules. Therefore, the probability of MWDSC enacting the WSAP will increase out to 2050. Historical MWDSC purchases are compared with potential imported supply caps from the 2015 WSAP under shortage levels 1, 5 and 10 using MWDSC's information regarding baseline water usage for 2013-2014 (Table 6). All calculations are derived from the 2015 WSAP. The Wholesale Minimum Allocation is based on Long Beach's 2013-14 baseline imported demand of 30,975 AF from MWDSC. The Retail Impact Adjustment Allocation is calculated by multiplying the baseline water demand by the Retail Impact Adjustment Factor for the specified Shortage Level and by Long Beach's dependence on MWDSC expressed as a percentage of purchased MWDSC supplies (30,975 AF) to total water demand (60,060 AF) or 51.6%. Conserving additional water is difficult when an agency has already significantly reduced GPCD over the baseline time period. MWDSC allots a certain amount of water to account for demand hardening which is a function of GPCD savings, Regional Shortage level, and dependence on MWDSC. The Minimum Per-Capita Adjustment ensured that all agencies receive 100 GPCD regardless of shortage level. If Long Beach's Minimum Wholesale Allocation amounts to anything below 100 GPCD, Long Beach would still receive 100 GPCD.

Table 6: Various stages of MWDSC's WSAP and subsequent supply reductions for each member agency including Long Beach.

Regional Shortage Level	Regional Shortage Percentage	Wholesale Minimum Allocation Factor	Retail Impact Adjustment Factor
1	5%	92.5%	2.5%
2	10%	85.0%	5.0%
3	15%	77.5%	7.5%
4	20%	70.0%	10.0%
5	25%	62.5%	12.5%
6	30%	55.0%	15.0%
7	35%	47.5%	17.5%
8	40%	40.0%	20.0%
9	45%	32.5%	22.5%
10	50%	25.0%	25.0%

A Regional Shortage Level 1 has almost no impact on Long Beach's overall imported supply, requiring the city to conserve only an additional 1.4% of supplies in order to meet demand. However, at Level's 5 and 10, Long Beach would fall 6,116 AF short of meeting baseline demand, requiring an additional 9% demand reduction (Table 7).

Table 7: Change in MWDSC imported water supply availability to Long Beach under Levels 1, 5 and 10 of the WSAP compared to baseline purchased supplies.

	Baseline (2013-2014)	Level 1	Level 5	Level 10
Wholesale Minimum Allocation		28,652	19,359	7,744
Retail Impact Adjustment Allocation		399	1,997	3,994
Conservation Demand Hardening Adjustment		1,137	2,654	4,550
Minimum Per-Capita Adjustment		0	849	8,572
TOTAL MWD ALLOCATION	30,975	30,188	24,859	24,859
Percent Reduction from Overall Demand		1.4%	9.0%	9.0%

Due to Long Beach's conservation successes, LBWD's retail level reliability is at nearly 90% (fraction of MWDSC Allocation and local supplies to allocation year demand) even under a Regional Shortage Level 10, one of the highest among MWD member agencies. The impacts from MWDSC's WSAP assume that Long Beach's demand and GPCD remains the same. As the City of Long Beach continues to conserve, reliability will increase and LBWD will have less imported restrictions if and when the WSAP in enacted. If supplies exist, LBWD has the option to purchase more water above their allocated amount at a much higher cost. MWDSC's WSAP guarantees total allocation for agencies that have reached 100 GPCD or less. It is highly likely that Long Beach will reach that goal in the next few years. However, even at a Regional Shortage Level of 10, MWDSC assumes that a least 1 MAF will be available from imported and stored water, which may not be the case under climate change scenarios.

4.0 Local Supply and Demand Changes

4.1 Population Growth and Demand Changes

Long Beach is a built out city, with few new developments. LBWD's 2010 UWMP estimated annual population growth of 0.38% was obtained by taking the average growth projections from the California Department of Finance and Southern California Association of Governments. As of January 2015, the DOF estimates Long Beach's population to be 472,779, slightly above the UWMP's projection of 471,107. From census data, Long Beach population increased just 0.01% from 2000 to 2010. However from 2010 to January 2015, annual population increased by 0.46%. The average change from 2000-2010 of 0.16% is used to project population for this study (Table 8).

