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**APPENDIX 5A, SECTION B**  
**MODELING TECHNICAL APPENDIX –**  
**ATTACHMENT 4 – CLIMATE CHANGE**  
**DEVELOPMENT FOR DELTA CONVEYANCE**  
**PROJECT**

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## Appendix 5A, Section B

# Modeling Technical Appendix – Attachment 4 – Climate Change Development for Delta Conveyance Project

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## B.1 Summary

CalSim 3 meteorologic and hydrologic boundary conditions were updated to represent 2040 climate conditions. The 2040 climate was developed with 20 Coupled Model Intercomparison Project 5 (CMIP5) global climate projections, selected by the California Department of Water Resources (DWR) Climate Change Technical Advisory Group (CCTAG) (California Department of Water Resources Climate Change Technical Advisory Group 2015: 2-38). Historical observed meteorological data, daily historical Livneh data with adjustments based on PRISM, were perturbed with the differences observed in the ensemble of the selected global climate projections (Livneh et al. 2016; Daly et al. 1994). Historical and perturbed meteorological data were input into the VIC model to estimate climate variables (runoff, surface water evaporation, and potential evapotranspiration). The differences between historical and projected meteorology and climate were applied to the historical CalSim 3 boundary conditions to represent 2040 conditions.

## B.2 Introduction

The purpose of this document is to detail the steps used in developing climate change boundary conditions for the CalSim 3 model. Figure 5A-B4.1. illustrates the dataset development and modeling sequence.

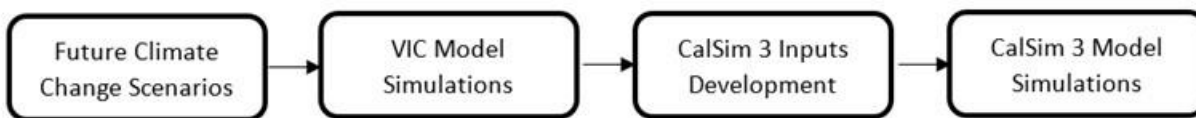


Figure 5A-B4.1. Dataset Development and Modeling Sequence

## B.3 Climate Change Scenarios Development

### B.3.1 Historical Observed Meteorology Data

Livneh et al. (2016) daily historical meteorology data at 1/16th degree (~6 km or ~3.75 miles) spatial resolution over the period 1915 through 2015 was used to develop historical VIC simulation and future climate change scenarios. This historical data was adjusted based on PRISM data (Daly et al. 1994) to correct biases found in the period of interest.

## **B.3.2 GCM Selections and Future Climate Change Scenario**

The 2040 (2026–2055) central tendency (CT) climate change scenario was developed using 20 Coupled Model Intercomparison Project 5 (CMIP5) global climate model projections. These projections were downscaled using the localized constructed analog (LOCA) method at 1/16th degree spatial resolution (Pierce et al. 2014). The LOCA method is a statistical scheme that uses future climate projections combined with historical analog events to produce daily downscaled precipitation, and maximum and minimum temperature time series data. More details on the LOCA downscaling can be found in Pierce et al. (2014) and WSIP Technical Reference Document Appendix A (California Water Commission 2016: A-4).

The 20 CMIP5 global climate projections were selected by DWR CCTAG as the most appropriate projections for California water resources evaluation and planning (California Department of Water Resources Climate Change Technical Advisory Group 2015) (Table 5A-B4.1.). This selection process is consistent with the Water Storage Investment Program (WSIP) Application, Sustainable Groundwater Management Act (SGMA), Reinitiation of Consultation of Long-Term Operation of the Central Valley Project and State Water Project (ROC on LTO) and the State Water Project Incidental Take Permit (SWP ITP). The global climate projections were selected with a three-step model screening process that assesses performance at the global, regional, and California spatial scales. Additionally, the selected global climate projections are a reasonable sample of the broader distribution of global climate projections. The 20 climate model projections were generated with ten global climate models and two emission scenarios, one optimistic (Representative Concentration Pathway [RCP] 4.5) and one pessimistic (RCP 8.5), identified by the IPCC for the Fifth Assessment Report (AR5) (Intergovernmental Panel on Climate Change 2014: 147).

**Table 5A-B4.1. California Department of Water Resources Climate Change Technical Advisory Group Recommended Global Climate Models**

| Model Number | Model Name | Model Institution                                                                                                                                                          | Model Resolution <sup>a</sup> |
|--------------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| 1            | ACCESS-1.0 | Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology                                                                                     | 192 x 145<br>(165 km)         |
| 2            | CCSM4      | National Center for Atmospheric Research                                                                                                                                   | 288 x 192<br>(110 km)         |
| 3            | CESM1-BGC  | National Science Foundation, Department of Energy, National Center for Atmospheric Research                                                                                | 288 x 192<br>(110 km)         |
| 4            | CMCC-CMS   | Centro Euro-Mediterraneo per I Cambiamenti Climatici                                                                                                                       | 192 x 96<br>(165 km)          |
| 5            | CNRM-CM5   | Centre National de Recherches Météorologiques, Centre Européen de Recherche et Formation Avancées en Calcul Scientifique                                                   | 256 x 128<br>(123 km)         |
| 6            | CanESM2    | Canadian Centre for Climate Modeling and Analysis                                                                                                                          | 128 x 64<br>(247 km)          |
| 7            | GFDL-CM3   | Geophysical Fluid Dynamics Laboratory                                                                                                                                      | 144 x 90<br>(219km)           |
| 8            | HadGEM2-CC | Met Office Hadley Centre                                                                                                                                                   | 192 x 145<br>(165 km)         |
| 9            | HadGEM2-ES | Met Office Hadley Centre; additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais                                                      | 192 x 145<br>(165 km)         |
| 10           | MIROC5     | Atmosphere and Ocean Research Institute at the University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology | 256 x 128<br>(123km)          |

Notes: Models are listed alphabetically.

<sup>a</sup> Size of the model's atmospheric grid (number of longitudes by number of latitudes)

Key: km = kilometer

Consistent with the Bay-Delta Conservation Plan/California WaterFix Analyses (ICF 2016), WSIP Application, SGMA, ROC on LTO and the SWP ITP, historical temperature and precipitation were adjusted based on climate model projections to represent future conditions with the quantile mapping approach. Adjustments to temperature and precipitation were calculated with cumulative distribution functions mapped with the 20 downscaled global climate model projections from the CMIP5 (Taylor et al. 2012). The quantile mapping approach involves the following steps:

- Extract a 30-year slice of climate model data (precipitation, and maximum and minimum temperatures) from downscaled ensemble climate projection centered on reference (1995: 1981-2010<sup>1</sup>) and future periods (2040: 2026-2055).

<sup>1</sup> This historical reference period was chosen for consistency with the NOAA 30-year climate normal period as of the date of the Notice of Preparation for this EIR. In addition, CMIP5 GCMs simulate historical climate conditions through 2005 and commence simulation of projected climate conditions beginning in 2006. This means it is inadvisable to use a more recent 30-year period as the historical reference period, e.g., 1991–2020.

- For each calendar month (e.g., January) of the future period, calculate cumulative distribution function (CDF) of temperature and precipitation at each grid cell.
- For each calendar month of the model simulated reference period, calculate CDFs of temperature and precipitation at each grid cell.
- Calculate the ratio (future period divided by reference period) for precipitation and “deltas” (future period minus reference period) for each quantile from the reference and future period CDFs.
- Apply these ratios and deltas to develop a monthly time series of temperature and precipitation at 1/16th degree over the period 1915–2015 that incorporates the climate shift of the future period.
- Convert monthly time series to a daily time series by scaling monthly values to daily sequence found in the observed record.

Figure 5A-B4.2 and Table 5A-B4.2 show the projected change in long-term average temperature for the major watersheds in the Sacramento and San Joaquin River Basins using the climate change scenario for the 2040 CT future conditions. Compared to the historical reference period (1995), average temperature is projected to increase by at least 1.6°C in all major watersheds. The highest temperature increases in the Sacramento River Basin occur in the Sacramento River (1.8°C) and Feather River (1.9°C) watersheds. All major San Joaquin River Basin watersheds are expected to increase by 1.8°C.

