# Groundwater Overdraft in California's Central Valley:
# Updated CALVIN Modeling Using Recent CVHM and C2VSIM Representations

By

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THESIS

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# Abstract

Updates have been made to the CALVIN hydro-economic optimization model of California's intertied water supply and delivery system. These updates better reflect water demands, groundwater availability, and local water management opportunities. This update project focused on improving groundwater representation in CALVIN, which included changing CALVIN groundwater parameters based on California Department of Water Resources' (DWR) California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and the United States Geological Survey (USGS) Central Valley Hydrologic Model (CVHM) model inputs and results. Using these models, a CALVIN model with updated groundwater representation now exists.

In updating CALVIN, a detailed comparison between C2VSIM and CVHM was conducted and the results are discussed in this thesis. The updated CALVIN model was used to study the effects of different cases of overdraft on Central Valley groundwater basins. When compared to the updated CALVIN model's case of overdraft, ending overdraft in the entire Central Valley results in less available groundwater and higher economic scarcities in all regions, driving the model to use more surface water to try to meet demands and also to use more artificial recharge to even out variability in surface water availability.

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# CHAPTER 1

# Introduction

This project included updating CALVIN's representation of Central Valley groundwater and revising some aspects of the CALVIN model framework to achieve more clarity in the terms representing groundwater conditions; this lays a streamlined framework for future CALVIN groundwater updates. With surface water reliability decreasing in California, groundwater continues to play a larger role in water supply. And because there is still much uncertainty in how much groundwater is actually available in California, this hydro-economic approach to modeling groundwater can be useful for water planners and managers. Using the updated model, several overdraft scenarios were examined to see how overdraft economically and physically affects Central Valley groundwater conditions and water users.

## Groundwater in California

Groundwater provides about 30 percent of California's water demands in a normal year. In drought years and in the Central Valley, dependence on groundwater is even higher. An estimated 15 million acre-feet of water is pumped per year, which is more than what is being recharged, causing overdraft in some areas (Faunt et al. 2009; DWR 2003). Overdraft has negative effects on water quality, increases pumping costs, causes land subsidence, and eventually decreases groundwater availability. DWR estimates the overdraft in the state's groundwater basins to be one to two million acre-feet annually, mostly in the Tulare Basin. Even with substantial overdraft, there are no statewide regulations on groundwater pumping (DWR 2003). Groundwater availability in the Central Valley is particularly important for droughts, when the absence of surface water brings water users to pump more groundwater. The storage capacity in the Central Valley's aquifers is much larger than the water storage capacity of its surface water reservoirs, making groundwater pragmatic for long-term drought water storage.

## CALVIN

CALVIN, the CALifornia Value Integrated Network model is an economic-engineering optimization model of California's water system. It covers 92% of California's population and 90% of the irrigated crop area (Howitt et al. 2012). The model uses a network flow optimization solver developed by the U.S. Army Corps of Engineers to provide results on surface and groundwater operations, and water use allocations based on maximizing statewide net economic benefit, or minimizing statewide water operations and scarcity costs. There are operating costs associated with infrastructure links in the system and scarcity costs are calculated from each area's water delivery demands. The current network consists of 41 urban demand areas, 25 agricultural demand areas, 44 reservoirs, 31 groundwater basins, and 1,767 links. Figure 1 shows the CALVIN coverage and network.

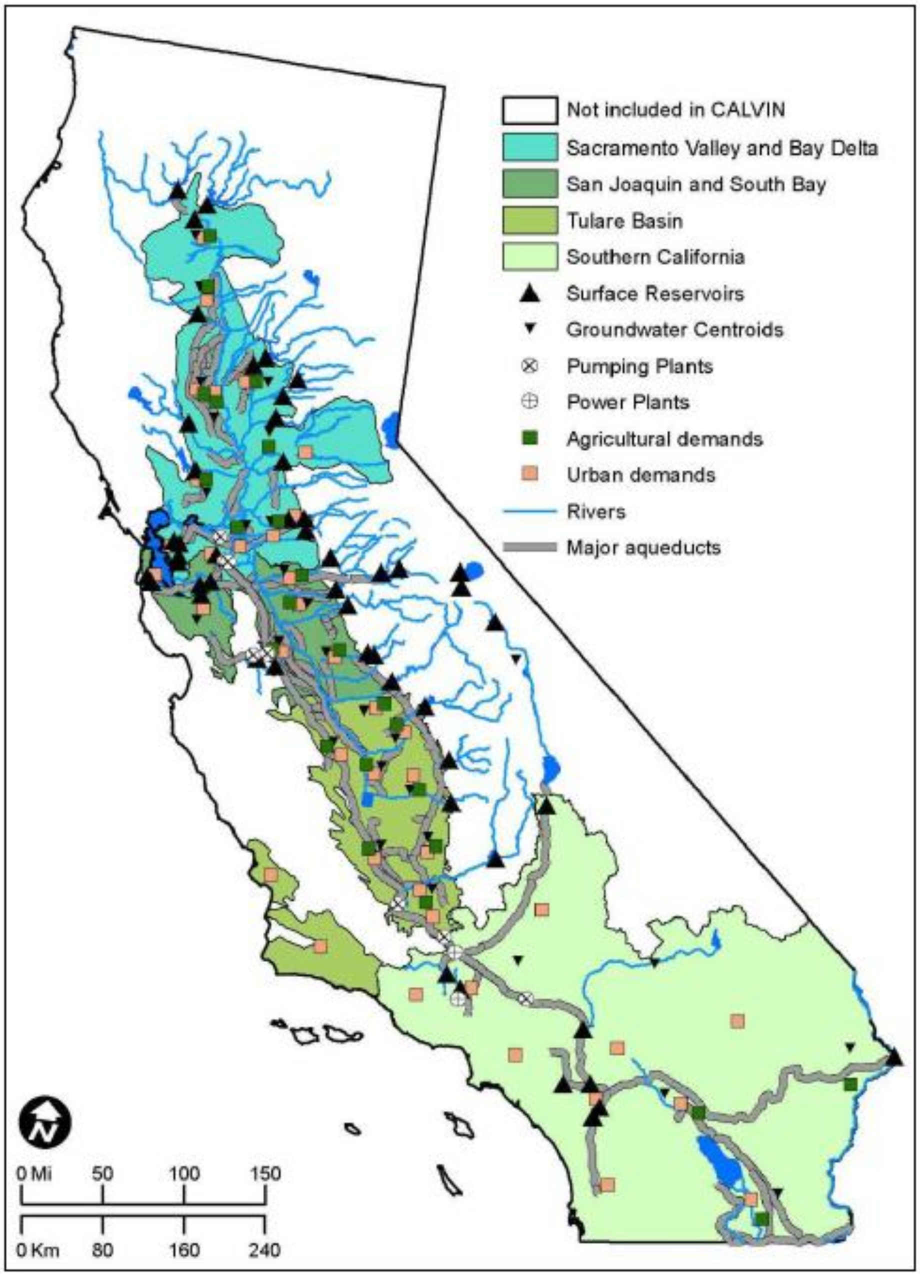


**Figure 1.1: CALVIN Coverage Area and Network**

## Previous CALVIN Studies

CALVIN has been used to study a wide variety of different California water problems including infrastructure, water use, climate change, policy, and now–overdraft. These previous CALVIN studies are described in Table 1.1. This groundwater update project is the first major study of changes to CALVIN’s Central Valley groundwater system since the model was developed in 2001.

