The previously proposed Technical Reference text is set forth below in normal type. The proposed changes are shown in single underline to indicate additions and ~~strikeout~~ to indicate deletions for this document only. Note that some webpage URL references are already in blue text and may be underlined, but do not indicate a proposed change unless accompanied by a strikeout. Due to the size of the Technical Reference, and for ease of downloading and reviewing, the document is split into two parts. This is the second of the two parts, consisting of the Appendices to the Technical Reference.

Appendix A Climate Change and Sea-Level Rise

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Climate Change and Sea-Level Rise Methods

Growing evidence indicates that Earth's atmosphere is warming. Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (National Academy of Sciences, 2006; Intergovernmental Panel on Climate Change [IPCC], 2007, 2013). The temperature of Earth's atmosphere is directly related to the concentration of atmospheric greenhouse gases (GHGs). Growing scientific consensus suggests that climate change will occur as the result of increased concentrations of GHGs (IPCC, 2007, 2013). While consensus exists regarding the observed global warming trend, uncertainty remains regarding regional projections of future temperature and precipitation.

This appendix provides detailed information on methods used to develop climate and sea-level projections at two reference points: 2030 (near future) and 2070 (late future) as required by regulations for the Water Storage Investment Program (WSIP). This document describes in detail the steps followed, from spatial downscaling of climate data to running the CalSim-II Water Resources Simulation Model (CalSim-II) and Delta Simulation Model II (DSM2) models to represent conditions under future climate conditions. Figure A-1 shows the dataset development and modeling sequence.

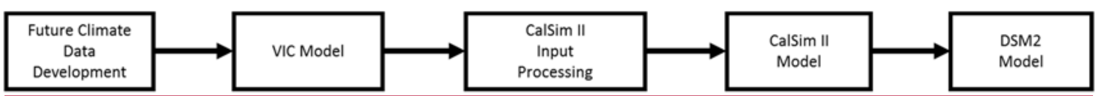

Figure A-1. Dataset Development and Modeling Sequence

Climate Scenarios Development Process

As described in the Technical Reference Document, the climate projections for 2030 and 2070 conditions were derived from the ensemble of 20 global climate projections selected by the California Department of Water Resources (DWR) Climate Change Technical Advisory Group (CCTAG) as the most appropriate projections for California water resources evaluation and planning (DWR CCTAG, 2015). The 20 climate projections, listed in Table 2-5 of the Technical Reference Document, were generated from 10 global climate models run with 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) (2014).

Scripps Institution of Oceanography downscaled the 20 climate projections using the localized constructed analog (LOCA) method at 1/16th degree (approximately 6 kilometers [km], or approximately 3.75 miles) spatial resolution (Pierce et al., 2014).

The climate projections for 2030 and 2070 future conditions were derived using a quantile mapping approach that adjusts changes in temperature and precipitation using cumulative distribution functions created from the 20 downscaled global climate model projections. Adjusted temperature and precipitation time series for 2030 and 2070 future conditions were used as input to the Variable Infiltration Capacity (VIC) hydrologic model to generate projections of future streamflows. Future streamflow and sea-level rise (SLR) projections were used as inputs to CalSim-II and DSM2 to generate projections of future State Water Project (SWP) and Central Valley Project (CVP) performance and Sacramento–San Joaquin Delta (Delta) conditions. The primary procedures for each step in the scenario development process are described in the following sections.

Spatial Downscaling of Global Climate Models using LOCA

Development and application of global climate models is a continuously advancing research area. However, to date, the resolution of the output data produced by global climate models is too coarse to assess impacts at a watershed scale. Thus, global climate model data from Coupled Model Intercomparison Project 5 (CMIP5) simulations is scaled to a finer resolution, or downscaled, in order to translate macro-scale climate changes that are either observed or identified in climate models to changes in meteorological parameters at a local scale.

Spatially downscaled data using the LOCA method was obtained from the Scripps Institution of Oceanography. It is one of the statistical downscaling methods that involve relating the statistical properties of observed meteorological measurements at various stations to broader climate parameters at a global climate model-scale. This relationship, based on historical observations, is used as a mapping function when spatially downscaling projected climate conditions. This downscaling method is also being used for analysis being done for California's Fourth Climate Change Assessment.

The LOCA method uses future climate projections combined with historical analog events to produce daily downscaled estimates of surface meteorological fields (minimum and maximum temperatures and precipitation). Developed by researchers at the Scripps Institution of Oceanography (Pierce et al., 2014), this spatial downscaling method includes a bias-correction process of the coarse-resolution global climate model daily temperature and precipitation fields prior to the spatial downscaling. A key feature of this bias correction is that it preserves the original global climate model-predicted change in temperature and precipitation, unlike other commonly used bias correction methods that alter the original model-predicted change in unexpected ways (Pierce et al., 2015).

Table A-1 provides summary statewide temperature and precipitation statistics for each downscaled climate projection.

Table A.1 Projected Changes in Statewide Conditions for each Model and RCP Combination, Representing Climate Periods 2016 to 2045 and 2056 to 2085, with Respect to Reference Period 1981 to 2010.

Scenarios	**Climate Period 2016-2045, with Respect to Reference Period 1981 to 2010**		**Climate Period 2056 to 2085, with Respect to Reference Period 1981 to 2010**	
	Average Precipitation Change (%)	**Average Temperature Change (°F)**	**Average Precipitation Change (%)**	**Average Temperature Change (°F)**
RCP 4.5 Scenarios				
ACCESS1-0_rcp45	-1.2	2.3	13.9	4.5
CCSM4_rcp45	-4.1	2.0	1.2	3.3
CESM1-BGC_rcp45	0.4	1.9	8.3	2.9
HadGEM2_CC_rcp45	-3.6	2.1	8.9	4.6
CMCC-CMS_rcp45	2.2	2.2	-4.8	4.0
CNRM-CM5_rcp45	21.6	1.5	22.2	3.5
CanESM2_rcp45	4.7	2.8	19.3	4.8
GFDL-CM3_rcp45	1.7	2.7	0.0	4.9
HadGEM2_ES_rcp45	-1.0	2.4	-5.8	5.4
MIROC5_rcp45	-1.6	2.2	-12.1	4.1
RCP 8.5 Scenarios				
ACCESS1-0_rcp85	0.9	2.8	-14.5	6.6
CCSM4_rcp85	-0.4	2.5	9.0	5.3
CESM1-BGC_rcp85	5.6	2.0	10.8	5.4
HadGEM2_CC_rcp85	0.4	3.0	-3.5	7.9
CMCC-CMS_rcp85	4.5	2.3	1.4	6.3
CNRM-CM5_rcp85	23.8	1.8	26.1	6.0
CanESM2_rcp85	2.4	3.1	35.9	7.2
GFDL-CM3_rcp85	-3.2	3.0	2.4	7.2
HadGEM2_ES_rcp85	4.2	3.0	-6.9	8.3
MIROC5_rcp85	-7.0	2.7	-4.3	5.5

Key:
% = percent
°F = degree Fahrenheit

Quantile Mapping Functions

Once spatially downscaled data was obtained for the 20 climate projections, cumulative distribution functions (CDFs) were produced for monthly temperature and monthly precipitation for the reference historical period (1981-2000) and each of the future climate periods (2016-2045 and 2056-2085) for the ensemble of the 20 climate projections at each of the 11,368 grid cells across the state (for a total of 818,496 CDFs). The CDFs were developed such that the entire probability distribution (including means, variance, and skew) at the monthly scale was transformed to reflect the mean of the 20 climate projections.

The reference historical period CDFs and future climate period CDFs were quantile mapped to determine the amount of change that would occur between the historical reference period and future climate period at each quantile.

Observed daily historical meteorology data from Livneh et al. (2013) at 1/16th degree (approximately 6 km, or 3.75 miles) spatial resolution were used as the reference meteorological data and were adjusted with the change factors created from the quantile mapping procedure. The quantile mapping procedure is explained in the steps following Figure A-2, which is a conceptual representation of the use of quantile maps.

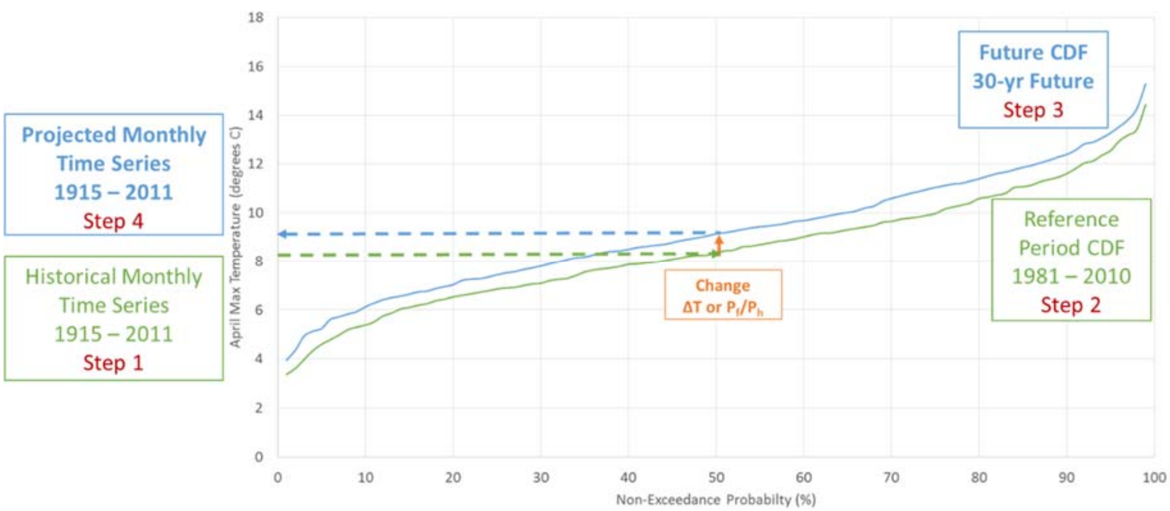

Figure A-2. Develop Climate Input Development Steps

Step 1: Development of Detrended Historical Monthly Time Series

Prior to using the historical record from Livneh et al. (2013) for quantile mapping, historical temperature data over the period 1915-2011 (centered around Year 1995) was 'anchored' (i.e., detrended) to 1981-2010.

These steps were followed to anchor the temperature data to the 1981-2010 climatological average:

1. Calculate monthly averages from daily data over the period 1915-2011.
2. Compute linear trend for each month (e.g., January, February, …, December) (time series for each month).
3. Remove the month-specific trend from the daily data. This results in a sequence of daily residuals.
4. Calculate monthly climatologies for 1981-2010 (i.e., the mean of all Januaries, the mean of all Februaries, and so on, from the values computed in Step 1).
5. Add the daily residuals calculated in Step 3 to the monthly climatology calculated in Step 4.

This approach was used for daily maximum temperature (T_{max}) and daily temperature range (DTR), and daily minimum temperature was estimated as:

$$T_{max} - DTR$$

Step 2: Development of a Mean Model-Simulated Reference Period CDF from 20 Climate Projections

To form a mean CDF representing model-simulated reference period conditions from all 20 climate projections, a 30-year slice of climate model data (precipitation, and maximum and minimum temperatures) was extracted from each of the 20 downscaled climate model simulations centered on the model-simulated reference period (i.e., 1995: 1981-2010).

For each calendar month (e.g., January) of the model-simulated reference period (1981-2010), the CDF for each climate model projection of temperature and precipitation at each grid cell was determined. There are 30 values over 30 years of reference period (e.g., for 1981-2010, one value from each year) to construct one CDF for each climate model projection. There are 20 CDFs from 20 climate model simulations.

The mean value for each quantile of the 20 CDFs was computed to form a mean model-simulated reference period CDF.

Step 3: Development of a Mean Future CDF from 20 Climate Projections

To form a mean CDF that represents simulated future conditions from all 20 climate projections, a 30-year slice of downscaled climate data (precipitation, and maximum and minimum temperatures) was extracted from each of the 20 downscaled climate model simulations centered on a future year of investigation (i.e., 2030: 2016-2045 and 2070: 2056-2085). The mean value for each quantile of the 20 CDFs was computed to form a mean simulated future CDF.

For each calendar month (e.g., January) of the future period, the statistical properties (CDF) for each climate model projection of temperature and precipitation at each grid cell was determined. There are 30 values over 30 years of future period (e.g., for 2016-2045, one value from each year) to construct one CDF for each model projection. There are 20 CDFs from 20 climate model simulations.

The mean value for each quantile of the 20 CDFs was computed to form a mean simulated future CDF.

Step 4: Development of Future Climate Change Time Series

To develop a time series of climate parameters representative of future conditions, the change was calculated as the ratio (future period divided by reference period) for precipitation and change in temperature, resulting in ‘deltas’ (future period temperature minus reference period temperature) for each quantile from the reference period and future period mean CDFs.

Using these ratios and deltas, and historical precipitation and detrended temperature data obtained from Step1, a monthly time series of temperature and precipitation at 1/16th degree (approximately 6 km, or 3.75 miles) over 1915-2011 that incorporates the climate shift of the future period was developed.

Tables 2-4 and 2-6 in Section 2.12.2 of this Technical Reference Document and Figure A-3 display the magnitude and direction of change in precipitation and temperature at each future climate condition and for each Hydrologic Unit Code-6 (HUC6) watershed within California. The average changes for the 2030 and 2070 future conditions are the results from Step 4 for 1915-2011 that incorporates the climate shift, based on the ensemble of all 20 models. The average changes for the extreme levels of climate change, represented by climate models HadGEM2-ES RCP 8.5 and CNRM-CM5 RCP4.5, are the estimated change based on the average of the deltas for those individual GCMs from Step 3.

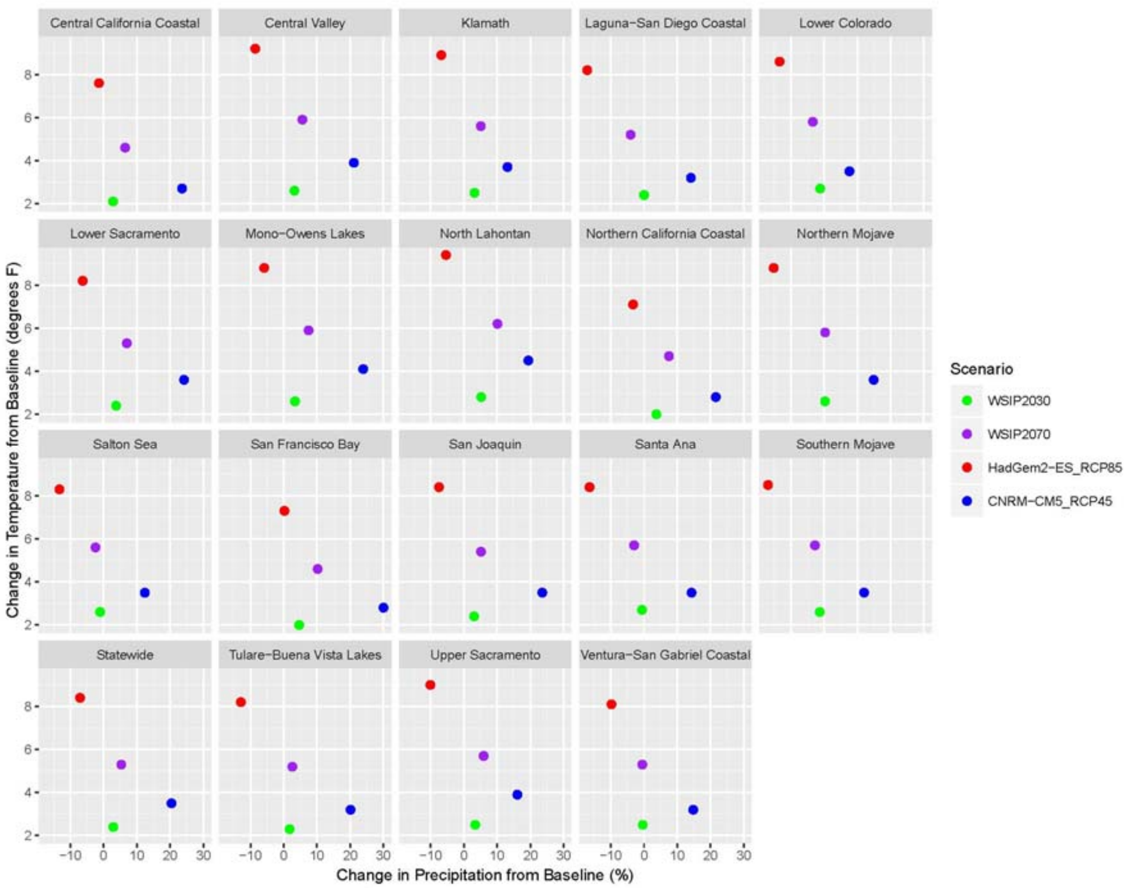

Figure A-3. Percent Change in Precipitation and Temperature Across Scenarios.

Rainfall-Runoff Modeling Using the VIC Model

The VIC Model (Liang et al., 1994, 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. It accepts input meteorological data directly from global or national gridded databases or from global climate model projections. To compensate for the coarseness of the discretization, VIC is unique in its incorporation of sub-grid variability to describe variations in the land parameters, as well as precipitation distribution. Figure A-5 shows the hydrologic processes included in the VIC Model.

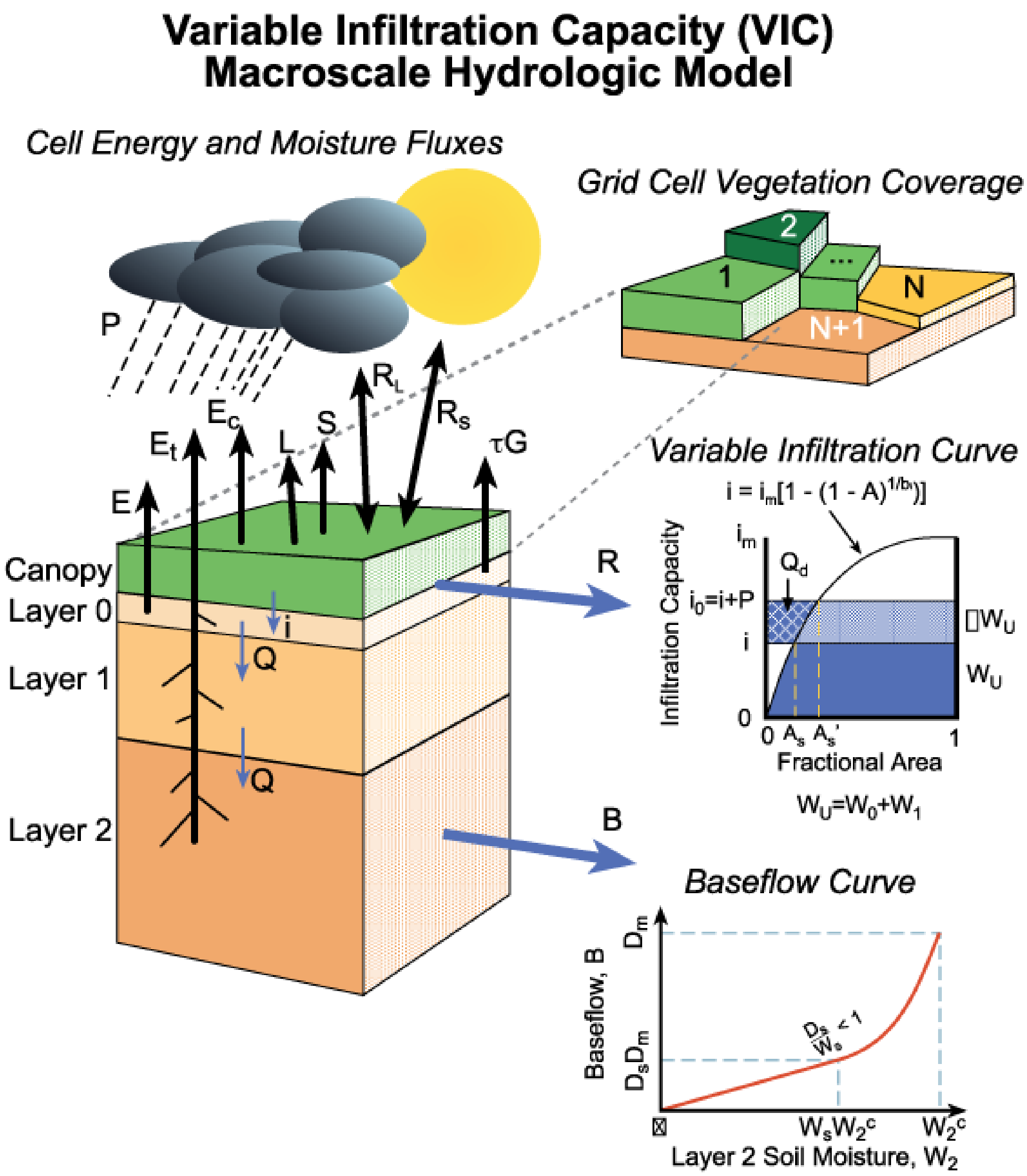

Figure A-5. Hydrologic Processes Included in the VIC Model

Source: University of Washington, 2016

The VIC Model has been applied to many major basins in the United States (U.S.), including large-scale applications to the following:

- California's Central Valley (Liang et al., 1994; Maurer et al., 2002, 2007; Maurer, 2007; Hamlet and Lettenmaier, 2007; Barnett et al., 2008; Cayan et al., 2009; Raff et al., 2009; Dettinger et al., 2011a, 2011b; Das et al., 2011a, 2013; DWR, 2014; Bureau of Reclamation [Reclamation], 2014)
- Colorado River Basin (Christensen and Lettenmaier, 2007; Das et al., 2011b; Vano and Lettenmaier, 2014; Vano et al., 2012, 2014)
- Columbia River Basin (Hamlet and Lettenmaier, 1999; Hamlet et al., 2007)
- Several other basins (Maurer and Lettenmaier, 2003; CH2M HILL, 2008; Livneh et al., 2013)

VIC Model Application for the WSIP

The VIC Model has been configured at 1/16th degrees (approximately 6 km, or 3.75 miles) spatial resolution throughout California. Improvements by Livneh et al. (2013) were used as a preliminary dataset in the VIC Model setup. Parameterization within the model is performed primarily through adjustments to parameters describing the rates of infiltration and base flow as a function of soil properties, as well as the soil layer depths. When simulating in water balance mode, as done for this California application, the model is driven by daily inputs of precipitation, maximum and minimum temperature, and wind speed. The model internally calculates additional meteorological forcings, such as short- and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficits.

Five elevation bands are included for each 1/16th degree (approximately 6 km, or 3.75 miles) grid cell in the VIC Model to capture the precipitation and snow variability over the grid cell. In addition, the model includes a sub-daily (1-hour) computation to resolve transients in the snow model. The soil column is represented by three soil zones extending downward from the land surface to capture the vertical distribution of soil moisture. The land cover is represented by multiple vegetation types.

Rainfall, snow, infiltration, evapotranspiration, runoff, soil moisture, and base flow are computed over each grid cell on a daily basis for the entire period of simulation. The VIC Model routing tool processes the individual cell runoff and base flow terms, and routes the flow to develop streamflow at various locations in the watershed.

Although the VIC Model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomenon. The VIC Model is currently best applied for regional-scale hydrologic analyses. The model is reasonable for capturing flow changes in the larger watersheds in the basin, but may have bias at smaller scales due, primarily, to model resolution.

VIC Model Watershed Delineation and Routing Network

A streamflow routing network in the VIC Model at 1/16th degree (approximately 6 km, or 3.75 miles) was developed using ArcMap's Flow Direction and Flow Accumulation tools. The Flow Direction tool first assigns the flow direction for each VIC Model grid cell to its steepest downslope neighbor. Prior to processing the VIC Model grid through this tool, a stream network shapefile was burned into the digital elevation model (DEM) to enhance the performance of the flow direction tool by increasing the slope toward the closest stream. The VIC Model also requires that flow from each grid cell be directed out of the cell and into another one, and is unable to process sinks. Sinks in the DEM were filled to accommodate this. The Flow Accumulation tool then creates a raster dataset of accumulated flow to each cell by accumulating the number of all upstream cells that flow into each downslope cell.

Once the VIC Model grid is processed through these two tools, watershed delineations were determined based on downstream U.S. Geological Survey (USGS) gage locations and were compared to USGS watershed boundaries. Due to the topographic complexity of the high-elevation regions and the coarseness of the VIC Model grid, adjustments were made to the model watershed delineations to more accurately align with USGS watershed boundary delineation.

VIC Model Calibration

The existing VIC Model had previously undergone only limited calibration for monthly streamflow for selected major river basins over the conterminous U.S. (Livneh et al., 2013). For WSIP application, further VIC Model calibration was performed for the 12 upper watershed locations in the Sacramento and San Joaquin River basins. The VIC Model was recalibrated for water years 1970-2003.

Daily VIC Model simulations were performed from 1915 to 2011. The daily runoff and base flow simulated from each grid cell was routed to various river flow locations. For the simulations performed for this application, streamflow was routed to the necessary river flow locations for CalSim-II modeling throughout the Sacramento and San Joaquin River basins. It is important to note that VIC Model routed flows are considered naturalized in that they do not include effects of diversions, imports, storage, or other human management of the water resource.

Bias Correction of VIC Model Results

Even though the VIC Model is calibrated, the model bias still needs to be removed from the model outputs. These biases result from several factors, including spatial and temporal errors in gridded climate forcings, complex groundwater interactions, and other complexities normally inherent to VIC hydrologic model parameter calibration. These steps were followed to correct the biases:

1. Evaluated the monthly and annual bias in VIC Model simulated streamflows as compared to the historical streamflows for each of the flow locations.
2. Developed a quantile map that aligns the historical streamflow CDF with the simulated CDF for each simulated month at each location. For each simulated value, determined the simulated percentile and adjusted the simulated flow to be equal to the historical flow at the same percentile. This method preserves the mean and variance of the unimpaired flows.
3. Rescaled the monthly values (if needed) to align the annual simulated CDF with the historical streamflow CDF. For each simulated annual flow value from Step 2, determined the percentile and adjusted it to be equal to the historical flow at the same percentile. This step confirms that the adjusted streamflows are consistent at the annual scale.

VIC Model Outputs and Limitations

The following key output parameters are produced on a daily and monthly time-step:

- Temperature, precipitation, runoff, base flow, potential evapotranspiration, soil moisture, and snow water equivalent on a grid-cell and watershed basis
- Routed streamflow at major flow locations to the Sacramento and San Joaquin valleys

The regional hydrologic modeling described using the VIC Model is intended to generate changes in inflow magnitude and timing for use in subsequent CalSim-II modeling. While the model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomenon. The VIC Model is currently best applied for regional-scale hydrologic analyses. Several limitations to long-term gridded meteorology related to spatial-temporal interpolation and bias correction should be considered.

In addition, the inputs to the model do not include transient trends in the vegetation or water management that may affect streamflows; they should only be analyzed from a naturalized flow change standpoint.

Finally, the VIC Model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin River watersheds that contribute approximately 80 to 90 percent of the runoff to the Delta; however, in the valley floor, groundwater management and surface water regulation is considerable. Water management models, such as CalSim-II, should be used to characterize the heavily managed portions of the system.

Sea-Level Rise

In the past century, global mean sea level has increased by 17 to 21 centimeters (cm) (7 to 8 inches) (IPCC, 2013). Sea level continues to rise due to a combination of melting glaciers and ice sheets, and thermal expansion of seawater as it warms. Global estimates of SLR made in the IPCC 4th Assessment indicate a range of 18 to 59 cm (7.1 to 23.2 inches) this century (IPCC, 2007). Estimates by Rahmstorf (2007) and Vermeer and Rahmstorf (2009) suggest that the SLR may be substantially greater than the IPCC projections. Using empirical models based on the observed relationship between global temperatures and sea levels, which have been shown to better simulate recent, observed trends, these studies indicate a mid-range rise this century of 70 to 100 cm (28 to 39 inches), with a full range of variability of 50 to 140 cm (20 to 55 inches).

Global estimates of SLR made from AR5 indicate a likely range of 26 to 82 cm (10.2 to 32.3 inches) this century (IPCC, 2013). These ranges are derived from CMIP5 climate projections, in combination with process-based models and assessment of glacier and ice sheet contributions. The global SLR projections in the IPCC AR5 (IPCC, 2013) are higher than the projections from the IPCC 4th Assessment Report (AR4) (IPCC, 2007).

Due to the limitations with the current physical models for assessing future SLR, several scientific groups, including the CALFED Bay Delta Program (CALFED) Independent Science Board (ISB), recommend the use of empirical models for short- to medium-term planning (Healy, 2007). Both the CALFED ISB and Climate Action Team 2009 assessments have used the empirical approach developed by Rahmstorf (2007) that projects future SLR rates based on the degree of global warming.