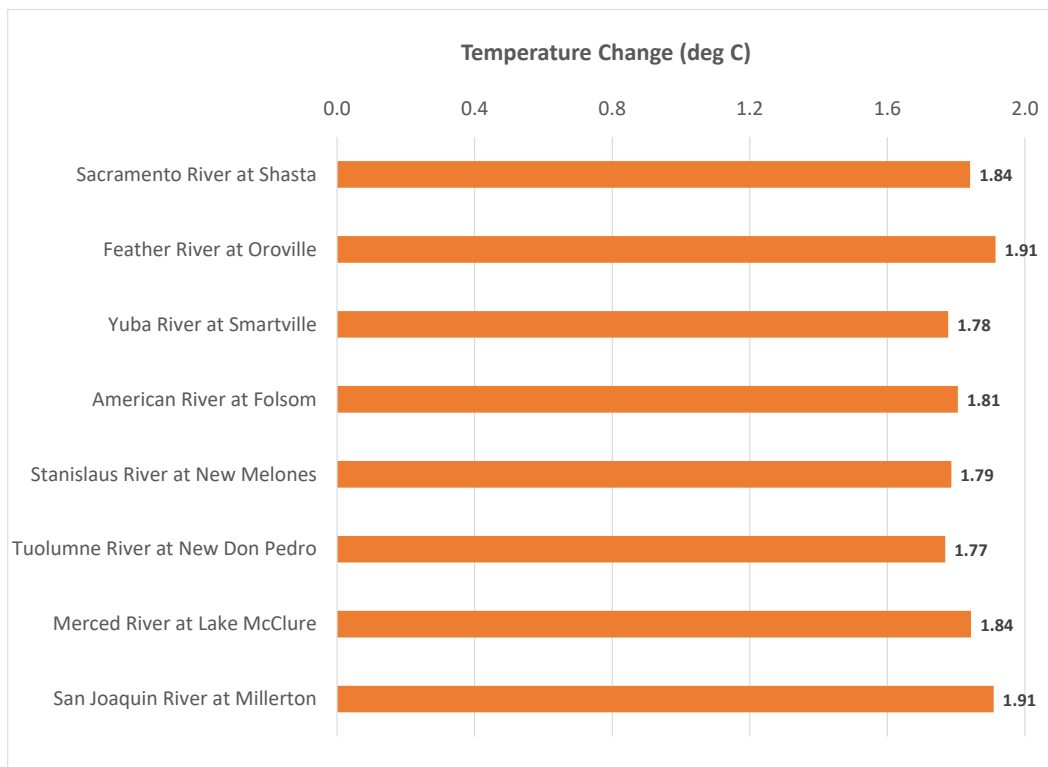
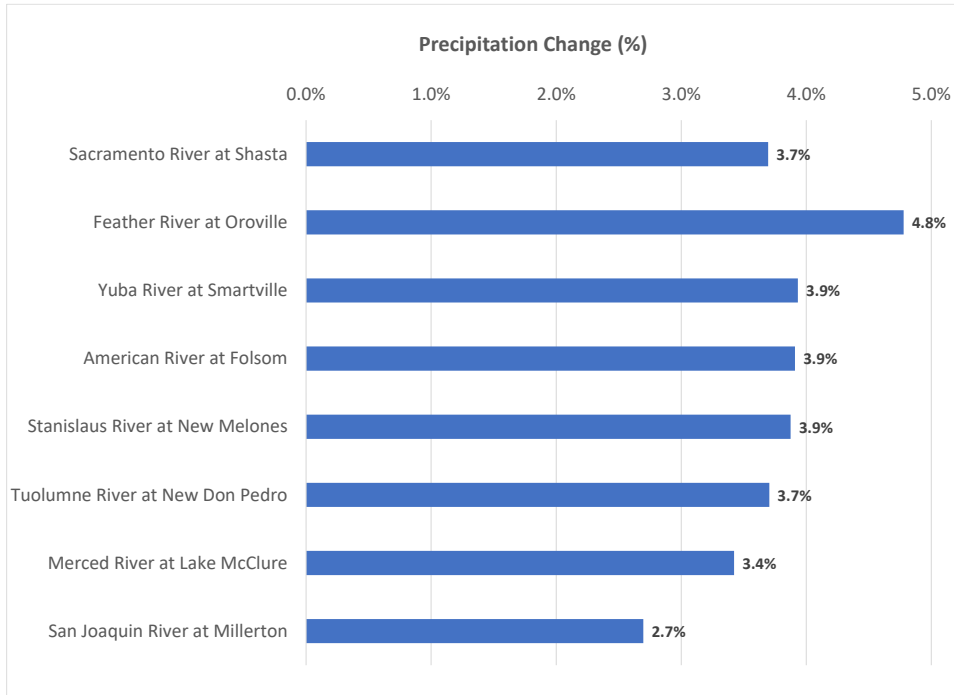


**Figure 5A-B4.2. Projected Changes in Average Temperature for Major Watersheds in the Sacramento and San Joaquin River Basins**

1 Projected change in long-term average precipitation for major watersheds in the Sacramento and  
2 San Joaquin River Basins are presented in Figure 5A-B4.3 and Table 5A-B4.3. Overall, all major  
3 watersheds are projected to be wetter, with average precipitation increases from 2.7% to 4.8%.  
4 Sacramento River Basin is projected to experience a higher increase in long-term average  
5 precipitation than the San Joaquin River Basin.



6  
7 **Figure 5A-B4.3. Projected Changes in Precipitation for Major Watersheds in the Sacramento and**  
8 **San Joaquin River Basins**

1 **Table 5A-B4.2. Projected Changes in Average Temperature for Major Watersheds in the Sacramento and San Joaquin River Basins**