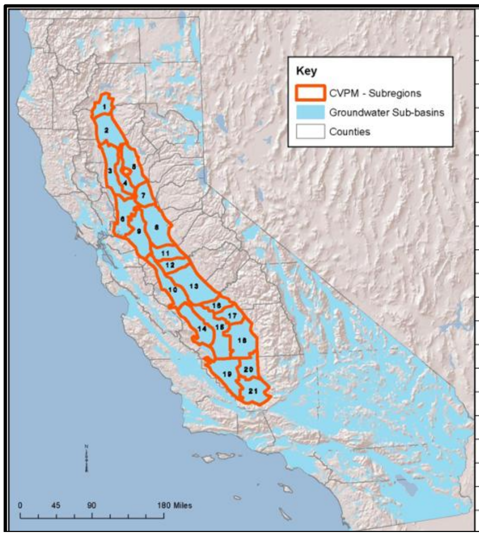
**Table 1.1: Previous CALVIN Studies**

| Description | Citation |
|---|---|
| Integrated water management, water markets, capacity expansion, at regional and statewide scales | Draper et al. (2003);<br>Jenkins et al. (2001; 2004); Newlin et al. (2002) |
| Conjunctive use and southern California | Pulido et al.(2004) |
| Hetch Hetchy restoration | Null (2004); Null and Lund (2006) |
| Perfect and limited foresight | Draper (2001) |
| Climate warming, wet and dry | Lund et al. (2003); Tanaka et al.(2006; 2008) |
| Climate warming, dry | Medellín-Azuara et al.(2008a; 2009) |
| Climate warming, dry and warm-only | Medellín-Azuara et al.(2008a; 2009); Connell (2009) |
| Severe sustained drought impacts and adaptation (paleodrought) | Harou et al. (2010) |
| Increasing Sacramento River outflows | Tanaka and Lund (2003) |
| Reducing Delta exports and increasing Delta outflows | Tanaka et al.(2006; 2008; 2011);<br>Lund et al.(2007; 2008) |
| Colorado River delta and Baja California water management | Medellín-Azuara et al.(2006; 2007; 2008b) |
| Ending overdraft in the Tulare Basin | Harou and Lund (2008) |
| Cosumnes River restoration and Sacramento metropolitan area water management | Hersh-Burdick (2008) |
| Bay Area adaptation to severe climate changes | Sicke (2011) |
| Urban water conservation with climate change and reduced Delta pumping | Ragatz (2011) |
| Economic Responses to Water Scarcity in Southern California | Bartolomeo (2011) |

(Adapted from Lund et al, 2010)

## CALVIN Groundwater

Central Valley groundwater basins in CALVIN are represented by the Central Valley Production Model (CVPM) subregions as shown in Figure 1.2.



| Subregion | Location |
|---|---|
| 1 | Redding Basin |
| 2 | Chico Landing to Red Bluff |
| 3 | Colusa Trough |
| 4 | Colusa Landing to Knight's Landing |
| 5 | Lower Feather R. and Yuba R. |
| 6 | Sacramento Valley Floor, Cache Cr., Putah Cr., Yolo BP |
| 7 | Lower Sacramento R. below Verona |
| 8 | Valley Floor east of Delta |
| 9 | Sacramento -San Joaquin Delta |
| 10 | Valley Floor west of San Joaquin River |
| 11 | Eastern San Joaquin Valley above Tuolumne R. |
| 12 | Eastern Valley floor between San Joaquin R. & Tuolumne R. |
| 13 | Eastern Valley floor between San Joaquin R. & Merced R. |
| 14 | Westland |
| 15 | Mid-Valley Area |
| 16 | Fresno Area |
| 17 | Kings R. Area |
| 18 | Kaweah R. and Tule R. Area |
| 19 | Western Kern County |
| 20 | Eastern Kern County |
| 21 | Kern R. Area |

**Figure 1.2: Groundwater Basins Modeled in CALVIN**

Since CALVIN is an optimization-based system engineering model, groundwater heads are not represented as in a groundwater model; changes in groundwater volumes are modeled instead (Draper et al. 2003). For each subregion, flows, volumes, and fractions have been extracted, calculated, and/or estimated from physical simulation groundwater models and inputted as parameters into CALVIN to represent the interactions within the subregions and storage volumes of these basins. These parameters are summarized in Table 1.2. More detailed descriptions of these terms and their calculations are found in Chapter 2 and Appendices 1, 2, and 4.  Figure 1.3 describes the terms and how groundwater interacts in CALVIN.

**Table 1.2: Groundwater Data Required by CALVIN for each GWSB**

| Item | Data for CALVIN | Data type |
|---|---|---|
| 1 | Agricultural return flow split (GW & SW) | Fraction (1a+1b=1) |
| 2 | Internal reuse | Amplitude (≥1) |
| 3 | Return flow of total applied water | Amplitude (<1) |
| 4 | External flows | Monthly time series |
| 4-1 | Inter-basin flows | Monthly time series |
| 4-2 | Deep percolation from streams and lakes | Monthly time series |
| 4-3 | Deep percolation from precipitation | Monthly time series |
| 4-4 | Boundary inflow | Monthly time series |
| 4-5 | Subsidence | Monthly time series |
| 4-6 | Gains from diversions (conveyance seepage) | Monthly time series |
| 4-7 | Non-recoverable losses | Monthly time series |
| 5 | Groundwater pumping capacity (maximum & minimum) | Number value |
| 6 | Depth to groundwater (pumping lift) for pumping cost | Number value & cost ($) |
| 7 | Initial Storage | Number value |
| 8 | Ending Storage | Number value |
| 9 | Storage capacity (maximum & minimum) | Number value |
| 10 | Calibration Flows | Monthly time series |
| 11 | Urban return flow | Amplitude (<1) |