The SLR estimates by the National Research Council (NRC) suggested SLR projections at three future times relative to 2000 (2030, 2050, and 2100), along with upper- and lower-bound projections for San Francisco (NRC, 2012). Their SLR projections range from 4.3 to 29.7 cm by 2030, with a mean SLR of about 14.4 cm. By 2050, the range is from 12.3 to 60.8 cm, with a mean SLR of about 28 cm. And by 2100, the range is from 42.4 to 166.5 cm, with a mean SLR of about 90 cm. The NRC's projections have been adopted by the California Ocean Protection Council as guidance for incorporating SLR projections into planning and decision making for projects in California.

The 2012 National Oceanic and Atmospheric Administration (NOAA) report on *Global Sea Level Rise Scenarios for the United States National Climate Assessment* includes four global SLR scenarios ranging from 20 to 200 cm (8 inches to 7 feet) by 2100 using mean sea level in 1992 as a baseline (Parris et al., 2012). The SLR projections in the most recent National Climate Assessment report (2014) was informed by the 2012 NOAA sea-level projections (Parris et al., 2012).

In December 2013, the U.S. Army Corps of Engineers (USACE) issued updated guidance on incorporating sea-level change in civil works programs (USACE, 2013). The guidance document reviews the existing literature and suggests use of a range of sea-level change projections, including the high probability of accelerating global SLR. The ranges of future SLR were based on the empirical procedure recommended by the NRC

(1987) and updated for recent conditions. The three scenarios included in the USACE guidance suggest end-of-century SLR in the range of 20 to 150 cm for San Francisco.

By 2030 and 2070, the median range of expected SLR as estimated by the NRC and other sources listed, and as widely accepted within the scientific community, is around 15 and 45 cm, respectively. For this analysis, SLR projections of 15 and 45 cm were selected as representative for 2030 future and 2070 future SLR conditions, respectively, for use in the CalSim-II and DSM2 models.

Development of CalSim-II Models and Datasets

The hydrology of the Central Valley and operation of the CVP and SWP systems are critical elements in any assessment of changed conditions throughout the Central Valley and in the Delta. Changes to system characteristics, such as flow patterns, demands, regulations, Delta configuration will influence the operation of the CVP and SWP reservoirs and export facilities. The operation of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive, and detailed analysis of this interaction often results in a new understanding of system responses.

Modeling tools are required to approximate these complex interactions under future conditions. CalSim-II is a planning model developed by DWR and Reclamation. It simulates the CVP and SWP and areas tributary to the Delta. CalSim-II provides quantitative hydrologic-based information to those responsible for planning, managing, and operating the CVP and SWP. As the official model of those projects, CalSim-II is typically the system model used for interregional or statewide analysis in California.

Climate and sea-level change is incorporated into CalSim-II in two ways: changes to the input hydrology, and changes to the flow-salinity relationship in the Delta due to SLR. The following methods were used to calculate projected CalSim-II inflow data:

1. For larger watersheds, which constitute the majority of the total inflow volume in the system, CalSim-II inflows were replaced with projected runoff obtained from the VIC Model.
2. For smaller inflows, for which using direct runoff from the VIC Model was not possible, simulated changes in runoff were applied to the CalSim-II inflows and downstream accretions and depletions as a fractional change from the observed inflow patterns at certain gauged locations (simulated future runoff divided by historical runoff). These fractional changes were first applied for every month of the 82-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. Similarly, fractional changes were also used to simulate change in precipitation and temperature as needed for calculation of certain parameters used in CalSim.

3. For larger 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 that were bias-corrected to unimpaired at a location upstream of the impairment.
4. Water year types and other indices used in system operation decisions by CalSim-II were regenerated using projected flows, precipitation, or temperature as needed in their respective methods.
5. SLR effects on the flow-salinity response in CalSim-II were incorporated by a separate Artificial Neural Network (ANN) for each climate projection (2030 and 2070).
6. SLR effects were used in the regression equations to estimate the flow split between the Sacramento River and Georgiana Slough at times when the Delta Cross Channel (DCC) is open or closed.

Use of Projected Runoff from the VIC Model for Impaired Streamflows

Impaired streamflows of larger watersheds that constitute the majority of the total inflow volume in the system are listed in Table A-2. As mentioned before, for these locations, CalSim-II inflows were replaced with projected runoff obtained from the VIC Model. The projected runoff was obtained through the hydrologic routing and bias correction process described in previous sections. Bias correction was based on impaired CalSim-II inflows for these locations to capture the level of development modeled in CalSim-II.

Table A-2. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Trinity River at Trinity Lake	I1	CalSim-II inflow[1]
Sacramento River at Shasta Dam	I4	CalSim-II inflow[1]
Feather River at Oroville	I6	CalSim-II inflow[1]
American River North Fork + Middle Fork	I300	Partitioned from American River (I300 + I8) based on monthly ratios (I300/(I300+I8)) in CalSim-II inflow[1]
American River South Fork + Local Flow	I8	Partitioned from American River (I300 + I8) based on monthly ratios (I8/(I300+I8)) in CalSim-II inflow[1]
Cosumnes River at Michigan Bar	I501	CalSim-II inflow[1]
Calaveras River at New Hogan	I92	CalSim-II inflow[1]
Merced River at Lake McClure	I20	CalSim-II inflow[1]
San Joaquin River at Millerton Lake	I18_SJR + I18_FG	CalSim-II inflow[1]
San Joaquin River at Millerton Lake (without Fine Gold Creek)	I18_SJR	Partitioned from San Joaquin River inflow to Millerton Lake (I18) based on monthly ratios in CalSim-II inflow[1]

Table A-2. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Fine Gold Creek	I18_FG	Partitioned from San Joaquin River at Millerton Lake (I18) based on monthly ratios in CalSim-II inflow[1]

[1]CalSim-II inflow data were obtained from the Delivery Capability Report (DCR), 2015 study.

Use of Projected Runoff from the VIC Model for Unimpaired Streamflows

Use of projected runoff from the VIC Model for unimpaired streamflows followed a similar bias-correction scheme as was implemented for impaired streamflow locations (as discussed in previous sections). Because the unimpaired runoff obtained from this step is used to calculate hydrologic indices, and to be consistent with the methodology used to calculate these indices, unimpaired streamflow locations were bias-corrected to unimpaired or full natural flow data[1] for that location.

Use of Fractional Changes for Climate Data

Fractional changes from the historical observed data based on simulated future climate conditions are used when direct use of future climate is not feasible. Streamflows of smaller watersheds, projected precipitation for use in hydrological index calculations, and projected change in temperature for use in calculating required Old and Middle River flow for modeling purposes are examples of where fractional changes have been used and are described in detail in the following subsections.

Streamflows

The existing VIC Model at 1/16th degree (approximately 6 kilometers [km], or approximately 3.75 miles) spatial resolution is insufficient to produce streamflows with good accuracy at small watersheds. Therefore, for smaller watersheds in the system, climate change ratios were used to adjust CalSim-II inflow data obtained from the 2015 SWP delivery capability study (DWR, 2015). Table A-3 lists these small watersheds. The climate change ratios were computed based on VIC Model simulations using historical, detrended climate forcing and climate change projections.

[1] Data obtained from California Data Exchange Center (CDEC).

Table A-3. River Locations for Small Watershed Tributaries in CalSim-II.		
Tributary	**CalSim Arc**	**Approach**
Cow Creek	I10801	Developed climate change ratio, and used as reference for other locations
Battle Creek	I10803	Used climate change ratio developed based on Cow Creek
Cottonwood Creek	I10802	Developed climate change ratio
Deer Creek	I11309	Developed climate change ratio, and used as reference for other locations
Paynes Creek	I11001	Used climate change ratio developed based on Deer Creek
Red Bank Creek	I112	Used climate change ratio developed based on Deer Creek
Antelope Creek	I11307	Used climate change ratio developed based on Deer Creek
Mill Creek	I11308	Used climate change ratio developed based on Deer Creek
Thomes Creek	I11304	Developed climate change ratio, and used as reference for other locations
Elder Creek	I11303	Used climate change ratio based on Thomes Creek
Lewiston inflow	I100	Not modified
Whiskeytown inflow	I3	Developed climate change ratio
Bear river inflow	I285	Developed climate change ratio
Butte Creek	I217	Developed climate change ratio, and used as reference for other locations
Big Chico Creek	I11501	Used climate change ratio developed based on Butte Creek
Kelly Ridge	I200	Not modified
Fresno River inflow to Hensley Lake	I52	Developed climate change ratio, and used as reference for other locations
Chowchilla River inflow to Eastman Lake	I53	Used climate change ratio developed based on Fresno River inflow to Hensley Lake
Inflow to Black Butte	I42	Developed climate change ratio, and used as reference for other locations
Stony Creek inflow East Park	I40	Used climate change ratio developed based on inflow to Black Butte
Inflow to Stony Gorge	I41	Used climate change ratio developed based on inflow to Black Butte

Precipitation

CalSim-II requires runoff forecasts for the Shasta, Feather, and American river basins. In practice, statistical forecast functions are developed based on observed precipitation and runoff. To mimic the same procedure for forecasts that would have occurred in future climate conditions, forecast functions were developed using projected precipitation and runoff. The following steps were taken:

7. Basin-wide average precipitation was computed for each climate scenario.
8. Sensitivity factors for precipitation were calculated in reference to historical data for each climate scenario.

9. Historical precipitation indices were perturbed to obtain estimated precipitation indices under each climate scenario. Sensitivity factors for precipitation indices are calculated as the ratio of climate precipitation to historical precipitation for each basin.
10. Perturbed precipitation index estimates were then used to develop regression equations for forecasted runoff.

Temperature

CalSim-II uses a temperature trigger based on temperature data at the Sacramento Executive Airport (SEA) to establish trigger date requirements for the U.S. Fish and Wildlife (USFWS) Biological Opinion Reasonable and Prudent Alternative Action 3 (BIOP A3) that sets the Old and Middle River flow requirement in spring months. 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 was applied to the DCR2015 temperature dataset to establish temperature trigger date requirements under each climate scenario. Sensitivity factors for temperature are calculated as a difference in temperature.

Use of Projected Runoff from the VIC Model for Impaired Streamflows

Projected VIC Model runoff that was bias-corrected to unimpaired flows at the upstream location of impaired streamflow locations were used to re-introduce the impairment that was observed in CalSim-II (Table A-4). Because information on specific local project operations (impairment) at these locations was not available, the impairment was calculated as the difference between the unimpaired historical flow and the CalSim-II inflow time series. The same difference was then applied to projected unimpaired flow to obtain impaired flows in future conditions. 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 because the information on how the local project operations would change is currently not available.

Table A-4. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Yuba River at Smartsville	I230	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows based on output from the YCWA HEC model)
American River at Folsom	I300 + I8	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows based on DWR American River HEC3 model)
Mokelumne River	I504	Unimpaired flows into Pardee Reservoir (I90, use input from EBMUDSIM) for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows at I504 based on output from EBMUD SIM; in this case re-impairment includes other smaller inflow between I90 and I504)
Stanislaus River at New Melones Dam	I10	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows)
Tuolumne River at New Don Pedro	I81	Unimpaired flows for use of re-impairment method (re-impairment method uses historical impairment included in CalSim-II inflows)

Key:
EBMUD SIM = East Bay Municipal Utility District Simulation
YCWA HEC = Yuba County Water Agency Hydrologic Engineering Center

Updating Water Year Types and Indices

Water year types and other hydrologic indices used in CalSim-II operational decisions were regenerated using the projected flows and temperatures based on VIC Model simulations. These indices and data they use are listed in Table A-5.

Table A-5. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	**Input**	**CalSim-II File Name**	**Specification**	**Raw Data**	**Raw Data Source**	**CDEC Station Location/ Station used in VIC Model for Projected Flows**
Forecasting	Folsom Inflow Forecast	American_Runoff_ Forecast.table	Fn (WY precip, known streamflows at the time of forecast)	Unimpaired; Basin Precipitation	CDEC; other DWR	AMF; Folsom Basin Precipitation (Index of Gaged)
	Oroville Inflow Forecast	Feather_Runoff_ Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	FTO; Feather Basin Precipitation (Index of Gaged)
	Shasta Inflow Forecast	Sacramento_Runoff_ Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	SIS; Shasta Basin Precipitation (Index of Gaged)
Indices for broad regulatory criteria (simulated with perfect foresight in CalSim-II)	8RI	EightRiver.table	Sum of eight stations' monthly flows (SacValleyIndex + SJValleyIndex)	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG
	X2 Days	x2days.table	Based on 8RI PMI	Full Natural Flow; Table of electrical conductivity requirements	CDEC; Table available in spreadsheet	8RI (previous line)
	SacValley Index	SacValleyIndex.table	Sum of four stations' monthly flows	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	Sacramento Index	wytypes.table	Water Quality Control Plan 40-30-30	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	San Joaquin Index	wytypes.table	Water Quality Control Plan 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index	wytypeSJR.table	Water Quality Control Plan 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index – 5-year average	wytypeSJR5.table	5-year running average of WQCP 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
Indices and other inputs for Operations policies (with regulatory significance)	Trinity Index	wytypes.table	Based on TNL WY Total	Full Natural Flow	CDEC	TNL
	Shasta Index	wytypes.table	Based on SIS Apr-Jul and WY Totals	Full Natural Flow	CDEC	SIS
	Feather River Index	wytypes.table	Based on FTO Apr-Jul and WY Totals	Full Natural Flow	CDEC	FTO

Table A-5. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	**Input**	**CalSim-II File Name**	**Specification**	**Raw Data**	**Raw Data Source**	**CDEC Station Location/ Station used in VIC Model for Projected Flows**
	UIFR	UIFR.table	Based on AMF Mar-Nov Totals	--	--	AMF
	AmerD893 Index	wytypes.table	Based on AMF Apr-Sep Totals	Full Natural Flow	CDEC	AMF
	Delta Index	Delta_Index.table	Based on Jan-May 8RI	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG

Key:
BRI = VAN DUZEN R NR BRIDGEVILLE AT GRIZZLY CR
AMF = AMERICAN R AT FOLSOM
Apr-Jul = April through July
Apr-Sep = April through September
FTO = FEATHER RIVER AT OROVILLE
Mar-Nov = March through November
MRC = MERCED R NR MERCED FALLS
SBB = SACRAMENTO RIVER ABV BEND BRIDGE
SIS = SACTO INFLOW-SHASTA
SJF = SAN JOAQUIN RIVER BELOW FRIANT
SNS = STANISLAUS R-GOODWIN
TLG = TUOLUMNE R-LA GRANGE DAM
TNL = TRINITY R AT LEWISTON
WY = wet years
YRS = YUBA RIVER NEAR SMARTVILLE

Incorporating Effects of SLR in CalSim-II through ANN

Determination of flow-salinity relationships in the Delta is critical to both water project operations and ecosystem management. Operation of the CVP and SWP facilities and management of Delta flows often depend on Delta flow needs for salinity standards. Salinity in the Delta cannot be simulated accurately by the simple mass balance routing and coarse time step used in CalSim-II. An ANN has been developed that attempts to mimic the flow-salinity relationships as simulated in DSM2 and provides a rapid transformation of this information into a form usable by CalSim-II (Sandhu et al., 1999). The ANN is implemented in CalSim-II to confirm the operations of the upstream reservoirs and the Delta export pumps satisfy specific salinity requirements in the Delta. A more detailed description of the use of ANNs in the CalSim-II model is provided by Wilbur and Munévar (2001).

The ANN developed by DWR (Sandhu et al., 1999; Seneviratne and Wu, 2007) statistically correlate the salinity results from a particular DSM2 model run to the peripheral flows (Delta inflows, exports, and diversions), gate operations, and an indicator of tidal energy. The ANN is trained on DSM2 results that may represent historical or future conditions using a full circle analysis (Seneviratne and Wu, 2007). For example, a future SLR may significantly affect the hydrodynamics of the system. The ANN is able to represent this new condition by being retrained using the results from the DSM2 model representing the conditions with the SLR.

The current ANN predicts salinity at various locations in the Delta using the following parameters as input:

- Northern inflows
- San Joaquin River inflow
- DCC gate position
- Total exports and diversions
- Net Delta consumptive use
- An indicator of the tidal energy
- San Joaquin River at Vernalis salinity

Northern inflows include Sacramento River at Freeport flow; Yolo Bypass flow; and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (eastside streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include those at the SWP Banks Pumping Plant, the CVP Jones Pumping Plant, and Contra Costa Water District (CCWD) diversions, including diversions to Los Vaqueros Reservoir. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory of antecedent conditions in the Delta.

The ANN model approximates DSM2 model-generated salinity at the following key locations for modeling Delta water quality standards:

- X2
- Sacramento River at Emmaton
- San Joaquin River at Jersey Point
- Sacramento River at Collinsville
- Old River at Rock Slough

In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project, and Los Vaqueros diversion locations.

The ANN may not fully capture the dynamics of the Delta under conditions other than those for which it was trained. It is possible that the ANN will exhibit errors for flow regimes beyond those for which it was trained. Therefore, a new ANN is needed for any SLR scenario or any new Delta configuration (physical changes in Delta) that may result in changed flow-salinity relationships in the Delta.

Two ANNs, retrained by the DWR Bay-Delta Modeling staff, each representing one of the two SLR scenarios assumed in the WSIP (15 cm at 2030 and 45 cm at 2070) were used with the two CalSim-II models that represent 2030 and 1070 conditions. ANN retraining involved the following steps:

1. The DSM2 model was corroborated using the UnTRIM model to account for SLR effects, enabling a one-dimensional (1-D) model, DSM2, to approximate changes observed in a three-dimensional (3-D) model, UnTRIM.
2. A range of example long-term CalSim-II scenarios were developed to provide a broad range of boundary conditions for the DSM2 models.
3. Using the grid configuration and the correlations from the corroboration process, several 16-year (water years 1976-1991) DSM2 planning runs were simulated based on the boundary conditions from the identified CalSim-II scenarios to create a training dataset for each new ANN.
4. ANNs were trained using the Delta flows and Delta cross-channel operations from CalSim-II, along with the salinity (electrical conductivity [EC]) results from DSM2 and the Martinez tide.
5. The training dataset was divided into two parts: one was used for training the ANN, and the other for validating.
6. Once the ANN was ready, a full circle analysis was performed to assess the performance of the ANN and confirm similar results were obtained from CalSim-II and DSM2.

A detailed description of the ANN training procedure and the full circle analysis is provided in DWR's 2007 annual report (Seneviratne and Wu, 2007).

Incorporating Effects of SLR in Sacramento River- Georgiana Slough Flow Split

The SLR expected by 2030 or 2070 would change the flow split between Sacramento River and DCC-Georgiana Slough flow. This requires modification of the linear regression equations used to estimate DCC-Georgiana Slough flow in CalSim-II. Table A-6 shows the equations to be used in CalSim-II for each SLR condition. The changes to the regression coefficients are made in the .\common\Delta\Xchannel\xc-gates.wresl file.

Table A-6. Regression Results for DSM2 Monthly Averaged Cross-Delta Flow (Y-axis) versus Sacramento River Flow Upstream of Sutter Slough (X-axis).

#	Scenario	DCC Open		DCC Closed	
		Slope	Intercept	Slope	Intercept
1	Current Conditions DSM2[1]	0.3217	1050.7	0.1321	1086.6
2	15 or 45 cm SLR DSM2[2]	0.3187	1094.6	0.1316	1102.0

Key:
BDCP = Bay Delta Conservation Plan
[1] Regression coefficients from 2009 DSM2 recalibration model.
[2] Regression coefficients from 2009 DSM2 recalibration model under 15- and 45-cm SLR using Bay Delta Conservation Plan 040110 No Action CalSim-II results.

The equations to be used with current sea level are:

*Cross-Delta flow (i.e., DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

Where:

slope = 0.3217, intercept = 1051 cubic feet per second (cfs) when DCC is open

slope = 0.1321, intercept = 1087 cfs when DCC is closed.

Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:

*Georgianna Sl. Flow = 0.1321*Qsac + 1087 (whether DCC is open or closed)*

and

*DCC Flow = 0.1896*Qsac - 36 when DCC is open*

DCC Flow = 0.0 when DCC is closed

The equation to be used with SLR of 15 or 45 cm are:

*Cross-Delta flow (i.e. DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

Where

slope = 0.3187, intercept = 1095 cfs when DCC is open

slope = 0.1316, intercept = 1102 cfs when DCC is closed

Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:

*Georgianna Sl. Flow = 0.1316*Qsac + 1102 (whether DCC is open or closed)*

and

*DCC Flow = 0.1871*Qsac - 7 when DCC is open*

DCC Flow = 0.0 when DCC is closed

DSM2 Modeling

Several tools are available to simulate hydrodynamics and water quality in the Delta. Some tools simulate detailed processes with two-dimensional (2-D) or 3-D representation; however, they are computationally intensive and have long runtimes. Other tools approximate certain processes and have short runtimes, while only compromising slightly on the accuracy of the results. For a long-term planning-level analysis, the simulation period should cover a range of hydrologic and tidal conditions to understand the resulting changes than can occur over a number of years. A tool with short run-times but that can simulate the changed hydrodynamics and water quality in the Delta accurately is ideal. DSM2, a 1-D hydrodynamics and water quality model, fits these criteria.

DSM2 has a limited ability to simulate 2-D features, such as open waterbodies (including reservoir, flooded islands, and tidal marshes); and 3-D transport processes, such as gravitational circulation, which is found to increase with SLR in the estuaries. Therefore, DSM2 must be recalibrated or corroborated based on a dataset that accurately represents the conditions in the Delta with SLR. Since the future SLR conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics is to simulate the Delta with higher dimensional models, which can resolve the 3-D processes well. These models generate the datasets needed to corroborate or recalibrate DSM2 under the future conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy.

Figure A-6 shows a schematic of how the hydrodynamics and water quality modeling is formulated under the SLR conditions. UnTRIM Bay-Delta Model, a 3-D hydrodynamics and water quality model, was used to simulate the SLR effects on hydrodynamics and salinity transport under the historical operations in the Delta.

The results from the UnTRIM model were used to corroborate DSM2 so that DSM2 can simulate the effect of SLR consistent with a higher-order model that can better resolve estuarine processes.

The corroborated DSM2 model was used to simulate hydrodynamics and water quality in the Delta by integrating SLR effects over an 82-year period (water years 1922-2003), using the hydrological inputs and exports determined by CalSim-II under the projected operations. It was also used to retrain ANNs to emulate modified flow-salinity relationships in the Delta.

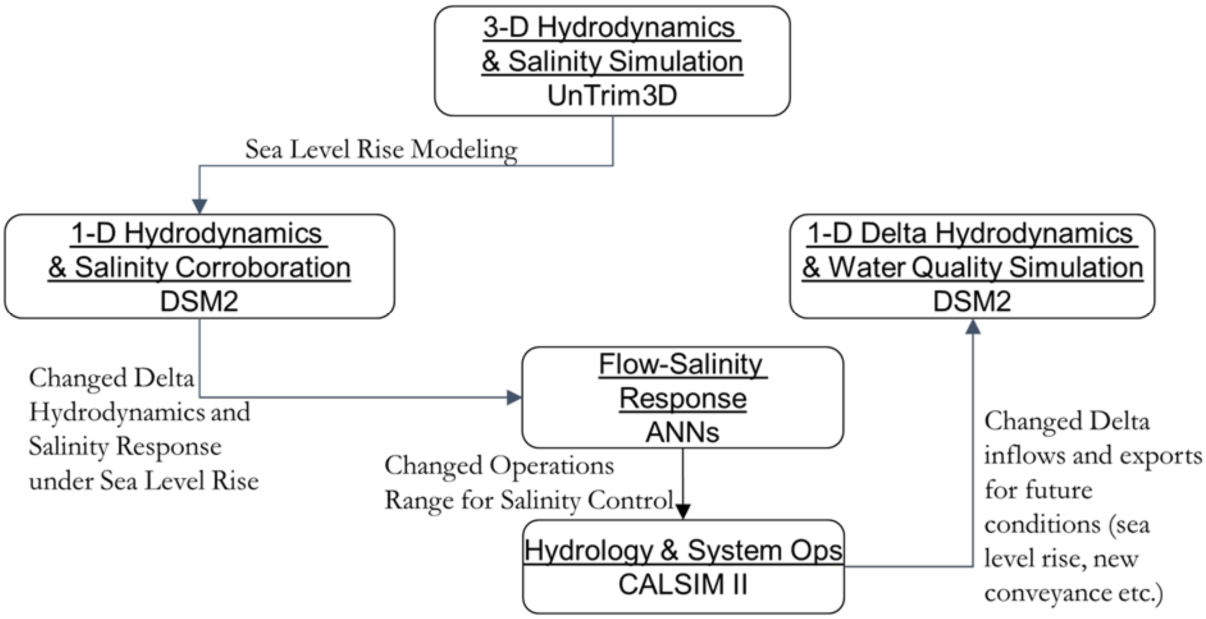

Figure A-6. Delta Hydrodynamics and Water Quality Modeling Methodology under SLR.

Based on the outcome of the SLR corroboration, an updated DSM2 model setup for each of the 2030 and 2070 projections was prepared for use in the WSIP analyses to account for the projected 15- and 45-cm SLR.

Using the results from the UnTRIM models, two correlations were developed to compute the resulting stage and EC at the Martinez location for each SLR scenario. Table A-7 shows the Martinez stage and EC correlations for the 15- and 45-cm SLR scenarios. It also shows the lag in minutes between the baseline stage or EC, and the resulting stage or EC under the scenarios with SLR. The regressed baseline stage or EC time series must be shifted by the respective lag time noted in Table A-7.

As noted earlier, adjusted astronomical tide at Martinez was used as the downstream stage boundary in the DSM2 planning simulation representing the current Delta configuration without SLR. This stage time series was modified using the stage correlation equation identified in Table A-7 for use in planning simulations with 15- and 45-cm SLR. The EC boundary condition in a DSM2 planning simulation was estimated using the G-model based on the monthly net Delta outflow simulated in CalSim-II and the pure astronomical tide (Ateljevich, 2001).

Although the rim flows and exports are patterned on a daily step in DSM2, the operational decisions, including exports, are still on a monthly time step. This means that the net Delta outflow may or may not meet the standards on a daily time step. Therefore, to estimate the EC boundary condition at Martinez, monthly net Delta outflow simulated in CalSim-II was used. For planning simulations with 15- and 45-cm SLR, the EC time series from the G-model was adjusted using the EC correlations for each SLR scenario listed in Table A-7 to account for the anticipated changes at Martinez.

Table A-7. Correlations for Martinez Stage.

Climate Condition	**Martinez Stage (ft NGVD 29)**		**Martinez EC (µS/cm)**	
	Correlation	**Lag (min)**	**Correlation**	**Lag (min)**
2030 Future Condition	Y = 1.0033*X + 0.47	-1	Y = 0.9954*X + 556.3	0
2070 Future Condition	Y = 1.0113*X + 1.4	-2	Y = 0.98*X + 1778.9	-2

Notes:
µS/cm = microSiemens per centimeter
ft = foot
min = minutes
NGVD 29 = National Geodetic Vertical Datum of 1929
X = 2015 Historical Condition Martinez stage or EC
Y = Scenario Martinez stage or EC

Climate Change and SLR Data Provided to Applicants and Potential Use of these Data by Applicants

The following is a list of product archive files included in the November 1, 2016 release:

Without-Project 2030 Future Conditions:

- Climate and VIC results: WSIP_2030_Statewide_Grid_Monthly_9-3-16.zip
- CalSim-II model and output: WSIP_2030_CALSIM_10-24-16.zip
- DSM2 model and output: WSIP_2030_DSM2_10-24-16.zip

Without-Project 2070 Future Conditions:

- Climate and VIC results: WSIP_2070_Statewide_Grid_Monthly_9-3-16.zip
- CalSim-II model and output: WSIP_2070_CALSIM_10-24-16.zip
- DSM2 model and output: WSIP_2070_DSM2_10-24-16.zip

1995 Historical Temperature - Detrended Conditions (reference):

- Climate and VIC results: WSIP_1995_HistTdetrended_Statewide_Grid_Monthly_9-3-16.zip

Use of VIC Model results for models other than CalSim-II can be implemented using similar methodologies as applied to the CalSim-II model. Applicants can choose to implement direct use of VIC Model output or sensitivity factor calculations, or apply a re-impairment scheme when applicable. For use of routed streamflow, a bias-correction scheme should be implemented to remove bias developed during VIC Model calibration. Depending on the use of bias-corrected streamflows, the bias-correction process can be implemented based upon impaired or unimpaired data. At the base level, the VIC Model simulation creates daily outputs. Outputs can then be summarized based on the time frame necessary for implementation into the simulation of model of interest.