|                            |                 | Oct   | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Annual |
|----------------------------|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Sacramento River at Shasta |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)               | Baseline Period | 17.87 | 10.13 | 5.69  | 5.31  | 7.15  | 9.82  | 13.66 | 18.62 | 23.43 | 29.02 | 28.31 | 24.56 | 16.13  |
|                            | Future Period   | 20.06 | 11.77 | 7.27  | 7.15  | 8.79  | 11.06 | 14.76 | 20.48 | 25.69 | 31.30 | 30.76 | 26.82 | 17.99  |
|                            | Absolute Change | 2.19  | 1.64  | 1.58  | 1.83  | 1.64  | 1.23  | 1.11  | 1.86  | 2.26  | 2.28  | 2.45  | 2.26  | 1.86   |
| Tmin (Deg C)               | Baseline Period | 1.82  | -2.03 | -4.70 | -5.48 | -4.15 | -2.65 | -0.58 | 2.98  | 6.48  | 9.85  | 8.74  | 5.87  | 1.35   |
|                            | Future Period   | 3.66  | -0.64 | -2.94 | -3.63 | -2.39 | -1.54 | 0.62  | 4.35  | 8.24  | 12.22 | 11.64 | 8.39  | 3.17   |
|                            | Absolute Change | 1.83  | 1.39  | 1.76  | 1.85  | 1.76  | 1.11  | 1.20  | 1.37  | 1.76  | 2.37  | 2.89  | 2.52  | 1.82   |
| Tavg (Deg C)               | Baseline Period | 9.85  | 4.05  | 0.49  | -0.08 | 1.50  | 3.58  | 6.54  | 10.80 | 14.96 | 19.44 | 18.53 | 15.21 | 8.74   |
|                            | Future Period   | 11.86 | 5.57  | 2.17  | 1.76  | 3.20  | 4.76  | 7.69  | 12.42 | 16.97 | 21.76 | 21.20 | 17.61 | 10.58  |
|                            | Absolute Change | 2.01  | 1.52  | 1.67  | 1.84  | 1.70  | 1.17  | 1.16  | 1.62  | 2.01  | 2.33  | 2.67  | 2.39  | 1.84   |
| Feather River at Oroville  |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)               | Baseline Period | 18.25 | 10.83 | 6.53  | 6.05  | 7.60  | 10.00 | 13.62 | 18.55 | 23.52 | 28.58 | 28.09 | 24.67 | 16.36  |
|                            | Future Period   | 20.45 | 12.49 | 8.06  | 7.87  | 9.37  | 11.45 | 14.98 | 20.63 | 25.78 | 30.88 | 30.59 | 27.17 | 18.31  |
|                            | Absolute Change | 2.21  | 1.66  | 1.53  | 1.82  | 1.77  | 1.45  | 1.36  | 2.08  | 2.26  | 2.30  | 2.50  | 2.50  | 1.95   |
| Tmin (Deg C)               | Baseline Period | 2.40  | -1.42 | -4.14 | -4.83 | -3.90 | -2.66 | -0.66 | 2.88  | 6.24  | 9.67  | 8.81  | 6.48  | 1.57   |
|                            | Future Period   | 4.29  | -0.09 | -2.52 | -3.07 | -2.14 | -1.45 | 0.59  | 4.29  | 7.83  | 12.12 | 12.07 | 9.46  | 3.45   |
|                            | Absolute Change | 1.88  | 1.34  | 1.62  | 1.76  | 1.76  | 1.22  | 1.24  | 1.42  | 1.59  | 2.45  | 3.26  | 2.98  | 1.88   |
| Tavg (Deg C)               | Baseline Period | 10.32 | 4.71  | 1.20  | 0.61  | 1.85  | 3.67  | 6.48  | 10.72 | 14.88 | 19.13 | 18.45 | 15.58 | 8.97   |
|                            | Future Period   | 12.37 | 6.20  | 2.77  | 2.40  | 3.61  | 5.00  | 7.78  | 12.46 | 16.81 | 21.50 | 21.33 | 18.32 | 10.88  |
|                            | Absolute Change | 2.05  | 1.50  | 1.57  | 1.79  | 1.76  | 1.33  | 1.30  | 1.75  | 1.93  | 2.37  | 2.88  | 2.74  | 1.91   |
| Yuba River at Smartville   |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)               | Baseline Period | 19.30 | 12.36 | 8.54  | 8.08  | 9.10  | 10.98 | 14.25 | 18.88 | 23.61 | 28.39 | 27.98 | 25.14 | 17.22  |
|                            | Future Period   | 21.60 | 14.01 | 9.90  | 9.85  | 10.50 | 12.26 | 15.35 | 20.90 | 25.93 | 30.63 | 30.29 | 27.34 | 19.05  |
|                            | Absolute Change | 2.30  | 1.64  | 1.36  | 1.77  | 1.40  | 1.28  | 1.10  | 2.02  | 2.32  | 2.24  | 2.31  | 2.20  | 1.83   |
| Tmin (Deg C)               | Baseline Period | 4.94  | 0.77  | -1.93 | -2.55 | -1.84 | -1.00 | 0.96  | 4.59  | 8.22  | 11.93 | 11.23 | 8.91  | 3.69   |
|                            | Future Period   | 6.91  | 2.20  | -0.53 | -0.91 | -0.49 | 0.03  | 1.92  | 6.01  | 9.93  | 14.43 | 14.03 | 11.39 | 5.41   |
|                            | Absolute Change | 1.97  | 1.43  | 1.39  | 1.63  | 1.35  | 1.03  | 0.96  | 1.42  | 1.72  | 2.50  | 2.81  | 2.48  | 1.72   |
| Tavg (Deg C)               | Baseline Period | 12.12 | 6.57  | 3.31  | 2.77  | 3.63  | 4.99  | 7.61  | 11.73 | 15.91 | 20.16 | 19.60 | 17.02 | 10.45  |

|                                 |                 | Oct   | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Annual |
|---------------------------------|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
|                                 | Future Period   | 14.26 | 8.10  | 4.68  | 4.47  | 5.00  | 6.15  | 8.64  | 13.45 | 17.93 | 22.53 | 22.16 | 19.37 | 12.23  |
|                                 | Absolute Change | 2.14  | 1.54  | 1.38  | 1.70  | 1.38  | 1.15  | 1.03  | 1.72  | 2.02  | 2.37  | 2.56  | 2.34  | 1.78   |
| American River at Folsom        |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)                    | Baseline Period | 19.57 | 12.87 | 8.99  | 8.49  | 9.52  | 11.63 | 14.56 | 19.23 | 24.11 | 28.94 | 28.53 | 25.49 | 17.66  |
|                                 | Future Period   | 21.76 | 14.54 | 10.48 | 10.37 | 10.98 | 13.01 | 15.89 | 21.30 | 26.38 | 31.15 | 30.85 | 27.73 | 19.54  |
|                                 | Absolute Change | 2.18  | 1.68  | 1.48  | 1.88  | 1.47  | 1.38  | 1.33  | 2.07  | 2.27  | 2.21  | 2.32  | 2.24  | 1.88   |
| Tmin (Deg C)                    | Baseline Period | 5.80  | 1.40  | -1.38 | -1.86 | -1.33 | -0.28 | 1.62  | 5.18  | 9.08  | 12.82 | 12.05 | 9.81  | 4.41   |
|                                 | Future Period   | 7.75  | 2.89  | 0.12  | -0.07 | 0.11  | 0.84  | 2.73  | 6.68  | 10.85 | 15.09 | 14.62 | 12.11 | 6.14   |
|                                 | Absolute Change | 1.95  | 1.49  | 1.51  | 1.79  | 1.44  | 1.11  | 1.11  | 1.50  | 1.77  | 2.27  | 2.57  | 2.31  | 1.73   |
| Tavg (Deg C)                    | Baseline Period | 12.69 | 7.14  | 3.80  | 3.32  | 4.09  | 5.68  | 8.09  | 12.20 | 16.60 | 20.88 | 20.29 | 17.65 | 11.03  |
|                                 | Future Period   | 14.76 | 8.72  | 5.30  | 5.15  | 5.55  | 6.92  | 9.31  | 13.99 | 18.62 | 23.12 | 22.74 | 19.92 | 12.84  |
|                                 | Absolute Change | 2.07  | 1.58  | 1.50  | 1.83  | 1.45  | 1.25  | 1.22  | 1.78  | 2.02  | 2.24  | 2.45  | 2.27  | 1.81   |
| Stanislaus River at New Melones |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)                    | Baseline Period | 18.60 | 11.85 | 7.89  | 7.40  | 8.52  | 10.61 | 13.71 | 18.27 | 23.22 | 28.04 | 27.52 | 24.29 | 16.66  |
|                                 | Future Period   | 20.85 | 13.63 | 9.44  | 9.11  | 9.90  | 12.15 | 14.88 | 20.25 | 25.52 | 30.38 | 29.88 | 26.49 | 18.54  |
|                                 | Absolute Change | 2.25  | 1.78  | 1.55  | 1.71  | 1.38  | 1.54  | 1.17  | 1.97  | 2.30  | 2.34  | 2.36  | 2.20  | 1.88   |
| Tmin (Deg C)                    | Baseline Period | 3.63  | -0.60 | -3.20 | -3.91 | -3.37 | -2.23 | -0.23 | 3.26  | 7.04  | 10.65 | 10.34 | 7.69  | 2.42   |
|                                 | Future Period   | 5.58  | 1.01  | -1.61 | -2.26 | -2.04 | -0.98 | 0.68  | 4.62  | 8.74  | 12.94 | 12.79 | 9.90  | 4.12   |
|                                 | Absolute Change | 1.95  | 1.61  | 1.60  | 1.65  | 1.33  | 1.25  | 0.91  | 1.36  | 1.71  | 2.29  | 2.45  | 2.21  | 1.69   |
| Tavg (Deg C)                    | Baseline Period | 11.11 | 5.63  | 2.34  | 1.74  | 2.58  | 4.19  | 6.74  | 10.77 | 15.13 | 19.35 | 18.93 | 15.99 | 9.54   |
|                                 | Future Period   | 13.21 | 7.32  | 3.92  | 3.43  | 3.93  | 5.59  | 7.78  | 12.44 | 17.13 | 21.66 | 21.33 | 18.20 | 11.33  |
|                                 | Absolute Change | 2.10  | 1.69  | 1.57  | 1.68  | 1.35  | 1.40  | 1.04  | 1.67  | 2.00  | 2.32  | 2.41  | 2.21  | 1.79   |
| Tuolumne River at New Don Pedro |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)                    | Baseline Period | 17.53 | 11.29 | 7.63  | 7.11  | 7.89  | 9.76  | 12.66 | 17.04 | 21.88 | 26.62 | 26.20 | 23.03 | 15.72  |
|                                 | Future Period   | 19.67 | 13.02 | 9.12  | 8.82  | 9.37  | 11.26 | 13.99 | 18.96 | 24.17 | 28.82 | 28.39 | 25.21 | 17.57  |
|                                 | Absolute Change | 2.14  | 1.73  | 1.49  | 1.72  | 1.48  | 1.49  | 1.32  | 1.92  | 2.29  | 2.19  | 2.19  | 2.18  | 1.85   |
| Tmin (Deg C)                    | Baseline Period | 2.72  | -1.60 | -4.28 | -5.08 | -4.66 | -3.52 | -1.26 | 2.39  | 6.26  | 10.02 | 9.58  | 6.85  | 1.45   |
|                                 | Future Period   | 4.62  | -0.09 | -2.76 | -3.45 | -3.25 | -2.30 | -0.15 | 3.67  | 7.88  | 12.34 | 11.97 | 9.22  | 3.14   |
|                                 | Absolute Change | 1.90  | 1.51  | 1.52  | 1.63  | 1.41  | 1.22  | 1.11  | 1.28  | 1.63  | 2.32  | 2.39  | 2.37  | 1.69   |