Table 8: Projected population changes to the City of Long Beach.

Year	Population
2015	472,779
2020	476,545
2025	480,341
2030	484,167
2035	488,024
2040	491,911
2045	495,829
2050	499,779

Long Beach's GPCD is 112 as of August 2014. Due to the city's history of significant water conservation and aftermath of the 2011-2015 drought, it is highly likely that Long Beach will reach 100 GPCD by 2025. However, the rate of GPCD reduction would be curtailed due to demand hardening. Of MWDSC member agencies, the city of Compton currently has the lowest GPCD from the 2013-2014 baseline of 85. With water intensive commercial businesses in Long Beach like the Port of Long Beach, it is unlikely that the city will get to 85 GPCD by 2050. Even with minimal population growth, without conservation beyond 100 GPCD, net water demand will rise for the city (Figure 14).

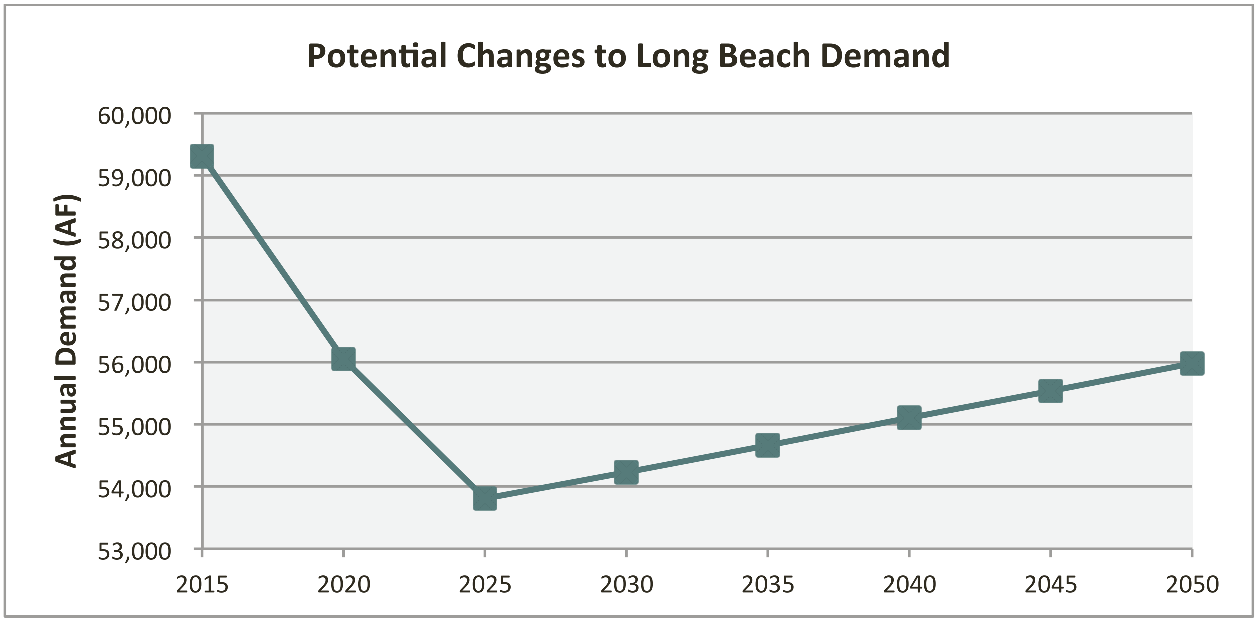


Figure 14: Change in annual demand assuming extensive conservation efforts resulting in 2025 demand dropping to 100 GPCD. Due to demand hardening, 2030-2050 demand remains at 100 GPCD. Population growth, although minimal, counteracts conservation efforts.