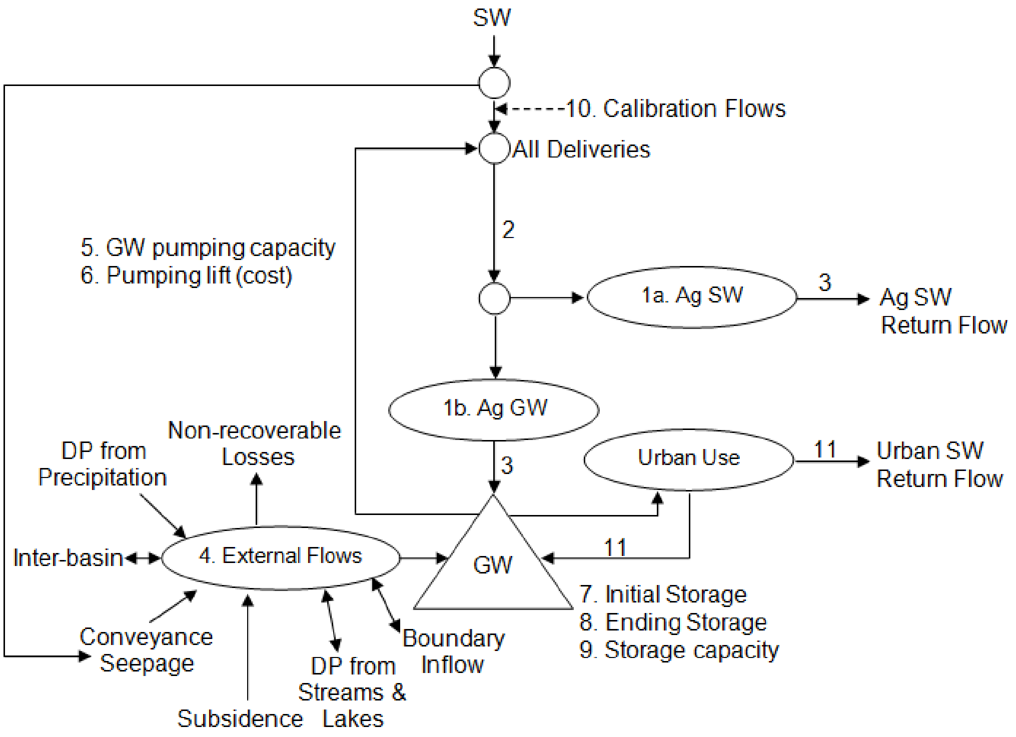


**Figure 1.3: Flows and Interactions in CALVIN Groundwater Sub-basins**

As seen in Figure 1.3, surface water and pumped groundwater come together at a node which represents all water deliveries to demand areas. These deliveries are then split between agricultural surface water and agricultural groundwater demands (term #1). A re-use amplitude (term #2) can be specified prior to this split. Following the water delivered to the surface water and groundwater demand areas, the return flow fraction (term #3) is the fraction of the water not used by the crops and is returned to groundwater or surface water. The external flows (term #4) include deep percolation from precipitation, inter-basin flows, boundary flows, stream leakage, subsidence, conveyance seepage, and non-recoverable losses (i.e. evapotranspiration and tile drain flows). Water pumped from the groundwater basin has capacity constraints (term #5) and also a pumping lift (term #6) to calculate pumping cost. The groundwater basin itself has initial, ending, minimum, and maximum storage constraints (terms #7-9). Any flows needed to maintain mass balance in the system or allow for feasible results are considered “Calibration flows” (term #10), which are added or removed prior to the delivery node to ensure that the appropriate amount of water can be delivered to the demand areas; calibration flows can be positive or negative. Such calibration flows also help reflect uncertainty in our understanding of California’s hydrology. Urban return flow (term #11) is also represented as an amplitude, like term #3.

### Previous CALVIN Groundwater Representation

Prior to this update project, CALVIN’s groundwater representation was based on pre- and post-processing data and results from the Central Valley Ground Surface Water Model (CVGSM) 1997 No Action Alternative (NAA) run (USBR 1997). CVGSM is a special application of the Integrated Ground Surface Water Model (IGSM) to the Central Valley of California, used in the Central Valley Project Improvement Act (CVPIA) Programmatic Environmental Impact Statement (PEIS) of 1992. A description of CVGSM representation of CALVIN groundwater can be found in Jenkins et al. 2001 and Davis et al. 2001 (Appendix J).

Since CVGSM was used for CALVIN groundwater, new studies have shown that some of the old IGSM algorithms are very different from those used in MODFLOW, whose algorithms are widely tested and established, bringing some question in whether or not this version of IGSM’s solutions are a good representation of the hydrologic system it is modeling (LaBolle et al. 2003). Considering that new and improved models like CVHM and C2VSIM (CVGSM’s successor) have been developed, it was decided to update CALVIN groundwater based on one of the new, more detailed models. The groundwater terms calculated from the CVGSM model are compared with the new calculated terms from CVHM and C2VSIM in Chapter 3.

### New California Groundwater Modeling Efforts

Several groundwater modeling efforts for California’s Central Valley exist and are on-going. The Department of Water Resources (DWR) has developed and continues to update a groundwater model of California’s Central Valley called the California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) using the Integrated Water Flow Model (IWFM) (Brush et al. 2008). In addition, the United States Geological Survey (USGS) also developed a groundwater model for the Central Valley using MODFLOW and published its development in Professional Paper 1766 in 2009 (Faunt et al. 2009). This model also continues to be developed. These two models have been studied extensively to draw data and results for improving CALVIN's groundwater representation. C2VSIM, CVHM, and CVGSM (old CALVIN) use the same subregion definitions (CVPM regions) for groundwater basins, allowing for direct comparisons of data and results.

Using MODFLOW and the FMP, CVHM simulates key groundwater and surface water processes in the Central Valley for the 21 water-balance regions for water years 1962 to 2003. The model is based on year 2000 land use. A Geographic Information System (GIS) was used to develop a geospatial database to manage the data. The model is divided horizontally into a square grid of 20,000 square mile cells, and vertically into 10 layers, ranging in thickness from 50-750 feet. A geologic texture model was developed for CVHM to better characterize the Central Valley aquifer system. More information on CVHM is in Chapter 2 and Faunt et al. 2009.

Using the 3-D finite element code IWFM, C2VSIM simulates groundwater flow and groundwater-surface water interactions for the 21 subregions on a monthly basis from water years 1921 to 2003. The model is represented by three layers of 1392 elements. More information on C2VSIM can be found in Brush et al. 2008.

Although there are similarities in the two models' hydrologic inputs, the models operate differently and the outputs and results are significantly different in some areas. Some differences and the effects of those differences on this application to CALVIN are discussed here. A detailed comparison of the theory, approaches, and features of the two models can be found in Dogrul et al. 2011.

## Project Description

This CALVIN groundwater update had several steps. First, CALVIN groundwater parameters were identified. Data for these parameters was then estimated based on C2VSIM and CVHM inputs and outputs for use and comparison with the previous CALVIN model (CVGSM) estimates. Following comparisons of these parameter estimates, separate simplified CALVIN model runs were conducted using these parameter values from each groundwater model. These results were compared and the decision was made to primarily use C2VSIM for the final CALVIN groundwater representation mostly due to C2VSIM's longer historical modeling period. Next, calibration of the 72-year CALVIN model based on C2VSIM was done and a new CALVIN model with updated groundwater representation based on C2VSIM emerged. Finally, additional studies were done by adjusting the overdraft scenarios based on CVHM and other simulated scenarios.

The major steps in this groundwater update project are summarized as follows:

1. Estimate, calculate, and/or extract terms from CVHM and C2VSIM to use as parameters (Table 1.2) for CALVIN update
2. Compare CVHM and C2VSIM terms and methods with CALVIN representation to determine which parameters from which model are to be used for the final CALVIN Groundwater update. Options included: CVHM, C2VSIM, or a combination of CVHM and C2VSIM.
3. Run the CALVIN model
4. Calibration of CALVIN model to ensure feasible and reasonable results
5. Additional overdraft studies to test updated model

## Overview of Thesis

This thesis work updated CALVIN groundwater representation in the Central Valley and also improved many aspects of the CALVIN model. Chapter 2 describes CALVIN groundwater input terms and the groundwater representation based on CVHM. Chapter 3 discusses and compares the groundwater input terms from C2VSIM, CVHM, and CVGSM. Chapter 4 presents the updated CALVIN model with Central Valley groundwater representation primarily based on C2VSIM and the calibration process that resulted in the final updated model from this research project. This chapter also presents a comparison between the updated CALVIN model with the version of the model prior to the update. Chapter 5 applies the updated model to investigate the economic and physical effects of different cases of overdraft in the Central Valley. Finally, Chapter 6 summarizes the results from this research project, discusses the limitations, and presents some ideas for future work on the CALVIN model.