|                                |                 | Oct   | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Annual |
|--------------------------------|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Tavg (Deg C)                   | Baseline Period | 10.13 | 4.84  | 1.67  | 1.01  | 1.61  | 3.12  | 5.70  | 9.71  | 14.07 | 18.32 | 17.89 | 14.94 | 8.59   |
|                                | Future Period   | 12.14 | 6.47  | 3.18  | 2.69  | 3.06  | 4.48  | 6.92  | 11.32 | 16.02 | 20.58 | 20.18 | 17.22 | 10.35  |
|                                | Absolute Change | 2.02  | 1.62  | 1.51  | 1.67  | 1.44  | 1.36  | 1.22  | 1.60  | 1.96  | 2.26  | 2.29  | 2.27  | 1.77   |
| Merced River at Lake McClure   |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)                   | Baseline Period | 18.54 | 12.35 | 8.64  | 8.16  | 8.91  | 10.65 | 13.54 | 17.93 | 22.90 | 27.61 | 27.29 | 24.21 | 16.73  |
|                                | Future Period   | 20.77 | 14.16 | 10.29 | 10.00 | 10.54 | 12.16 | 14.93 | 20.07 | 25.21 | 29.77 | 29.40 | 26.51 | 18.65  |
|                                | Absolute Change | 2.24  | 1.80  | 1.65  | 1.84  | 1.63  | 1.51  | 1.39  | 2.14  | 2.31  | 2.16  | 2.11  | 2.30  | 1.92   |
| Tmin (Deg C)                   | Baseline Period | 3.66  | -0.68 | -3.26 | -3.92 | -3.43 | -2.34 | -0.19 | 3.25  | 7.10  | 10.94 | 10.50 | 7.75  | 2.45   |
|                                | Future Period   | 5.62  | 0.90  | -1.68 | -2.23 | -1.84 | -1.08 | 0.97  | 4.66  | 8.72  | 13.31 | 12.85 | 10.34 | 4.21   |
|                                | Absolute Change | 1.96  | 1.58  | 1.58  | 1.69  | 1.59  | 1.26  | 1.15  | 1.41  | 1.62  | 2.37  | 2.36  | 2.59  | 1.76   |
| Tavg (Deg C)                   | Baseline Period | 11.10 | 5.83  | 2.69  | 2.12  | 2.74  | 4.15  | 6.68  | 10.59 | 15.00 | 19.27 | 18.89 | 15.98 | 9.59   |
|                                | Future Period   | 13.20 | 7.53  | 4.30  | 3.89  | 4.35  | 5.54  | 7.95  | 12.36 | 16.96 | 21.54 | 21.13 | 18.43 | 11.43  |
|                                | Absolute Change | 2.10  | 1.69  | 1.61  | 1.77  | 1.61  | 1.39  | 1.27  | 1.77  | 1.96  | 2.26  | 2.23  | 2.45  | 1.84   |
| San Joaquin River at Millerton |                 |       |       |       |       |       |       |       |       |       |       |       |       |        |
| Tmax (Deg C)                   | Baseline Period | 15.96 | 10.36 | 6.63  | 6.08  | 6.71  | 8.47  | 11.17 | 15.49 | 20.35 | 24.72 | 24.28 | 21.24 | 14.29  |
|                                | Future Period   | 18.24 | 12.04 | 8.14  | 7.95  | 8.34  | 9.98  | 12.77 | 17.88 | 22.67 | 27.09 | 26.68 | 23.66 | 16.29  |
|                                | Absolute Change | 2.28  | 1.68  | 1.50  | 1.87  | 1.63  | 1.51  | 1.60  | 2.39  | 2.32  | 2.37  | 2.41  | 2.41  | 2.00   |
| Tmin (Deg C)                   | Baseline Period | 1.77  | -2.36 | -5.03 | -6.00 | -5.89 | -4.73 | -2.38 | 1.38  | 5.38  | 9.09  | 8.55  | 5.82  | 0.47   |
|                                | Future Period   | 3.77  | -0.85 | -3.60 | -4.21 | -4.32 | -3.51 | -1.08 | 3.13  | 7.16  | 11.49 | 11.07 | 8.36  | 2.29   |
|                                | Absolute Change | 2.00  | 1.52  | 1.43  | 1.79  | 1.57  | 1.21  | 1.30  | 1.75  | 1.78  | 2.41  | 2.52  | 2.54  | 1.82   |
| Tavg (Deg C)                   | Baseline Period | 8.87  | 4.00  | 0.80  | 0.04  | 0.41  | 1.87  | 4.39  | 8.43  | 12.86 | 16.90 | 16.41 | 13.53 | 7.38   |
|                                | Future Period   | 11.01 | 5.60  | 2.27  | 1.87  | 2.01  | 3.23  | 5.84  | 10.50 | 14.91 | 19.29 | 18.88 | 16.01 | 9.29   |
|                                | Absolute Change | 2.14  | 1.60  | 1.47  | 1.83  | 1.60  | 1.36  | 1.45  | 2.07  | 2.05  | 2.39  | 2.46  | 2.48  | 1.91   |

1 **Table 5A-B4.3. Projected Changes in Average Precipitation for Major Watersheds in the Sacramento and San Joaquin River Basins**