Average daily temperatures for the greater Los Angeles area including Long Beach are projected to increase by 1-1.25°C by 2030 and 1.25-1.5°C by 2050 (Figure 15a). Annual total precipitation is also projected to increase 15-25% by 2030 and 2.5-10% by 2050 however, as explained in the section regarding Extreme Precipitation Events, precipitation will occur in more extreme patterns during the winter months when demand is low (Figure 15b). Therefore, warmer temperatures will increase evaporation and water demand, specifically for outdoor irrigation during the summer months. Bias corrected annual ETo in Long Beach increases by 4-8% for both Periods (Figure 15c).

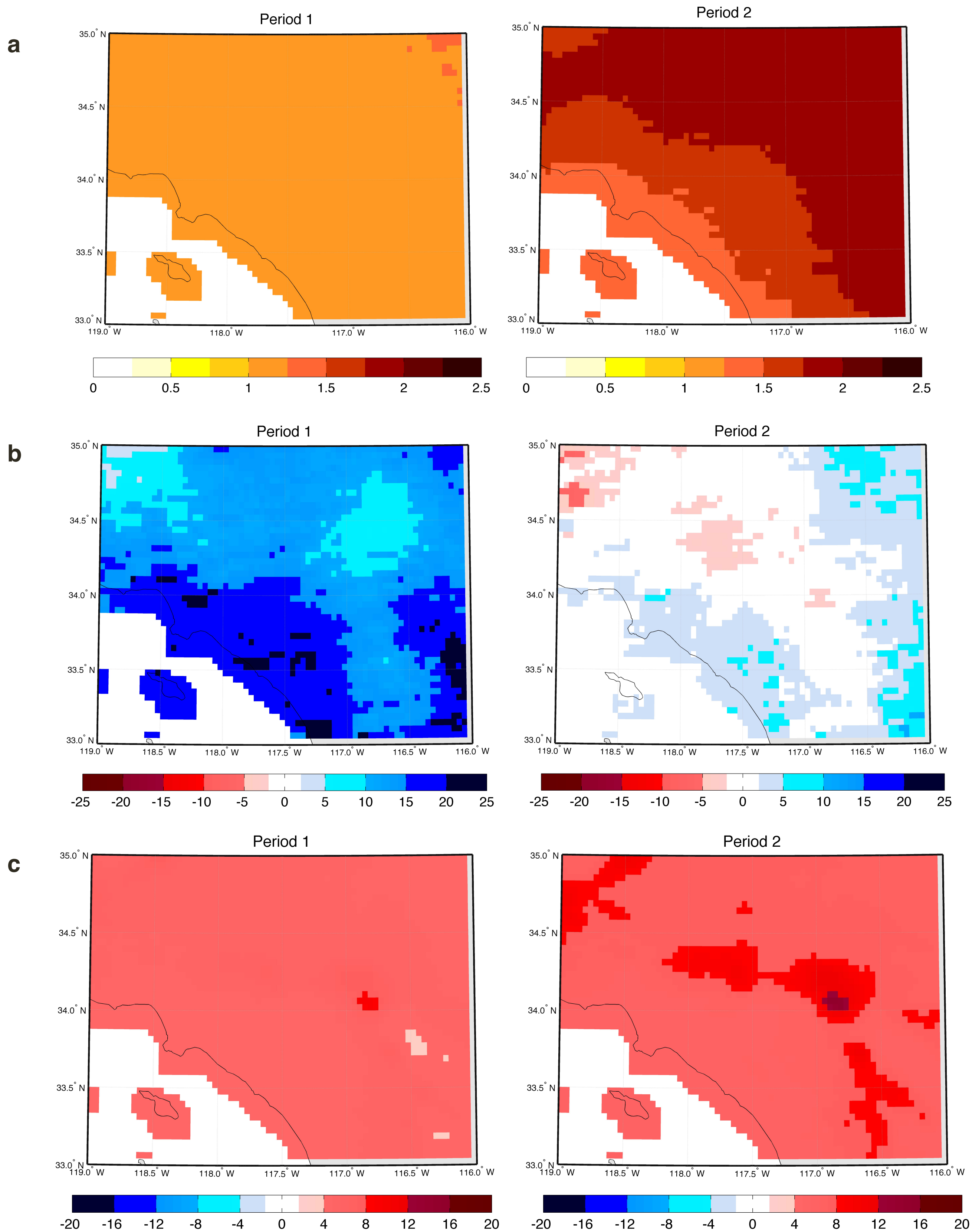


Figure 15: Ensemble average a) daily temperature changes (°C), b) daily cumulative annual precipitation percent change and c) bias corrected annual ETo percent change by Period 1 (2030) and Period 2 (2050) from baseline to RCP 8.5 for the greater Los Angeles region.

In order to quantify outdoor irrigation demand changes the Blaney Criddle method is used to calculate the average monthly change in ETo for both Periods. ETo is bias corrected using CIMIS data from 1990-2005. Monthly and annual outdoor demand is calculated for three residential customer classes: single family (SF), duplex (DPLX) and multi-family (MF) . Estimated current demand assumes an existing Kc of 0.66 where 90% of residential landscaped areas in Long Beach are a mixture of cool and warm season grasses (Kc=0.7) and the remaining 10% are drought tolerant (Kc=0.25). Different values of Kc are used to estimate future demand and determine the potential water savings of programs like Lawn to Garden, which incentivize Long Beach customers to replace grass lawns with drought tolerant plants. Two additional Kc's are tested assuming 30% (Kc=0.57) or 50% (Kc=0.48) of residential landscape area is converted to drought tolerant plants by 2050. We assume that all irrigation management and equipment efficiency remain constant, although efficiency is expected to improve as new technologies develop.