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~~Appendix A~~
~~Climate Change~~
~~and Sea Level Rise~~

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~~Climate Change and Sea-Level Rise Methods~~

~~This appendix provides detailed information on methods used to develop climate and sea-level projections, how those projections were incorporated as inputs into the CalSim-II and DSM2 models, and how the models were used to generate projections of 2030 and 2070 conditions.~~

~~Climate Change~~

~~Growing evidence indicates that Earth's atmosphere is warming. Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (National Academy of Sciences, 2006; Intergovernmental Panel on Climate Change [IPCC], 2007, 2013). The temperature of Earth's atmosphere is directly related to the concentration of atmospheric greenhouse gases. Growing scientific consensus suggests that climate change will occur as the result of increased concentrations of greenhouse gases and related temperature increases (IPCC, 2007, 2013). While consensus exists regarding the observed global warming trend, considerable uncertainty remains regarding regional projections of future precipitation. This section provides detailed information on techniques used for downscaling climate data and obtaining projected runoff/stream flows.~~

~~Quantile Mapping~~

~~The median climate projections at 2030 future and 2070 future conditions were derived based on a quantile mapping approach using changes in temperature and precipitation from 10 general circulation models (GCMs). Twenty downscaled GCM projections were selected from 10 GCMs and 2 selected representative concentration pathways (RCPs) (RCP 4.5 and RCP 8.5). The 10 GCMs were chosen by the California Department of Water Resources (DWR) Climate Change Technical Advisory Group (CCTAG) based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG, 2015). The 20 climate projections were downscaled using a localized constructed analog (LOCA) at 1/16th degree (approximately 6 km, or approximately 3.75 miles) spatial resolution by Scripps Institution of Oceanography (Pierce et al., 2014). The LOCA method uses future climate projections combined with historical analog events to produce daily downscaled precipitation and temperature time series. The primary steps for the LOCA method are described further in this document.~~

The quantile mapping approach involves the following steps:

1. Extract a 30-year slice of climate model simulations (precipitation, maximum and minimum temperatures) from 20 downscaled climate model simulations centered on model simulated reference period (i.e., 1995: 1981-2010). There are 20 downscaled climate model projections generated from 10 GCMs using the emission scenarios RCP 8.5 and RCP 4.5. These 10 GCMs were chosen by the DWR CCTAG based on a regional evaluation of climate models to reproduce a range of historical climate conditions.
2. Extract a 30-year slice of downscaled climate projections (precipitation, maximum and minimum temperatures) from 20 downscaled climate model simulations centered on future year of investigation (i.e., 2030: 2016-2045 and 2070: 2056-2085). There are 20 downscaled climate model projections generated from 10 GCMs using the emission scenarios RCP 8.5 and RCP 4.5. These 10 GCMs were chosen by the DWR CCTAG based on a regional evaluation of climate models to reproduce a range of historical climate conditions.
3. For each calendar month (e.g., January) of the model simulated reference period (1981-2010 in our case), determine the cumulative distribution function (CDF) for each climate model projection of temperature and precipitation at each grid cell. There are 30 values over 30 years of reference period (e.g., for 1981-2010, one value from each year) to construct the CDF for each climate model projection. There are 20 CDFs from 20 climate model simulations. Average value for each quantile is computed from the 20 CDFs developed from 20 climate model simulations.
4. For each calendar month (e.g., January) of the future period, determine the statistical properties (CDF) for each climate model projection of temperature and precipitation at each grid cell. There are 30 values over 30 years of future period (e.g., for 2016-2045, one value from each year) to construct the CDF for each model projection. There are 20 CDFs from 20 climate model simulations. Average value for each quantile is computed from the 20 CDFs developed from 20 climate model simulations.
5. Compute ratio (future period/reference period) for precipitation and deltas (future period - reference period) for temperature for each quantile from the historical and future period average CDFs.
6. Using the ratios and deltas, redevelop a monthly time series of temperature and precipitation at 1/16th degree (approximately 6 km, or approximately 3.75 miles) over 1915 -2011 that incorporates the climate shift of the future period.

All 20 climate model projections have been used for quantile mapping for every grid in California.

LOCA Downscaled Climate Projections

The LOCA method produces daily downscaled estimates of surface meteorological fields (minimum and maximum temperatures and precipitation) suitable for hydrological simulations using a multiscale spatial matching scheme to pick appropriate analog days from observations. This new technique for statistically downscaling climate model simulations of daily temperature and precipitation has been developed by researchers at the Scripps Institution of Oceanography (Pierce et al., 2014). This spatial downscaling method includes a bias-correction process based on frequency-dependent correction of the coarse resolution GCM daily temperature and precipitation fields prior to the spatial downscaling (Pierce et al., 2015). A key feature of this bias correction is that it preserves the original GCM-predicted change in temperature and precipitation, unlike other commonly used bias correction methods, such as quantile mapping, that alter the original model-predicted change in unexpected ways.

As described in Pierce et al. (2014), the primary steps for the LOCA spatial downscaling process follow:

- Select the locations at which a pool of candidate observed analog days for the downscaling (30 analog days in this case) will be chosen. This differs from existing constructed analog techniques, which use the same analog days at all points in the domain, and lends a natural domain-independence aspect to LOCA that is not found in existing constructed analog approaches. This region is identified where the temporal correlation with the point being downscaled is > 0. The regions are calculated by season (e.g., DJF, MAM, JJA, SON) and variable (precipitation, daily maximum and minimum temperatures, etc.). This step is only done once; the following steps are repeated for each day being downscaled.
- Select the pool of 30 analog days at each location identified in Step 1. Analog days are selected based on the lowest root mean square error (RMSE) with respect to the climate model day being downscaled, where the RMSE is evaluated over the region identified in Step 1.
- Out of the pool of 30 analog days, find the one that best matches the model field being downscaled in the local neighborhood (1 degree latitude/longitude box when downscaling to 1/16th degree spatial resolution) of the point to which it is being downscaled. Points whose selected analog day is different from a neighbor's (edge points), use a weighted average of the relevant analog days. By contrast, existing constructed analog methods typically use a weighted average of the same 30 analog days for the entire domain. By reducing this averaging, LOCA produces better estimates of extreme days, constructs a more realistic depiction of the spatial coherence of the downscaled field, and reduces the problem of producing too many light-precipitation days.
- Construct the final downscaled field by scaling the selected observed day to match the amplitude of the model day being downscaled.

Rainfall-Runoff Modeling Using Variable Infiltration Capacity (VIC)

The VIC model (Liang et al., 1994, 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. It accepts input meteorological data directly from global or national gridded databases or from GCM projections. To compensate for the coarseness of the discretization, VIC is unique in its incorporation of sub-grid variability to describe variations in the land parameters as well as precipitation distribution. Figure A-1 shows the hydrologic processes included in the VIC model.

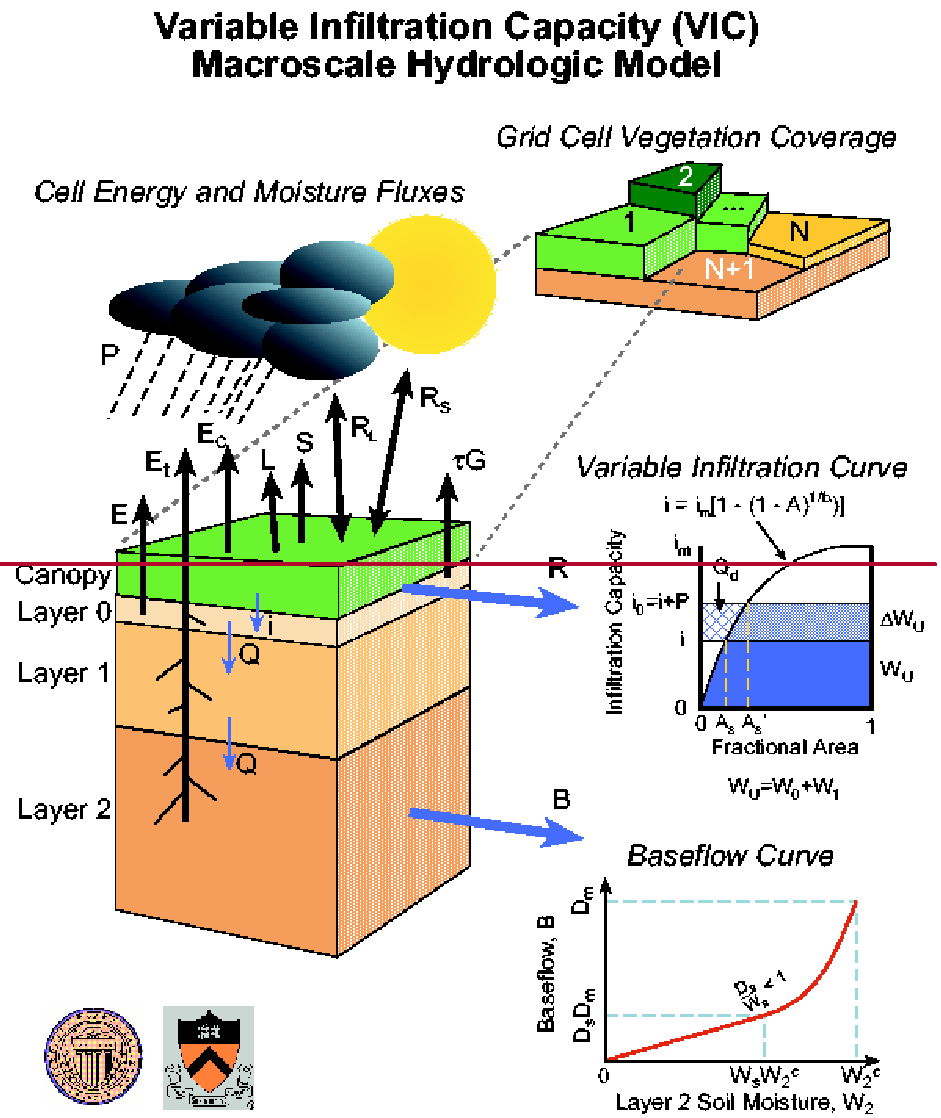

Figure A-1. Hydrologic Processes Included in the VIC Model
Source: University of Washington, 2016

~~The VIC model has been applied to many major basins in the United States, including large-scale applications to the following:~~

- ~~California's Central Valley (Liang et al., 1994; Maurer et al., 2002, 2007; Maurer, 2007; Hamlet and Lettenmaier, 2007; Barnett et al., 2008; Cayan et al., 2009; Raff et al., 2009; Dettinger et al., 2011a, 2011b; Das et al., 2011a, 2013; DWR, 2014; Bureau of Reclamation [Reclamation], 2014)~~
- ~~Colorado River Basin (Christensen and Lettenmaier, 2007; Das et al., 2011b; Vano et al., 2012, 2014a, 2014b)~~
- ~~Columbia River Basin (Hamlet and Lettenmaier, 1999; Hamlet et al., 2007)~~
- ~~Several other basins (Maurer and Lettenmaier, 2003; CH2M HILL, 2008; Livneh et al., 2013)~~

~~The VIC model has been configured at 1/16th degrees (approximately 6 km, or approximately 3.75 miles) spatial resolution throughout California. Improvements by Livneh et al. (2013) in the VIC model dataset at 1/16th degrees (approximately 6 km, or approximately 3.75 miles) were used as a preliminary dataset in the VIC model setup. Parameterization within VIC is performed primarily through adjustments to parameters describing the rates of infiltration and base flow as a function of soil properties, as well as the soil layer depths. When simulating in water balance mode, as done for this California application, VIC is driven by daily inputs of precipitation, maximum and minimum temperature, and wind speed. The model internally calculates additional meteorological forcings, such as short-wave and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficits.~~

~~Five elevation bands are included for each 1/16th degree (approximately 6 km, or approximately 3.75 miles) grid cell in the VIC model to capture the precipitation and snow variability over the grid cell. In addition, VIC includes a sub-daily (1-hour) computation to resolve transients in the snow model. The soil column is represented by three soil zones extending downward from the land surface to capture the vertical distribution of soil moisture. The land cover is represented by multiple vegetation types.~~

~~Rainfall, snow, infiltration, evapotranspiration, runoff, soil moisture, and base flow are computed over each grid cell on a daily basis for the entire period of simulation. The VIC routing tool processes the individual cell runoff and base flow terms and routes the flow to develop stream flow at various locations in the watershed.~~

~~Although the VIC model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local-scale phenomenon. The VIC model is currently best applied for the regional scale hydrologic analyses. The model is reasonable for capturing flow changes at the larger watersheds in the basin, but may have bias at smaller scales due primarily to the model resolution.~~

VIC Model Watershed Delineation and Routing Network

A streamflow routing network in the VIC model at 1/16th degree (approximately 6 km, or approximately 3.75 miles) was developed using ArcMap's Flow Direction and Flow Accumulation tools. The Flow Direction tool first assigns the flow direction for each VIC grid cell to its steepest downslope neighbor. Prior to processing the VIC grid through this tool, a stream network shapefile was burned into the digital elevation model (DEM) to enhance the performance of the flow direction tool by increasing the slope toward the closest stream. VIC also requires that flow from each grid cell be directed out of the cell and into another one and is unable to process sinks. Sinks in the DEM were filled to accommodate this. The Flow Accumulation tool then creates a raster dataset of accumulated flow to each cell by accumulating the number of all upstream cells that flow into each downslope cell.

Once the VIC grid is processed through these two tools, watershed delineations were determined based on downstream U.S. Geological Survey (USGS) gage locations and were compared to USGS watershed boundaries. Due to the topographic complexity of the high elevation regions and the coarseness of the VIC model grid, adjustments were made to the model watershed delineations to more accurately align with USGS watershed boundary delineation.

VIC Model Calibration

The existing VIC model had previously undergone only limited calibration for monthly stream flow for selected major river basins over the conterminous United States (Livneh et al., 2013). Further VIC model calibration was performed for this application for the 12 upper watershed locations in the Sacramento and San Joaquin River basins. The VIC model was calibrated for water years 1970-2003.

Daily VIC model simulations were performed from 1915 to 2011. The daily runoff and base flow simulated from each grid cell was routed to various river flow locations. For the simulations performed for this application, stream flow was routed to the necessary river flow locations for CalSim-II modeling throughout the Sacramento and San Joaquin River basins. It is important to note that VIC routed flows are considered naturalized in that they do not include effects of diversions, imports, storage, or other human management of the water resource.

VIC Model Outputs and Limitations

The following key output parameters are produced on a daily and monthly time-step:

- Temperature, precipitation, runoff, base flow, evapotranspiration, soil moisture, and snow water equivalent on grid-cell and watershed basis
- Routed stream flow at major flow locations to the Sacramento and San Joaquin valleys

~~The regional hydrologic modeling described using the VIC model is intended to generate changes in inflow magnitude and timing for use in subsequent CalSim-II modeling. While the model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local scale phenomenon. The VIC model is currently best applied for the regional scale hydrologic analyses. Several limitations to long-term gridded meteorology related to spatial-temporal interpolation and bias correction should be considered. In addition, the inputs to the model do not include transient trends in the vegetation or water management that may affect stream flows; they should only be analyzed from a naturalized flow change standpoint. Finally, the VIC model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin River watersheds that contribute approximately 80 to 90 percent of the runoff to the Delta; however, in the valley floor, groundwater management and surface water regulation is considerable. Water management models such as CalSim-II should be used to characterize the heavily managed portions of the system.~~

~~Sea-Level Rise~~

~~In the past century, global mean sea level has increased by 17 to 21 centimeters (cm) (7 to 8 inches) (IPCC, 2013). Sea level continues to rise due to a combination of melting glaciers and ice sheets and thermal expansion of seawater as it warms. Global estimates of sea-level rise made in the IPCC 4th Assessment indicate a range of 18 to 59 cm (7.1 to 23.2 inches) this century (IPCC, 2007). Estimates by Rahmstorf (2007) and Vermeer and Rahmstorf (2009) suggest that the sea-level rise may be substantially greater than the IPCC projections. Using empirical models based on the observed relationship between global temperatures and sea levels, which have been shown to better simulate recent observed trends, these studies indicate a mid-range rise this century of 70 to 100 cm (28 to 39 inches), with a full range of variability of 50 to 140 cm (20 to 55 inches).~~

~~Global estimates of sea-level rise made in the most recent assessment by the IPCC 5th Assessment Report (IPCC, 2013) indicate a likely range of 26 to 82 cm (10.2 to 32.3 inches) this century. These ranges are derived from Coupled Model Intercomparison Project Phase 5 (CMIP5) climate projections in combination with process-based models and assessment of glacier and ice sheet contributions. The global sea-level rise projections in the IPCC 5th Assessment Report (IPCC, 2013) are higher than the projections from the IPCC 4th Assessment Report (IPCC, 2007).~~

~~Due to the limitations with the current physical models for assessing future sea-level rise, several scientific groups, including the CALFED Independent Science Board (ISB) (Healy, 2007), recommend the use of empirical models for short- to medium-term planning. Both the CALFED ISB and Climate Action Team 2009 assessments have used the empirical approach developed by Rahmstorf (2007) that projects future sea-level rise rates based on the degree of global warming.~~

~~The sea-level rise estimates by the National Research Council (NRC, 2012) suggested sea-level rise projections at three future times relative to 2000 (2030, 2050, and 2100), along with upper- and lower-bound projections for San Francisco. The sea-level rise by 2030 ranges from 4.3 to 29.7 cm, with a mean sea-level rise of about 14.4 cm. The sea-level rise by 2050 ranges from 12.3 to 60.8 cm, with a mean sea-level rise of about 28 cm. The sea-level rise by 2100 ranges from 42.4 to 166.5 cm, with a mean sea-level rise of about 90 cm. The National Research Council's projections have been adopted by the California Ocean Protection Council as guidance for incorporating sea-level rise projections into planning and decision making for projects in California.~~

~~The 2012 National Oceanic and Atmospheric Administration (NOAA) report on Global Sea Level Rise Scenarios for the United States National Climate Assessment (Parris et al., 2012) includes four global sea-level rise scenarios ranging from 20 to 200 cm (8 inches to 7 feet) by 2100 using mean sea level in 1992 as a baseline. The sea-level rise projections in the most recent National Climate Assessment (2014) report was informed by the 2012 NOAA sea-level projections (Parries et al., 2012).~~

~~In December 2013, the U.S. Army Corps of Engineers (USACE) issued updated guidance on incorporating sea-level change in civil works programs (USACE, 2013). The guidance document reviews the existing literature and suggests use of a range of sea-level change projections, including the high probability of accelerating global sea-level rise. The ranges of future sea-level rise were based on the empirical procedure recommended by the NRC (1987) and updated for recent conditions. The three scenarios included in the USACE guidance suggest end-of-century sea-level rise in the range of 20 to 150 cm for San Francisco.~~

~~Using the work conducted by Rahmstorf, the sea-level rise for the WSIP climate projections are approximately 15 cm (range of 12 to 18 cm, or 5 to 7 inches) for 2030 and 45 cm (range of 30 to 60 cm, or 12 to 24 inches) for 2070. The scenarios of 15 cm and 45 cm were selected as representative for 2030 future and 2070 future sea-level rise conditions, respectively, for use in the CalSim-II and DSM2 models. These scenarios fall within the range provided by the NRC report (2012) and other sources that are accepted within the scientific community.~~

~~Development of CalSim-II Models and Datasets~~

~~The hydrology of the Central Valley and operation of the Central Valley Project/State Water Project (CVP/SWP) systems are critical elements in any assessment of changed conditions throughout the Central Valley and in the Sacramento-San Joaquin Delta. Changes to system characteristics such as flow patterns, demands, regulations, and/or Delta configuration will influence the operation of the CVP/SWP reservoirs and export facilities. The operation of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive, and detailed analysis of this interaction often results in new understanding of system responses.~~

~~Modeling tools are required to approximate these complex interactions under future conditions. CalSim-II is a planning model developed by DWR and Reclamation. It simulates the CVP/SWP and areas tributary to the Sacramento-San Joaquin Delta. CalSim-II provides quantitative hydrologic-based information to those responsible for planning, managing, and operating the SWP and CVP. As the official model of those projects, CalSim-II is typically the system model that is used for interregional or statewide analysis in California.~~

~~Climate and sea-level change is incorporated into CalSim-II in two ways: changes to the input hydrology, and changes to the flow-salinity relationship in the Delta due to sea-level rise. The following methods were used to calculate projected CalSim-II inflow data:~~

1. ~~For larger watersheds, which constitute the majority of the total inflow volume in the system, CalSim-II inflows were replaced with projected runoff obtained from VIC model.~~
1. ~~For smaller inflows, for which using direct runoff from VIC was not possible, simulated changes in runoff were applied to the CalSim-II inflows and downstream accretions/depletions as a fractional change from the observed inflow patterns at certain gauged locations (simulated future runoff divided by historical runoff). These fractional changes were first applied for every month of the 82-year period consistent with the VIC simulated patterns. A second order correction was then applied to ensure that the annual shifts in runoff at each location were consistent with that generated from the VIC modeling.~~
2. ~~Water year types and other indices used in system operation decisions by CalSim-II were regenerated using projected flows, precipitation, or temperature as needed in their respective methods.~~
3. ~~Sea-level rise effects on the flow-salinity response in CalSim-II were incorporated by a separate Artificial Neural Network (ANN) for each climate projection (2030 and 2070).~~
4. ~~Sea-level rise effects were used in the regression equations to estimate the flow split between the Sacramento River and Georgiana Slough at times when the Delta Cross Channel (DCC) is open or closed.~~

~~Use of Projected Runoff from VIC~~

~~The stream flows for which VIC bias-corrected, simulated flows were directly used for CalSim-II simulations for the upper watersheds are listed in Table A-1.~~

~~For these locations, a statistical procedure was applied to correct biases in VIC simulations. The process accounted for monthly and annual statistical bias at each flow location in consideration. The steps are described below:~~

1. ~~The monthly and annual bias was evaluated to compare the VIC simulated stream flows to the unimpaired stream flows for each of the flow locations.~~

1. A quantile map was developed that aligned the unimpaired streamflow CDF with the simulated CDF for each simulated month at each location. For each simulated value, the simulated flow was adjusted to equal the unimpaired flow at the same percentile. This method preserved the mean and variance of the unimpaired flows.
2. The monthly values were rescaled (if needed) to ensure that the annual simulated CDF aligned with the unimpaired streamflow CDF. For each simulated annual flow value from Step 2, the flow percentile was adjusted to equal the unimpaired flow at the same percentile. This step ensured that the adjusted stream flows were consistent at the annual scale.
3. A verification check was performed based on the annual flows to ensure that mass balance and corrections were implemented correctly.

Table A-1. River Locations for Upper Watersheds in CalSim-II.

River Locations	CalSim Arc	Basis of Bias Correction
Trinity River at Trinity Lake	I1	Unimpaired inflow
Sacramento River at Shasta Dam	I4	Unimpaired inflow
Feather River at Oroville	I6	CalSim-II inflow[1]
Yuba River at Smartville	I230	CalSim-II inflow (output from YCWA HEC model)
American River at Folsom	I300 + I8	CalSim-II inflow
American River North Fork + Middle Fork	I300	Partitioned from American River (I300 + I8) based on monthly ratios (I300/(I300+I8)) in CalSim-II inflow
American River South Fork + Local Flow	I8	Partitioned from American River (I300 + I8) based on monthly ratios (I8/(I300+I8)) in CalSim-II inflow
Cosumnes River at Michigan Bar	I501	Unimpaired inflow
Mokelumne River	I504	Developed climate change ratio at Mokelumne River Inflow to Pardee Reservoir (I90) and apply the factor to modify CalSim-II inflow at I504 (output from EBMUDSIM)
Calaveras River at New Hogan	I92	Unimpaired inflow
Stanislaus River at New Melones Dam	I10	CalSim-II inflow
Tuolumne River at New Don Pedro	I81	CalSim-II inflow
Merced River at Lake McClure	I20	Unimpaired inflow
San Joaquin River at Millerton Lake	I18_SJR + I18_FG	CalSim-II inflow
San Joaquin River at Millerton Lake (w/o Fine Gold Creek)	I18_SJR	Partitioned from San Joaquin River inflow toMillerton Lake (I18) based on monthly ratios in CalSim-II inflows
Fine Gold Creek	I18_FG	Partitioned from San Joaquin River at Millerton Lake (I18)

Table A-1. River Locations for Upper Watersheds in CalSim-II.		
River Locations	**CalSim Arc**	**Basis of Bias Correction**
		based on monthly ratios in CalSim-II inflows

Use of Fractional Changes for Climate Data

The existing VIC model at 1/16th degree spatial resolution is insufficient to produce stream flows with good accuracy at small watersheds. Therefore, for smaller watersheds in the system, climate change ratios were used to adjust CalSim-II inflow data obtained from the 2015 SWP delivery capability study (DWR, 2015). Table A-2 lists these small watersheds. The climate change ratios were computed based on VIC simulations using historical, de-trended climate forcing and climate change projections.

Table A-2. River Locations for Small Watershed Tributary in CalSim-II.

Tributary	**CalSim Arc**	**Approach**
Cow Creek	I10801	Developed climate change ratio and used as reference for other locations
Battle Creek	I10803	Used climate change ratio developed based on Cow Creek
Cottonwood Creek	I10802	Developed climate change ratio and used as reference for other locations
Paynes Creek	I11001	Used climate change ratio developed based on Deer Creek
Red Bank Creek	I112	Used climate change ratio developed based on Deer Creek
Antelope Creek	I11307	Used climate change ratio developed based on Deer Creek
Mill Creek	I11308	Used climate change ratio developed based on Deer Creek
Deer Creek	I11309	Developed climate change ratio and used as reference for other locations
Elder Creek	I11303	Used climate change ratio based on Thomes Creek
Thomes Creek	I11304	Developed climate change ratio and used as reference for other locations
Big Chico Creek	I11501	Used climate change ratio developed based on Butte Creek
Lewiston inflow	I100	Not modified
Whiskeytown inflow	I3	Developed climate change ratio and used as reference for other locations
Bear river inflow	I285	Developed climate change ratio and used as reference for other locations
Butte Creek	I217	Developed climate change ratio and used as reference for other locations
Kelly Ridge	I200	Not modified
Fresno River inflow to Hensley Lake	I52	Developed climate change ratio and used as reference for other locations
Chowchilla River inflow to Eastman Lake	I53	Used climate change ratio developed based on Fresno River inflow to Hensley Lake
Stony Creek inflow East Park	I40	Used climate change ratio developed based on inflow to Black Butte
Inflow to Stony Gorge	I41	Used climate change ratio developed based on inflow to Black Butte

Inflow to Black Butte	I42	Developed climate change ratio and used as reference for other locations
[1]CalSim-II inflow data were obtained from DCR 2015 study.		

Updating Water Year Types and Indices

Water year types and other hydrologic indices used in CalSim-II operational decisions were regenerated using the projected flows and temperatures based on VIC simulations. These indices and data they use are listed in Table A-3.

Table A-3. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	Input	CalSim-II File Name	Specification	Raw Data	Raw Data Source	CDEC Station Location/ Station used in VIC for Projected Flows
Forecasting	Folsom Inflow Forecast	American_Runoff_ Forecast.table	Fn(WY precip, known streamflows at the time of forecast)	Unimpaired; Basin Precipitation	CDEC; other DWR	AMERICAN R AT FOLSOM (AMF); Folsom Basin Precipitation (Index of Gaged)
	Oroville Inflow Forecast	Feather_Runoff_ Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	FEATHER RIVER AT OROVILLE (FTO); Feather Basin Precipitation (Index of Gaged)
	Shasta Inflow Forecast	Sacramento_Runoff_ Forecast.table		Unimpaired; Basin Precipitation	CDEC; other DWR	SACTO INFLOW-SHASTA (SIS); Shasta Basin Precipitation (Index of Gaged)
Indices for broad regulatory critieria (simulated with perfect foresight in CalSim-II)	8RI	EightRiver.table	Sum of eight stations monthly flows (SacValleyIndex + SJValleyIndex)	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG
	X2 Days	x2days.table	Based on 8RI PMI	Full Natural Flow; Table of electrical conductivity requirements	CDEC; Table available in spreadsheet	8RI (previous line)
	SacValley Index	SacValleyIndex.table	Sum of four stations monthly flows	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	Sacramento Index	wytypes.table	WQCP 40-30-30	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS
	San Joaquin Index	wytypes.table	WQCP 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index	wytypeSJR.table	WQCP 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
	San Joaquin Index – 5 year average	wytypeSJR5.table	5-year running average of WQCP 60-20-20	Full Natural Flow	CDEC	MRC, SJF, SNS, TLG
Indices and other inputs for Operations policies	Trinity Index	wytypes.table	Based on TNL WY Total	Full Natural Flow	CDEC	TNL
	Shasta Index	wytypes.table	Based on SIS Apr-Jul and WY Totals	Full Natural Flow	CDEC	SIS

Table A-3. Water Year Types and Other Hydrologic Indices Used in CalSim-II.