|                                          | Oct    | Nov  | Dec   | Jan   | Feb   | Mar  | Apr   | May    | Jun    | Jul   | Aug   | Sep   | Annual |
|------------------------------------------|--------|------|-------|-------|-------|------|-------|--------|--------|-------|-------|-------|--------|
| Sacramento River at Shasta (inches)      |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 2.06   | 3.82 | 5.02  | 4.85  | 4.36  | 3.85 | 2.62  | 1.90   | 1.17   | 0.30  | 0.36  | 0.79  | 31.10  |
| Future Period                            | 1.86   | 4.01 | 5.51  | 5.18  | 4.60  | 4.12 | 2.67  | 1.74   | 1.06   | 0.35  | 0.36  | 0.77  | 32.25  |
| Absolute Change                          | -0.20  | 0.19 | 0.49  | 0.33  | 0.24  | 0.27 | 0.04  | -0.16  | -0.11  | 0.05  | 0.00  | -0.02 | 1.15   |
| Percent Change                           | -9.5%  | 5.0% | 9.7%  | 6.9%  | 5.6%  | 7.0% | 1.7%  | -8.3%  | -9.3%  | 18.1% | 1.1%  | -2.4% | 3.7%   |
| Feather River at Oroville (inches)       |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 2.47   | 5.08 | 7.47  | 7.57  | 7.45  | 5.97 | 3.40  | 1.97   | 0.95   | 0.24  | 0.28  | 0.73  | 43.56  |
| Future Period                            | 2.19   | 5.38 | 8.30  | 8.22  | 7.82  | 6.55 | 3.32  | 1.72   | 0.80   | 0.31  | 0.34  | 0.69  | 45.65  |
| Absolute Change                          | -0.28  | 0.31 | 0.83  | 0.66  | 0.37  | 0.58 | -0.08 | -0.25  | -0.15  | 0.07  | 0.06  | -0.04 | 2.08   |
| Percent Change                           | -11.4% | 6.0% | 11.1% | 8.7%  | 5.0%  | 9.8% | -2.4% | -12.6% | -15.7% | 29.9% | 20.7% | -5.4% | 4.8%   |
| Yuba River at Smartville (Inches)        |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 3.60   | 7.58 | 10.88 | 10.74 | 10.42 | 8.85 | 5.25  | 2.82   | 1.05   | 0.17  | 0.29  | 0.89  | 62.55  |
| Future Period                            | 3.20   | 7.94 | 12.17 | 11.53 | 10.80 | 9.56 | 5.14  | 2.41   | 0.84   | 0.22  | 0.35  | 0.84  | 65.01  |
| Absolute Change                          | -0.40  | 0.36 | 1.29  | 0.79  | 0.38  | 0.71 | -0.11 | -0.41  | -0.22  | 0.05  | 0.06  | -0.05 | 2.46   |
| Percent Change                           | -11.1% | 4.8% | 11.8% | 7.3%  | 3.6%  | 8.1% | -2.0% | -14.5% | -20.5% | 29.6% | 21.5% | -6.0% | 3.9%   |
| American River at Folsom (inches)        |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 2.80   | 6.00 | 8.50  | 8.64  | 8.24  | 7.35 | 4.44  | 2.32   | 0.89   | 0.18  | 0.22  | 0.70  | 50.28  |
| Future Period                            | 2.61   | 6.24 | 9.41  | 9.24  | 8.56  | 7.94 | 4.36  | 1.97   | 0.71   | 0.22  | 0.27  | 0.72  | 52.25  |
| Absolute Change                          | -0.19  | 0.24 | 0.91  | 0.60  | 0.33  | 0.59 | -0.08 | -0.35  | -0.17  | 0.04  | 0.05  | 0.01  | 1.97   |
| Percent Change                           | -6.9%  | 4.0% | 10.7% | 6.9%  | 4.0%  | 8.1% | -1.9% | -15.0% | -19.5% | 21.9% | 21.0% | 2.1%  | 3.9%   |
| Stanislaus River at New Melones (inches) |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 2.46   | 5.08 | 7.56  | 7.65  | 7.59  | 6.61 | 4.26  | 1.99   | 0.68   | 0.29  | 0.23  | 0.78  | 45.17  |
| Future Period                            | 2.34   | 5.20 | 8.37  | 8.22  | 7.88  | 7.11 | 4.12  | 1.65   | 0.55   | 0.32  | 0.29  | 0.87  | 46.92  |
| Absolute Change                          | -0.12  | 0.12 | 0.82  | 0.57  | 0.29  | 0.50 | -0.13 | -0.34  | -0.13  | 0.03  | 0.06  | 0.09  | 1.75   |
| Percent Change                           | -4.9%  | 2.5% | 10.8% | 7.4%  | 3.8%  | 7.6% | -3.1% | -17.3% | -19.0% | 9.9%  | 25.1% | 11.5% | 3.9%   |
| Tuolumne River at New Don Pedro (inches) |        |      |       |       |       |      |       |        |        |       |       |       |        |
| Baseline Period                          | 2.21   | 4.65 | 7.21  | 7.34  | 7.22  | 6.11 | 3.89  | 1.85   | 0.65   | 0.29  | 0.21  | 0.73  | 42.36  |
| Future Period                            | 2.10   | 4.70 | 7.92  | 7.95  | 7.52  | 6.48 | 3.77  | 1.51   | 0.54   | 0.32  | 0.27  | 0.85  | 43.93  |

|                                         | Oct   | Nov  | Dec  | Jan  | Feb  | Mar  | Apr   | May    | Jun    | Jul   | Aug   | Sep   | Annual |
|-----------------------------------------|-------|------|------|------|------|------|-------|--------|--------|-------|-------|-------|--------|
| Absolute Change                         | -0.10 | 0.05 | 0.71 | 0.61 | 0.29 | 0.36 | -0.11 | -0.34  | -0.11  | 0.03  | 0.05  | 0.12  | 1.57   |
| Percent Change                          | -4.7% | 1.2% | 9.9% | 8.3% | 4.1% | 5.9% | -2.9% | -18.5% | -16.9% | 8.8%  | 25.5% | 16.9% | 3.7%   |
| Merced River at Lake McClure (inches)   |       |      |      |      |      |      |       |        |        |       |       |       |        |
| Baseline Period                         | 1.99  | 4.10 | 6.88 | 7.06 | 6.88 | 5.70 | 3.53  | 1.58   | 0.53   | 0.23  | 0.15  | 0.64  | 39.27  |
| Future Period                           | 1.87  | 4.13 | 7.50 | 7.66 | 7.22 | 5.93 | 3.45  | 1.28   | 0.43   | 0.24  | 0.20  | 0.72  | 40.61  |
| Absolute Change                         | -0.12 | 0.02 | 0.62 | 0.60 | 0.34 | 0.23 | -0.08 | -0.30  | -0.10  | 0.01  | 0.05  | 0.08  | 1.34   |
| Percent Change                          | -6.3% | 0.5% | 9.0% | 8.5% | 4.9% | 4.0% | -2.3% | -19.0% | -18.0% | 4.2%  | 30.7% | 13.1% | 3.4%   |
| San Joaquin River at Millerton (inches) |       |      |      |      |      |      |       |        |        |       |       |       |        |
| Baseline Period                         | 1.77  | 3.70 | 6.67 | 6.62 | 6.50 | 5.42 | 3.59  | 1.64   | 0.55   | 0.32  | 0.21  | 0.70  | 37.68  |
| Future Period                           | 1.68  | 3.70 | 7.06 | 7.25 | 6.84 | 5.55 | 3.47  | 1.29   | 0.46   | 0.31  | 0.28  | 0.81  | 38.69  |
| Absolute Change                         | -0.09 | 0.00 | 0.39 | 0.64 | 0.33 | 0.13 | -0.12 | -0.35  | -0.09  | -0.01 | 0.07  | 0.12  | 1.02   |
| Percent Change                          | -4.8% | 0.1% | 5.8% | 9.6% | 5.1% | 2.4% | -3.4% | -21.4% | -16.8% | -2.1% | 32.2% | 16.8% | 2.7%   |

## B.4 VIC Model Simulations

Historical and projected surface runoff, baseflow, surface water evaporation and potential evapotranspiration at 1/16th degree were generated by inputting historical and projected meteorological data into the VIC model. The VIC Model (Liang et al. 1996; Nijssen et al. 1997) simulates land-surface-atmosphere exchanges of moisture and energy at each model grid cell. The VIC Model incorporates spatially distributed parameters describing topography, soils, land use, and vegetation classes.

VIC simulated surface runoff, baseflow, surface water evaporation and potential evapotranspiration were used to perturb CalSim 3 boundary conditions. Surface runoff and baseflow were used to produce total runoff at all locations that correspond to CalSim 3 rim inflows and unimpaired flow. Potential evapotranspiration was used to estimate crop evapotranspiration throughout the Sacramento and San Joaquin Valleys. Surface water evaporation was used to estimate evaporation rates at lakes, reservoirs, and refuges within the CalSim 3 model domain.

## B.5 CalSim 3 Inputs Development

The following methods were used to develop projected CalSim 3 input climate data:

- For all watersheds, simulated changes in streamflows (simulated future streamflows divided by historical simulated streamflows) were applied to the CalSim 3 inflows. These fractional changes were first applied for every month of the 95-water year period consistent with the VIC Model simulated patterns. A second order correction was then applied to confirm that the annual shifts in runoff at each location were consistent with that generated from the VIC Model.
- Total flows of major watersheds were perturbed with the two-step process described above. Then, the perturbed runoff of each contributing watershed was adjusted to match the perturbed total flow in the watershed.
- For watersheds where streamflows are heavily impaired, a process was implemented by calculating historical impairment based on observed data and adding that impairment back onto the VIC Model simulated flows at a location upstream of the impairment. This approach is consistent with the approach used in the WSIP CalSim II modeling under future conditions.
- Similarly, fractional changes (described in the first bullet) were also used to simulate change in precipitation, temperature, surface water evaporation and evapotranspiration as needed for calculation of certain parameters used in CalSim 3.