Using the zoning data dictionary provided with the Zoning GIS information from the City of Long Beach, Specific Zoning District Classifications were used to calculate parcel, landscape and rooftop areas for the three customer classes (Table 9).

Table 9: Specific Zoning District Classifications obtained from the City of Long Beach which are used to extract GIS information on SF, DPLX and MF customers.

Customer Class	Code	Description
SF	111	R-1-S (Single-family Residential, small lot)
	112	R-1-M (Single-family Residential, moderate lot)
	113	R-1-N (Single-family Residential, standard lot)
	114	R-1-L (Single-family Residential, large lot)
	115	R-1-T (Single-family Residential, townhouses)
DPLX	121	R-2-S (Two-family Residential, small lot)
	122	R-2-I (Two-family Residential, intensified development)
	123	R-2-N (Two-family Residential, standard lot)
	124	R-2-A (Two-family Residential, accessory second unit)
	125	R-2-L (Two-family Residential, large lot)
MF	131	R-3-S (Low-density Multi-family Residential, small lot)
	132	R-3-4 (Low-density Multi-family Residential)
	133	R-3-T (Multi-family Residential, townhouses)
	141	R-4-N (High-density Multifamily Residential)
	142	R-4-H (High-density Multiple Residential, high-rise)
	143	R-4-U (High-density Multifamily Residential, urban)
	144	R-4-R (Moderate-density Multiple Residential)
	150	RM (Mobile homes, modular and manufactured housing)
	151	R-4-M (Subdivided Mobilehome Park District)

A summary of data derived from GIS and used to calculate outdoor irrigation demand can be found in Table 10.

Table 10: Data obtained from GIS in order to estimate total irrigated area for SF, MF and DPLX customers. Rooftop area information is used to determine potential stormwater capture offsets to outdoor irrigaiton demand.