Item/Index	Input	CalSim-II File Name	Specification	Raw Data	Raw Data Source	CDEC Station Location/ Station used in VIC for Projected Flows
(with regulatory significance)	Feather River Index	wytypes.table	Based on FTO Apr-Jul and WY Totals	Full Natural Flow	CDEC	FTO
	UIFR	UIFR.table	Based on AMF Mar-Nov Totals			AMF
	AmerD893 Index	wytypes.table	Based on AMF Apr-Sep Totals	Full Natural Flow	CDEC	AMF
	Delta Index	Delta_Index.table	Based on Jan-May 8RI	Full Natural Flow	CDEC	AMF, FTO, SBB, YRS, MRC, SJF, SNS, TLG

Incorporating Effects of Sea-Level Rise in CalSim-II through ANN

Determination of flow-salinity relationships in the Sacramento-San Joaquin Delta is critical to both water project operations and ecosystem management. Operation of the CVP/SWP facilities and management of Delta flows often depend on Delta flow needs for salinity standards. Salinity in the Delta cannot be simulated accurately by the simple mass balance routing and coarse time step used in CalSim-II. An Artificial Neural Network (ANN) has been developed (Sandhu et al., 1999) that attempts to mimic the flow-salinity relationships as simulated in DSM2 and provides a rapid transformation of this information into a form usable by CalSim-II. The ANN is implemented in CalSim-II to ensure the operations of the upstream reservoirs and the Delta export pumps satisfy specific salinity requirements in the Delta. A more detailed description of the use of ANNs in the CalSim-II model is provided in Wilbur and Munévar (2001).

The ANN developed by DWR (Sandhu et al., 1999; Seneviratne and Wu, 2007) statistically correlate the salinity results from a particular DSM2 model run to the peripheral flows (Delta inflows, exports, and diversions), gate operations, and an indicator of tidal energy. The ANN is trained on DSM2 results that may represent historical or future conditions using a full circle analysis (Seneviratne and Wu, 2007). For example, a future sea-level rise may significantly affect the hydrodynamics of the system. The ANN is able to represent this new condition by being retrained using the results from the DSM2 model representing the conditions with the sea-level rise.

The current ANN predicts salinity at various locations in the Delta using the following parameters as input: Northern inflows, San Joaquin River inflow, DCC gate position, total exports and diversions, net Delta consumptive use, an indicator of the tidal energy, and San Joaquin River at Vernalis salinity. Northern inflows include Sacramento River at Freeport flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (eastside streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include those at the SWP Banks Pumping Plant, the CVP Jones Pumping Plant, and Contra Costa Water District (CCWD) diversions including diversions to Los Vaqueros Reservoir. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory of antecedent conditions in the Delta. The ANN model approximates DSM2 model-generated salinity at the following key locations for modeling Delta water quality standards: X2, Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project, and Los Vaqueros diversion locations.

~~The ANN may not fully capture the dynamics of the Delta under conditions other than those for which it was trained. It is possible that the ANN will exhibit errors for flow regimes beyond those for which it was trained. Therefore, a new ANN is needed for any sea-level rise scenario or any new Delta configuration (physical changes in Delta) that may result in changed flow-salinity relationships in the Delta.~~

~~Two ANNs, retrained by the DWR Bay-Delta Modeling staff, each representing one of the two sea-level rise scenarios assumed in the WSIP (15 cm at 2030 and 45 cm at 2070) were used with the two CalSim-II models that represent 2030 and 1070 conditions. ANN retraining involved the following steps:~~

- ~~The DSM2 model was corroborated using the UnTRIM model to account for sea-level rise effects, enabling a one-dimensional model, DSM2, to approximate changes observed in a three-dimensional model, UnTRIM.~~
- ~~A range of example long-term CalSim-II scenarios were developed to provide a broad range of boundary conditions for the DSM2 models.~~
- ~~Using the grid configuration and the correlations from the corroboration process, several 16-year (water years 1976-1991) DSM2 planning runs were simulated based on the boundary conditions from the identified CalSim-II scenarios to create a training dataset for each new ANN.~~
- ~~ANNs were trained using the Delta flows and Delta cross-channel operations from CalSim-II, along with the salinity (electrical conductivity [EC]) results from DSM2 and the Martinez tide.~~
- ~~The training dataset was divided into two parts: one was used for training the ANN, and the other for validating.~~
- ~~Once the ANN was ready, a full circle analysis was performed to assess the performance of the ANN and ensure similar results were obtained from CalSim-II and DSM2.~~

~~A detailed description of the ANN training procedure and the full circle analysis is provided in DWR's 2007 annual report (Seneviratne and Wu, 2007).~~

~~Incorporating Effects of Sea-Level Rise in Sacramento River-Georgiana Slough Flow Split~~

~~The sea-level rise expected by 2030 or 2070 would change the flow split between Sacramento River and DCC-Georgiana Slough flow. This requires modification of the linear regression equations used to estimate DCC-Georgiana Slough flow in CalSim-II. Table A-5 shows the equations to be used in CalSim-II for each sea-level rise condition. The changes to the regression coefficients are made in the .\common\Delta\Xchannel\xc-gates.wresl file.~~

Table A-5. Regression Results for DSM2 Monthly Averaged Cross-Delta flow (Y-axis) versus Sacramento River Flow Upstream of Sutter Slough (X-axis).

#	Scenario	DCC Open		DCC Closed	
		Slope	Intercept	Slope	Intercept
1	Current Conditions DSM2[1]	0.3217	1050.7	0.1321	1086.6
2	15 cm or 45 cm Sea-Level Rise DSM2[2]	0.3187	1094.6	0.1316	1102.0

[1] Regression coefficients from 2009 DSM2 recalibration model.

[2] Regression coefficients from 2009 DSM2 recalibration model under 15cm and 45cm SLR using BDCP 040110 No Action CalSim-II results.

The equations to be used with current sea level are:

*Cross-Delta flow (i.e. DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

where:

slope = 0.3217 , intercept = 1051 cfs when DCC is open

slope = 0.1321 , intercept = 1087 cfs when DCC is closed.

Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:

*Georgianna Sl. Flow = 0.1321*Qsac + 1087 (whether DCC is open or closed)*

and

*DCC Flow = 0.1896*Qsac - 36 when DCC is open*

DCC Flow = 0.0 when DCC is closed

The equations to be used with sea-level rise of 15 cm or 45 cm are:

*Cross-Delta flow (i.e. DCC flow plus Georg. Sl. Flow) = (slope * Sac Flow) + intercept*

where

slope = 0.3187 , intercept = 1095 cfs when DCC is open

slope = 0.1316 , intercept = 1102 cfs when DCC is closed

~~Assuming the Georgianna Slough flow portion would remain the same whether DCC is open or closed, the split between Georgianna Slough and DCC is calculated as:~~

~~*Georgianna Sl. Flow = 0.1316*Qsac + 1102 (whether DCC is open or closed)*~~

~~and~~

~~*DCC Flow = 0.1871*Qsac - 7 when DCC is open*~~

~~*DCC Flow = 0.0 when DCC is closed*~~

~~DSM2 Modeling~~

~~Several tools are available to simulate hydrodynamics and water quality in the Delta. Some tools simulate detailed processes with two- or three-dimensional representation; however, they are computationally intensive and have long runtimes. Other tools approximate certain processes and have short runtimes, while only compromising slightly on the accuracy of the results. For a long-term planning level analysis, the simulation period should cover a range of hydrologic and tidal conditions to understand the resulting changes than can occur over a number of years. A tool with short run-times but that can simulate the changed hydrodynamics and water quality in the Delta accurately is ideal. DSM2, a one-dimensional hydrodynamics and water quality model, fits these criteria.~~

~~DSM2 has a limited ability to simulate two-dimensional features, such as open water bodies (reservoir, flooded islands, tidal marshes, etc.), and three-dimensional transport processes, such as gravitational circulation, which is found to increase with sea-level rise in the estuaries. Therefore, DSM2 must be recalibrated or corroborated based on a dataset that accurately represents the conditions in the Delta with sea-level rise. Since the future sea-level rise conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics is to simulate the Delta with higher dimensional models which can resolve the three-dimensional processes well. These models generate the datasets needed to corroborate or recalibrate DSM2 under the future conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy.~~

~~Figure A-2 shows a schematic of how the hydrodynamics and water quality modeling is formulated under the sea-level rise conditions. UnTRIM Bay-Delta Model, a three-dimensional hydrodynamics and water quality model, was used to simulate the sea-level rise effects on hydrodynamics and salinity transport under the historical operations in the Delta.~~

~~The results from the UnTRIM model were used to corroborate DSM2 so that DSM2 can simulate the effect of sea-level rise consistent with a higher-order model that can better resolve estuarine processes.~~

The corroborated DSM2 was used to simulate hydrodynamics and water quality in the Delta by integrating sea-level rise effects over an 82-year period (water years 1922-2003), using the hydrological inputs and exports determined by CalSim-II under the projected operations. It was also used to retrain ANNs to emulate modified flow-salinity relationships in the Delta.

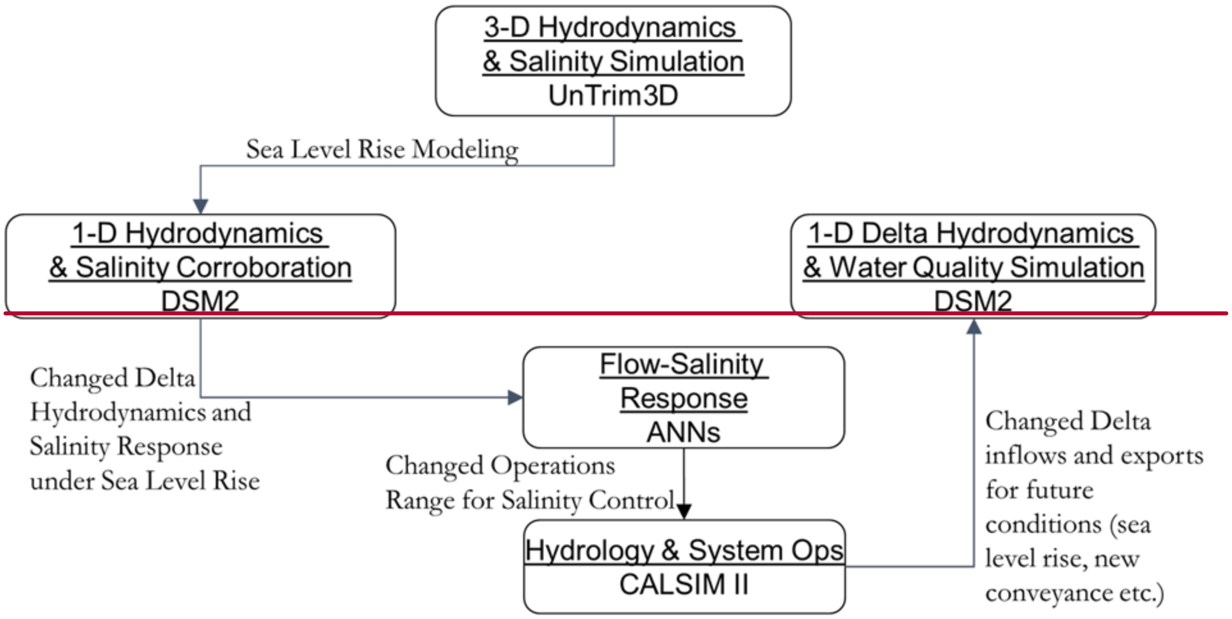

Figure A-2. Delta hydrodynamics and Water Quality Modeling Methodology under Sea-Level Rise.

Based on the outcome of the sea-level rise corroboration, an updated DSM2 model setup for each of the 2030 and 2070 projections was prepared for use in the WSIP analyses to account for the projected 15-cm and 45-cm sea-level rise.

Using the results from the UnTRIM models, two correlations were developed to compute the resulting stage and EC at the Martinez location for each sea-level rise scenario. Table A-6 shows the Martinez stage and EC correlations for the 15-cm and 45-cm sea-level rise scenarios. It also shows the lag in minutes between the baseline stage or EC and the resulting stage or EC under the scenarios with sea-level rise. The regressed baseline stage or EC time series must be shifted by the respective lag time noted in Table A-6.

As noted earlier, adjusted astronomical tide at Martinez was used as the downstream stage boundary in the DSM2 planning simulation representing the current Delta configuration without sea-level rise. This stage time series was modified using the stage correlation equation identified in Table A-6 for use in planning simulations with 15-cm and 45-cm sea-level rise. The EC boundary condition in a DSM2 planning simulation was estimated using the G-model based on the monthly net Delta outflow simulated in CalSim-II and the pure astronomical tide (Ateljevich, 2001).

Although the rim flows and exports are patterned on a daily step in DSM2, the operational decisions, including exports, are still on a monthly time step. This means that the net Delta outflow may or may not meet the standards on a daily time step. Therefore, to estimate the EC boundary condition at Martinez, monthly net Delta outflow simulated in CalSim-II was used. For planning simulations with 15-cm and 45-cm sea-level rise, the EC time series from the G-model was adjusted using the EC correlations for each sea-level rise scenario listed in Table A-6 to account for the anticipated changes at Martinez.

Table A-6. Correlations for Martinez Stage.

Climate Condition	Martinez Stage (ft NGVD 29)		Martinez EC (µS/cm)	
	Correlation	Lag (min)	Correlation	Lag (min)
2030 Future Condition	Y = 1.0033*X + 0.47	-1	Y = 0.9954*X + 556.3	0
2070 Future Condition	Y = 1.0113*X + 1.4	-2	Y = 0.98*X + 1778.9	-2

Notes:
NGVD = National Geodetic Vertical Datum
X = 2015 Historical Condition Martinez stage or EC
Y = Scenario Martinez stage or EC

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Appendix B
Description of CalSim-II Model

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CalSim-II is a water operations planning model developed by DWR and Reclamation. It simulates the SWP and the CVP, and areas tributary to the Sacramento-San Joaquin Delta. CalSim-II provides quantitative, hydrologic-based information to agencies responsible for planning, managing, and operating the SWP and federal CVP. As the official model for those projects, CalSim-II is typically the system model used for any inter-regional or statewide analysis in California. CalSim-II uses descriptive optimization and rules-based simulation techniques to route water through a CVP/SWP system network representation. The network includes over 300 nodes and over 900 arcs (i.e., stream or canal reaches), representing 24 surface water reservoirs and the interconnected flow system.

The CVP, operated by Reclamation and local operating authorities, is composed of 20 reservoirs with a combined storage capacity of more than 11 million acre-feet, 11 power plants, and more than 500 miles of major canals and aqueducts. The SWP, operated and maintained by DWR, is composed of 17 pumping plants, 8 hydroelectric power plants, 32 storage facilities, and more than 660 miles of aqueducts and pipelines. The SWP serves more than two-thirds of the state's population and approximately 600,000 acres of irrigated farmland in the Feather River area, San Francisco Bay Area, San Joaquin Valley, Central California Coast, and Southern California. The managed facilities provide water supply to contracting agencies, flood control, recreation, fish and wildlife enhancement, power generation, and salinity control in the Sacramento-San Joaquin Delta. The major water facilities in the Central Valley included in CalSim-II are:

- Shasta Lake
- Keswick Reservoir and Red Bluff Diversion Dam on the Sacramento River
- Trinity Lake on the Trinity River
- Whiskeytown Reservoir on Clear Creek
- Lake Oroville and Thermalito Afterbay on the Feather River
- Folsom Lake and Folsom South Canal on the American River
- San Luis Reservoir
- New Melones Lake on the Stanislaus River
- Millerton Lake on the San Joaquin River

CalSim-II operates on a monthly time step from water year 1922 through 2003. It uses historical streamflow data, which have been adjusted to describe existing and future projected conditions, including changes in water and land use that have occurred or may occur in the future. The model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period.

CalSim-II models all areas that contribute major flows to the San Francisco Bay. The geographical coverage includes the Sacramento River Valley, the San Joaquin River Valley, the Sacramento-San Joaquin Delta, the Upper Trinity River, and the CVP and SWP service areas.

The model operates the reservoirs and pumping facilities of the SWP and CVP to assure the flow and selected water quality requirements for these systems are met. For a projected condition, the model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development. The model output includes monthly reservoir releases, channel flows, reservoir storage volumes, water diversions, Delta pumping, and parameters describing San Joaquin River and Delta water quality conditions.

Model Mathematics

CalSim-II represents California's water resources system as a linked network of nodes and arcs. CalSim-II routes water through the arcs according to a set of user-defined priorities. CalSim-II uses optimization techniques to route water through the network. A linear programming/mixed integer linear programming (MILP) solver determines an optimal set of decisions for each time period given a set of priority weights and system constraints. The physical description of the system is expressed through a user interface with tables representing the system characteristics. The priority weights and basic constraints are also entered in the system tables.

Hydrology

Reservoir inflows, stream gains, diversion requirements, irrigation efficiencies, return flows, and groundwater operation are all components of the hydrology for CalSim-II.

The monthly time step simulations are conducted over the 82-year period using the adjusted historical rainfall/runoff data. This approach incorporates the important assumption that the next 82 years will have similar rainfall/snowmelt amount, range of variability, and pattern, both within-year and from year to year, as the period 1922 through 2003.

The hydrology used for CalSim-II may be adjusted for the impacts of climate change. Techniques for making these adjustments and datasets available for use with CalSim-II are provided in Appendix A.

Demands

Demands are preprocessed independent of CalSim-II and may vary according to the specified level of development (e.g., 2015, 2030) and according to hydrologic conditions. Demands are typically input to a model as a monthly time series. Demands are classified as CVP, SWP, local project, or non-project. CVP and SWP demands are classified according to water delivery rules and shortage criteria, recognizing priorities of water rights, refuge deliveries, settlement or exchange contracts, and other delivery contract types.

Demands are disaggregated into project demands and non-project demands. Project demands are subject to reduced water allocations based on CVP and SWP contract provisions, while non-project demands are satisfied from sources other than project storage and project conveyance facilities and are reduced as a function of water availability in the absence of project operations.

The demands used for CalSim-II can be adjusted for the impacts of climate change if desired. However, due to the complex response of demands and related water operations associated with climate change, adjustments in demands are not required for the WSIP.

Environmental Water Requirements

Environmental water requirements are included in the model where appropriate, including minimum reservoir storage requirements, minimum in-stream flows, and deliveries to national wildlife refuges and wildlife management areas that are stipulated in current regulatory requirements and discretionary interagency agreements.

Allocation Decisions

CalSim-II uses allocation logic for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. The delivery logic is intended to simulate actual operations, and uses runoff forecast information that incorporates uncertainty and standardized rule curves (i.e., a water supply index versus a demand index curve). The rule curves relate forecasted water supplies to deliverable demand, and then use deliverable demand to assign subsequent delivery levels to estimate the water available for delivery and carryover storage. Updates of delivery levels occur monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as runoff forecasts become more certain. The south-of-Delta SWP delivery is determined based on water supply parameters and operational constraints. The CVP system-wide delivery and south-of-Delta delivery are determined similarly using water supply parameters and operational constraints, with specific consideration for export constraints.

Reservoir System Operation

CalSim-II requires operating rules to release flows to meet water demands and water quality standards. Reservoirs are operated using rule curves that represent the desired monthly storage levels according to flood-space filling requirements. The rule curves have been derived from historical hydrologic conditions, and may not be appropriate if there are significant changes to system operations or if there are changes from the historical reservoir inflow hydrology. Reservoirs provide flood control capacity during the high runoff season (i.e., winter and spring), when they need to have flood space available. This flood control space requirement limits the amount of water stored during the wet season and available to deliver for other uses later in the year.

Delta

The State Water Board specifies water quality standards for the Delta. The CVP and SWP share the obligation to meet these standards as defined by the COA. Salinity standards must be converted into flow equivalents to be modeled in CalSim-II. However, flow-salinity relationships in the Delta involve complex dynamics based on the hydraulics of the Delta under different flow levels and durations. CalSim-II uses DWR's Artificial Neural Network (ANN) model to simulate flow-salinity relationships for the Delta by estimating salinity at water quality stations in the Delta. The ANN model is a set of equations and logic used to approximate the flow-salinity relationships of the more complex DSM2 model. The ANN estimates electrical conductivity at the following four locations for the purpose of modeling Delta water quality standards:

- Old River at Rock Slough
- San Joaquin River at Jersey Point
- Sacramento River at Emmaton
- Sacramento River at Collinsville

For its estimates, the ANN model considers antecedent conditions up to 148 days, and considers a carriage-water effect associated with Delta exports.

CalSim-II passes antecedent (i.e., previous month) flow conditions and known (or estimated) current month flows to an ANN dynamic link library. The dynamic link library returns coefficients for a linear constraint that binds Sacramento River Delta inflows to Delta exports based on a piecewise-linear approximation of the flow-salinity relationship.

Surface Water/Groundwater Interaction

Groundwater has a limited representation in CalSim-II. On the Sacramento Valley floor, groundwater is explicitly modeled in CalSim-II using a multiple-cell approach based on depletion study area boundaries, resulting in 12 groundwater cells in the model. Stream-aquifer interaction, groundwater pumping, recharge from irrigation, and sub-surface flow between groundwater cells are calculated at each time step. All other groundwater flow components are pre-processed and represented in CalSim-II as a fixed time series. In areas of high groundwater elevation, CalSim-II calculates groundwater inflow to the stream as a function of the groundwater head and stream stage. In areas of low groundwater elevation, where the groundwater table lies below the streambed, CalSim-II assumes the stream and aquifer are hydraulic disconnected. In this case, seepage from streams depends only on stream stage.

Regulatory Conditions

The following sections describe common regulatory requirements represented in CalSim-II to reflect the current regulatory environment.

Water Rights

The State Water Board's Water Quality Control Plan (WQCP) and other applicable water rights decisions, as well as other agreements, are important factors in determining the operations of both the CVP and the SWP.

Historically, approximately 90 percent of the CVP water has been delivered to agricultural users, including to prior water rights holders. Total annual contracts for CVP water exceed 9 million acre-feet per year, including over 1 million acre-feet per year of Friant Division Class II supply, which is generally available only in wet years. The CVP also delivers water from the San Joaquin River to CVP contractors and water rights holders located along the Madera and Friant Kern canals. Water from New Melones

Reservoir is used by water rights holders in the Stanislaus River watershed and CVP contractors located in the northern San Joaquin Valley. In addition, water is conveyed via the Sacramento and American rivers to CVP contractors and water rights holders along the Sacramento and American rivers.

The SWP delivers water to water rights holders in the Feather River Service Area prior to meeting its other contracts. The contract entitlement in CalSim-II for the Feather River Service Area water rights holders downstream of Lake Oroville is 948 TAF per year in non-drought years; this can drop to 630 TAF per year when deficiencies of up to 50 percent are imposed in drought years on some parts of the contract amount. The historical 24-year average annual SWP deliveries to the Feather River Service Area including the senior water rights holders downstream of Lake Oroville are 840 TAF per year. CalSim-II represents this by imposing 50 percent deficiencies in 1977, 1988, and 1991. In non-drought years, the land use-based demand is usually significantly less than the contract entitlement.

Water Service Contracts and Deliveries

The CVP has 253 water service contracts consisting of settlement contracts, agricultural water service contracts, urban water service contracts, and refuge requirements. CVP contracts south of the Sacramento-San Joaquin Delta consist of exchange contracts, agricultural service contracts, and M&I service contracts.

The SWP has 29 long-term contracts for water supply totaling about 4.2 million acre-feet annually, of which about 4.1 million acre-feet are for contracting agencies with service areas south of the Sacramento-San Joaquin Delta. About 70 percent of this amount is the contract entitlement for urban users and the remaining 30 percent for agricultural users. CalSim-II allocations are set per the Monterey Agreement criteria, which imposes any deficiencies equally between agricultural and M&I requests, as a percentage of each contract amount.

Coordinated Operations Agreement

The COA is both an operations agreement and a water rights settlement defined by State Water Board Decision 1485. Decision 1485 ordered the CVP and SWP to guarantee certain conditions for water quality protection for agricultural, M&I, and fish and wildlife uses.

The purpose of the COA is to ensure that the CVP and the SWP each obtain its share of water from the Delta and bear its share of obligations to protect the other beneficial uses of water in the Delta and Sacramento Valley. Coordinated operation by agreed-upon criteria can increase the efficiency of both the CVP and the SWP.

COA sharing formulas are used as constraints in the linear programming formulation within the model. These formulas or constraints ensure that the COA is maintained in the model.

Central Valley Project Improvement Act 3406(b)(2) Operations

According to the 1992 Central Valley Project Improvement Act (CVPIA), the CVP must "dedicate and manage annually 800,000 acre-feet of Central Valley Project yield for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes and measures authorized by this title; to assist the State of California in its efforts to protect the waters of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary; and to help to meet such obligations as may be legally imposed upon the Central Valley Project under State or Federal law following the date of enactment of this title, including but not limited to additional obligations under the Federal Endangered Species Act." This dedicated and managed water, or (b)(2) water as it is called, is water that the USFWS, in consultation with Reclamation and other agencies, has at its disposal to use to meet the primary restoration purposes of CVPIA 3406(b)(2), the CVP's WQCP obligations, and any legal requirements imposed on the CVP after 1992. CVPIA 3406 (b)(2) water may be managed to augment river flows and also to curtail pumping in the Delta to supplement the WQCP requirements.

Decision 1641 Operations

The December 1994 Accord committed the CVP and SWP to a set of Delta habitat protection objectives that were incorporated into the 1995 WQCP and later, along with the Vernalis Adaptive Management Plan, were implemented by Decision 1641. The actions the CVP and SWP took implementing Decision 1641 significantly reduced the export water supply of both projects. Significant elements in the Decision 1641 standards include X2 standards, export/inflow ratios, real-time Delta Cross Channel operation, and San Joaquin flow standards.

Operations Under 2008 USFWS and 2009 NMFS Service Biological Opinions

USFWS Biological Opinion Actions

The USFWS Biological Opinion for delta smelt was released on December 15, 2008, in response to Reclamation's request for formal consultation with the USFWS on the coordinated operations of the CVP and SWP in California. To develop CalSim-II modeling assumptions for the reasonable and prudent alternative (RPA) documented in this Biological Opinion, DWR led a series of meetings that involved members of fisheries and project agencies. This group prepared the assumptions and CalSim-II implementations to represent the RPA in a No Action Alternative CalSim-II simulation. The following actions of the USFWS Biological Opinion RPA have been included in the No Action Alternative CalSim-II simulations:

- Action 1: Adult Delta Smelt migration and entrainment. Impose a fixed duration condition on OMR flow to protect pre-spawning adult delta smelt from entrainment during the first flush, and to provide advantageous hydrodynamic conditions early in the migration period. (RPA Component 1, Action 1 – First Flush)
- Action 2: Adult Delta Smelt migration and entrainment. Manage OMR flow using an adaptive process to tailor protection to changing environmental conditions after Action 1. As in Action 1, the intent is to protect pre-spawning adults from entrainment

and, to the extent possible, from adverse hydrodynamic conditions. (RPA Component 1, Action 2)

- Action 3: Entrainment protection of larval and juvenile Delta Smelt. Manage OMR flow to minimize the number of larval delta smelt entrained at the facilities by managing the hydrodynamics in the Central Delta flow levels pumping rates spanning a time sufficient for protection of larval delta smelt. Because protective OMR flow requirements vary over time (especially between years), the action is adaptive and flexible within appropriate constraints. (RPA Component 2)
- Action 4: Estuarine habitat during fall. Improve fall habitat for delta smelt by managing X2 through increasing Delta outflow during fall when the preceding water year was wetter than normal. This will help return ecological conditions of the estuary to that which occurred in the late 1990s when smelt populations were much larger. (RPA Component 3)
- Action 5: Temporary spring Head of Old River barrier and the Temporary Barrier Project. Manage the barriers to minimize entrainment of larval and juvenile delta smelt at Banks and Jones or from being transported into the South and Central Delta, where they could later become entrained. (RPA Component 2)

A detailed description of the assumptions that have been used to model each action is included in the technical memorandum “Representation of U.S. Fish and Wildlife Service Biological Opinion Reasonable and Prudent Alternative Actions for CalSim-II Planning Studies,” prepared by an interagency working group under the direction of the lead agencies (Reclamation, 2015).

NMFS Biological Opinion Salmon Actions

The NMFS Salmon Biological Opinion on long-term operations of the CVP and SWP was released on June 4, 2009. To develop CalSim-II modeling assumptions for the RPAs documented in this Biological Opinion, DWR led a series of meetings that involved members of fisheries and project agencies. This group has prepared the assumptions and CalSim-II implementations to represent the RPA in the No Action Alternative CalSim-II simulations for future planning studies. The following NMFS Biological Opinion RPAs have been included in the No Action Alternative CalSim-II simulations:

- Action I.1.1: Clear Creek spring attraction flows. Use pulse flows in May and June to encourage spring-run movement to upstream Clear Creek habitat for spawning.
- Action I.4: Wilkins Slough operations. Enhance the ability to manage temperatures for anadromous fish below Shasta Dam by operating Wilkins Slough in the manner that best conserves the dam’s cold water pool for summer releases.
- Action II.1: Lower American River flow management. Implement a flow schedule in the Lower American River to provide minimum flows for all steelhead life stages.
- Action III.1.4: Stanislaus River flows below Goodwin Dam. Implement operational criteria for Eastside Division to ensure viability of the steelhead population on the Stanislaus River, and halt or reverse adverse modification of steelhead critical habitat.