## B.6 Use of Fractional Changes for Climate Data

Fractional changes (simulated future data divided by historical simulated data) were applied to the CalSim 3 inflow, precipitation, surface water evaporation, and evapotranspiration boundary conditions. Absolute changes (difference in simulated future data and historical simulated data) were applied to CalSim 3 temperature boundary conditions. For the CalSim 3 boundary conditions, climate variables and perturbation methods used are further detailed below.

## B.6.1 Rim Inflows

CalSim 3 operates a system of reservoirs, channels, and diversions with rim inflows, or inflows from the “rim” of the California watershed. Perturbation of CalSim 3 rim inflows, or inflow boundary conditions, were based on VIC simulated watershed area-weighted total runoff (surface runoff plus baseflow). The following steps were used to perturb CalSim 3 rim inflows and major watershed flows:

- Monthly change factors were calculated for every month in the simulation period from 1921 to 2015 using VIC historical and 2040 CT simulated flows.
- Monthly historical rim inflows were perturbed using the monthly change factors from the previous step.
- Apply annual (water year) perturbation to the monthly perturbed flows. These water year change factors were calculated as the ratio between the water year change factors of the VIC simulated (2040 CT and historical) flows and the water year change factors of the monthly perturbed historical and observed historical flows.
- For each major watershed flow location, calculate the difference between perturbed runoff at the major flow location and the sum of perturbed runoff from all contributing watersheds at that major runoff location. Major watershed flow locations and the number of contributing watersheds to each location are tabulated in Table 5A-B4.4.
- Apply the calculated difference (step above) to the perturbed runoff at the contributing watersheds. At each time step, the difference is proportionally applied to perturbed runoff. Proportioning of error distribution is based on the ratio of the perturbed runoff volume from an individual watershed to the total perturbed volume from all contributing watersheds.

**Table 5A-B4.4. Major Watershed Flow Locations in CalSim 3**

| Basin Name       | Flow Location                               | No. Contributing Watersheds |
|------------------|---------------------------------------------|-----------------------------|
| Feather River    | Total Inflow to Lake Oroville               | 21                          |
| Yuba River       | Yuba River at Smartville                    | 18                          |
| Bear River       | Bear River at Confluence with Feather River | 5                           |
| American River   | Total Inflow to Folsom Lake                 | 46                          |
| Mokelumne River  | Total Inflow to Pardee Reservoir            | 9                           |
| Stanislaus River | Total Inflow to New Melones Lake            | 21                          |
| Tuolumne River   | Total Inflow to New Don Pedro Reservoir     | 4                           |

Projected change in the Eight River Index (8RI), Sacramento Valley Four Rivers Index (SAC-4), San Joaquin Valley Four Rivers Index (SJR-4), and runoff at each of the eight major rivers is provided in Figure 5A-B4.4. 8RI runoff change is dominated by the increase in runoff in the Sacramento Valley. Increase to runoff in the Sacramento Valley is greater than increases to runoff in the San Joaquin Valley. Runoff increases in all major basins except for the San Joaquin River basin, where runoff decreases by 1 percent. Generally, in reviewing basins from North to South, relative change to runoff decreases, as evapotranspiration losses overcome precipitation increases.

Long-term average monthly flows of SAC-4 and SJR-4 are presented in Figures 5A-B4.5. and 5A-B4.6., respectively. As compared to historical runoff, increased precipitation under 2040 CT leads to a higher peak in SAC-4 peak runoff. 2040 CT SJR-4 peak runoff volume and timing remain similar to

historical runoff. In both basins, runoff increases in winter and decreases in spring and summer. Increased winter temperatures lead to a higher portion of precipitation that directly results in runoff, as opposed to snowpack. Similarly, with decreased snowpack, runoff during the summer, when the majority of runoff is snowmelt under historical conditions, decreases.