	SF	DPLX	MF
Total Parcel Area (ft^2)	406,047,806	64,652,885	82,604,503
Number of Parcels	55,898	10,376	6,261
Average Parcel Area (ft^2)	7,264	6,231	13,193
Average Landscape Size (ft^2)*	2,060	1,975	1,561
Fraction of Landscape Area to Average Parcel Area	28.4%	31.7%	8.5%
Total Rooftop Area (ft^2)	120,258,487	26,071,963	27,893,738
Number of Rooftops	71,767	14,643	10,321

** Average landscape size for each customer class estimated from a random sample by the Long Beach Water Department for SF and Loyola Marymount University for DPLX and MF properties.*

LBWD expects no new single-family developments for Long Beach. Instead, currently commercial or single family zoned areas would be converted to higher density multi-family properties. Since this portion of the study focuses on outdoor irrigation needs, the total area of irrigated landscapes for 2050 in Long Beach is assumed to remain equal to current estimates. SF, DPLX and MF accounts make up roughly 66% of LBWD's demand of about 40,000 AF. LBWD estimates that 50% of total single family demand goes to outdoor irrigation. That proportion drops for multi-family properties as they tend to have much smaller landscaped areas in proportion to parcel. Average annual modeled historical outdoor water consumption from 1966-2005 using the bias corrected Blaney Criddle method and a Kc of 0.66 yielded 9,100-13,200 AF, equivalent to stating that outdoor irrigation accounts for 23-33% of all demand for the combined customer classes.

If baseline Kc remained the same and residents of Long Beach halted drought tolerant conversions but installed two rain barrels (SWC) per residential property, average annual outdoor irrigation demand would increase by 5% or approximately 530 AF of water per year due to warming temperatures. If 30% of irrigation landscapes were converted to California friendly gardens along with SWC, the City of Long Beach would on average save 1,060 AF of water per year or 10% of water used for outdoor irrigation. If 50% of lawns are converted with SWC, savings potential increases to 2,630 AF per year, 24% lower than baseline outdoor irrigation water demand and 4% of overall demand for the city (Figure 16). This analysis was completed with and without potential storm water capture optimistically assuming that each residential property has two 55-gallon rain barrels which, if filled, could be used to offset a portion of irrigation demands twice per month. Additional savings from rain barrels were minimal, saving an annual average of 110-130 AF per year or 0.18-0.22% of total citywide water consumption. While demand drops off quickly for both drought tolerant conversion scenarios, water demands continue to rise out to 2050 due to warming temperatures driving summer evapotranspiration.