- Action IV.1.2: Delta Cross Channel (DCC) gate operations. Modify DCC gate operation to reduce direct and indirect mortality of emigrating juvenile salmonids and green sturgeon in November, December, and January.
- Action IV.2.1: San Joaquin River flow requirements at Vernalis and Delta export restrictions. Increase the inflow to export ratio to reduce the vulnerability of emigrating CV steelhead within the lower San Joaquin River to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta. Enhance the likelihood of salmonids successfully exiting the Delta at Chipps Island by creating more suitable hydraulic conditions in the main stem of the San Joaquin River for emigrating fish, including greater net downstream flows.
- Action IV.2.3: Old and Middle river flow management. Reduce the vulnerability of emigrating juvenile winter-run, yearling spring-run, and CV steelhead within the lower Sacramento and San Joaquin rivers to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta.

Action I.2.1 is a performance measure rather than an operational action. It calls for a percentage of years to meet certain specified end-of-September and end-of-April storage and temperature criteria resulting from the operation of Lake Shasta. No specific CalSim-II modeling code is implemented to simulate the performance measures identified; CalSim-II results are evaluated to determine performance.

A detailed description of the assumptions that have been used to model each action is included in the technical memorandum “Representation of National Marine Fisheries Service Biological Opinion Reasonable and Prudent Alternative Actions for CalSim-II Planning Studies,” prepared by an interagency working group under the direction of the lead agencies (Reclamation, 2015).

CDFW Incidental Take Permit (ITP) for Longfin Smelt

CDFW has issued an ITP to the SWP for protection of Longfin Smelt under the California Endangered Species Act (CDFW 2009). The permit includes a number of conditions on flow, entrainment, management, salvage, and monitoring. CalSim-II does not include specific SWP operations criteria for these conditions, but for modeling purposes the criteria imposed for the two federal Biological Opinions are considered to provide compliance with the ITP conditions.

Minimum Flow for Navigation — Wilkins Slough

Historical commerce on the Sacramento River resulted in the requirement to maintain minimum flows of 5,000 cfs at Chico Landing to support navigation. No commercial traffic currently travels between Sacramento and Chico Landing, and USACE has not dredged this reach to preserve channel depths since 1972. However, long-time water users diverting from the river have set their pump intakes just below this level. Therefore, the CVP is operated to meet the navigation flow requirement of 5,000 cfs to Wilkins

Slough (i.e., the gaging station on the Sacramento River) under all but the most critical water supply conditions to facilitate pumping.

State Water Resources Control Board Water Rights Order 90-05 and Water Rights

Order 91-01

In 1990 and 1991, the State Water Board issued Water Rights Orders 90-05 and 91-01, modifying Reclamation's water rights for the Sacramento River. The orders included a narrative water temperature objective for the Sacramento River and stated that Reclamation shall operate Keswick and Shasta dams and the Spring Creek Power Plant to meet a daily average water temperature of 56 degrees Fahrenheit at Red Bluff Diversion Dam in the Sacramento River during periods when higher temperatures would be harmful to fisheries.

Under the orders, the water temperature compliance point may be modified when the objective cannot be met at Red Bluff Diversion Dam. In addition, Order 90-05 modified the minimum flow requirements initially established in the 1960 MOA for the Sacramento River below Keswick Dam.

Flood Control

Monthly flood control space requirements are provided by USACE for flood control operation of reservoirs modeled in CalSim-II.

State Water Project Monterey Agreement

The 1994 Monterey Agreement revised the water management strategy of the SWP and its contractors, and eventually led to SWP contract amendments. The Monterey Agreement changed the allocation procedure of SWP deliveries so that cuts would be made proportionally to all SWP contractors, authorized the transfer of 130,000 acre-feet of agricultural contract amounts to M&I contractors, aggregated several contractual obligations for water delivery into one water type (Article 21), and resulted in Kern County Water Agency's assumption of the Kern Water Bank.

Documentation and Peer Review

Many sources of information document the CalSim-II Model. The 2008 Operations Criteria and Plan Biological Assessment (Reclamation, 2008) and the Coordinated Long-Term Operations of the Central Valley Project and State Water Project (Reclamation, 2015) provide detailed descriptions and applications of CalSim-II. In addition, two major peer reviews of the model have been conducted to evaluate the applicability of CalSim-II to the CVP/SWP system and California water management (DWR and Reclamation, 2004).

Other documents describing the features and use of CalSim-II are:

- An analysis of an historical operations simulation (DWR, 2003)
- A sensitivity analysis of selected parameters upon model results (DWR, 2005)
- An analysis of the significance of the simulation time step to the estimated SWP delivery amounts (DWR, 2005).
- CALFED Common Model Package (CALFED Bay-Delta Program, 2005)

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Appendix C
Guidance Documents
for Benefit-Cost Analysis

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Guidance Documents for Benefit-Cost Analysis

Numerous textbooks and documents provide general direction for benefit cost analysis. Five documents specifically related to benefit-cost analysis of water resources projects are summarized below.

Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G)

In 1983, the U.S. Water Resources Council published the P&G. The P&G is the most cited and used economic guidance for water-related projects. It was developed for the water-related projects of Reclamation, USACE, the Tennessee Valley Authority, and USDA's Natural Resources Conservation Service under the Water Resources Development Act (WRDA) of 1974 through Public Law 93-251. Consistency with the P&G, and now, the Principles, Requirements and Guidelines (PR&G) has been critical for most water projects that seek federal cost-sharing participation.

The P&G describes the federal planning process and four accounts that were used to develop and evaluate water resources projects. The accounts were used to quantify and describe the effects of a proposed project from a national perspective, and include: national economic development (NED), environmental quality (EQ), regional economic development (RED), and other social effects (OSE). The NED account was designed to provide quantitative evaluation of a project's benefits and costs from a national perspective. Detailed procedures are included on how to quantify benefits of water supply (i.e., both M&I and irrigation uses), flood damage reduction, navigation, hydropower, and recreation. Quantification methods for benefits to water quality, ecosystem restoration, and emergency response are not provided, although urban water quality is discussed within urban water supply, and some aspects of emergency response are discussed within flood damage. Agencies including Reclamation and USACE have used the P&G as the basis for more detailed and comprehensive policies, directives, and regulations for evaluating benefits and costs of water resources projects.

In Section 2031 of the 2007 WRDA, Congress directed the Secretary of the Army to revise the P&G. During the process of revising the P&G, lead responsibility was reassigned to the Council on Environmental Quality (CEQ). The CEQ released its "Proposed National Objectives, Principles and Standards for Water and Related Resources Implementation Studies" in December 2009. Among the proposed changes to the NED account was a minimum benefit cost ratio of 1.5 for project consideration.

The CEQ's description of proposed changes states that the revised Principles and Standards include a number of important changes that modernize the current approach to water resources development in the United States, which include:

- Achieving Co-Equal Goals: While the 1983 standards placed greatest emphasis on economic development, the new approach calls for development of water resources projects based on sound science that maximize net national economic, environmental, and social benefits.
- Considering Monetary and Non-Monetary Benefits: The revised Principles and Standards consider both monetary and non-monetary benefits to justify and select a project that has the greatest net benefits—regardless of whether those benefits are monetary or non-monetary. The Principles and Standards do not specify how monetary and non-monetary benefits are to be combined or weighed.
- Avoiding the Unwise Use of Floodplains: The decision to modify water resources and floodplains will be based on evaluations of the services gained and lost by such an action. Only those actions that provide a net benefit will be further pursued or recommended for construction. For the first time such evaluations must give full and equal consideration to nonstructural approaches that can solve the flooding problem without adversely impacting floodplain functions.
- Increasing Transparency and "Good Government" Results: The revised Principles and Standards are intended to promote the transparency of the planning and implementation process for water resource development projects in this country.

The Final Principles, Requirements and Guidelines (PR&G) were published in March 2013 (CEQ, 2014). Chapter 2 states:

> *"It is important that potential Federal investments be evaluated for their performance with respect to the Federal Objective using a common framework. Evaluation methods should be designed to ensure that potential Federal investments in water resources are justified by public benefits, particularly in comparison to costs associated with those investments. Such methods should apply an ecosystem services approach in order to appropriately capture all effects (economic, environmental and social) associated with a potential Federal water resources investment.*
>
> *Services and effects of potential interest in water resource evaluations could include, but are not limited to: water quality; nutrient regulation; mitigation of floods and droughts; water supply; aquatic and riparian habitat; maintenance of biodiversity; carbon storage; food and agricultural products; raw materials; transportation; public safety; power generation; recreation; aesthetics; and educational and cultural values. Changes in ecosystem services are measured monetarily and non-monetarily, and include quantified and unquantified effects.*
>
> *Heretofore, Federal investments in water resources have been mostly based on economic performance assessments which largely focus on maximizing net economic development gains and typically involve an unduly narrow benefit-cost comparison of the monetized effects. A narrow focus on monetized or monetizable effects is no longer reflective of our national needs, and from this point forward, both quantified and*

unquantified information will form the basis for evaluating and comparing potential Federal investments in water resources to the Federal Objective. This more integrated approach will allow decision makers to view a full range of effects of alternative actions and lead to more socially beneficial investments."

In 2014, CEQ published updated interagency guidelines to implement the new PR&G (CEQ, 2014). The current direction is for individual agencies such as Reclamation or USACE to develop guidelines that are consistent with the interagency guidelines but provide more detailed direction for project evaluation. ~~The U.S~~The U.S. Department of the Interior (USDI) published procedures for its member agencies, including Reclamation, to use for project evaluation (USDI, 2015).

Economic Analysis Guidebook

DWR published the Economic Analysis Guidebook in 2008 (DWR, 2008). The guidebook states:

"Because of its considerable water management partnerships with the federal government, DWR has a policy that all economic analyses conducted for its internal use on programs and projects be fundamentally consistent with the P&G. It is also DWR policy to adopt, maintain, and periodically update its own Economics Analysis Guidebook, which is consistent with the P&G but can also incorporate innovative methods and tools when appropriate."

State policy for benefit cost analysis has differed from federal policy in several ways. First, the state's analysis perspective focuses on California, and some costs and benefits to the nation may not apply or may be calculated a bit differently for California. Second, the state has used a discount rate of 6 percent, whereas the federal government uses a rate for investment in water resources projects that changes annually based on the cost of federal borrowing. Other than these specific differences, DWR intends that its benefit cost analyses will be consistent with the P&G.

DWR has used the Economic Analysis Guidebook as a basis for economic evaluations required in recent proposals for grant funding from the state. Proposals from local water suppliers and other agencies for integrated regional water management and stormwater flood management grants have require such economic analysis. Guidelines for these grant programs provide specific instructions and calculation templates for applicants.

Guidelines for Preparing Economic Analysis for Water Recycling Projects

De Souza et al. (2011) provides useful information and ideas related to surface storage. In particular, it provides information related to the nexus between financial and economic analysis, and offers useful summaries of benefits information in the appendices. For example, it includes summaries of U.S. studies regarding the value of water quality, ecosystem improvements, and recreation.

Planning Guidance Notebook

Engineer Regulation 1105-2-100 (USACE, 2000) is perhaps the most detailed implementation document for the P&G. This document offers guidance for projects that provide flood damage reduction, ecosystem restoration, and recreation. In addition, some of the guidance for storm damage reduction might apply to emergency response. Also, guidance is provided where water quality and recreation result from ecosystem restoration. It has been used extensively around the nation, and methods should be familiar to federal partners in California.

Guidance for estimating most benefits is provided in Appendix E, Civil Works Missions and Evaluation Procedures. Appendix D, Economic and Social Considerations, provides guidance for “other direct benefits” that “are the incidental effects of a project that increase economic efficiency.”

Bureau of Reclamation Economics Guidebook

In 2010, Reclamation’s Technical Workgroup published the Bureau of Reclamation Economics Guidebook (Reclamation, 2010). Reclamation maintains this detailed economic guidance based on the P&G for internal use. The WSIP guidance references some important parts of this guidance. However, the guidebook is a working document. Any potential users should contact Reclamation to obtain updated guidance.

DWR Handbook for Assessing Value of State Flood Management Investments (HAV)

The HAV (DWR, 2014) provides comprehensive guidance on the principles, concepts, and methods that can be used to evaluate flood management investment in California. It provides a good summary of methods for some benefit types, but it is not comprehensive for others.

For flood risk management benefits, the HAV states that “DWR shall use HEC-FDA to estimate urban IR [inundation reduction] benefits” (page 3-14; parentheses added). The WSIP does not require using any specific model, although HEC-FDA is a widely-accepted tool to use for projects with large, urban flood management components. The HAV can be used as a complete reference for the recommended USACE recreation methods, but USACE's 2015 guidance memorandum (USACE, 2014) provides the same guidance with updated 2015 baseline unit values.

For ecosystem benefits, the HAV details USACE's cost-effectiveness/incremental cost approach. This approach could help to document cost-effectiveness and evaluate costs of feasible alternatives as suggested by this the WSIP technical guidance. The HAV does not provide details on the various willingness-to-pay approaches to ecosystem valuation, and instead refers to DWR's Economic Analysis Guidebook (DWR, 2008).

Determining the Economic Value of Water

Published in 2005 by Resources for the Future Press, Determining the Economic Value of Water is a relatively current guide to benefit-cost analysis of water resources investments (Young, 2005). It provides an excellent discussion of the conceptual basis for different methods for quantifying benefits, and the pros and cons of methods.

Griffin (2006) also covers the fundamentals of economic analysis for water resource policy and projects. The book discusses both economic principles and many of the applied concepts included in this technical reference, including methods to quantify and monetize benefits, cost allocation procedures, discounting, and overall project justification. A new edition has been released in 2016.

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Appendix D
Unit Values for Water

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Unit Values for Water

Commission staff has developed unit values for water (in dollars of benefit per acre-foot) that applicants shall use, where applicable, for estimating the willingness-to-pay for water supply and the avoided or alternative cost of water provided for some public benefits by a water storage project. The unit values were developed using two different methods; a statistical analysis of recent water transfers and a structural model of irrigated agricultural production. This approach was originally applied in 2006 (Mann and Hatchett, 2006a; Mann and Hatchett, 2006b) for analysis of environmental water supply costs. The unit values are based on a statistical analysis of water market transaction data from 1992 through 2015, and estimates of unit values of water in agricultural production from SWAP.

Much has changed since the earlier work was completed ten years ago. Actions to protect endangered species have reduced the amount of water that can be exported from the Delta for agricultural and urban use. Commodity prices, and especially rice prices, increased in real terms to record levels in 2009. Real crop price increases should, all else equal, increase the price required for farmers to forego irrigated production and increase the prices bid by farmers for water.

The economic benefits of agricultural water use have also been influenced by continued conversion of annual to perennial crops in the Central Valley. Some perennial crops require a much larger investment per acre than the annual crops they replaced, and land in perennial crops cannot be temporarily idled to reduce water demand in response to reduced water supply or to provide water for transfer to others. San Joaquin Valley acreage in trees, nuts, and grapes increased by almost 300,000 between 2007 and 2012 alone (USDA, 2012). After 2011, California entered an extended period of severe drought that has substantially increased water transfer prices. In 2015, spot market prices reached unprecedented levels. In the future, the Sustainable Groundwater Management Act (SGMA) is expected to increase water scarcity, especially in areas of the San Joaquin Valley, and further increase willingness to pay for water that would be reflected in open market prices.

The unit values are provided for different year types, for different future conditions, and for different locations for the source of the water. The unit values also consider the effects of SGMA after 2040, primarily reduced average annual groundwater supply south-of-Delta, but have not been adjusted for any climate change effects.

To use the unit values for a particular project, an applicant must explain why they apply to the project and, where appropriate, adjust the values based on consumptive use fraction, conveyance costs, and losses required to move the water from the unit values location to the location of demand served by their project. The unit values shall be used consistently across benefit categories for which water delivery or flow is the measure for monetizing benefits and water is provided in similar conditions. Use of unit values could include water supply, but could also include water for ecosystem or other public benefits. In addition, the applicant should demonstrate that beneficiaries of the non-public water supply could commit to paying the cost allocated to them based on the unit values. The unit values do not represent recommended charges to local users of the project's water. Expected project water charges should be based on allocated costs, not directly on benefits. If the project is economical (i.e., the B/C ratio is greater than one) and the cost allocation is completed correctly, planned water charges per unit should be less than the unit values.

Statistical Analysis of Water Market Transactions

Analysis Approach

This section documents the analysis of water transfer prices used to support the unit values. A statistical analysis included 350 individual transfer prices and quantities from 1992 to 2015. The water transfer and price information was compiled from a combination of published and unpublished information. Up to 2006, data were compiled from the Water Strategist© (Stratecon, various years). Additional information was drawn from reports of water transfer program activities, including the Environmental Water Account and the Drought Water Bank (Mann and Hatchett, 2006a). The Water Transfer Level Dataset (University of California at Santa Barbara, 2015) was developed from transactions reported in Water Strategist©, which ended publication in 2010. For 2011 through 2015, prices were obtained using publicly available information from newspaper articles, water board minutes, and district publications, and from a graduate thesis from University of California, Davis (Scheer, 2015).

Several different statistical analyses were developed. A preliminary, aggregate analysis was prepared which estimated annual average price (each transfer weighted by its quantity) for the 1992 through 2015 period as a function of annual hydrologic and economic indicators and trends. The aggregate analysis explored and identified important relationships between hydrologic and economic conditions, land use, and water price.

A number of independent hydrologic variables were tested, including the Sacramento Valley Index, the San Joaquin Valley Index, and binary variables (which take the value of one if a condition is met and zero if not) for dry and/or critical years (DWR, 2016). SWP average allocation was provided by DWR (~~Sou~~DWR, 2015). The real price of rice (USDA, 2015) was assessed for whether it affected the price required for water transfers. Almond acreage (USDA, 2016) was used as an indicator to assess how agriculture's willingness to pay for or willingness to sell water has been affected by acreage that cannot readily be adjusted to variable water supply conditions.

Hydrologic and water supply indicators were also tested using previous-year (lagged) variables to capture how dry conditions in the previous year affect transfer prices. Rice prices and perennial acreage were also tested as lagged variables. For rice, price expectations when water transfer decisions must be made depends on expected price, which in turn is highly influenced by the price of rice in the previous year. Almond acreage includes non-bearing acreage whose full water use may be felt in the next year. All transfer and rice price data were expressed in real dollars using the Gross National Product Implicit Price deflator (Federal Reserve Bank of St. Louis, 2015).

The aggregate analysis tested the hypothesis that a structural change in the market began in 2013. By 2013, the combination of severe drought and inelastic demand for water, driven by population and perennial crops, sharply increased water transfer prices. A variable was defined as the product between a binary variable (assigned the value zero prior to 2013 and one afterward) and a measure of drought severity, being one divided by the San Joaquin River index.

The aggregate price analysis considered factors that affect average price (weighted by quantities) in each year of the 1992 through 2015 period. No transfers observations were identified for water year 2010-11, a wet year, resulting in 22 available observations.

Variables included in the selected price equation were almond acreage lagged one year, the structural change variable, the San Joaquin River index in the previous year, and rice price lagged one year. Other variables were added but were not significant. These independent variables explained 94 percent of the variation in average annual transfer price. The structural change variable alone accounted for most of the variation in annual water prices. The San Joaquin River index in the previous year was significant, and lagged almond acreage and rice price are both significant, but only at the 10-percent level.

Estmated unit values of water from the preliminary aggregate regression analysis alone are shown in Table D-1. This simulation takes advantage of the 1906 through 2015 hydrology in terms of the San Joaquin Valley index during that entire period. For predicting price, it was assumed that the structural change variable continues into the future in all year types except above normal and wet. Perennial acreage does not continue to increase as it has the previous two decades, so the lagged almond acreage variable holds constant at the 2015 level; this assumption is generally consistent with DWR land use forecasts

Table D-1. Preliminary Simulated Annual Average Water Transfer Prices Using Aggregate Regression Equations

Using 1906 to 2015 Hydrology			Sacramento Valley	San Joaquin
Year Type	**Average SJV t**	**Average SJV t-1**	**2030 Price**	**2030 Price**
Wet	4.91	3.44	$170	$254
Above Normal	3.49	3.51	$168	$253
Below Normal	2.78	3.20	$282	$366
Dry	2.27	3.96	$293	$377
Critical	1.65	2.56	$367	$451

Independently of this analysis, a master's thesis published at the University of California at Davis explored factors that affected water transfers and prices in the Sacramento Valley during the recent drought (Scheer, 2015). The thesis work used a survey format to obtain price and quantity information for the 2011 through 2015 period. The analysis included many transfers within the Sacramento Valley that were not included in the preliminary analysis just described. These transfers, which often did not require new permitting, generally had a much lower price than those in the WSIP analysis. Similar to the preliminary WSIP analysis, the thesis found that the water year type in the past year predicts price better than the current year water year type.

A new, combined dataset was created that included all of the data used in the preliminary analysis plus data gathered by Scheer (2015) on temporary transfers from agricultural to M&I use, or to a destination south-of-Delta. A revised regression model used individual observations of transfer quantities and prices, rather than the aggregated weighted average process used in the preliminary analysis. This approach improves on the preliminary analysis in that it uses all the information contained in the observations and can control for variation across regions and across time. A number of improvements were made to the dataset – various binary variables, new explanatory variables, interaction terms, updated data, and various nonlinear (log, quadratic) functional forms – were investigated. Specifically, the following changes were made:

1. The new 2011 to 2015 transfer observations from Sacramento Valley were included in the transfer data set.

~~7.~~2. All transfer observations were assessed for consistency.

~~8.~~3. A series of binary variables were created to control for district (or groups of districts), type of water purchaser or seller, and an identified structural change affecting water shortages. These binary variables identified

    - ~~1.~~ Sacramento Vallley, San Joaquin Valley, and Kern County buyers or sellers
    - ~~2.~~ Southern California or Bay Area M&I buyers or sellers
    - ~~3.~~ Sellers within a rice producing region
    - ~~4.~~ State or federal agency buyers or sellers
    - ~~5.~~ Post-2009 transfers, affected by increased water scarcity following the 2009 ESA BiOp, court decision and reduced Delta exports

~~9.~~4. Perennial crop acreage was updated to reflect total Central Valley acreage of orchards, vineyards, and berries. This allowed for the calculation of perennial acreage as a share of total irrigated acreage.

~~10.~~5. The preliminary work suggested that the San Joaquin River Index is a good predictor of price, but the increase in transfer price as the index declined from, say 2 to 1 (critical to very critical) was much more than when price declined from, say 4 to 3. Therefore, a non-linear transformation of the index, being one divided by the index, was used instead.

Results

Results of the analysis are shown in Table D-2 below. The independent variables explain aboout 60 percent of the variation in the real price of transfers (expressed in constant 2015 dollars). The F statistic for the regression equation is significant at better than a 1% level.

The following discussion provides interpretation of some specific regression coefficients to help readers understand the results. If a buyer was an agency buyer (agencyb), expected transfer price was reduced by about $55 per AF. CVP or SWP buyers (cvpb and swpb) both had a significant relationship to price, though opposite in sign. Sales within the Sacramento Vallley (intra_sac_ag) were associated with a lower price, and transfers whose sellers were within the San Joaquin Valley (sjvs) or that represented cross-Delta transfers (CrossDelta) were both associated with a $42 per AF higher price, all else equal.

Table D-2. Results of Revised Regression Analysis of Individual Transfer Prices

Regression Statistics

Multiple R	77.425%
R Square	59.946%
Adjusted R Square	58.979%
Standard Error	107.313
Observations	468

Regression Coefficients, Standard Errors, and t-Statistics

Variable Name	Coefficient	Standard Error	t Stat	P-value
Intercept	-424.101	43.68542	-9.71	0.0000
Agency	-55.550	14.20895	-3.91	0.0001
cvpb	-29.334	14.57718	-2.01	0.0448
swpb	57.034	13.40639	4.25	0.0000
intra_sac_ag	-79.847	16.72242	-4.77	0.0000
sjvs	42.357	15.12096	2.80	0.0053
1/SJVt-1	97.604	45.75155	2.13	0.0334
peren_share	1728.005	165.10103	10.47	0.0000
CrossDelta	42.745	15.37293	2.78	0.0057
1/SJV	58.019	35.18474	1.65	0.0998
cvp_wanger	-0.786	1.46221	-0.54	0.5909
swp_wanger	-1.606	0.84604	-1.90	0.0583

Two hydrologic variables, the inverse of the San Joaquin Valley Index (1/SJV), and the inverse of the lagged San Joaquin Valley Index (1/SJVt-1), are included. The share of perennial acreage in the Central Valley (peren_share) was positively associated with higher transfer prices, and after 2009, the percent CVP and SWP allocations (cvp_wanger and swp_wanger) are associated with lower transfer prices relative to the pre-2009 period.

Table D-3 shows implied unit values of water at 2030 and 2070 conditions, expressed in real 2015 dollars.

Table D-3. Unit Values Using Revised Regression Analysis.				
SJV Index	**2030**		**2070**	
	Sacramento Valley	**San Joaquin Valley**	**Sacramento Valley**	**San Joaquin Valley**
Wet	$185	$228	$270	$312
Above Normal	$244	$286	$328	$371
Below Normal	$280	$322	$365	$407
Dry	$301	$343	$385	$428
Critical	$351	$393	$436	$478

Water transfer prices predicted for the 2030 condition, shown in Table D-3, are similar to those from the aggregate analysis (Table D-1) except that simulated prices from the aggregate analysis are higher in the critical years and lower in above normal years. For 2070 conditions, the perennial share is allowed to increase from 44.6 to 49.5 percent.The predicted prices for 2070 do not include any effects of SGMA, including increased water scarcity and potential effect on the share of perennial acreage in the future. The SWAP analysis described below was used to assess these factors.

It should be noted that the Table D-1 and D-3 values for critical years reflect an average critical year among those in the 1906 to 2015 hydrology. The severity of drought in 2014 and, even more so in 2015, caused transfer prices to increase well above the critical year average.

SWAP Analysis of Water Values

The SWAP is a calibrated optimization model that can estimate the benefit per AF of changes in water supply to agricultural production for locations in the Central Valley. SWAP was applied to assess the potential unit values of water for the WSIP. Specifically, this analysis used SWAP to estimate willingness to sell water from agricultural regions that have participated as sellers of water in recent years, and the willingness to pay for water by agricultural regions that have purchased water transfers in recent years.

The model included hydrology to reflect the current Biological Opinion, the San Joaquin River Agreement, and in 2070, implementation of SGMA. The analysis evaluated how the implementation of SGMA groundwater safe yield pumping restrictions would affect the unit value of water once such restrictions are implemented. Calibration results from C2VSIM were used to derive an approximation of sustainable yield for purposes of this analysis. C2VSIM does not develop a precise or accurate estimate of sustainable pumping (which is not possible given the current state of knowledge), but rather it provides an assessment of direction and rough magnitude of change that such limits could impose on future average pumping.

Modeling Approach

SWAP version 6.1 was used for the analysis, which was calibrated using crop acreage and water use information from 2010 and crop prices and costs from 2011-12. The model structure is described in Reclamation (2012), and its application to the 2014 drought analysis is described in Howitt et al. (2014). The analysis of unit values uses as its future baseline the no-action alternative in the Draft Environmental Impact Statement for the Coordinated Long-Term Operation of the CVP and SWP (Reclamation, 2015). The no-action alternative includes full implementation of the 2008 USFWS Biological Opinion and the 2009 NMFS Biological Opinion RPAs, in addition to other ongoing and future programs that would be reasonably foreseeable to be implemented by 2030.

In the results summarized below, three year types are represented: an overall average water supply condition, a dry condition, and a critically dry condition. For project water supplies, CALSIM-II results for 2030 were used based on the 2015 analyses (Reclamation, 2015). For local surface supplies, calibration data were used to represent average water year conditions. Critically dry conditions were represented by information gathered and analyzed for the recent 2014 drought impact analysis (Howitt et al., 2014). Dry conditions for local surface supplies were assumed to be the midpoint between the average and the critically dry conditions.

Estimated unit values with SGMA implemented also used CALSIM-II inputs for 2030 level of development, even though full sustainable groundwater conditions are not required until 2040 or later. No recent CALSIM-II No Action run was available representing 2040 or later future conditions. Sustainable pumping limits by region are only rough approximations because careful groundwater modeling of SGMA implementation is not yet available.

Unit values for water were measured as the incremental change in net return to agricultural production as water supply available for irrigation changes by an acre-foot. This measure is more precisely called the marginal value of water. It represents the incremental value of irrigation water to growers, net of any variable cost per AF for delivery by the local water district. For agricultural regions that might be willing to sell water to other regions, or to sell water as an alternative to water provided from a proposed project, marginal value is the willingness to accept payment for giving up a small amount of water. No additional profit over marginal value was included as an inducement to sellers. For agricultural regions that would potentially pay for water provided by a proposed project, marginal value is the willingness to pay for an extra increment of water supply.