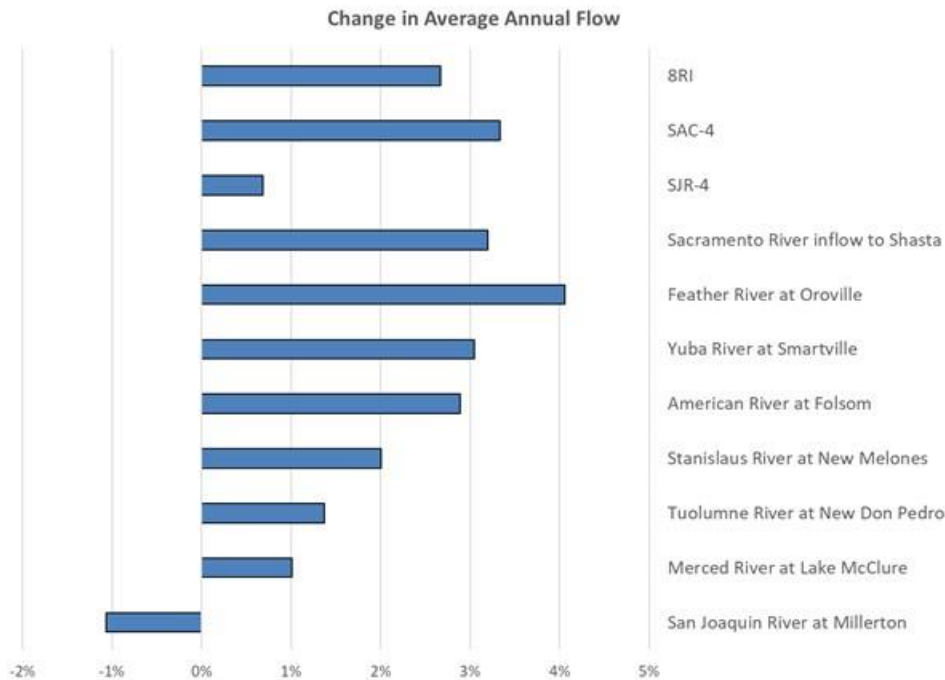


**Figure 5A-B4.4. Projected Changes in Runoff for Major Watersheds in the Sacramento and San Joaquin River Basins**

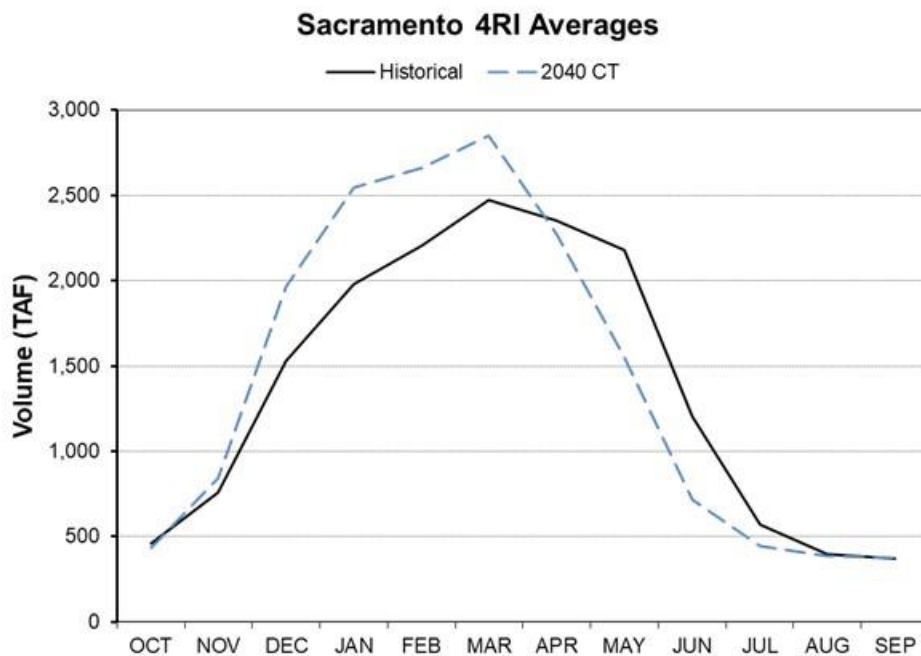


**Figure 5A-B4.5. Projected Changes in Monthly Pattern of Runoff for the Sacramento Basin (SAC-4)**

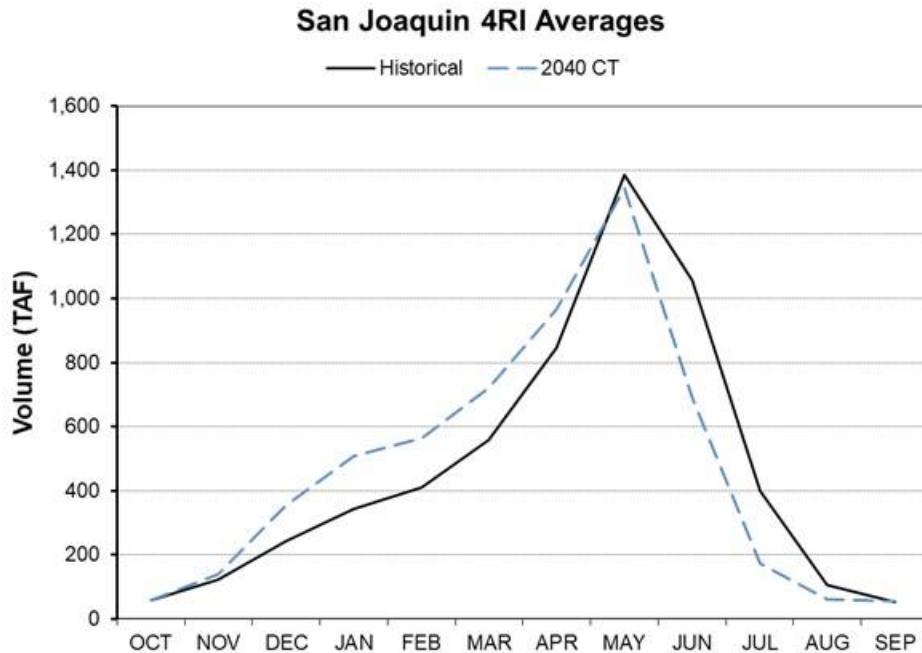


Figure 5A-B4.6. Projected Changes in Monthly Pattern of Runoff for the San Joaquin Basin (SJR-4)

## B.6.2 Valley Floor Flows

CalSimHydro is a surface water hydrologic model that estimates CalSim 3 boundary conditions in the Sacramento and San Joaquin Valleys. With precipitation, evapotranspiration, surface water evaporation, land use and urban demands, the CalSimHydro model estimates applied crop water, surface runoff, return flow and deep percolation timeseries data for use in CalSim 3. Please review the CalSimHydro Reference Manual for more details regarding the CalSimHydro model (California Department of Water Resources 2021).

The following steps were used to perturb all input variables to CalSimHydro:

- Monthly change factors were calculated for every month in the simulation period from 1921 to 2015 using VIC historical and 2040 CT simulated flows.
- Monthly historical data were perturbed using the monthly change factors from the previous step.
- Apply annual (water year) perturbation to the monthly perturbed data. These water year change factors were calculated as the ratio between the water year change factors of the VIC simulated (2040 CT and historical) data and the water year change factors of the monthly perturbed historical and observed historical data.

Projected change to applied crop water in the Sacramento and San Joaquin Valleys, as estimated with the CalSimHydro model, is provided in Figure 5A-B4.7. Applied water increases in both valleys due to increased evapotranspiration, a result of increased temperature (Figure 5A-B4.1.). As estimated with CalSimHydro, changes to pattern and magnitude of precipitation (Figure 5A-B4.2.) result in small increases to surface runoff, return flow, and deep percolation.

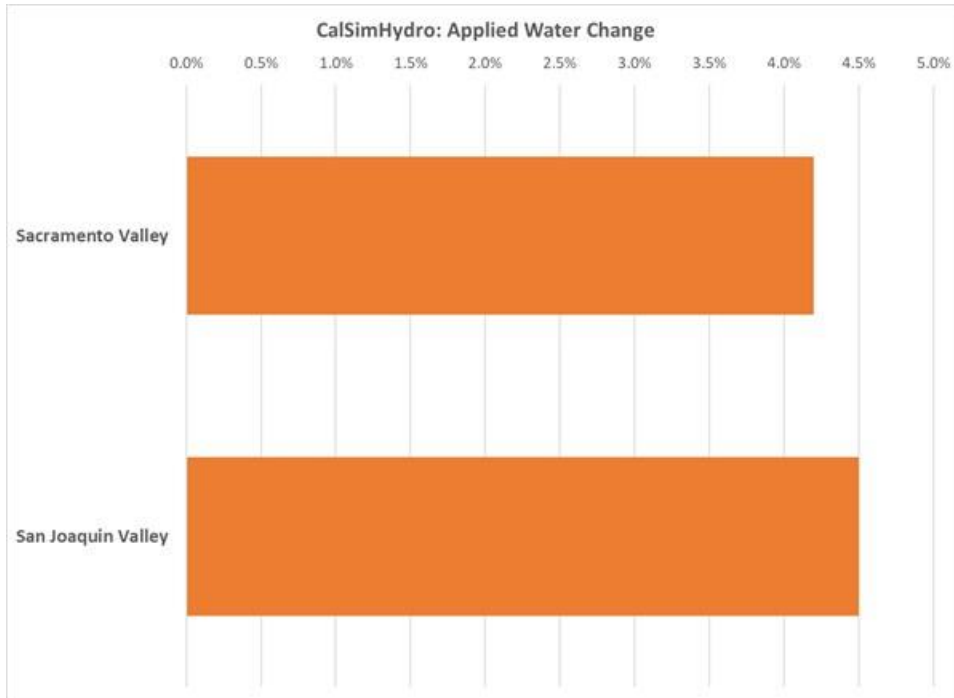


**Figure 5A-B4.7. Projected Changes in Applied Water for Sacramento and San Joaquin Valleys**

### **B.6.3 Delta Channel Depletion**

CalSim 3 irrigation, drainage, and seepage in the Sacramento – San Joaquin River Delta is estimated with the Delta Channel Depletion (DCD) model. The DCD model relies upon the Delta Evapotranspiration of Applied Water (DETAW) model to estimate Delta crop evapotranspiration. Inputs to the DCD model include daily timeseries of precipitation and temperature at several locations throughout the Delta. Please review Methodology for Flow and Salinity Estimates in the Sacramento–San Joaquin Delta and Suisun Marsh, Chapter 2: Calibrating and Validating Delta Channel Depletion Estimates for more details regarding the DCD model (California Department of Water Resources 2018).

Precipitation data were perturbed with the monthly and water year climate change rate-based approach described in Section B.6.2, Valley Floor Flows.

Daily maximum and minimum temperature boundary conditions are referenced to estimate Delta evapotranspiration. Perturbation of temperature data is detailed below:

- Monthly absolute differences, or deltas, were calculated for every month in the simulation period from 1921 to 2015 using VIC historical and 2040 CT simulated flows.
- Monthly historical temperature data were perturbed using the monthly absolute differences from the previous step.

Projected change to Sacramento – San Joaquin River Delta irrigation, drainage, and seepage, as estimated with the DCD model, is provided in Figure 5A-B4.8. Irrigation and seepage increase due to increased evapotranspiration, a result of increased temperature (Figure 5A-B4.1.). As estimated with DCD, changes to pattern and magnitude of precipitation (Figure 5A-B4.2.) and increased irrigation result in a small increase to Delta Island drainage.