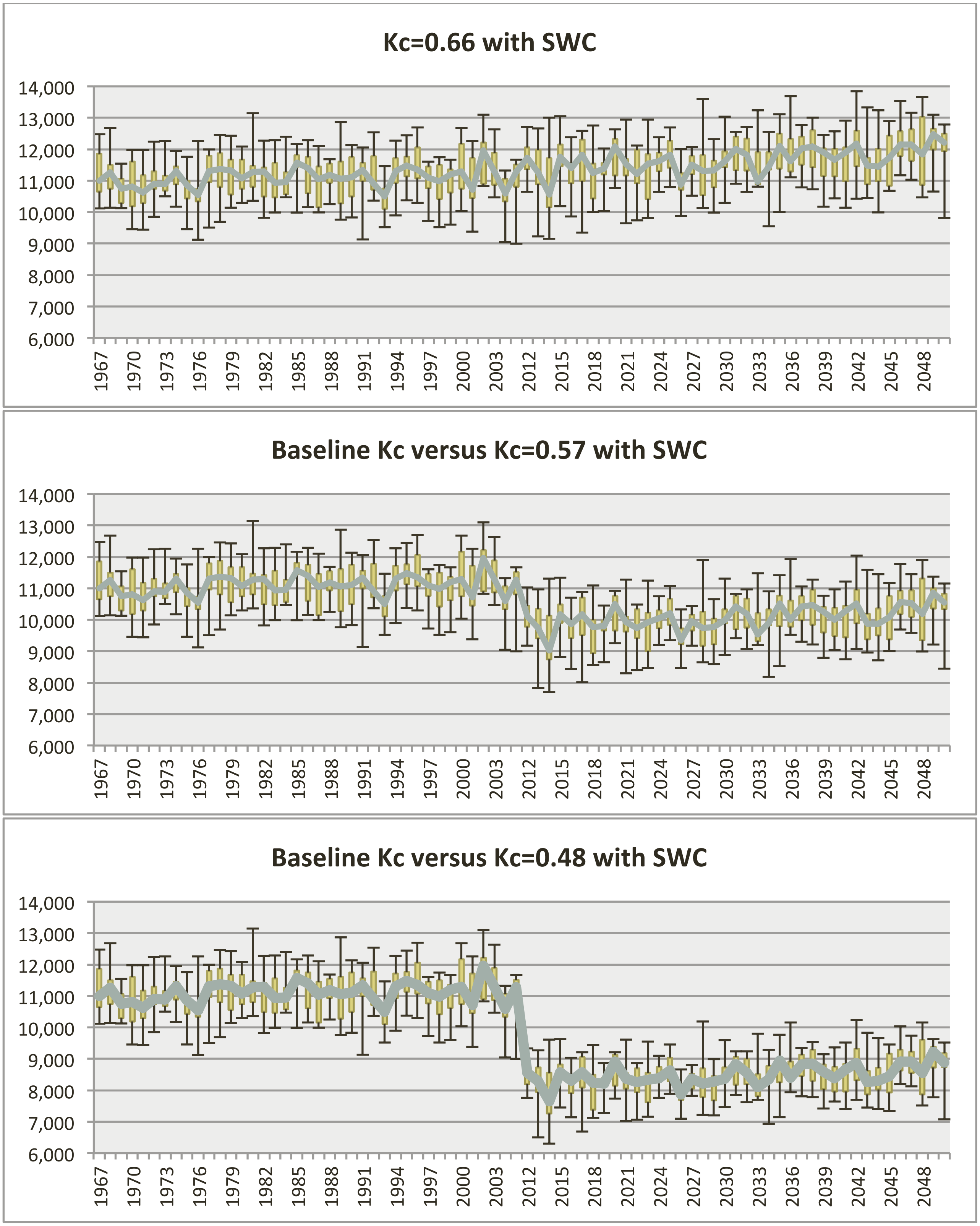


Figure 16: Projected outdoor irrigation demand changes for combined SF, MF and DPLX. Each boxplot represents the 10-model spread of annual demand comparing baseline Kc of 0.66 without SWC to Kc of 0.66 with SWC, Kc of 0.57 with SWC and Kc of 0.48 with SWC.

4.2 Recycled Water

LBWD's Recycled Water System Expansion Program was intended to increase recycled water usage to 9,000 AF per year, or about 15% of total water demand. Due to system load issues and a limited amount of recycled water available from the Long Beach Water Reclamation Plant (operated by the Los Angeles County Sanitation Districts), LBWD has not pursued recycled water expansion to the degree intended for the program. Currently recycled water usage is approximately 4,200 AF per year and prospective recycled water users warned about the potential water interruptions due to lack of supply.

Most recycled water consumed in Long Beach goes towards outdoor irrigation. As shown in the analysis of residential users, ETo is expected to increase driven by warmer temperatures. As a result demand for recycled water will increase, causing even more system load problems. Installing isolated reclaimed water pipelines in an extensively urbanized city like Long Beach drives construction expenses upwards to a point where expanding recycled water efforts is not a cost effective option for an agency. As is the case across the majority of Southern California, LBWD choose to continue to purchase cheaper imported supplies of water.

4.3 Groundwater

Long Beach currently has the rights to pump 32,692 AF per year from the Central Basin and 0.7 acre-feet per year from the West Coast Basin. The 32,692 AF is a set amount that cannot be exceeded unless additional water rights are obtained and due to lack of wells groundwater from the West Coast Basin is not utilized (UWMP, 2010). Groundwater is largely viewed as a local source, however recharge is necessary to prevent over pumping. While recharge can consist of recycled and captured storm water, a large portion originates from imported sources. From MWDSC's 2015 WSAP the 10-year historical average groundwater replenishment from MWDSC to its member agencies was 150,000 AF. Many Southern California water agencies have argued whether or not purchases of imported water for groundwater recharge should be given equal priority during drought conditions. Under extreme drought conditions it is plausible that utilizing imported supplies for groundwater recharge could completely halt. Until recharge requirements can be fulfilled entirely by recycled or captured stormwater runoff, groundwater should not be viewed as an entirely local reliable source of supply under climate change scenarios.