# CHAPTER 2

# CALVIN Groundwater Representation Based on CVHM

This chapter discusses the CVHM model and how it was used to calculate the groundwater input terms for CALVIN. This chapter also provides a description of the groundwater terms used for CALVIN and the CVHM calculated term results. Although CVHM was ultimately not used as the primary basis for Central Valley groundwater representation in CALVIN, studying the CVHM calculation of the groundwater terms was very useful for understanding CALVIN groundwater and the CVHM results were used for comparisons during model calibration (discussed in Chapter 4).

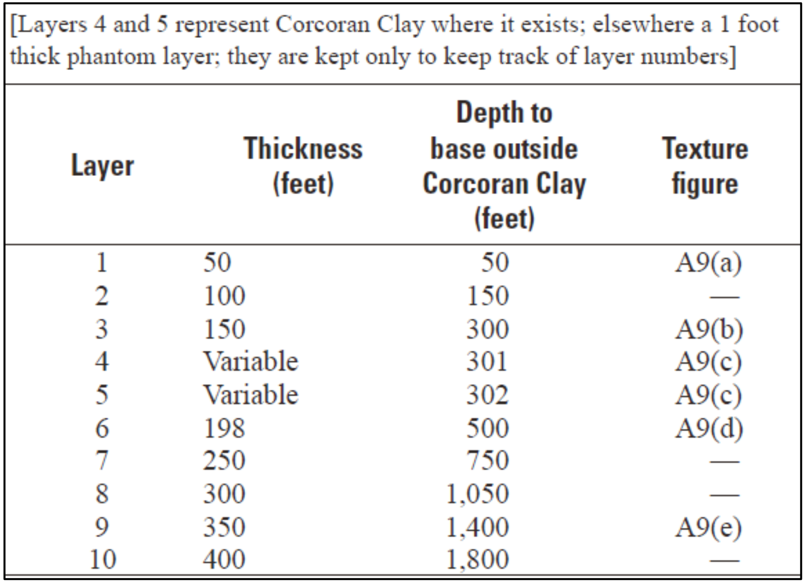
## CVHM Description

CVHM was developed by the United States Geological Survey (USGS) to support a study assessing groundwater availability in California's Central Valley. This study, described in Faunt et al. 2009, had 3 major objectives:

1. To develop a better understanding of the freshwater-bearing deposits of the Central Valley; this objective was achieved by developing a new texture model.
2. To use improved water-budget analysis techniques to estimate water-budget components for the groundwater flow system in areas dominated by irrigated agriculture; this objective was achieved through the development of the Farm Process (FMP) to be used in conjunction with MODFLOW-2000 (MF2K).
3. To quantify the Central Valley's groundwater-flow system; this objective was accomplished by developing CVHM, which links the texture and landscape-process models with the groundwater-flow process model.

CVHM builds on many previous studies, but is primarily an update to the USGS Central Valley Regional Aquifer System and Analysis (CV-RASA), with the major update components being incorporating MODFLOW-2000 with the FMP into the model and spatial re-discretization of the model to finer spatial scales. Table 2.1 describes the model layer thicknesses and depths and Figure 2.1 shows a generalized vertical hydrogeologic cross section of the groundwater flow system. Figure 2.2 shows the farm process balance of the groundwater system. A detailed description of the CVHM development can be found in Faunt et al. 2009.

**Table 2.1: CVHM layer thicknesses and depths (Table A3 from Faunt et al. 2009)**



[Layers 4 and 5 represent Corcoran Clay where it exists; elsewhere a 1 foot thick phantom layer; they are kept only to keep track of layer numbers]

| Layer | Thickness (feet) | Depth to base outside Corcoran Clay (feet) | Texture figure |
|---|---|---|---|
| 1 | 50 | 50 | A9(a) |
| 2 | 100 | 150 | — |
| 3 | 150 | 300 | A9(b) |
| 4 | Variable | 301 | A9(c) |
| 5 | Variable | 302 | A9(c) |
| 6 | 198 | 500 | A9(d) |
| 7 | 250 | 750 | — |
| 8 | 300 | 1,050 | — |
| 9 | 350 | 1,400 | A9(e) |
| 10 | 400 | 1,800 | — |