SWAP Analysis Detail

SWAP regions that have been active as buyers of water transfers, according to the transfers database, have relatively unreliable surface water supply, and use volumes of groundwater that exceed, on average, the safe yield amount estimated as described above. Imposing safe yield limits on these regions has the potential for affecting crop mix. Annual variability in surface supply, coupled with limits on groundwater pumping, means that perennial crop acreage will, in future, be constrained by what can be irrigated during very dry years using the available surface water plus groundwater recharged during wetter years. Growers cannot and will not bear the cost of removing and replanting perennial crops like orchards and vineyards as water conditions change from year to year.

Therefore, the first step in the analysis of future conditions with SGMA used SWAP to calculate crop mix under critical year conditions. That acreage was used as a constraint on perennial crop acreage in other year types. Specifically, the analysis assumed an average 25-year life of orchards and vines, so that in any single year, one-twenty-fifth of acreage would typically be removed and replaced regardless of year type. Stands that are one year away from replacement were also allowed to be removed if the year is critically dry. The analysis imposed the constraint that perennial crop acreage in non-critical years can be two-twenty-fifths greater than what can be supported by the water supply in a critically dry year. This approach was not intended to be precise, but simply recognized that long run perennial crop mix must be reasonably consistent with variable water supply conditions.

Steps in the analysis to estimate unit values were:

- Calibrate SWAP to 2010 acreage and water supply conditions.
- Evaluate baseline 2030 for average, dry, and critically dry water conditions. Crop demand shifts and real pumping cost increases are incorporated to reflect 2030 conditions.
- Use critical year perennial crop acreage to create upper limits on perennial crop acreage in average and dry conditions. Re-analyze the 2030 average, dry, and critical conditions with the constraints imposed.
- Display the marginal value of water ($ per AF of applied water) by region.
- Repeat steps above with estimated safe yield pumping restrictions in place.
- Summarize results.
- Escalate to 2015 dollar values.

Some SWAP regions have a relatively reliable surface water supply and have been active sellers of water on the transfer market, according to the water transfer database. Even regions that have not been important sellers of water in past could potentially provide water from current uses as an alternative to water provided from a proposed storage project. For these regions, only the consumptively used portion of the water can be sold and transferred out of region or to another use.

SWAP Results

Results are shown in Table D-4 below. For 2030, results are provided without-SGMA pumping limits, and 2030 with-SGMA includes the restrictions. SWAP regions that include Glenn-Colusa Irrigation District, Yuba County Water Agency, Butte County water districts, and Placer County Water Agency have been active in the water transfer market and these SWAP regions were used to represent the Sacramento Valley region. SWAP regions that include Oakdale, South San Joaquin Modesto, Turlock, and Merced Irrigation Districts represent the Eastside San Joaquin region.

SWAP regions used to calculate unit value of water in the Delta export service areas of the Central Valley include Westlands Water District for the CVP and five regions in the Kern County Water Agency service area of Kern County. The Friant service area of the CVP is represented using SWAP regions that include many Friant contractors in Tulare County and a portion of Kern County. All of these regions and their water agencies are used as examples for the analysis; other potential regions could participate in a storage project or provide water for purposes of an alternative cost analysis.

Table D-4. Estimated Unit Values of Water in Central Valley Agricultural Regions from SWAP

Year	Type	Unit Values from SWAP in 2015 $/AF of Applied Water			
		Sacramento Valley	Eastside San Joaquin Basin	Friant Service Area	Delta Export Regions
2030	AVG	$59	$94	$179	$225
2030	DRY	$92	$142	$199	$226
2030	CRIT	$189	$265	$232	$326
2030 w/SGMA	AVG	$63	$274	$230	$519
2030 w/SGMA	DRY	$94	$330	$366	$674
2030 w/SGMA	CRIT	$197	$515	$790	$1,056

Notes:

- No adjustment for Delta carriage losses (outflow or water quality requirements) or conveyance losses have been made.
- Unit values may need to be converted to $/AF of consumptive use, depending on how and where the water is used.
- No additional profit or transactions costs over marginal value has been included as an inducement to sellers.

Proposed Unit Values of Water Supply

Unit values calculated by SWAP were used for comparison to those from the water transfer analysis and to project values for future conditions with safe yield limits imposed by SGMA. This section describes how the two analyses are combined to develop the proposed unit values.

Table D-5 shows results from the transfer price regression analysis alongside comparable estimates from SWAP. The values in Table D-4 above are on an applied water basis – that is, in dollars per acre-foot of applied irrigation water. However, water provided for agricultural use by a proposed water storage project would have value not just in its initial application, but also as return flow (non-consumptively used water) is used by others. In addition, water provided from existing uses for water transfers or instream flow generally is restricted to prevent harm to third party uses of the water. The effective value per acre-foot transferred to another use should account for that value to third parties.

To account for the total value of new water supply, and the effective value of water provided for instream flow or other uses, the values for Sacramento Valley, Eastside San Joaquin, and Friant displayed in Table D-5 are shown on a consumptive use basis. Unit values for the Delta Export region are not adjusted to a consumptive use basis because a relatively small fraction of applied water is reused. Reasons are that application efficiency is relatively high in these areas and part of the non-consumptive use returns to degraded shallow groundwater. Applicants should consider actual reuse fractions in areas receiving or providing water in order to calculate the appropriate effective value per acre-foot.

Even with adjustment for consumptive use fraction, most 2030 unit values estimated from SWAP are less than those from the water transfer analysis. The SWAP analysis does not consider the willingness to pay for water by all buyers, or transactions costs; rather, it can be interpreted as the minimum price sellers should be willing to take. Therefore, the estimated market prices might be expected to be higher than the SWAP values as is the case. For the San Joaquin Basin, the values are provided on an applied water basis.

Table D-5. Comparing Water Transfer Unit Values from Transfer Price Regressions to SWAP Unit Values

Year Type	Unit Value Estimates (in 2015 $/AF)									
	Sacramento Valley			San Joaquin						
		Comparable from SWAP			Comparable from SWAP					
	Table D-3 2030 unit value	2030 (CU)	2045 and later, with SGMA (CU)	Table D-3 2030 unit value	Delta Export 2030 (AW)	East San Joaq 2030 (CU)	Friant 2030 (CU)	2045 and later, with SGMA		
								Delta Export (AW)	East San Joaq (CU)	Friant (CU)
Wet	$185			$228						
Above Normal	$244	$138	$143	$286	$225	$133	$251	$519	$388	$321
Below Normal	$280			$322						
Dry	$301	$248	$256	$343	$226	$201	$278	$674	$466	$512
Critical	$351	$338	$347	$393	$326	$375	$324	$1,056	$728	$1,105

Notes

- AW indicates SWAP estimates per acre-foot of applied water
- CU indicates SWAP estimates per acre-foot of consumptive use

Table D-6 provides the unit values for water supply based on this information, rounded to the nearest $5 per acre-foot due to the uncertainty inherent in the analysis. For 2030, for the Sacramento Valley and Delta Export regions, the average of the transfer price and the SWAP price is suggested for years that have both. For example, for the critical year type in the Sacramento Valley, the average of the transfer price regression and the SWAP result is used: ($351+$338) / 2 = $345 per acre-foot. The transfer price analysis provides information regarding wet and below normal years that is not provided by

SWAP. The ratio of the transfer prices in below normal to dry years times the dry year unit value is used to calculate the below normal unit value, and the ratio of the wet to above normal transfer price, times the above normal unit value is used to calculate the wet year unit value for 2030.

The Delta Export values for 2030 are calculated similarly. The transfer price analysis could not identify unique estimates for transfers from the East San Joaquin region, so the above normal, dry and critical values are those from the SWAP analysis in Table D-5. The water transfer price analysis for San Joaquin transfers in general provides information regarding how the wet and below normal values differ from the above normal and dry values, respectively.

For 2045 and after, the unit values use estimates from SWAP to calculate the difference between with and without SGMA conditions. For the above normal, dry and critical condition, the unit values are those in 2030 without SGMA, times the ratio of the with-SGMA and without-SGMA SWAP results. For example, for the above normal year in Sacramento Valley, Table D-5 shows the SWAP ratio of with-SGMA to without-SGMA value as $143/$138. This ratio is applied to the 2030 value of $191, so 191*(143/138) = $198 ($200 per acre-foot after rounding). The values for the wet and below normal years are again developed using information for those year types from the water transfer analysis.

The unit values by year type in Table D-6 do not include any influence of climate change. Much of the climate change effect should be captured by a shift in the distribution of water year types, but there could be additional effect that is not captured, for example, if years classified as critical got even drier.

Table D-6. Unit Values of Water for WSIP, by Year Type, Future Condition, and Region.

Type	Sacramento Valley (in $/AF of consumptive use)	Delta Export (in $/AF of applied water)	Eastside San Joaquin Basin (in $/AF of consumptive use)	Friant Service Area (in $/AF of consumptive use)
2030 Conditions (2015 Dollars)				
Wet	$145	$205	$105	$200
Above Normal	$190	$255	$135	$250
Below Normal	$255	$265	$190	$260
Dry	$275	$285	$200	$280
Critical	$345	$360	$375	$325
2045 and later conditions with SGMA (2015 Dollars)				
Wet	$150	$415	$310	$255
Above Normal	$200	$520	$390	$320
Below Normal	$265	$635	$435	$480
Dry	$285	$675	$465	$510
Critical	$355	$1,055	$730	$1,105

Type	Sacramento Valley (in $/AF of consumptive use)	Delta Export (in $/AF of applied water)	Eastside San Joaquin Basin (in $/AF of consumptive use)	Friant Service Area (in $/AF of consumptive use)
Notes Applicants will need to develop their own estimates for water-related benefits not covered by the regions provided here.				

Table D-6. Unit Values of Water for WSIP, by Year Type, Future Condition, and Region.

To use these unit values, adjustments may need to be made depending on the source of water and location of use. For example, if the source of water is Sacramento Valley but the purchaser is in the Delta Export region, adjustment for Delta carriage losses (outflow or water quality requirements) or conveyance losses must be considered. Applicants are responsible for any adjustments to account for such losses. In addition, accommodation may be needed to account for the value of surface return flow that would be reused.

The unit values of water are based on estimates that do not, in general, incorporate third party economic costs. See section 5.3.6 of this Technical Reference for a discussion of such costs and how applicants may consider them.

Finally, the unit values that are shown in Table D-6 are in dollars per AF of consumptive use to represent the value of an acre-foot in both its initial use and in its value as return flow (except for the Delta Export region as explained above). Applicants should make their own estimates of the actual reuse to calculate appropriate total value per AF. In some cases, using the value per AF of consumptive use may be appropriate. For example, suppose an instream water quality benefit would be provided by a proposed project's release from storage. The applicant wishes to monetize the benefit as the alternative cost of purchasing the same water from existing agricultural uses, but in order to avoid harm to local users of the return flow, only the consumptive use portion can be purchased.

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Appendix E
Methods, Data, and Sources for Monetizing Ecosystem Benefits

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Methods, Data, and Sources for Monetizing Ecosystem Benefits

This appendix provides information and representative data regarding avoided cost, alternative cost and willingness-to-pay estimates for ecosystem benefits. Information is provided regarding:

- Alternative costs of habitat measures
- Recovery goals and costs for special-status species
- Contingent valuation and benefits transfer studies for Central Valley salmonids

First, the attachment shows examples of alternative cost measures where water supply is not the only potential physical measure of habitat provided. For example, wetlands and riparian areas might be created by water supply, but they could also be provided by acquiring and protecting existing wetland and riparian areas. Temperature reduction might be provided by more releases from a cold-water pool, but temperature might also be reduced by shading or by a temperature control device. The examples themselves may not be representative of conditions in a specific study area, but they show the approach and types of information that might be helpful.

Under the ESA, recovery plans must include costs, and the alternative cost of the recovery action could be used as a measure of benefit. Furthermore, recovery plans are generally not a compliance obligation, so recovery plans are useful in showing some specific ecosystem improvements that might qualify for funding.

Finally, this appendix details the potential application of contingent valuation and benefits transfers to California salmonids. This discussion supports the recommendations for valuing salmonids in Section 5.4.2.

Alternative Cost of Habitat Measures

Wetlands and Riparian Areas

No known database exists that compiles recent wetland acquisition and improvement costs. Where wetlands will be protected, improved, or created, applicants should identify similar wetland acquisitions or improvements as close to the project improvements as possible. The following recent wetland restoration projects show a variety of project types that provide alternative cost information representative of information that might be used:

- Pitkin Marsh. This 27-acre site on Highway 116 cost almost $1 million under a financial deal approved in August 2007 by the Sonoma County supervisors. Acquisition cost was about $37,000 per acre. More information about this project can be found at http://www.sonomalandtrust.org/news_room/press_coverage.html
- Sears Point Wetlands. The Sonoma Land Trust recently helped purchase lands for wetland restoration and has begun implementing restoration plans. The Sonoma

Land Trust acquired 2,327 acres of Sears Point wetlands in 2005 for about $20 million, including tidal marsh, seasonal wetlands and uplands. An additional $18 million is planned for restoration, recreation and other improvements. Total costs are about $14,200 per acre. More information about the project can be found at: http://www.pressdemocrat.com/csp/mediapool/sites/PressDemocrat/News/story.csp?cid=2371129&sid=555&fid=181

- Haire Ranch. The Sonoma Land Trust coordinated the purchase of the 1,092-acre Haire Ranch on Skaggs Island in December 2013. The cost was $8.3 million, or about $8,300 per acre. More information about the project can be found at: http://www.sonomalandtrust.org/news_room/press_coverage.html
- Cullinan Ranch. The 2010 National Coastal Wetland Conservation Grant Program Project provided $1 million for the Cullinan Ranch Restoration Project to restore 1,575 acres of vital estuarine tidal salt marsh and uplands at the San Pablo Bay National Wildlife Refuge in north San Francisco Bay. These funds leverage $6,282,940 in non-federal cost share, so the total cost per acre was $4,624. More information about the project can be found at http://www.fws.gov/coastal/CoastalGrants/docs/2010_Coastal_Grants_Project_Descriptions_State_Order.pdf and http://www.restorecullinan.info/home.htm
- San Francisco Wetland Ecosystem Restoration Program. The Wetland Ecosystem Restoration Program, proposed as a project for funding the San Francisco Bay Area 2011 IRWM, cost $25.668 million, would "create or significantly restore" 2,300 acres of coastal wetlands. The project costs $11,160 per acre.

Table E-1 summarizes information from these projects.

Table E-1. Representative Recent Costs of Wetlands Acquisition and Restoration

Name	Location	Type	Acres	Cost in dollars/acre
Pitkin Marsh	Sonoma County	Freshwater, rare species	27	$37,000
Sears Point	Sonoma County	tidal marsh, seasonal wetlands and uplands	2,327	$14,200
Haire Ranch	Sonoma County	diked baylands to wetlands	1,092, enables 4,400 restored	$8,300
Cullinan Ranch	Solano County	tidal salt marsh and uplands	1,575	$4,624
Wetland Ecosystem Restoration Program		Coastal wetlands	2,300	$11,160

Some additional information about wetland projects are their costs are provided at:

http://wsfrprograms.fws.gov/Subpages/GrantPrograms/

Table E-2 is a reproduction of the Coughlin et al. (2006) table of wetland acquisition prices up to the mid-2000s.

Table E-2. Representative Costs for Wetlands from Coughlin et al. (2006)

Name	Area acres	Price in Dollars/Acre	Date	County
Cargill Salt Flats	16,000	$8,181	2002	Alameda/Santa Clara
Ormond Beach	276	$46,739	2005	Oxnard/San Diego
San Elijo Lagoon	8	$125,000	2004	San Diego
Highway 37 Marsh	2,327	$8,637	2004	Marin/Sonoma
Rancho Santa Fe	15	$24,500	2004	San Diego
Bolsa Chica	880	$28,400	2004	Orange
Ormond Beach	500	$46,000	2004	Ventura
Santa Ana River	83	$69,500	2004	Los Angeles
San Dieguito River	132	$37,200	2004	San Diego
Huntington Beach	17	$44,000	2004	Orange

Table E-3 is a reproduction of the Coughlin et al. (2006) table of riparian land acquisition prices up to the mid-2000s.

Table E-3. Representative Costs for Riparian Lands, from Coughlin et al. (2006)

Name	Area acres	Price in Dollars/Acre	Date	County
Stornetta Ranch	1,132	$6,796	2004	Mendocino
Garcia River Forest	24,000	$750	2004	Mendocino
Monte Vista Ranch	4,056	$3,920	2005	San Diego
Santa Clara River	377	$1,525	2005	Ventura
Homer Ranch	1,837	$817	2004	Tulare
Gilroy Hot Springs	242	$9,917	2003	Santa Clara
Arroyo Seco	1,675	$1,731	2002	Monterey
Mount Hamilton	61,000	$311	1998	Santa Clara
Howard Ranch	12,360	$1,100	1999	Sacramento
San Pasqual Valley	75	$21,218	2004	San Diego
Santa Ysabel West	1,512	$1,984	1999	San Diego
Joughin Ranch	1,733	$4,155	2003	Los Angeles
Ahmanson Ranch	2,983	$50,285	2003	Los Angeles
Palo Corona Ranch	9,898	$3,738	2002	Carmel
Garcia River Watershed	23,780	$1,409	2004	Mendocino

Land purchase might be used for part of the costs of wetland habitat creation. The American Society of Farm Managers and Rural Appraisers provides current land rent and price estimates for California regions and for subregions within each of these regions by crop type (American Society of Farm Managers and Rural Appraisers, 2009). Prices are estimated by consensus of appraisers operating in each region. American Society of Farm Managers and Rural Appraisers data are available for most regions of the state with agricultural land. If agricultural land acquisition costs are used, the analysis should use sales from properties that are comparable to the area affected by the project. Costs of converting or restoring the agricultural land to the proposed type of ecosystem land use would be additional to the land cost and must be included if using this approach.

Salmon Habitat Improvements

Thomson and Pinkerton (2008) provide references for habitat restoration costs of salmon recovery planning. For each restoration activity, one or more tables are provided that include cost estimates for that activity by location, year, project scale, cost per scale unit, and data source. Restoration activities and costs covered by the report are:

- Fish ladders
- Fish passage at stream crossings — culvert replacement/improvement
- Fish screening of diversions
- Instream barrier modification — modification of fish passage barriers in the stream channel and along the streambank (tide gates, sandbars, dams, other non-culvert barriers)
- Instream habitat restoration — enhancement of stream channel and streambank habitat (instream structures, spawning gravel supplementation, floodplain tributary reconnection, side channel reconnection, wetland/floodplain restoration, levee evaluation/repair/setback)
- Riparian restoration — restoration of area, including fencing, between the fence and middle of stream (e.g., livestock exclusion, revegetation)
- Streambank stabilization — stabilization of eroding, collapsing of otherwise de-stabilized banks
- Upland watershed restoration — largely pertains to upslope erosion control (e.g., road decommissioning/upgrade, landslide/gully stabilization, upslope planting)
- Tailwater management
- Water conservation — e.g., ditch lining, piping
- Water purchase/lease
- Habitat acquisition and conservation easement
- Monitoring status and trends — monitoring of baseline conditions and status/trends in habitat, watershed processes and/or populations.

- Monitoring watershed restoration — monitoring to determine if project treatments were constructed correctly and as planned, effectiveness monitoring to determine if restoration has produced desired habitat conditions and/or watershed processes, and validation monitoring to determine if hypothesized responses of habitat, watershed processes and/or populations to restoration were correct
- Watershed evaluation, assessment and planning — developing watershed plans with site-specific, prioritized recommendations for restoration of salmon/steelhead habitat. Includes partial assessments (e.g., road erosion surveys, stream surveys).
- Watershed organizational support and assistance — organizational support to local watershed groups and development/maintenance of databases that facilitate organizational aspects of restoration
- Cooperative fish rearing
- Water measuring devices — e.g., head gate
- Wildlife management — e.g., control of exotic species such as pike minnow
- Research — general research on productivity (e.g., life cycle monitoring/analysis), spatial structure (fish distribution surveys), genetic diversity (laboratory analysis of tissue samples), and estimation of abundance.

Allen et al. (2004) provide references for salmonid habitat costs including stream restoration, riparian restoration, road improvements, floodplain restoration, and fish protection facilities.

Recovery Goals and Costs for Special-Status Species

A variety of sources are available that document special-status fish recovery goals and costs of fish recovery actions and improvements. For Central Valley winter-run salmon and steelhead, the most recent recovery plan was produced in 2014 (NMFS, 2014). Table E-4 summarizes the status and recovery goals for the covered fish. In total, at least 1,500 escaping winter-run Chinook salmon, with at least 500 in each of three populations, would be needed for Endangered Species Act (ESA) recovery. For winter-run Chinook, all of the populations would be in the Basalt and Porous Lava diversity group.

Table E-4. Extinction Risk and Recovery Goals for Winter Run Salmon, Spring Run Salmon and Steelhead Trout

Extinction Risk	Minimum Escapement/ Population	Winter Run	Spring Run	Steelhead	Catastrophic Events in Last 10 years	Hatchery Influence
		Total Number of Populations to Recover				
		3	9	9		
		Total Escapement Goal, evenly distributed among populations				
High	N<50	N<150	N<450	N<450		High
Medium	50<N<500	150<N<1500	450<N<4500	450<N<4500	none	Med

Table E-4. Extinction Risk and Recovery Goals for Winter Run Salmon, Spring Run Salmon and Steelhead Trout

Extinction Risk	Minimum Escapement/ Population	Winter Run	Spring Run	Steelhead	Catastrophic Events in Last 10 years	Hatchery Influence
		Total Number of Populations to Recover				
		3	9	9		
		Total Escapement Goal, evenly distributed among populations				
Low	N>500	N>1500	N>4500	N>4500	none	Low
Recovery	N>500	N>1500	N>4500	N>4500	none	Low
	Additional populations		More populations maintained at medium risk or better		none	Low

Central Valley steelhead trout and spring-run Chinook salmon each require at least 500 escaping adults in nine populations each, or at least 4,500 escaping fish, with additional fish in other populations, each with 50 to 500 individuals. For both of these species, two populations would be in the Basalt and Porous Lava diversity group, one in Northwestern California, four in Northern Sierra, and two in the Southern Sierra.

It is unlikely that any one water storage project would provide substantial help with recovery for all of the species' populations slated for recovery. For spring-run salmon and steelhead trout, the nine populations for each species are spread around the Central Valley. The recovery targets will require that new populations be established for each species. Even for winter-run Chinook salmon, only one out of the three populations, the one in the mainstem Sacramento River, currently exists. Two other habitats, the McCloud River and Battle Creek populations, are classified as primary:

> *"Primary areas for reintroductions are areas where there is a known high likelihood of success based on species-specific life history needs, and available habitat quality and quantity."* (NMFS, 2014 p. iv)

The populations proposed for recovery, and their re-introduction plans and priorities, are shown in Tables 3-4 through 3-6 of the recovery plan.

The 2014 recovery plan provides detailed tables of recovery plan actions and expected costs. Actions covered in the document are listed by watershed. Most could potentially be affected by a WSIP-funded project. Table E-5 lists some recovery actions and the costs provided.

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	Million $, One-Time Cost Unless Noted
Central Valley	
Ecosystem based management approach	$9.6

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	Million $, One-Time Cost Unless Noted
Enforcement poaching, stream alterations, pollution	$60.0
Central Valley Steelhead Monitoring Plan	$7.5
Evaluate and implement actions for invasive species	$551.0
Coordinate operations and transfers for fish	$5.0
Assess opportunities for re-introductions above big dams	$5.0
San Francisco, San Pablo and Suisun Bay	
Wastewater and stormwater capture/management	$3,331.0
Complex portfolio of habitats	$100.0
San Francisco Estuary Partnership Comprehensive Conservation Management Plan	$60-$80
Agricultural drainage management	$20 to $110 per acre
Reduce anthropogenic inputs of NH4 to achieve concentrations below 4 µmol L-1 (Sacramento Regional Wastewater Treatment Plant)	$1,000 to $2,000
Evaluate and implement predator control actions	$0 to $75
Quantify predation on juvenile salmonids	$0.2 to $0.4
Identify and manage predation hot spots	$0.038 per site
Educational outreach	$0.4
Marine mammal predation studies	$1.5
Delta	
Reduce hydrodynamic and biological impacts of exporting water through Jones and Banks ~~(Medellín-Azuara et. al 2013)~~	$8,600 to $14,500 plus $85.0 annual
Landscape scale ecological restoration	$600 to $13,000
Targeted smolt research and monitoring	$627.0
New South Delta floodplain habitat for San Joaquin River salmonids	$950.0
Prospect Island Tidal Habitat Restoration Project	$32.0
Southport Floodplain Restoration Project	$55 to $160
Dutch Slough Tidal Marsh Restoration Project	$25 to $30
Projects to reduce predation at weirs, diversions, etc.	$50.0
McCormack Williamson Tract Integrated Flood Management	$10.0
Lindsay Barker Slough	$0.4 to $3.4
Reconnect Elk Slough to the Sacramento River	$5.2
Grizzly Slough Floodplain and Riparian Habitat	$0.25 to $4.0
Screen Delta Diversions	$20.0
Implement Actions for Invasive Aquatic Species	$551.0
Sacramento River	

Table E-5. Central Valley Winter Run Salmon, Spring Run Salmon and Steelhead Selected Recovery Actions and Related Costs from 2014 Recovery Plan

Region/Action	Million $, One-Time Cost Unless Noted
Reintroduce winter run, spring run and steelhead salmon above Shasta Dam through pilot reintroduction phase	$50.2
Restore and maintain diverse riparian and floodplains	$42.1
M&T Ranch adequately screened	$9.5
Flow management plan below Shasta, Keswick	$0.7
Gravel augmentation plan	$2.3
Secondary winter run Chinook trapping for Livingston National Fish Hatchery	$27.4 plus $0.14 to $0.69 annual
O&M Lewiston and Whiskeytown Temperature Control Curtains	$0.15 annual
Whiskeytown replacement every 15 years	$3.5
Lewiston if needed	$1.5
Adult fish rescues	$0.1 in 2013
Restore current lake Red Bluff footprint to riparian	up to $6.75
Clear Creek	
Clear Creek floodplain, riparian, instream habitat	$5.0
Feather River	
Reintroduce spring run and steelhead salmon above Oroville Dam	$50.2
Yuba River	
Reintroduce spring run and steelhead salmon above Englebright	$50.2
American River	
Reintroduce spring run and steelhead salmon above Folsom	$50.2
Gravel management	$5.0
Wood management	$1.2
Mokelumne	
Reintroduce steelhead above dams	$20.2
San Joaquin River	
Develop and implement flow regime	$16.9
Wastewater and stormwater capture/management	Up to $0.1 each
Reintroduce steelhead above Friant Dam	$50.2

Few studies of restoration actions include both the expected amount of improvement for aquatic species and the costs. DWR (2015) provides engineering and cost estimates for Delta actions intended to reduce juvenile salmonid exposure to Delta export facilities. The report concludes:

"Based on current information that was evaluated by the TWG, if there is a demonstrated need to implement an engineering option at one or more of the five junctions, the following are the currently preferred options for implementation:

- *Georgiana Slough – Bio-Acoustic Fish Fence (BAFF)*
- *Threemile Slough – BAFF*
- *Head of Old River – Floating Fish Guidance System*
- *Turner Cut – BAFF*
- *Columbia Cut – BAFF"*

With costs and protection efficiencies, the cost per unit of protection can be estimated. For Georgianna Slough, for example, the BAFF reduced entrainment from about 24 to 12 percent (p. 3-11). The cost comparison on page ES-7 of the report shows that the present worth cost of this BAFF was $25.6 million dollars. Therefore, the present worth cost of reducing salmonid entrainment by 1 percent is roughly $2 million.

The existing recovery plan for Delta smelt and other resident fishes (1996) "is out of date. We are currently working on a new plan" (USFWS, 2015). The new plan might be available in 2017. If it is available before WSIP applications are due, there may be useful cost information.

California Department of Fish and Game and DWR (2005) shows costs of actions to increase populations of Delta smelt. Table E-6 summarizes expected costs. Total one-time cost for all of these actions was expected to be about $100 to $125 million, not including new Delta conveyance, plus $40 to $85 million in annual costs, mostly for Environmental Water Account purchases to reduce entrainment.

Table E-6. Delta smelt related costs from 2005 Delta Smelt Action Plan

Action	Description/Source	Million $ Annual Cost	Million $ One-Time Cost
Interagency Ecological Program	Estuary monitoring and research program conducted by six federal and three state agencies. Includes longfin smelt, threadfin shad, and other pelagics.	$13.5	
Additional funds to augment IEP		$1.7	
Future POD work	Page viii of the Action Plan	$5.0	
Delta Regional Ecosystem Restoration Imp. Plan	Funds are for approved ERP monitoring projects		$3.0
Suisun Marsh Actions	Currently approved restoration projects and up to an		
	Additional $5 million for future projects '05 to '08		$10.0
Increase Food Web Productivity	Freshwater and brackish tidal marsh and seasonal floodplains		$5 to $30

Table E-6. Delta smelt related costs from 2005 Delta Smelt Action Plan			
Action	**Description/Source**	**Million $ Annual Cost**	**Million $ One-Time Cost**
Reduce Entrainment at Power Plants	Gunderbooms	$0.6	$7.0
Environmental Water Account Equivalent	Historic cost. May includes actions for all fish	$20 to $64	
Environmental Water Account Decision-Making for Export Curtailments	More rapid response to critical time-sensitive issues	Additional Environmental Water Account cost	
Alternative conveyance		Could be billions	
Modified Barrier Installation at Head of Old River	Look for SDIP draft EIS/R Would save $2 million annually in temporary barrier costs?		$75.0
Contaminants Management			$0.2 to $0.5
Control of Invasive Species			unknown
TOTAL	Not including modified conveyance	$40.8 to $84.8	$100.2 to $125.5

The Draft Environmental Impact Statement for the Coordinated Long-Term Operation of the Central Valley Project and the State Water Project (Reclamation, 2015) compares delta smelt entrainment and water supply under long-term operating alternatives. Analysis of trade-offs between entrainment and the value of water supply could be developed based on information provided in the impact statement.