4.4 Desalination

Long Beach's 2010 UWMP projected approximately 10% of water demand would be met by desalination in the future. LBWD operated its own desalination research facility starting in 2001, even obtaining a patent for the "Long Beach Method", a process that reduced the amount of energy needed and environmental impacts associated with desalination. However, even with energy savings using the Long Beach Method, desalination was determined to be too costly and the research facility was closed. Currently, imported water supplies are still less expensive than investing in desalination. However, LBWD has not entirely ruled out the possibility of building a large-scale plant if imported water costs rise, which is plausible under climate change scenarios.

4.5 Graywater

LBWD sponsored a Graywater Pilot Program administered by Long Beach's Office of Sustainability. In 2011, 33 homes were selected to participate in "Laundry to Landscape" where washing machine discharge water was diverted to outdoor irrigation. Surprisingly, water usage increased among the homes that participated in the program. There are a number of factors that could have influenced participant's water consumption (i.e. the economy, current water use restrictions, additional or less family members in the household). However, one critical flaw and limitation to graywater systems is California's health code which prevents graywater from being used in typical pop-up spray heads to avoid exposure to people. Grass lawns, which consume large amounts of water, are typically irrigated by these spray heads therefore graywater could not offset these demands. City-wide expansion of graywater systems are not likely to occur at this point.

5.0 Conclusions

Climate change will result in warmer temperatures over the WUS and more extreme precipitation and runoff events impacting imported water supply availability to Long Beach by three main ways:

1) The frequency of extreme precipitation and runoff events increases.

2) A higher fraction of precipitation will fall as rain rather than snow, diminishing snowpack and filling storage reservoirs quickly.

3) Remaining snowpack will melt earlier in the year.

Due to limitations of current surface water storage and to maintain flood control standards, reservoirs in the WUS, especially Northern California, will not be capable of capturing more frequent, concentrated amounts of rainfall and earlier snowmelt. As a result, water must be released during winter months when demand is low throughout the state. A signficaint amount of water would be lost to the coean without additional facilities to store or convey surface water for purposes like groundwater recharge, thus leaving the area prone to shortage conditions. Cumulative annual runoff also has an increased probability of being significantly less than historical amounts. The increased frequency of abnormally low annual runoff increases the regions susceptibility to droughts.

LBWD is much less reliant on imported sources compared to other MWDSC member agencies. However, Long Beach could still be negatively impacted if ever MWDSC cannot fulfill delivery requirements due to a decreased amount of imported supply availability which is plausible under climate change scenarios. Further reductions beyond LBWD's 100 GPCD goal will be difficult to achieve due to demand hardening. Although minimal, population growth has the potential to exceed further GPCD reductions, resulting in a net increase in water usage. Average annual precipitation may increase for the Long Beach area however precipitation events are more likely to occur in less frequent but larger magntitude events limited to winter months. Irrigation requirements are low in the winter and with lack of city scale storm water capture, additional rainfall would not significantly offset demand. Simply equipping residents with rain barrels would also have little effect on demand. Warmer summer temperatures increase ETo and plant watering requirements. Large scale drought tolerant conversions could save Long Beach an additional 2,630 AF per year despite a warmer climate. Groundwater makes up over half of LBWD's water supply, but should not be considered a truly local supply resilient to climate change as a portion of recharge water originiates from the same imported supplies. Plans for recycled water expansion have not been realized. Currently, purchasing imported water is more financially sound for LBWD than expansion of recycled water lines. Investing in recycled water treatment and expansion despite being more expensive than imported water would greatly increase Long Beach’s self reliance. Although significant demand reductions have been achieved, there are still a number of ways for Long Beach to further reduce reliance on imported supplies which will be necessary in order to become a truly sustainable and climate resilient city.

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