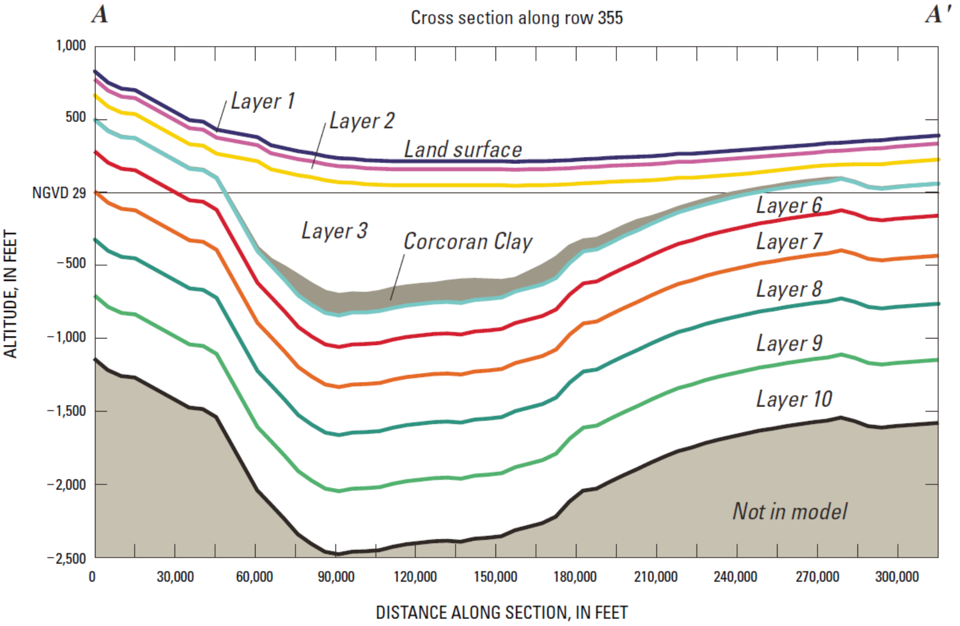


**Figure 2.1: Generalized hydrogeologic section (A-A’) (Figure A11 from Faunt et al. 2009)**

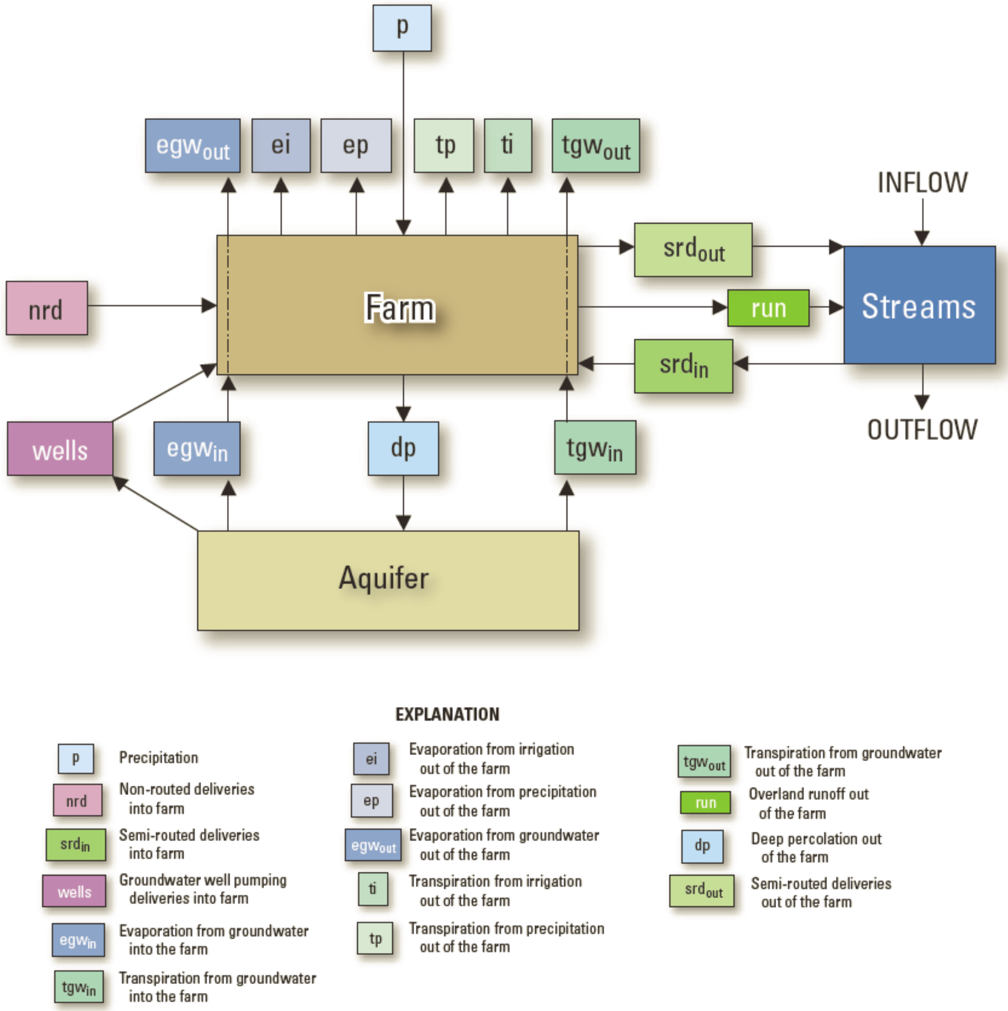


**Figure 2.2: Inflows and outflows simulated by the FMP (Figure C5 from Faunt et al. 2009)**

## CVHM Datasets

Using pre- and post-processor results from CVHM, the parameters for CALVIN groundwater representation were calculated. The parameters were calculated for three different sets of data. The first set of data is based only on the data from 1980-2003 to focus on the time period after most major infrastructure changes in California ("CVHM Hist 1980-2003"). The second set of data is calculated from the entire historical time series (1961-2003) of the CVHM results ("CVHM Hist"). The third set of data is based on a CVHM run made with updated land use based on year 2000 ("CVHM 2000"). However, this run showed some obvious problems in Region 21 (in southern Tulare basin) and was ultimately not used, but its results were used for comparisons between the different CVHM datasets (Appendix 1).

Different approaches were taken when calculating the CALVIN groundwater parameters. The parameters summarized in this section will primarily be for calculations from results from the Zonebudget post-processor (“CVHM”), which estimates a mass balance for each region. Other versions of these calculations include results from FB_details.OUT and other input files, but these ultimately were not chosen to represent CVHM since it involved using terms from different post-processors that did not result in mass balance. However, these calculations still reflect reasonable methods to calculate these terms so some descriptions and results are summarized in Appendix 1. The calculations that were independent of these post-processors have the same results regardless of dataset. A summary of the different sets of CVHM data is shown in Table 2.2. This chapter presents and discusses the results used for CVHM to compare with C2VSIM and CVGSM.

**Table 2.2: CVHM Datasets**

| Dataset name | Description |
|---|---|
| CVHM Historical (1980-2003)<br>“CVHM Hist 1980-2003” | Based on historical CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1980-2003. |
| CVHM Historical (1961-2003)<br>“CVHM Hist” | Based on historical CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1961-2003. |
| CVHM 2000 Land Use (1961-2003)<br>“CVHM 2000”* | Based on an updated 2000 land use CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1961-2003. |
| CVHM Historical ZB (1980-1993)<br>“CVHM” | Based on historical CVHM run using Zonebudget post-processor; averages based on 1980-1993. Used as final CVHM result for CALVIN comparisons with other groundwater models. |

*Note that this run had obvious problems in some of the Tulare Basin regions so the results from this run were ultimately not used for any formal comparison.

## CVHM Calculation of Terms

This section summarizes methods used to calculate the terms and the resulting values used for the final comparison between CVHM and the other models. For each term, there is a brief description followed by some tabulated results of calculated values. More details on these terms, alternative calculation methods, and a comparison of these terms’ results are in Appendix 1.

### Agricultural Return Flow Split

The agricultural return flow split term represents the fate of applied water that is not consumed by crops or other consumptive uses. Return flow may return either to groundwater by deep percolation or to surface water. This term defines the fraction of agricultural use which returns to surface water (1a) and to groundwater (1b) as shown in Figure 1.3. Applied water is the amount of water used to meet demands.

Using the crop categories and properties in Table 2.3 and the corresponding subregion index data in the model input files, the splits to surface water and groundwater return flows were estimated. Based on the crop distribution file from the input files (a matrix of crop category numbers), the average of all the fractions of surface water runoff from irrigation for each subregion was taken. This results in the proportion of return flow to surface water. The proportion of return flow to groundwater is 1 minus this value. CALVIN takes only one fraction for surface water and one fraction for groundwater for each region over the model time period; these split fractions do not change over time in CALVIN. The results are shown in Table 2.4.

**Table 2.3: Summary of Central Valley, California, crop categories and properties (from Table C4 from Faunt et al 2009)**

| Virtual crop category # | Land Use | Fraction of SW Runoff from Precipitation | Fraction of SW Runoff from Irrigation |
|---|---|---|---|
| 1 | Water | 0.050 | 0.010 |
| 2 | Urban | 0.015 | 0.010 |
| 3 | Native classes | 0.207 | 0.010 |
| 4 | Orchards, groves, and vineyards | 0.102 | 0.010 |
| 5 | Pasture/Hay | 0.102 | 0.017 |
| 6 | Row Crops | 0.102 | 0.061 |
| 7 | Small Grains | 0.102 | 0.045 |
| 8 | Idle/fallow | 0.060 | 0.010 |
| 9 | Truck, nursery, and berry crops | 0.102 | 0.100 |
| 10 | Citrus and subtropical | 0.102 | 0.010 |
| 11 | Field crops | 0.102 | 0.077 |
| 12 | Vineyards | 0.013 | 0.012 |
| 13 | Pasture | 0.102 | 0.017 |
| 14 | Grain and hay crops | 0.102 | 0.045 |
| 15 | Semiagricultural | 0.323 | 0.350 |
| 16 | Deciduous fruits and nuts | 0.107 | 0.048 |
| 17 | Rice | 0.011 | 0.030 |
| 18 | Cotton | 0.102 | 0.102 |
| 19 | Developed | 0.102 | 0.078 |
| 20 | Cropland and pasture | 0.102 | 0.078 |
| 21 | Cropland | 0.102 | 0.078 |
| 22 | Irrigated Row and Field Crops | 0.102 | 0.068 |

## Agricultural Reuse

CVHM does not explicitly “reuse” water locally for repeated irrigation. This might be included in future versions of the model, but is not in the version used here. As far as basic representation of this term using CVHM, 1 is used for all regions indicating no reuse, meaning water delivered to the region is the same as the applied (and re-applied) water in the region.