Market Prices

Market price techniques in this context refer to the use of market price as the measure of gross willingness-to-pay per unit for the public benefit. Market prices should be used to value goods that are sold in competitive markets. Market price techniques can often be applied to estimate use values, but usually cannot be used to estimate non-use values. For California, ecosystem services sold in competitive markets include commercial fall-run salmon and recreational charter and guide services for salmon and steelhead.

Many ecosystem services have value because they are inputs in a production process or they are end-user products that are bought and sold in reasonably competitive markets.

For commercial fishing, Engineer Regulation 1105-2-100 (USACE, 2000) provides this guidance:

> *“Estimate the harvest of the exploited stocks. Estimate the seasonally corrected current price of the harvested species and the total cost of harvesting in each of the relevant years if a plan is undertaken. Calculate the ex-vessel value of the harvest (output) for each alternative plan and for the without plan condition. Determine the harvesting costs, for the level of catch (output) identified by each alternative plan and the without plan condition. Compute the benefit as the value of the change in harvest less the change in harvesting cost from the without plan condition to the with plan condition.”*

Data related to the recreational and commercial catch of salmon is provided by the Pacific Fisheries Management Council (PFMC) (PFMC, 2016a). Recreational fishing benefits from fishing for native fish can be counted as an ecosystem benefit.

Hedonic Pricing Method

Hedonic pricing refers to techniques that use observed market prices to estimate the value of specific attributes of a good or service. In the case of public benefits, real estate values can sometimes be used to estimate at least some of the value of the public benefit. The prices of real estate and information about the public benefits attributes of the real estate can be used to infer the value of the attributes. The method is appropriate where an important share of the public benefit is captured by landowners and where the benefit for these lands is large enough to be measurable by comparison to similar lands that do not enjoy the public benefit.

A hedonic price equation is estimated using statistical methods from a cross section of sales and attribute data for properties in a given property market. The hedonic price equation calculates a property’s price as a function of its attributes. In this context, the analysis would include public benefit attributes such as presence or amount of ecosystem services or recreational amenities, water quality measures, amount of waterfront, or incidence of flood damage. Coefficients in the hedonic price equation can be used to estimate the share of property value attributable to the public benefit. Additional use values and non-use values usually apply for people who do not receive the property related benefit, and their benefits must be estimated separately, taking care not to double-count benefits.

Revealed Preference Studies

Revealed preference methods use observed behavior, but not market purchases of the good itself, to infer willingness to pay. Travel cost models value recreation use based on distance travelled; more distance travelled implies a higher willingness-to-pay. Votes for an initiative that raises taxes to fund public benefits imply willingness-to-pay. Voluntary contributions to environmental causes or to the provision of public benefits suggest willingness-to-pay. Preferences are also revealed by behaviors that seek to avert, avoid, or insure against damages or costs. Examples include purchases of bottled water, home water filters, and flood insurance. The costs of such behaviors indicate willingness-to-pay. Revealed preference methods can be used for use and non-use values, but some "free-riders" may never act on their non-use values; for example, they may never give to environmental charities even though they value endangered species because they are satisfied that enough others are already giving.

Revealed preference methods can be used for certain ecosystem benefits. Recreation and water quality benefits are discussed in their respective sections. The method requires that individuals will be aware of the benefits they will receive. This is sometimes not the case when benefits are distributed over a large population because the improvement per capita is small.

Survey-Based Methods

Survey-based methods seek to estimate willingness-to-pay by using questionnaires. Contingent valuation uses a questionnaire to ask people if they would be willing to pay, or if they would pay, for some hypothetical improvements. Willingness-to-pay can also be derived from questions regarding whether the respondent would vote for a measure that would increase taxes to finance specified improvements. Conjoint analysis asks individuals about attributes of goods and uses rankings to infer value. Survey-based methods may be important for obtaining information on amount of use where data are not routinely collected. In particular, much recreation use is not counted through observed market sales, so surveys are often used to count visitors, determine their characteristics, and build use-estimating or travel cost models.

Contingent valuation and survey methods are controversial methods in economics. Many studies have cast doubt on the validity of survey methods for accurately eliciting willingness to pay (Hausman, 2012; Diamond and Hausman, 1994; Neill et al., 1994). These studies do not question that people place some value on the good in question, but on the ability of a survey to elicit reliable answers. It is clear that survey methods must be carefully designed to avoid bias. Additional issues arise in extrapolating survey results to the larger population.

Survey-based methods for ecosystem benefits are widely used in economics, primarily because ecosystem values often have multiple attributes and a large non-use component. Few other methods are available to estimate non-use values. A number of California applications are discussed below.

Reclamation's Economic Guidebook does not mention non-use values as part of the value of fish and wildlife, nor does it suggest use of survey-based methods. Fish and wildlife values include commercial, recreational, or non-consumptive use such as bird watching. USACE guidance specifically discourages use of survey-based methods for ecosystem values.

Reclamation (Reclamation Technical Service Center, 2008) recently reviewed the state of science for non-use valuation and recommended (p. 62):

> *"… a study only be considered for nonuse valuation if T&E (threatened and endangered) species are involved and significantly affected (the significance determination should be made by study team biologists)*

But later:

> *"… the decision was made to forgo pursuing a site- and study-specific nonuse value survey and simply exclude quantification of nonuse values from the feasibility-level BCA. Instead, a qualitative discussion of nonuse values will be included in the feasibility study/EIS."*

Benefit Transfer

Benefit transfer is the technique of interpolating or extrapolating benefit estimates from studies done for other similar locations or resources and then applying those values to the proposed project, for which such studies have not been performed. The term has been most widely applied to transfer of results from survey based methods, but the same procedures and problems generally apply for other methods as well. Benefit transfer methods have recently been summarized (Wilson and Hoehn, 2006; Rosenberger and Loomis, 2001; Johnston et. al., 2015).

Benefit transfer usually invokes many issues involving comparability. The available benefit estimate may need to be adjusted for differences in time, location, quantities, and qualities between the original benefit estimate and the subject project, including species, size, productivity, aesthetics, inflation, location, and demographic differences. Benefit transfer has great potential for error, but it is often used because it is inexpensive or because no other information is available.

Benefit transfer methods are often used for ecosystem valuation. The Beneficial Use Values Database (BUVD), maintained at the University of California Davis, provides many studies that might be used for benefit transfer (Larson and Lew, 2011). A useful discussion of benefit transfer methods is also provided in Ghermandi et al. (2008).

The Benefit Transfer and Recreation Use Estimating Model Toolkit (Toolkit) is another resource (Loomis and Richardson, 2008). The Toolkit is available through the Agricultural and Resource Economics Department of Colorado State University. The Toolkit consists of several spreadsheet tables, templates, and models that estimate values for wildlife recreation, common wildlife habitats, and threatened and endangered species. Technical documentation provides guidance selecting appropriate benefit transfer methods and visitor use estimating models. Benefit transfer examples are also included in the technical documentation.

The spreadsheet tables, templates, and models include the following

- Use values for fish and wildlife
- Use values per day of hunting, fishing, and viewing
- Use and non-use values per acre of habitat
- Use and non-use values per household of threatened and endangered species

The use and non-use values include average values, databases of the individual studies, and meta-analysis equations to tailor the benefit transfer to specific study sites.

Visitor characteristics for hunting, fishing, and wildlife viewing are available for National Wildlife Refuges, Wildlife Management Areas, and private, state, and federal lands in California (for example, Sexton et al., 2012). The visitor use estimates might be used with values per visitor day to undertake recreation benefit transfer studies.

Links to some other, potentially useful databases, valid as of June 2016, are provided below:

- http://www.environment.nsw.gov.au/publications/evri.htm
- http://www.environment.nsw.gov.au/envalueapp/
- https://www.evri.ca/Global/Splash.aspx
- http://www.ecosystemvaluation.org/links.htm

Benefits Transfers Using Contingent Valuation Studies for Anadromous Salmonids

In the last 20 years, more than a half dozen contingent valuation studies have estimated the use and non-use value of west coast anadromous salmonids (i.e., salmon and steelhead trout). Hanemann et al. (1991) estimated the willingness-to-pay of California, Nevada, Oregon, and Washington state households for restoring salmonid runs to the upper San Joaquin River. This study introduced the double-bounded, or double referendum survey format. Respondents were offered an increase of about 15,000 fish from a base of about 100 (Loomis, 1999). The statistical analysis estimated a point estimate of willingness-to-pay from the double-bounded model of $181 per household. Adjusting for inflation to 2015, and multiplying by 15 million households expected by 2030, the benefit per fish worked out to be about $300,000.

Since then, this format has been tested and scrutinized for its potential bias. Most recently, Kim et al. (2012) summarized a large amount of literature that criticized the double referendum survey format:

> *"… the double referendum method has been criticized because it suffers from various forms of response bias… including starting-point bias, in which responses to the follow-up question depend on the initial bid amount offered… shifting-effect bias, in which the respondent interprets a*

> *change in the offered price to be a signal of altered quality of the project… and strategic bias, in which respondents see the new bid amount as a signal that they can bargain over the price…"*

Given these uncertainties, and because the study is now 25 years old, results from the Hanemann et al. (1991) study are not recommended for a direct application to the WSIP (though see Hanemann's more recent survey and results discussed below).

Olsen et al. (1991) estimated the willingness-to-pay of households in the Pacific Northwest for increases in salmon and steelhead fisheries in the Columbia River Basin. This study is not discussed further because the more recent Layton et al. (1999) study, see below, covers the same general area and provides similar results.

Bell et al. (2003) conducted a study that proposed an improvement of coho salmon populations in Washington coastal communities, but the improvements were not expressed in population numbers. Rather, increases in allowable catch were shown. Payments for 5 years were assumed. This study is not considered for additional analysis for WSIP because the primary metric of improvement was catch. The main species of interest in California are endangered or threatened, and catch is a minor share of potential economic value.

Four additional studies provide more recent or potentially more comparable information.

Loomis (1996) estimated the willingness-to-pay of households across the nation for an increase in salmonid populations based on the removal of dams on the Elwha River in Washington State. In this study, the population increment was 300,000 fish. Payments for 10 years were assumed. The mean annual 1994 willingness to pay per household was $59 in Clallam County, a rural coastal county on the Olympic Peninsula, $73 for the rest of Washington, and $68 for households in the rest of the United States. The fish population increases proposed in the survey questions included 200,000 pink salmon, a species not often sought for sport or food, plus chum, another less-sought after species, both which are not proposed for recovery in California. Only one population increase, 300,000 Chinook salmon, was proposed for a species relevant to California. The recovery goals for California salmon and steelhead are 1,500 to 4,500 fish (Table C-2), roughly two orders of magnitude less than the numbers posited in the Elwha study. Therefore, there would seem to be little basis for a benefits transfer to the substantially different populations in California.

The Klamath River Basin Restoration Nonuse Valuation Study (Mansfield et al., 2012) attempted to elicit total willingness-to-pay for fishery improvements in the Klamath River, California and Oregon. The fish species of concern were Coho and Chinook salmon, steelhead trout, and shortnose and Lost River sucker. The survey instrument showed "numbers of wild Chinook salmon and steelhead trout" and "risk of extinction for suckers and Coho salmon," Respondents were asked if they would pay a fixed amount ($12, $48, $90 or $168 per household for 20 years) for improvements, which were "increasing numbers of wild Chinook salmon and steelhead trout" (30 percent, 100 percent or 150 percent) and "lower risk of extinction for suckers and Coho salmon" (varying from very high to low).

Page ES-10 of their report describes the statistical results. Apparently, these important attributes of the plan accounted for “a modest share of the total value of the plan.” Stated differently, different levels of fish populations did not have an important influence on stated willingness-to-pay. Similar to many contingent valuation studies, many votes might represent a general approval or disapproval with the concept of an “Action Plan” or with ecosystem restoration as a concept, rather than a calculated willingness-to-pay based on levels of fish or extinction risk. Contingent valuation results often show a surprising lack of response to scale, a drawback that has been called “embedding” (McFadden, 1994; Hausman, 2012).

Simulation using regression equations were used in the study to estimate willingness to pay for specified scenarios. Action Plan 1 proposed to increase numbers of wild Chinook salmon and steelhead trout by 30 percent, reduce risk of extinction of Coho salmon from high to moderate, and reduce risk of sucker extinction from very high to high. The restricted sample removed surveys where respondents strongly agreed that “It is important to restore the Klamath River Basin no matter what it costs” (pages 7 to 14). Using the restricted sample, the annual willingness-to-pay for households in the 12-county region for 20 years was estimated to be $121.85 per year, and for the rest of California and Oregon, $213.03 (Table ES-7, page ES-12). The small confidence interval around this estimate reflects a significant willingness-to-pay for Action Plan 1.

However, Tables 7-9 through 7-14 and 8-2 and 8-3 of the study suggest that the important attributes of the plan can account for only a small share of the total willingness to pay. In Tables 7-9 through 7-14, coefficients on salmon and steelhead population size, and on Coho risk of extinction, are often not significant. In Table 8-2, the reduced Coho extinction risk from high to moderate accounted for only about $50 of willingness to pay, with a large confidence interval, and in Table 8-3, the population increase from 30,000 more to 100,000 more apparently did not contribute positively to the willingness to pay, and improvement from 30,000 more to 150,000 more contributed just $10.59 to the willingness to pay, and the confidence interval ranged from -$28 to $50. The annual willingness-to-pay for 20 years for households for just the Coho risk of extinction improvement (from high to moderate) in the 12-county region was $37.75 per year, and for the rest of California and Oregon, was $49.10 (Table ES-7, page ES-12), both with large confidence intervals.

In summary, the Klamath Survey might provide usable willingness to pay estimates for reduced Coho extinction risk, but with low confidence. However, based on Table 8-3, we cannot reliably assign any willingness to pay to the population increases for Chinook and steelhead based on this study. Comparable Central Valley special status species are generally Chinook salmon and steelhead, not Coho. This is another reason why this study may be unreliable as a basis for benefits transfer to California.

For projects applying for WSIP finding, a desirable benefits transfer study would provide willingness to pay estimates that could be applied to different baseline populations and population increments. The Klamath study does not provide a useful basis for benefits transfer for Chinook salmon and steelhead because there was no consistently significant positive relationship between population levels and willingness to pay.

In another recent study involving salmonids in the Pacific Northwest, respondents were asked to value increases in fish populations in Washington (Layton et al., 1999). Useful results relative to the California case are provided for the Columbia River migratory fish and for Puget Sound migratory fish, using a high baseline fish population in 20 years (assumed to be recent population levels) and a low baseline where future populations would be a quarter of the size (Columbia) or half (Puget Sound) of what they are now. In this study, respondents seemed to provide values highly dependent on the overall size of the improvement. Unlike the Mansfield et al. study, the statistical estimates on population increase were very significant. Reclamation (Reclamation Technical Service Center, 2008) has also reviewed this study for its potential application to valuing salmonids in the Yakima River basin.

Willingness to pay values can be simulated using the Layton et al. equation (7) (page 15) which is based on their preferred modified logarithmic specification. This allows an implicit average value per fish to be estimated using the willingness to pay at the 5 percent improvement. The study assumed payments for 20 years. This calculation can easily be changed to be consistent with WSIP assumptions regarding constant dollar year, planning horizon, and discount rate. The household willingness to pay can also be adjusted for the response rate (68 percent) assuming that non-respondents have no willingness to pay.

For the smallest baseline population in the study (Eastern Washington and Columbia River Migratory Fish, 500,000 fish) the 5 percent increment is 25,000 fish. The annual 2000 willingness to pay per household for this improvement for 20 years is estimated to be $7.80. The equivalent annual value of $7.80 for 20 years, if paid over 100 years, is $4.01 (using a real 3.5 percent discount rate). With about 15 million households in California by 2030, a response rate of 68 percent, and escalating the values by 42 percent to account for inflation between 2000 and 2015, the value of each of the 25,000 fish would be $2,335 per year for 100 years. Rounding provides a value of about $2,500 per fish.

This result from the Layton et al. study is reasonably representative for escapement of non-listed, fall-run Chinook salmon in California. Numbers of these fish are roughly 500,000 per year (PFMC, 2016b), similar to the baseline CM population used by Layton et al. In keeping with the original study, the representative value derived above can be applied to adults entering freshwater (as opposed to spawners). Helvoigt and Charlton (2009) reviewed use values of commercial and recreationally caught fish. Based on the combination of these studies, a t total value of $3,000 per fish entering fresh water should be sufficient to cover commercial and sport values as well as the additional ecological and non-use values.

For special-status salmon and steelhead runs, a number of arguments can be made for different willingness to pay values per fish. Most importantly, the baseline populations for special-status species in California are generally much smaller. From Table C-2, the recovery goal for winter-run Chinook salmon is 1,500 adults, and for spring-run Chinook and Central Valley steelhead, 4,500 adults. Generally, the status of these fish and the smaller baselines should result in a much higher value per fish compared to what the Layton et al., estimate suggests. That study provides a good basis for benefits transfer for species with large populations, but does not apply well for the range of baseline special-status species populations and improvements likely to be provided by California projects applying for WSIP funding.

For this purpose, a more recent and local study by Hanemann (2005) provides an alternative that is update to his earlier work on the San Joaquin River. The survey instrument asked:

> *"I would like to ask you a couple questions regarding a potential bond measure that may be on the ballot in an upcoming election. The San Joaquin River, one of four major rivers in the San Joaquin Valley, is the second longest river in California. Since the late 1940s most of the water that once flowed in, almost 150 miles of the San Joaquin River downstream of the Friant Dam (near Fresno), has been diverted – and 60 miles of the river now go completely dry in most years. Whereas there used to be tens of thousands of salmon in this stretch of river, these salmon runs have been completely destroyed, along with much of the river habitat for other fish, birds, and wildlife.*
>
> *There is currently a proposal to increase water flows in the San Joaquin River in order to restore the salmon runs, which would include sufficient water to maintain a continuous flowing river in almost all years. Additional benefits would include increased habitat for other San Joaquin Valley fish and wildlife, and increased recreational opportunities such as canoeing and rafting."*

Results found that 11.9 million California households would be willing to pay an average of $137 to $162 per household annually, or $1.6 billion to $1.7 billion annually for the proposed improvement.

From the survey language above, the proposal would "restore the salmon runs" which "used to be tens of thousands." It is hard to say exactly how respondents would have interpreted this scenario. If the range of potential improvement perceived was 20,000 to 50,000 fish, then the apparent willingness to pay per fish, for 15 million households, is $41,000 to $122,000.[2] The median of these values is roughly $80,000 per fish. If this value per fish is extended to the size of recovered populations, it suggests that each of 15 million 2030 households would be willing to pay $8 per year for winter run Chinook salmon recovery, and $24 per year for recovery of spring run Chinook salmon or central valley steelhead, or a total of $56 per year for recovery of all three species.

Many benefits transfer studies use contingent valuation results to extrapolate to other fish populations. Benefits transfer studies, because they are based on the existing contingent valuation studies previously discussed, do not add empirical content, and they generally do not address the small population sizes in the California case.

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2 15,000,000*137/50000 to 15,000,000*162/20000 equals $41,100 to $121,500.

Weber (2015) reviews the available information from contingent valuation studies to consider a potential benefits transfer to the Willamette River in Oregon. Results show the large potential variation in benefits per household ($47 to $4,370) when using a range of reasonable benefits transfer methods. The author recommends structural benefits transfer as opposed to meta-analysis, and provides a reference list.

Loomis and Richardson (2008) provide technical documentation for a benefits transfer model for recreation, species, and habitats. A salmon meta-analysis developed a statistical analysis using all of the studies above except the more recent Klamath basin study. The resulting equation was:

$$\text{Willingness to pay} = 0.843577P - .001182P^2$$

Where

Willingness to pay is household willingness to pay, per year, for percent increases in salmon populations, and

P is percent increase in salmon population.

So, for example, a 5 percent increase in salmon population would provide an annual increase in household willingness to pay of $4.19. This value is similar to the willingness to pay for a 5 percent improvement from the Layton et al. (1999) study where the baseline was 500,000 fish. Another meta-analysis (Loomis and Richardson, 2009) was applied to rare species. This model calculated willingness to pay estimates that were about double those of the 2008 study (Weber, 2015).

Loomis (1999) developed a benefits transfer equation that estimated willingness-to-pay per household based on fish population size using results from Loomis (1996), Olsen et al. (1991) and Hanemann et al. (1991). The valuation equation suggested, for a population of 4,000 fish, a willingness-to-pay of over $1 million per fish. Helvoigt and Charlton (2009) used this same benefits transfer method to value non-use benefits of salmon in the Rogue River in Oregon.

These benefits transfer studies, or a new benefit transfer analysis using an existing contingent valuation study, shall only be used with justification based on the specific proposed salmonid benefit. None of the studies just described used survey results where respondents were asked to value small population increments added to small populations, as would be applicable for most species of interest in California. Hanemann (2005) provides the most recent study in California for species proposed for recovery in the Central Valley. Benefits transfers based on this study, using the implied unit value of $100,000 per escapement, may be applicable for Central Valley listed salmonids. See Section 5.4.2 for additional discussion. ~~None of the available contingent valuation studies or the benefits transfers studies used survey results where respondents were asked to value small population increments added to small populations, as is most applicable for the species of interest in California. However, Hanemann (2005) is the most recent study in California, covering the actual species proposed for recovery, and it provided a value per fish that is consistent with most other studies.~~

In a study regarding the value of preserving natural habitats unrelated to salmonids, the State Water Board considered changes in water diverted for use in Southern California from streams flowing into Mono Lake. Reduced flows into the lake were affecting resident and migratory birds. California households received a mail survey asking whether they would pay more on their water bill to restore flows to the lake. The average willingness-to-pay per household was estimated to be $156 per year. This supported the idea that the general public's interest in increased water in Mono Lake could be an important part of the water allocation decision.

The state hired a consulting firm to conduct a more in-depth survey. The survey included images showing the lake at different water levels and provided information about effects of lake levels on different bird species. Survey respondents were asked how they would vote in a hypothetical referendum. This study also suggested that the benefits of a moderately high (but not the highest) lake level were greater than the costs.

A benefits transfer analysis should consider the willingness to pay of non-respondents. The Klamath River Basin Restoration Nonuse Valuation Study had a response rate of 32.8 percent (Mansfield et al., 2012). The researchers found that the "non-respondents may have been systematically different" so they aggregated "over a portion of households equal to the proportion of the sample that returned the survey" (See page ES-13 of the study). Stated differently, the willingness to pay was not aggregated over the entire population of households in the region; the willingness to pay of non-respondents was assumed to be zero. This convention should be applied for any use of benefits transfer to estimate benefits for WSIP.

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Appendix F
Economic Models for Evaluating Public Benefits

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Economic Models for Evaluating Public Benefits

This appendix covers some economic models that might be used to help monetize public benefits. Applicants are not required to use the models described.

Ecosystem Improvement

No relevant, practical economic models of general application are known. Specific studies that may be used, where appropriate and justified, to estimate benefit values for salmonids are described in Appendix E.

Water Quality

Lower Colorado River Basin Water Quality Model

This model estimates benefits of source water salinity reductions for urban water supplies. The Lower Colorado River Basin Water Quality Model was developed by Reclamation (Lower Colorado Region) and Metropolitan in 1998. This model was updated as part of Metropolitan's and Reclamation's 1999 Salinity Management Study. The current version of the model maintained by DWR was updated with population data from DWR, and costs have been updated to 2007 levels. Most salinity costs are the reduced life of appliances and infrastructure, treatment costs, and degradation of groundwater resources. Metropolitan and Reclamation's Salinity Management Study (1999) contains a complete reference of the data and their source material.

Additional SWP water generally reduces south coast salinity costs because SWP water is less saline than most other south coast water supplies. The model inputs from CalSim-II and DSM2 are SWP East and West Branch deliveries and TDS of these deliveries in mg/L, respectively. Some water diverted at Banks Pumping Plant is conveyed directly to Southern California; other supplies are mixed in San Luis Reservoir with water diverted at Jones Pumping Plant. Salinity inputs from the California Aqueduct should be calculated at a point south of San Luis Reservoir.

Lower Colorado River Basin Water Quality Model divides Metropolitan's service area into 15 subareas. The division of the south coast region into subareas provides detail regarding sources of water and salts in each area. This detail is necessary because each region obtains very different shares of supply from different sources; and some sources, the Colorado River and groundwater in particular, have higher salinity than others.

The model is large and complex. Mann (2011) used regression analysis to develop an equation that can estimate south coast salinity benefits from changes in SWP supplies and salinity. The Lower Colorado River Basin Water Quality Model was run for export salinities ranging from 160 to 280 mg/l, and with SWP water supplies ranging from 9,000 to 190,000 AF to obtain 177 observations for a regression analysis. Economic cost was estimated as a function of the level of SWP supply and TDS in mg/l. The regression equation with the best fit is:

Cost = 4948-0.2526SWP+.16458TDS+0.00066147(SWP*TDS)

Where

Cost = Million 2010 $ south coast salinity cost,

SWP = TAF of SWP supplies, and

TDS = mg/l salinity of SWP supply

This functional form provided an R-squared of 0.992 and an adjusted R-squared of 0.984. This equation can be used to approximate salinity reduction benefits from changes in south coast SWP supplies; estimates should be updated to 2015 dollars using factors provided elsewhere in this Technical Reference.

Bay Area Water Quality Model

The Bay Area Water Quality Model estimates benefits of source water salinity reductions for urban water supplies in the portion of the Bay Area region from Contra Costa County south to Santa Clara County. The model was developed and used for the economic evaluation of a proposed expansion of Los Vaqueros Reservoir (Reclamation, 2006).

Separate calculations are provided for Contra Costa Water District and another region consisting of Alameda County Water District, Zone 7, and Santa Clara Valley Water District. The model inputs include water supply to the South Bay Aqueduct and Contra Costa Canal (provided by CalSim-II) and chloride concentrations in mg/L from DSM2. For Contra Costa Water District, water quality estimates are based on diversion volume and water quality at Old River and Rock Slough. For the other areas, water quality is based on diversion volume and salinity at Banks Pumping Plant. In the districts receiving SWP water, water quality is a function of other supplies as well as SWP imported supplies.

This model calculates residential benefits only. Input data on the percent of households having certain appliances such as water softeners, and the initial cost of the appliances, are required. Data on the salinity of supplies obtained through Contra Costa Water District's intakes, through the South Bay aqueduct, and through the San Felipe system must be developed for alternatives. The model also requires the average salinity of any other non-project supplies.

Agricultural Salinity Model

This model estimates benefits from a reduction in salinity of agricultural water deliveries south of the Delta. SWP and CVP deliveries to south-of-Delta agricultural users are allocated to a large geographic area that supports numerous crops and irrigation methods. Some of these areas are salt- and drainage affected and have limitations for virtually all crops. Crop production in these areas requires careful irrigation management and leaching of salts. Other irrigated areas are not drainage affected (as yet), but sensitive crops such as orchards and vegetables still require that growers maintain adequate leaching to prevent salt from accumulating in the root zone. The savings in irrigation water used for leaching is calculated for each of these areas south of Delta based on the crops grown and their salt sensitivities.

Water saved as a result of growers applying a smaller leaching requirement is assumed to be available for other irrigation use within the area. The benefit of the water saved is the unit value of water for irrigation in that area times the volume saved. Because the saved water would have been delivered to farms anyway, neither the project (SWP or CVP) nor the local district incurs any additional cost of delivery. Therefore, the marginal value of irrigation water is an appropriate measure of the benefit of an AF of water not needed for leaching and therefore available to meet other crop water uses. The saved water could be used to reduce groundwater pumping, to reduce land fallowing, or for both. The SWAP Model is typically used to estimate the value of water for irrigation (see Appendix D)

The CalSim-II and DSM2 models are used to estimate TDS and electrical conductivity of water pumped by the SWP and CVP facilities. Jones PP supplies water to the Delta Mendota Canal, which is the primary source of CVP water delivered into the Grasslands salinity analysis area. Banks Pumping Plant supplies water to the California Aqueduct, which either delivers it directly to contractors or conveys it to San Luis Reservoir, from which it is delivered to contractors. The other salinity analysis areas receive their Delta supply from this source.