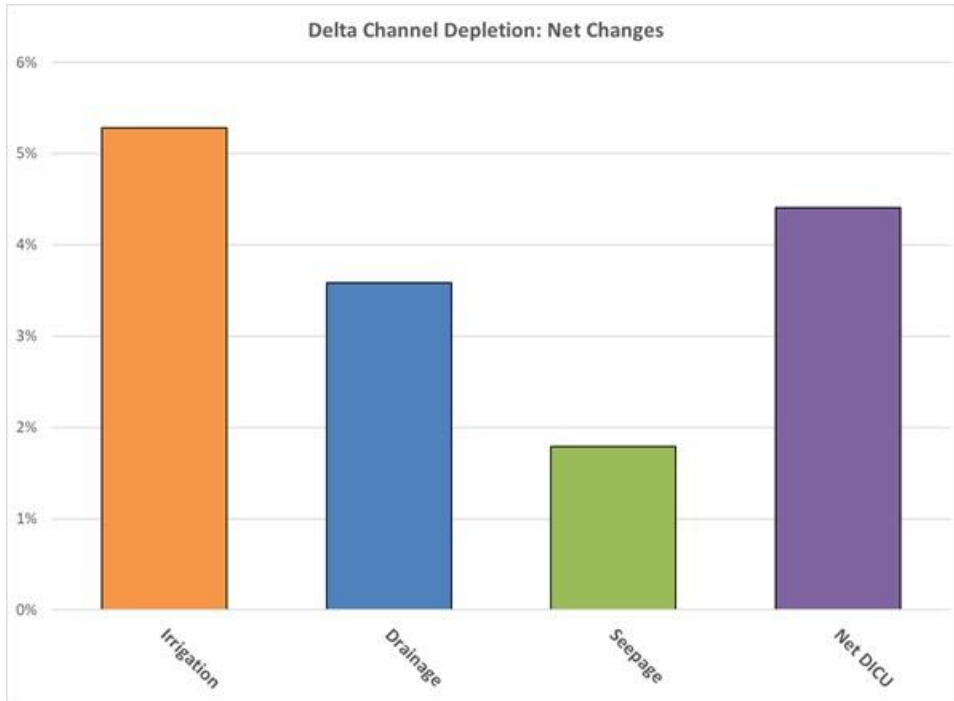


Figure 5A-B4.8. Projected Changes in Delta Island Consumptive Use

## B.6.4 Reservoir Evaporation

Evaporation rate boundary conditions are applied to all lakes and reservoirs in the CalSim 3 spatial domain. Gross evaporation rates were applied at most reservoirs. Net evaporation rates (evaporation rate minus precipitation) boundary conditions were applied at terminal reservoirs, or reservoirs without natural inflow. To develop net evaporation at future climate conditions, evaporation and precipitation were perturbed separately.

Surface water evaporation and precipitation data were perturbed with the monthly and water year climate change rate-based approach described in Section B.6.2, Valley Floor Flows.

Similar to temperature increases, evaporation rates consistently increase throughout the Central Valley (Figure 5A-B4.9.).

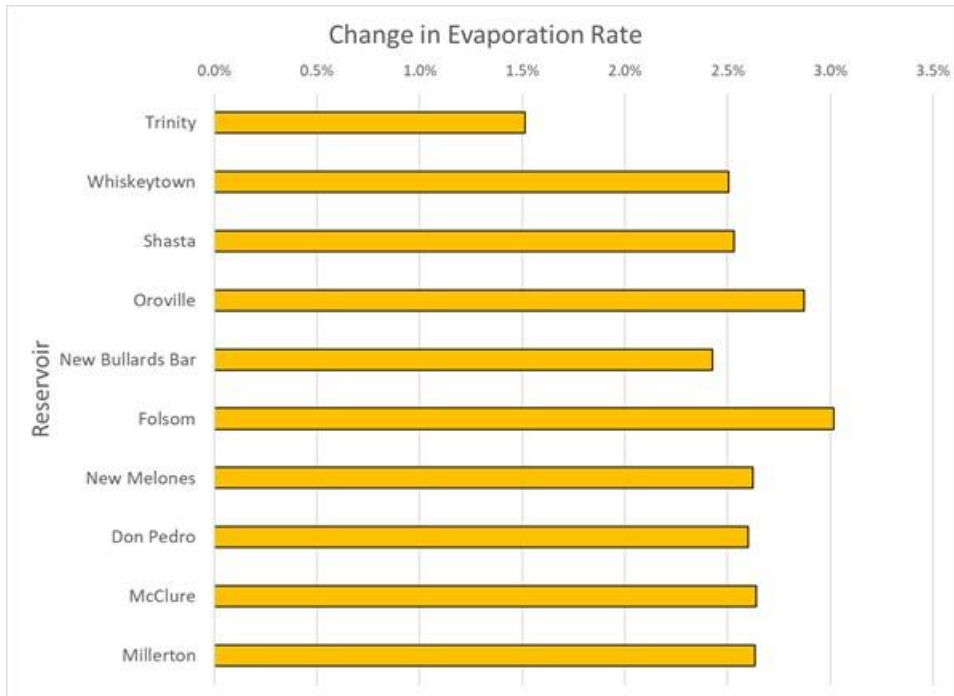


**Figure 5A-B4.9. Projected Changes in Evaporation Rate at Major Reservoirs**

## B.6.5 Inputs for Lookup Tables

CalSim 3 operations decisions are based upon several water year types, and meteorologic and hydrologic indices. CalSim 3 calculates these indices based on unimpaired runoff at 10 distinct locations Table 5A-B4.5.

**Table 5A-B4.5. Unimpaired Flow Inputs to CalSim 3**

| CDEC Station Name | Station Description                 |
|-------------------|-------------------------------------|
| AMF               | American River at Folsom            |
| MRC               | Merced River at Exchequer Reservoir |
| ORO               | Feather River at Oroville           |
| SIS               | Sacramento River inflow to Shasta   |
| SJF               | San Joaquin River at Millerton      |
| SBB               | Sacramento River above Bend Bridge  |
| SNS               | Stanislaus River at New Melones     |
| TNL               | Trinity River at Lewiston           |
| TLG               | Tuolumne River at New Don Pedro     |
| YRS               | Yuba River near Smartville          |

CalSim 3 requires precipitation data to forecast runoff in several river basins, including the eight major river basins. In practice, statistical forecast functions are developed based on observed precipitation and runoff. To mimic the same procedure for forecasts in future climate conditions, CalSim 3 implements forecast functions based on precipitation and runoff.

The following steps were taken:

- Basin-wide average precipitation or point precipitation at a given station were computed for VIC simulated historical and future climate condition.
- Sensitivity factors, based on simulated historical and future conditions, for precipitation were calculated and applied to historical data. Sensitivity factors were developed with the monthly and water year change ratio approach. This process is identical to the steps described in Section B.6.2, Valley Floor Flows.

CalSim 3 uses temperature data at Sacramento Executive Airport (SEA) to establish trigger dates for Old and Middle River flow requirement in spring months, per U.S. Fish and Wildlife (USFWS) Biological Opinion Reasonable and Prudent Alternative Action 3. To mimic these modeled trigger dates under future climate, temperature sensitivity factors for each climate scenario were calculated at the VIC Model grid location best representative of SEA. Perturbation, as described in Section B.6.3, Delta Channel Depletion, was applied to the baseline temperature dataset to establish future climate temperature trigger dates.

## **B.6.6 Groundwater**

CalSim 3 requires two types of groundwater boundary conditions along the edges of its spatial domain: (1) deep percolation and (2) lateral flows. Deep percolation and later flow boundary conditions are developed by the CalSimHydroEE and SmallWatersheds models, respectively. Both models estimate groundwater flow with assumptions consistent to the CalSimHydro model. These models are described in Chapter 15 of the CalSim 3 Draft Report (California Department of Water Resources 2017).

Precipitation and evapotranspiration inputs, for estimating rainfall-runoff, evapotranspiration and percolation, in the CalSimHydroEE and SmallWatersheds models were perturbed with the monthly and water year climate change rate-based approach described in Section B.6.2, Valley Floor Flows.

Perturbed deep percolation and lateral flow input boundary conditions slightly increase under future climate conditions. Relative to all other CalSim 3 boundary conditions, these increases are negligible.

## **B.7 Use of Project Runoff from the VIC Model for Impaired Streamflows**

Impaired rim inflows in the upper San Joaquin of CalSim 3 were unimpaired before perturbation process. The rim inflows were “re-impaired” after perturbing the unimpaired inflows to represent future climate conditions. As information on specific local project operations (impairment) at these locations was not available, impairment was calculated as the difference between the unimpaired historical flow and the CalSim 3 inflow time series. This method assumes the local project operations will be the same in future climate conditions and does not account for any adaptation in local project operations.

## B.8 References Cited

### B.8.1 Printed References

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