Return Flow of Total Applied Water

This term represents the return flow of total applied water, which applies to return flow to both surface water and groundwater. This term can be calculated by using given information on irrigation efficiencies (evapotranspiration of applied water, ETAW). In CVHM, the irrigation efficiencies are specified as a matrix of efficiencies for each subregion and each crop for each monthly stress period. The efficiencies vary from crop to crop for different subregions and they change through time. Table C6 from Faunt et al. 2009 gives the average area-weighted composite efficiency, by decade, for each subregion. Using the values from Table C6, the Return Flow of Total Applied Water is calculated as follows: Return Flow (%) = 1-ETAW (%). The composite efficiency and return flow of total applied water values for year 2000 are in columns 4 and 5 in Table 2.4.

**Table 2.4: CVHM Agricultural Return Flow Splits, Composite Efficiencies, and Amplitudes of Return flow of Total Applied Water**

| Subregion | Agricultural Return Flow Split to GW | Agricultural Return Flow Split to SW | Composite Efficiency (fraction to ETAW) | Return Flow of Total AW |
|---|---|---|---|---|
| 1 | 0.99 | 0.01 | 0.74 | 0.26 |
| 2 | 0.98 | 0.02 | 0.73 | 0.27 |
| 3 | 0.97 | 0.03 | 0.83 | 0.17 |
| 4 | 0.96 | 0.04 | 0.79 | 0.21 |
| 5 | 0.97 | 0.03 | 0.8 | 0.2 |
| 6 | 0.97 | 0.03 | 0.77 | 0.23 |
| 7 | 0.98 | 0.02 | 0.77 | 0.23 |
| 8 | 0.98 | 0.02 | 0.75 | 0.25 |
| 9 | 0.96 | 0.04 | 0.78 | 0.22 |
| 10 | 0.95 | 0.05 | 0.79 | 0.21 |
| 11 | 0.97 | 0.03 | 0.77 | 0.23 |
| 12 | 0.96 | 0.04 | 0.76 | 0.24 |
| 13 | 0.97 | 0.03 | 0.79 | 0.21 |
| 14 | 0.92 | 0.08 | 0.87 | 0.13 |
| 15 | 0.94 | 0.06 | 0.76 | 0.24 |
| 16 | 0.98 | 0.02 | 0.81 | 0.19 |
| 17 | 0.97 | 0.03 | 0.8 | 0.2 |
| 18 | 0.96 | 0.04 | 0.79 | 0.21 |
| 19 | 0.97 | 0.03 | 0.77 | 0.23 |
| 20 | 0.97 | 0.03 | 0.81 | 0.19 |
| 21 | 0.96 | 0.04 | 0.81 | 0.19 |

### External Flows

The External Flows time series is the sum of several source flows into and out of the groundwater subregion, excluding pumping and recharge of agricultural applied water, which are represented separately in CALVIN. These flows include groundwater-surface water interactions (stream leakage), inter-basin groundwater flows, deep percolation from precipitation, boundary inflows, subsidence, and evapotranspiration/non-recoverable losses. The sum of these individual time series comprise the net external flows monthly time series that are used as input source flow in CALVIN.

Inter-basin flows represent the groundwater flow between subregions. For CVHM, these numbers were extracted from ZoneBudget output, “Inter-zone.” Positive values are flow into the groundwater subbasin and negative values are flows out of the basin to adjoining basins.

Stream leakage flows represent groundwater-surface water interaction within each region. These values are extracted from the ZoneBudget output, **“**Stream Leakage.” Positive values are flows into the groundwater subbasin and negative values are flows out of groundwater to surface water flow.

Deep percolation of precipitation is the volume of water percolating into groundwater from precipitation. This term was estimated using fractions calculated from the FB_details.OUT and applying those fractions to the Zonebudget “Farm Net Recharge” term. Using FB_details.OUT, the fraction $ET_{precip} / (ET_{irrig} + ET_{precip})$ was computed, where $ET_{irrig}$ is the evapotranspiration from irrigation (applied water) and $ET_{precip}$ is the evapotranspiration from precipitation (also called effective precipitation). This fraction was multiplied by the “Farm Net Recharge” term from Zonebudget to estimate the recharge from precipitation. The underlying assumption is that the relative contribution of precipitation to recharge is the same as that to evapotranspiration.

Boundary flow is the flow at each region’s boundary from either surface or basins from outside of the 21 subregions (not including inter-basin flow). For CVHM, only Region 9, the Delta, has boundary inflows. Positive values are flow into the groundwater subbasin and negative values are flows out of the subbasin.

Subsidence flows represent the effects of subsidence in each respective region on groundwater storage. For CVHM, subsidence flows are accounted for in the “Interbed Storage” term in ZoneBudget. Since this term had resulting values that were both positive and negative, it was evident that this term was not solely subsidence. However, the interbed storage flow would need to be accounted for in the CALVIN mass balance regardless of if it was solely subsidence or not, so this term was included in the External

Flows. Positive values are flow into the groundwater subbasin and negative values are flows out of the subbasin.

Evapotranspiration from groundwater is estimated by taking the negative irrigation recharge values from Zonebudget. This would be the fraction of Farm Net Recharge that is not recharge from precipitation and is negative, indicating a loss from the groundwater basin.

The average annual flows per region are summarized in Table 2.5. These flows are from the groundwater perspective; positive values are flows into the groundwater basin and negative values are flows out of the basin.

**Table 2.5: Average Annual 1980-1993 CVHM-CALVIN External Flows (TAF/month)**

| Subregion | Inter-basin | Stream Leakage | Deep Perc. from Precipitation | Boundary flow | Subsidence | ET from GW | Net External Flow |
|---|---|---|---|---|---|---|---|
| 1 | -312.1 | -131.5 | 440.2 | 0.0 | 18.3 | -8.0 | 6.8 |
| 2 | 44.2 | -293.1 | 631.4 | 0.0 | 23.6 | -0.0 | 406.1 |
| 3 | -225.8 | -234.0 | 613.5 | 0.0 | 1.7 | -124.5 | 30.9 |
| 4 | 558.6 | -533.4 | 260.6 | 0.0 | -0.4 | -262.2 | 23.2 |
| 5 | -184.9 | -213.3 | 690.1 | 0.0 | 0.0 | -227.8 | 64.2 |
| 6 | -47.2 | 13.8 | 556.4 | 0.0 | -0.3 | -69.3 | 453.5 |
| 7 | 19.4 | -42.9 | 278.0 | 0.0 | 7.6 | -75.8 | 186.2 |
| 8 | 50.3 | 84.8 | 546.4 | 0.0 | 5.1 | -0.7 | 685.8 |
| 9 | 237.7 | 551.8 | 263.2 | -90.5 | -0.6 | -515.5 | 446.1 |
| 10 | -79.9 | 38.2 | 158.0 | 0.0 | 15.1 | -101.4 | 30.0 |
| 11 | -54.9 | -102.3 | 180.7 | 0.0 | 0.6 | -4.3 | 19.8 |
| 12 | -73.4 | 20.7 | 137.5 | 0.0 | 2.2 | -29.2 | 57.9 |
| 13 | -0.8 | 125.3 | 350.6 | 0.0 | 92.7 | -3.6 | 564.2 |
| 14 | 85.2 | 5.6 | 100.5 | 0.0 | 69.1 | 0.0 | 260.4 |
| 15 | 621.8 | 177.6 | 177.4 | 0.0 | 140.2 | 0.0 | 1117.0 |
| 16 | -196.1 | 35.0 | 106.4 | 0.0 | 45.9 | 0.0 | -8.8 |
| 17 | -176.8 | 174.8 | 159.7 | 0.0 | 40.3 | 0.0 | 197.9 |
| 18 | -20.1 | 106.9 | 217.6 | 0.0 | 259.9 | 0.0 | 564.3 |
| 19 | 212.2 | 0.0 | 93.7 | 0.0 | 103.8 | 0.0 | 409.7 |
| 20 | -164.4 | 19.3 | 62.2 | 0.0 | 104.0 | 0.0 | 20.9 |
| 21 | -292.9 | 107.2 | 79.3 | 0.0 | 42.4 | 0.0 | -63.9 |
| Sac TOTAL | 140.1 | -797.8 | 4279.9 | -90.5 | 54.9 | -1283.7 | 2302.9 |
| SJ TOTAL | -209.0 | 81.9 | 826.8 | 0.0 | 110.6 | -138.5 | 671.8 |
| TL TOTAL | 68.8 | 626.4 | 996.7 | 0.0 | 805.6 | 0.0 | 2497.5 |
| CV TOTAL | 0.0 | -89.6 | 6103.4 | -90.5 | 971.1 | -1422.2 | 5472.2 |