Flood Damage Reduction

A number of different models are available to assist with flood damage benefits estimation; some examples are discussed below.

HEC-FDA

The most widely used model for urban flood damage reduction is probably the USACE's HEC-FDA (USACE, 2011). The HEC-FDA software provides the capability to perform an integrated hydrologic engineering and economic analysis. It can estimate direct flood damage losses by category (e.g., single family residential, multi-family residential, commercial, and industrial).

According to DWR (2010), advantages of using HEC-FDA include the following:

- USACE developed and uses the software.
- Uncertainty is directly incorporated into the analysis using Monte Carlo simulation, which explicitly accounts for uncertainty in key parameters and relationships.
- Levee failure assumptions (probabilities based on water surface elevations below top-of-levee) can be entered into the analysis.
- Although designed for urban flood damage analyses, it can be applied to agricultural analyses.

- The model develops the stage-damage functions using structural inventories that are directly input into the software; or stage-damage functions can be developed outside of the software and then directly input into it.
- Project performance statistics (annual exceedance probability, long-term risk, and conditional non-exceedance) are outputs that can be used for determining "levels of protection."

Disadvantages of using HEC-FDA include the following:

- Training is typically required.
- HEC-FDA is data intensive, requiring hydrologic, hydraulic, geotechnical (if levees are present), and economic data.
- HEC-FDA is not GIS-based.

The USACE HEC-FDA model was recently applied for a project near Hamilton City, California (USACE, 2004). An existing private levee, although not constructed to any formal engineering standards, provided flood protection to the town and surrounding area. Since Shasta Dam was constructed in 1945, flood fighting was necessary in 5 years to prevent flooding, and flood damage occurred in 1 year. Glenn County built a backup levee about 1,000 feet long to protect the community in the event that toe erosion caused failure at the northern end of the private levee.

A HEC-FDA application was completed in 2001 and again in 2003. The more detailed 2003 application included site-specific hydrology and hydraulics and disaggregated impact areas and analysis zones. The economic analysis included a structure inventory, structure valuation using the Marshall and Swift valuation service with assumed contents of 50 percent, generic depth-damage relationships using Economics Guidance Memorandum 01-03, an automobile depth-damage curve, crop damages, and levee failure assumptions. Uncertainty was included by use of Monte Carlo simulation. Benefits for seven levee setback alternatives were estimated, and benefit cost measures were provided.

HEC-FIA

HEC has developed Flood Impact Analysis (HEC-FIA) to estimate direct urban and agricultural damage and loss of life that would occur if existing USACE projects had not been built. HEC-FIA estimates are provided to Congress to help document the achievements of existing USACE projects. EAD estimates are not provided by HEC-FIA, but event damage estimates from HEC-FIA can be input into HEC-FDA and other models to obtain EAD estimates.

In California, USACE has developed HEC-FIA data for areas protected by federal levees in the Delta (USACE, 1999) for the 1995 and 1997 flood events. The USACE found that "HEC-FIA did approximate the damage values and location of damage for the Sacramento and San Joaquin River Systems."

HAZUS-MH

FEMA developed a model called HAZUS MH (MH stands for multi-hazard), or just HAZUS for short. This software is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high risk locations due to earthquake, hurricane, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process.

HAZUS is used for mitigation and recovery as well as preparedness and response. Government planners, GIS specialists, and emergency managers use HAZUS to determine losses and the most beneficial mitigation approaches to take to minimize them. HAZUS can be used in the assessment step in the mitigation planning process, which is the foundation for a community's long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage. Being ready will aid in recovery after a natural disaster.

HAZUS contains a flood loss estimation model that includes flood hazard analysis and flood loss estimation modules for riverine and coastal analyses. The flood hazard analysis module uses characteristics such as frequency, discharge, and ground elevation to estimate flood depth, flood elevation, and flow velocity. The loss estimation module estimates direct and indirect economic losses using the results of the flood hazard analysis and structural inventories. HAZUS-MH analyses can be conducted at different levels of rigor (FEMA, 2016).

According to DWR (2010), advantages of using HAZUS include the following:

- It is GIS-based
- It can be adapted to different analysis levels depending upon user-input data; default values are available for "reconnaissance" studies
- The availability of default values allows for analyses that otherwise could not be conducted because of the lack of local data

Disadvantages of using HAZUS include the following:

- Users are required to have ArcGIS software and expertise
- It does not directly incorporate uncertainty (as opposed to risk), although this can be addressed by sensitivity analyses
- It may not have adequate geographic coverage for all potential flood damage categories. Potential users must determine its data coverage and augment if needed.

FEMA Mitigation BCA Toolkit

FEMA developed the Mitigation BCA Toolkit specifically for use by local and state agencies applying for funding to several mitigation grant programs. The software is menu-driven and is therefore relatively easy to use. Default data are provided for many variables (e.g., the value of contents as a percentage of structural value), although local data can be input into the model. The software then computes net benefits and the benefit cost ratio. The software comes with extensive online resources, including training.

Disadvantages include the following:

- It does not directly incorporate uncertainty
- The discount factor is fixed at 7 percent, which FEMA uses, and cannot be changed

F-RAM

Consultants to DWR have developed a spreadsheet model F-RAM to estimate flood damage. This model develops loss-probability curves for with- and without-project conditions based upon hydrologic and hydraulic data, probability of levee failure data, structural and crop inventories, and depth-damage curves. Damage categories include crops, roads, and residential, commercial, and industrial properties; however, other categories can be added. The model is flexible in that many of the analysis assumptions and parameters can be changed (e.g., structural foundation heights, unit replacement values, and depreciation factors; depth-damage curves; discount rates; analysis period; and other indirect damage “adjustment factors”).

Advantages of using F-RAM include the following:

- It can provide relatively quick estimates of EADs depending upon the availability of input data
- It can be adapted to different analysis levels depending upon the quality of the input data
- It incorporates probability of levee failure
- Users can easily see data inputs and calculations (i.e., it is transparent)

Disadvantages of using F-RAM include the following:

- It does not directly incorporate uncertainty in inputs or other parameter values
- The model has not been widely reviewed or approved by federal agencies

F-RAM does not account for some damages that might be important:

- Loss of net revenues in commercial and industrial enterprises

- Costs of flooding disruption to utilities (gas, electricity, water, sewerage, telecommunications and postal services)
- Amount or value of loss of life
- Costs imposed on public services, such as education and health services
- Damages to public gardens, and recreation assets

Recreation

Existing methods for estimating recreation use are summarized in Section 4.8 Recreation, and methods for estimating economic value of recreation are discussed in Section 5.4.5 Recreation. The section below provides a statistical model of surface storage recreation visitation that applicants may use to estimate recreation use at a proposed surface water reservoir.

WSIP Recreation Visitation Model

This section documents a model of surface storage recreation visitation based on monthly July 2001 through December 2015 visitation data for seven California State Park units where surface water recreation on reservoirs is the primary attraction. The statistical model is a set of regression equations that predict total monthly day visits and total monthly camping visits based on the reservoir and park characteristics. The estimates do not provide monetary benefits associated with the visitation.

California State Parks compiles daily visitation data of varying quality and makes estimates of monthly visitation for their annual reports. A visit is defined as any person entering a State Park. One person entering three parks in one day would be counted as three visits, and a camping visit is the equivalent of two or more days. State Parks has standardized estimating methods, but visitation estimates may not be consistently calculated over time and across the different sites. For example, cars may be counted or estimated but persons per car are based on brief subsamples and estimates of varying frequency and accuracy. More detail is provided in State Parks' annual Statistical Report (e.g., California State Parks, 2015), produced for each Fiscal Year.

Data for all California State Parks was reviewed to select a sample of parks where a reservoir is the primary attraction. Some State Parks are operated by concessionaires or other agencies and visitation data is not as readily available. California State Parks (2016) provided monthly visitation data for July 2001 through December 2015 for these seven units that we selected:

- Lake Oroville State Recreation Area (SRA)
- Folsom Lake SRA
- San Luis Reservoir SRA
- Turlock Lake SRA
- Millerton Lake SRA

- Lake Perris SRA
- Silverwood Lake SRA

The general form of the visitation equation is

$$(1)\ Visitation_m = \beta_0 \cdot A + \beta_1 \cdot A^2 + \beta_2 \cdot F_m + \beta_3 \cdot P + \beta_4 \cdot S + \beta_5 \cdot B + \beta_6 \cdot C$$

$$+ \beta_7 \cdot W_{SU} + \beta_8 \cdot W_{SP} + \beta_9 \cdot W_{FA}$$

$$+ \beta_{10\text{-}15} \cdot W_{SU}(A^2 + F_m + P + S + B + C)$$

$$+ \beta_{16\text{-}21} \cdot W_{SP}(A^2 + F_m + P + S + B + C)$$

$$+ \beta_{22\text{-}27} \cdot W_{FA}(A^2 + F_m + P + S + B + C) + \beta_{28} \cdot G$$

Where:

$Visitation_m$ = day visits or camping visits during the month m

A = maximum surface acreage of the reservoir, in acres

F_m = the average storage during the month m as a percent of maximum

P = the 2010 population residing within 60 miles of the facility, in thousands

S = the maximum (when full) acreage of substitute reservoirs within 30 miles

B = the number of boat lanes

C = the number of campsites (only in camping equation)

W represents a set of binary variables (0 or 1) for seasons. Spring, W_{SP}, is April or May, summer, W_{SU}, is June through September, and fall, W_{FA}, is October and November.

G = the real annual average price of gasoline

β_0 - β_{28} are regression coefficients

This functional form uses the binary variables as intercept and slope shifters to estimate one equation rather than separate equations for individual months or groups of months. Four groups of months were selected based on preliminary analysis that found that the months within each group predicted similar levels of visitation, all else equal.

The relationship between visitation and maximum surface acreage is quadratic, with the expectation that each additional acre will raise visitation but at a decreasing rate. Therefore, the coefficient estimate β_0 in (1) is expected to be positive and β_1 is expected to be negative. This relationship can also be estimated with a transformed visitation variable. The dependent variable used in the following regression uses visitation per maximum surface acre, shown in (2).

(2) $Visitation_m/A = \beta_0 + \beta_1 A + \ldots$

Only the independent variables that include acreage in equation (1) were transformed. The statistical analysis includes two visitation regressions: monthly day visits per maximum reservoir surface acre and monthly camping visits per maximum surface acre. The explanatory, or independent variables, are:

1. Maximum surface acreage. Visitation is expected to increase with maximum surface acreage, but at a decreasing rate. The maximum surface acreage includes all lake surface within each State Park: Folsom includes Lake Natoma, Oroville includes Thermalito forebay and afterbay, and San Luis includes O'Neill Forebay and Los Banos Detention Reservoir.

2. Average storage in the main reservoir at the middle of each month as a percent of capacity (0 < Percent < 100). Data are from CDEC (DWR, 2016). The amount of storage as a share of maximum is expected to increase visits per acre. This variable should capture the effect of loss of boat lanes as reservoir storage declines.

3. 2010 population within 60 miles, in thousands. Local population, which can be estimated from census data, is associated with more visits and more visits per acre. The population within a radius of a reservoir can be estimated using online map tools which locate and count census populations. The center of the area is measured at the dam, or at the primary parking facility if much different.

4. Maximum (when full) surface acreage of substitute reservoirs within 30 miles. The sum of the maximum surface acreage of other reservoirs in the region is expected to decrease visits per acre. This acreage is also estimated from the dam, or at the primary parking facility, using online mapping tools to locate substitute facilities. Only lakes that are generally suitable and large enough for power boating were included. Their maximum surface acreage is generally from DWR (2014).

5. Number of campsites. Number of camp visits and visitation per maximum surface acre should be positively related to number of campsites. Data are from the State Parks annual statistical reports (California State Parks, 2004 to 2015), except DWR (2000) is used for the number of campsites without moorage or boat-in facilities. Campsite numbers change over the period for two of the seven facilities. For four facilities, the number of total sites including boat-in and moorage sites is used for the summer period (June through September), but only campground sites are used for the other seasons. Number of campsites is not included in the day visitation per maximum surface acreage regression because day visits should not be affected by camping facilities.

6. Number of boat launch lanes. Camp and day visitation per maximum surface acre should be positively related to number of boat launch lanes. Data are from

Fraser (2016), DWR (2000), and, for Oroville, from two websites.[3] Data were checked by visual inspection of aerial photographs.

7. The real price of gasoline. Data are calculated from the state weekly average price of gasoline from the California Energy Commission (2016) indexed by the California CPI to 2015 dollars.

8. Seasonal Variables. The four seasons were specified as following: winter: December-March; spring: April-May; summer: June-September; fall: October-November. This grouping of months was selected based on preliminary analysis using data for individual months.

9. Interaction between seasonal binary variables and other independent variables were included to allow season to affect the response of visitation to other variables.

Other variables were tested but not included. Unemployment data and a binary variable to represent 2008 and 2009 (impacts from the recession) were not statistically significant. A time trend was also tested but was not statistically significant. Different measurements of population were tested. Conceptually, it should be possible to estimate participation rates separately for populations within a range of distances. Population within 20 miles and the additional population from 20 to 60 miles were tested. This disaggregation did not provide additional explanation of visitation.

Independent variables of reservoir characteristics that do not vary by month, and also change relatively little over the years, are shown in Table F-1 below.

Table F-1. Data for Visitation Regression Analysis That Do Not Vary By Month

Location	Max Surface Acreage	Substitute Acreage within 30 Miles	1000's of Population within 60 Miles	Campsites[1, 2]	Boat Lanes[1]
Folsom	11,950	2,050	3,041	150, 197	67
Millerton	4,900	12,592	1,483	173, 234	26
Oroville	20,737	13,292	1,071	312, 1765	84
Perris	2,340	13,200	10,916	450	12
San Luis	15,720	0	3,724	194, 196	22
Silverwood	990	3,429	12,418	149	8
Turlock	3,260	50,167	1,599	63	3

[1]Some campsite and lane numbers change slightly over the period of analysis
[2]The first number is October through May, the second is June through September

[3] Oroville has 71 boat lanes plus 13 at Thermalito. http://www.lakeoroville.net/boating-overview.htm

http://www.water.ca.gov/recreation/locations/oroville/recreation.cfm

The California State Parks monthly visitation data included 1218 observations (seven facilities from July 2001 through 2015). The data included seven observations of zero for monthly day visitation and eight observations of zero for camping visits. These might be due to the respective parks' closure, visitor monitoring was canceled, or data was simply nor recorded or not kept. These observations of zero were not included in the analysis.

Results of the day visitation and camp visitation analysis are shown below in Tables F-2 and F-3, respectively. The analysis shows that almost 80% of the variation in visitation per maximum surface acreage across the facilities and months is explained by the independent variables.

Table F-2. Dependent Variable: Monthly Day Visits per Maximum Surface Acreage

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.8475770	1.1621830	5.032	0
Percent full	0.0353250	0.0079520	4.442	0.00000
Max surface acres	-0.0001020	0.0000275	-3.727	0.00020
Boat lanes	0.0512670	0.0053190	9.639	0.00000
Population 60mi	0.0004470	0.0000581	7.696	0.00000
Substitute acres	0.0000012	0.0000100	0.118	0.90610
Summer	-2.4052540	2.1980070	-1.094	0.27410
Spring	1.2661990	2.3032310	0.550	0.58260
Fall	-0.3457190	1.1304340	-0.306	0.75980
Summer*percent	0.0577690	0.0221770	2.605	0.00930
Spring*percent	0.0216570	0.0250850	0.863	0.38810
Fall*percent	-0.0073300	0.0148410	-0.494	0.62150
Summer*acreage	-0.0010790	0.0000751	-14.371	0.00000
Spring*acreage	-0.0007210	0.0000831	-8.680	0.00000
Fall*acreage	0.0000151	0.0000467	0.323	0.74660
Summer*lanes	0.2308750	0.0140640	16.415	0.00000
Spring*lanes	0.1544260	0.0145520	10.612	0.00000
Fall*lanes	-0.0099650	0.0100680	-0.990	0.32250
Summer*pop60	0.0029900	0.0001760	16.944	0.00000
Spring*pop60	0.0015160	0.0002060	7.350	0.00000
Fall*pop60	0.0002680	0.0001020	2.618	0.00900
Summer*subacres	-0.0000023	0.0000264	-0.086	0.93180
Spring*subacres	-0.0000316	0.0000288	-1.096	0.27340
Fall*subacres	0.0000136	0.0000163	0.835	0.40360

Table F-2. Dependent Variable: Monthly Day Visits per Maximum Surface Acreage				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Petrolyear	-2.2151940	0.3007810	-7.365	0.00000
R-squared	0.81902	Mean of dependent variable		10.06451
Adjusted R-squared	0.81536	Std. Dev. of dependent variable		14.37562
Std. Error of regression	6.17724	Observations		1211
F-statistic	223.63050	Prob of F-statistic		0.0000

Table F-3. Dependent Variable: Monthly Camping Visits Per Maximum Surface Acreage				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	0.8497630	0.3006410	2.827	4.80E-03
Percent full	0.0054520	0.0015960	3.416	0.00070
Max surface acres	-0.0000341	0.0000053	-6.397	0.00000
Boat lanes	0.0000500	0.0000147	3.409	0.00070
Population 60mi	0.0000018	0.0000015	1.194	0.23280
Substitute acres	-0.0172530	0.4091530	-0.042	0.96640
Summer	-1.6345800	0.4072860	-4.013	0.00010
Spring	-0.7072540	0.3381390	-2.092	0.03670
Fall	0.0035410	0.0005290	6.688	0.00000
Campsites	0.0350930	0.0059390	5.909	0.00000
Summer*percent	0.0215120	0.0048320	4.452	0.00000
Spring*percent	0.0132050	0.0051320	2.573	0.01020
Fall*percent	-0.0002970	0.0000176	-16.883	0.00000
Summer*acreage	-0.0001200	0.0000175	-6.850	0.00000
Spring*acreage	0.0000043	0.0000130	0.328	0.74300
Fall*acreage	0.0006920	0.0000434	15.965	0.00000
Summer*pop60	0.0003940	0.0000652	6.051	0.00000
Spring*pop60	0.0001310	0.0000434	3.022	0.00260
Fall*pop60	-0.0000339	0.0000047	-7.226	0.00000
Summer*subacres	0.0000053	0.0000044	1.208	0.22740
Spring*subacres	0.0000084	0.0000040	2.126	0.03370
Fall*subacres	-0.0004370	0.0005540	-0.789	0.43050
Summer*campsites	0.0006650	0.0018110	0.367	0.71340
Spring*campsites	-0.0007840	0.0013550	-0.579	0.56290

Table F-3. Dependent Variable: Monthly Camping Visits Per Maximum Surface Acreage				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Fall*campsites	-0.0012990	0.0010510	-1.236	0.21660
Summer*lanes	-0.0087420	0.0032270	-2.709	0.00680
Spring*lanes	0.0207990	0.0043080	4.828	0.00000
Fall*lanes	-0.0028380	0.0037520	-0.756	0.44950
Petrolyear	-0.4147160	0.0855330	-4.849	0.00000
R-squared	0.80494	Mean of dependent variable		1.93471
Adjusted R-squared	0.80031	Std. Dev. of dependent variable		3.83206
Std. Error of regression	1.71242	Observations		1210
F-statistic	174.0507	Prob of F-statistic		0.0000

Only summer, spring, and fall months have associated binary variables (winter visitation is represented in the overall constant term). As a result, during winter months, all variables associated with the other three seasons have no effect on estimated visitation per acre. For spring months, all variables with the word “spring” in the variable name have non-zero values and also affect the estimated visitation per acre, and similarly for summer and fall. To see the effect of, for example, maximum acreage during the summer, add the coefficients for MAX SURFACE ACRES and SUMMER*ACREAGE.

The maximum acreage of a facility is generally associated with less visitation per maximum acre. Table F-2 shows that, for day visits, this effect is not significant in the fall. However, the maximum acreage is strongly significant in spring and summer when most visitation occurs. For camp visits, the effect (-0.0000341) is negative in winter, spring and summer, but acreage is positively associated with visits per acre in the fall (-0.0000341 + 0.0006920).

The monthly storage as a percent of maximum, regional population, and number of boat lanes are all generally associated with more visitation per acre. For day visits in the fall, the total effect per one percent increase in storage is positive (0.035325 - 0.00733) even though the slope shifter (the cross-effect between the fall season and percent full) is negative (-0.00733). The number of boat lanes is positively related to day visits per acre.

The acreage of other reservoirs within 30 miles does not significantly affect day visitation per acre in most periods. However, the variable is retained because the effect, though small, is believed to be real. The net effect of more substitute acres on visits per acre is negative in every period except for day visits in fall (0.0000012 + 0.0000136).

The number of campsites has positive effects on camp visits per acre in all seasons. In winter, a campsite is associated with 0.0351 more camp visits per acre, and the size of this effect does not change much in the other seasons.

As a validation test, the model was used to predict historical visitation at New Melones Lake. Visitation and campsite data for 2004 through 2007 were obtained from

Reclamation (2011), and the number of boat lanes were estimated from aerial photographs. Data on monthly storage, storage capacity and maximum acreage were obtained from DWR and CDEC (DWR, 2014; DWR, 2016). Table F-4 shows that the model estimated about 17 percent less than the actual average visitation. Most of this difference could be attributable to high gasoline prices experienced in 2007 and summer of 2008. Apparently, visitation at New Melones did not decline as much as expected during these high gasoline price conditions.

Table F-4. Predicted Visitation per Maximum Acre at New Melones Compared to Actual

Year	Predicted Camp Visits per Acre	Predicted Day Visits per acre	Predicted Total Annual	Actual Total Annual	Difference	Percent Difference
2004	-0.5	53.4	53.0	56.0	3.0	5.4%
2005	5.4	60.8	66.2	54.5	-11.7	-21.5%
2006	6.8	60.6	67.4	63.4	-4.0	-6.3%
2007	-0.6	40.8	40.2	58.5	18.2	31.2%
2008	-6.7	20.3	13.6	58.1	44.5	76.6%

Notes:
Actual visitation from Reclamation (2011)
Average % Difference from 2004-2008 28.6%

As part of a recreation market study, the WSIP recreation model is one method for predicting visitation at a proposed surface storage reservoir that is within the range of reservoir size used to estimate the visitation model - one and a half square miles of surface area or greater (see Table F-1). Also, to be applicable, the proposed reservoir should include campsites and facilities to enable private boating. If these characteristics apply, applicants can use the model to predict 1) visitation at the proposed reservoir, and 2) loss of visitation at existing facilities within 30 miles. To predict visitation at the proposed reservoir, an applicant would estimate visitation per maximum acre for the proposed reservoir and then multiply by the maximum acres. The applicant should ensure that recreation facilities are properly planned for the reservoir; facilities should include a suitable mix in relation to the size of the reservoir and expected visitation even if those facilities are not included in the WSIP visitation model. A real gasoline price of $3.27, the average of monthly gas prices in the analysis, can be used to project visitation for future with-project conditions.

Visitation at proposed reservoirs that are much different from those in the State Parks data set should be estimated using different methods, and results should be compared to other, similar facilities where data are available.

To use the WSIP visitation model for estimating economic benefits, the number of visits must be associated with a number of recreation days that can be valued using the Army Corps of Engineers Unit Values. Visits are not the same as a recreation day. When using the WSIP model for visitation, a day visit may be assumed to be one recreation day, and a camping visit may be assumed to last an average of three recreation days.

In summary, the visitation regression model provides a reasonable method that applicants may use to estimate recreational use at a similar proposed surface reservoir. However, the test validation using data from New Melones Reservoir indicates that the model somewhat under-predicts visitation for that particular site.

If available time and budget are available, it is recommended that applicants proposing a large surface reservoir use their recreation facilities plan and a market analysis to estimate visitation. The market analysis should consider the amount of visitation at other, similar facilities. For small proposed reservoirs, and where recreation benefits are not a large share of public benefits, visitation can be estimated based on visits per surface area for similar small local reservoirs.

Emergency Response

No relevant, practical models are known.

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Appendix G
Discounting and Discount Rates

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Discounting and Discount Rates

The discount rate is a real (inflation-free) interest rate that allows all benefits and costs occurring in future years to be compared and combined. If two projects use different discount rates, their benefits and costs are weighed differently and therefore they cannot be compared fairly.

Some discount rates applied to public investments are displayed in Table E-1. Economists have developed three fundamental approaches regarding how to implement discounting: the social rate of time preference, the social opportunity cost of capital, and the shadow price of capital. In general, the social rate of time preference tends to provide the lowest discount rate (i.e., 1 to 4 percent) although some economists propose long-term, inter-generational rates that are near zero. The social opportunity cost of capital tends to provide the highest rates at perhaps 5 to 8 percent.

Table G-1. Options for Discount Rate

Option Name	Description	Current value	Advantages	Disadvantages
DWR Rate	Has been used by DWR for state project evaluations for years	6 percent[1]	Precedent in DWR grant programs; may approximate opportunity cost of capital	No recent, formal documentation or update.
FEMA Rate	Rate for Pre-Disaster Mitigation grant program	7 percent	Compliance with OMB BCA guidelines, intended to be based on the marginal opportunity cost of private investment per OMB Circular A-94	OMB Circular A-94 BCA rate not changed since 1992.
WRDA rate	Rate for federal water projects	3.375 percent[2]	Consistency with federal feasibility studies; related to federal cost of capital	Changes very slowly over time, so lags changes in federal cost of capital[4]
California cost of borrowing, Legislative Analyst's Office Proposition 1	Legislative Analyst's Office assumed a nominal rate of just over 5 percent	About 3 percent[3]	Reflects state costs of capital	Not known how Legislative Analyst's Office developed[4]
California cost of borrowing, independent	Develop a rate based on California bond interest costs	3.5 percent (tentative)	Reflects state costs of capital	Must be calculated – no publication to use as standard reference[4]

1. The DWR rate of 6 percent was based generally on an estimate of the opportunity cost of capital.
2. Discounting methods for the federal Water Resource Development Projects are specified by the WRDA. The rate is based on a mix of federal Treasury bond yields, but the annual change in the rate is capped. During periods of rapid change in interest rates, the WRDA rate can diverge from the federal cost of capital by a substantial amount.
3. The California Legislative Analyst's Office (2014) prepared an analysis of borrowing costs for Proposition 1. After adjusting for an estimated expected long-term inflation rate of 2 percent, the real rate is 3 percent.
4. These rates can be heavily influenced by short and medium term federal monetary policy (e.g., quantitative easing).

California's appropriate discount rate for evaluating public benefits of water projects should not be based on the private opportunity cost of capital. First, repayment of general obligation bonds does not draw money out of the private sector because no new tax revenue is made available when the public passes a bond measure. Rather, bond repayment diverts existing tax revenue from other state-funded programs. Second, most bond buyers are likely to be out of state, so the opportunity cost of their investments do not matter from a state perspective.

The real interest rate at which California General Obligation bonds are sold is arguably the most realistic basis for the State's cost of capital and therefore the appropriate discount rate for public benefits. The WSIP technical team conducted a review of recent bond costs to estimate the likely nominal rate for State bonds. Since 2008, the state has paid an average of 3.22 percent for revenue bonds. The current 30-year general obligation bond rate has ranged from about 3.0 to 3.5 percent during 2015 (California State Treasurer, 2015). Several adjustments to this rate are appropriate.

- First, the bonds will not be sold immediately and then might be sold over a period of 10 years. Current bond rates reflect expansionary monetary policy (low Federal Reserve interest rates). Recent expectations by the Federal Reserve Board of Governors (Federal Reserve Board of Governors, 2015) indicate that longer-term federal funds rates could rise by 2 to 3 percentage points by 2017. In response, bond rates are expected to increase over the next several years.
- Second, the state's borrowing rate reflects investors' (bond buyers') assessment of the risk that they will be repaid by the state. However, the risk that taxpayers take in investing in public benefits of water storage projects is likely to be greater than that, considering the significant uncertainties about future hydrologic, economic, climate, and ecosystem conditions. Therefore, the WSIP team believes that an appropriate discount rate, though based on the State's real borrowing rate, should be higher to reflect the larger risk of achieving the future public benefits.
- The nominal rate must be adjusted for expected inflation. The Federal Reserve Bank of Cleveland reports that its latest estimate of 10-year expected inflation is 1.88 percent, and its estimate of 30-year expected inflation is 2.2 percent (Federal Reserve Bank of Cleveland, 2015). The Federal Reserve Board of Governors (Federal Reserve Board of Governors, 2015) expects inflation to be about 2 percent in the long run.

Commission staff has considered these factors of expected inflation, changes in monetary policy that the Federal Reserve Board has signaled, and the inherent risk in future levels of public benefits, and recommends that, for purposes of allocating costs and calculating expected return on investment, all public and non-public benefits and costs must be evaluated using a real discount rate of 3.5 percent.

Applicants may need to use a different interest rate for some financial calculations related to non-public benefits. This private rate should be based on the applicant's borrowing costs to finance the private share of construction costs, reduced for expected inflation of 2 percent.

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