### Pumping Capacity

This term is the upper-bound constraint for groundwater pumping in CALVIN. These are estimated as the maximum values of pumping extracted from the ZoneBudget output, **“**Farm Wells” from 1980 to 1993. These capacities are shown in Table 2.6.

### Pumping Lift

Depth to groundwater (“pumping depth” or “pumping lift”) is used in CALVIN to determine agricultural pumping costs. CALVIN assumes a fixed cost per foot of lift and these calculated costs are used as model inputs (CALVIN Appendix G, 2001). Depth to Groundwater is essentially the ground surface elevation minus the water elevation. Taking these values from the input and output files for the original CVHM run for year 2000, the average lift per region was calculated. The head values used were from MODFLOW so they represent the average head for a 1 square mile cell, and not the water level in a well, which will typically be lower. This indicates that this value, in addition to all other assumptions, is likely to be an overestimate since the average head is likely to be a smaller value than the effective water level. These average lift values are summarized in Table 2.6.

Since DWR measured groundwater level data for year 2000 exists, it was decided that using measured data of groundwater heads would best represent pumping lift for these regions. Details of how these averages were calculated can be found in Appendix 2. These average lift values are also summarized in Table 2.6.

**Table 2.6: CVHM Pumping Terms and DWR Measured Well Depths**

| Subregion | Pumping Capacity (TAF/mo) | CVHM 2000 Pumping Depth (ft) | DWR 2000 Average Measured Well Data (ft) |
|---|---|---|---|
| 1 | 2.3 | 153 | 71 |
| 2 | 354.7 | 43 | 40 |
| 3 | 4.4 | 63 | 27 |
| 4 | 2.4 | N.A. | 16 |
| 5 | 25.1 | 14 | 27 |
| 6 | 181.8 | 57 | 25 |
| 7 | 73.8 | 19 | 40 |
| 8 | 474.5 | 17 | 90 |
| 9 | 90.0 | 43 | 24 |
| 10 | 7.9 | 73 | 17 |
| 11 | 22.8 | 22 | 47 |
| 12 | 19.0 | 42 | 68 |
| 13 | 524.5 | 113 | 75 |
| 14 | 214.8 | 176 | 235 |
| 15 | 1066.5 | 36 | 93 |
| 16 | 32.1 | 123 | 57 |
| 17 | 275.5 | 80 | 34 |
| 18 | 570.8 | 186 | 80 |
| 19 | 471.2 | 165 | 139 |
| 20 | 162.2 | 366 | 298 |
| 21 | 113.3 | 250 | 191 |

### Storage

The maximum storage is the upper-bound constraint for groundwater storage capacity in CALVIN. The “Storage” term from the Zonebudget post-processor is used here. The data in Zonebudget represents change in storage. Effective storage is used for this term to represent the absolute maximum available water. Calculation is as follows:

1. Arbitrarily set the initial storage to a very large number ($1x10^9$) such that the created storage time series is never negative.
2. Once storage values are converted from change in storage to storage, the effective storage can be calculated: Absolute Maximum storage – Absolute Minimum Storage (note that the original arbitrarily high number is now cancelled out).

The initial storage was calculated to be the effective initial storage, the maximum amount of water available in September 2003. This was calculated: Storage in 2003- Absolute Minimum storage. The results are shown in Table 2.7 below. A more detailed discussion of the method can be found in Appendix 1.

Change in storage is also estimated directly from the Zonebudget storage change values. The totals of changes in storage per month for 1980-1993 are summed up by year and averaged to get the average annual change in storage. Then this yearly change in storage value is multiplied by 72 years to get an estimated storage change for 72 years. These storage changes are shown in the last column of Table 2.7. Positive values indicate overdraft and negative values indicate an increase in groundwater storage. The ending storage values were calculated from the initial storage minus the change in storage over 72 years. Additional overdraft scenarios and calculation methods will be discussed in Chapter 5.

**Table 2.7: CVHM Storage Capacity, Initial & Ending Storage, and 1921-1993 Change in Storage (TAF)**

| Subregion | Maximum Storage Capacity | Initial Storage | Ending Storage | Change in Storage* |
|---|---|---|---|---|
| 1 | 19,543 | 16,346 | 13,302 | 3,045 |
| 2 | 33,133 | 19,031 | 15,954 | 3,077 |
| 3 | 22,782 | 10,350 | 11,124 | -773 |
| 4 | 15,730 | 8,552 | 9,810 | -1,257 |
| 5 | 23,850 | 16,587 | 16,897 | -311 |
| 6 | 34,350 | 11,683 | 15,140 | -3,457 |
| 7 | 12,190 | 10,180 | 9,148 | 1,032 |
| 8 | 31,153 | 12,230 | 10,634 | 1,595 |
| 9 | 81,528 | 18,419 | 29,742 | -11,323 |
| 10 | 20,844 | 11,311 | 11,061 | 251 |
| 11 | 10,704 | 4,905 | 4,617 | 289 |
| 12 | 16,651 | 3,683 | 4,407 | -723 |
| 13 | 48,168 | 33,636 | 22,880 | 10,756 |
| 14 | 32,789 | 32,789 | 23,293 | 9,495 |
| 15 | 38,000 | 22,341 | 9,786 | 12,555 |
| 16 | 27,274 | 27,274 | 17,839 | 9,435 |
| 17 | 31,370 | 24,960 | 15,818 | 9,142 |
| 18 | 58,956 | 58,956 | 38,607 | 20,349 |
| 19 | 28,006 | 28,006 | 20,750 | 7,256 |
| 20 | 20,229 | 20,229 | 13,575 | 6,654 |
| 21 | 58,804 | 58,699 | 53,088 | 5,611 |
| Sac TOTAL | 274,260 | 123,377 | 131,750 | -8,372 |
| SJ TOTAL | 96,367 | 53,536 | 42,964 | 10,572 |
| TL TOTAL | 295,428 | 273,254 | 192,757 | 80,497 |
| CV TOTAL | 666,055 | 450,167 | 367,470 | 82,697 |

* Positive values indicate overdraft and negative values indicate an increase in groundwater storage.

Calibration Flow

For each groundwater basin, a mass balance could be achieved with a calibration flow to correct for the model error. To determine the mass balance, only the flows that directly flow in and out of the groundwater basin were considered: external flows, pumping, recharge from applied water, and changes in storage. Figure 2.3 shows these components and flow interactions. Recharge to groundwater, pumping, and storage changes ultimately will be modeled explicitly in final CALVIN, since these are actively managed as decision variables with associated management costs. But to check CVHM's representation of groundwater flows, the recharge flows and changes in storage are extracted and used here. As mentioned earlier, the change in storage is an output in the Zonebudget post-processor. The recharge flows are only the positive recharge flows from applied water (irrigation) because the recharge from precipitation and negative recharge terms are included in the external flows term. The mass balance results are summarized in Table 2.8. As seen in the results, the calibration flows to achieve the mass balance are rather small, which agrees with CVHM results presented in Faunt et al. 2009. In the overall CALVIN network, if the calibration flow was to be added or removed from the system, it would not be a direct interaction with the groundwater basin, as shown in Figure 1.3.

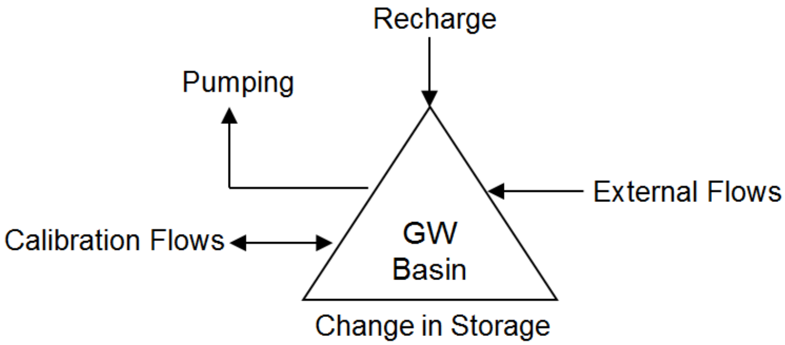


**Figure 2.3: Groundwater Mass Balance Flows**

Table 2.8: 13-year Average Annual Groundwater Mass Balance (TAF/yr)

| Subregion | External Flows (+/-) | Pumping (-) | Total Recharge from Applied Water (+) | Change in Storage (+/-) | Calibration Flow (+/-) |
|---|---|---|---|---|---|
| 1 | 7 | 49 | 0 | -42 | 0 |
| 2 | 406 | 542 | 93 | -43 | 0.02 |
| 3 | 31 | 32 | 12 | 11 | 0.04 |
| 4 | 23 | 6 | 1 | 17 | 0.08 |
| 5 | 64 | 62 | 2 | 4 | 0.02 |
| 6 | 453 | 414 | 8 | 48 | 0.18 |
| 7 | 186 | 201 | 1 | -14 | 0.05 |
| 8 | 686 | 843 | 135 | -22 | 0.03 |
| 9 | 446 | 284 | 2 | 157 | 3.44 |
| 10 | 30 | 45 | 13 | -3 | 0.98 |
| 11 | 20 | 74 | 51 | -4 | 0.12 |
| 12 | 58 | 59 | 13 | 10 | 0.88 |
| 13 | 564 | 816 | 104 | -149 | 0.86 |
| 14 | 260 | 588 | 196 | -132 | 0.01 |
| 15 | 1117 | 1837 | 547 | -174 | 0.8 |
| 16 | -9 | 184 | 62 | -131 | 0.06 |
| 17 | 198 | 495 | 170 | -127 | 0.18 |
| 18 | 564 | 1288 | 442 | -283 | 0.09 |
| 19 | 410 | 725 | 215 | -101 | 0.07 |
| 20 | 21 | 273 | 160 | -92 | -0.01 |
| 21 | -64 | 183 | 170 | -78 | 0.37 |
| Sac Total | 2303 | 2433 | 255 | 116 | 4 |
| SJ Total | 672 | 993 | 181 | -147 | 3 |
| TL Total | 2498 | 5573 | 1961 | -1118 | 2 |
| CV Total | 5472 | 8999 | 2396 | -1149 | 8 |

### Urban Return Flow

CVHM accounts for urban land use in its calculation of crop efficiencies; urban land use is considered a “virtual crop” as seen in Table 2.3 above. Specific fractions for just urban return flows were not separated for CVHM. Urban flows are generally small compared to agricultural flows so the return flows are also generally lower. CVGSM and C2VSIM do account for this term separately, and this is discussed in the next chapter, which compares the three models.

## Discussion

This chapter focuses on how CVHM was summarized for the CALVIN update project. Although CVHM was ultimately not used as the groundwater basis for the updated CALVIN model, studying the model and calculating the terms provided useful insights during the calibration process and in the overdraft studies (Chapter 5). Future versions of CVHM will likely fit CALVIN purposes more closely and should be considered again when it is time for the next CALVIN groundwater update. The next chapter will present and compare the calculated terms for CALVIN from CVHM, C2VSIM, and CVGSM.

# CHAPTER 3

# Comparison of Models and Calculated Terms

This chapter discusses and compares the CALVIN calculated terms from C2VSIM, CVHM, and CVGSM. CVGSM was based on IGSM, a basin planning model that includes groundwater, surface water, groundwater quality and reservoir operation simulation routines (USBR 1997). C2VSIM is based on IWFM, whose precursor was the IGSM, but has been renamed to IWFM since many major changes and improvements were made. The calculated CALVIN terms show this similarity in the basis of the model's results in similar calculations and representations of some terms. CVHM is MODFLOW based with the Farm Process (FMP) package, which treats and represents many terms very differently than IWFM and IGSM, so some calculated terms differ greatly. However, some terms show strong agreement between CVHM and C2VSIM when compared with CVGSM, likely due to the more detailed discretization, calibration, and use of accepted and tested algorithms. IWFM and MODFLOW-FMP are newer models that address the physical and economic water balance in a watershed, allowing for simulations that account for both physical flow processes and water management practices. A detailed description and comparison of the theory, approaches, and features of the two models can be found in Dogrul et al. 2011. A comparison of IGSM and older versions of MODFLOW can be found in LaBolle et al. 2003.

## Calculated Terms Comparison

The 21 groundwater subbasins (subregions) in all three models correspond with the CVPM regions used in CALVIN, allowing for direct comparisons. The same calculated terms for each model often account for additional flows or features that might be accounted for in a different term in the other model. Many different term calculation methods were used and the ultimate decision to use one method over others was based on trying to capture the term as best suited for representation in CALVIN, as a water management model, and looking at how the term compared with the other models and measured data. Different methods used in the calculations cause some differences in the calculated terms. Because C2VSIM output terms are similar to those of CVGSM, the calculations used for these two models were often more similar than the calculations used to calculate CALVIN terms from CVHM results. The effects of the differences in methods will be discussed in the sections below and the detailed descriptions of the terms can be found in Appendix J (Jenkins et al. 2001 and Davis et al. 2001), and Appendix 1 and 3 of this thesis. The various parameters representing groundwater in CALVIN are summarized in Table 1.2 and Figure 1.3. The comparison is structured by these sections below.

Agricultural Return Flow Splits

Table 3.1 shows some large differences for Agricultural Return Flow Splits between the models. The calculations for C2VSIM and CVGSM follow similar methods but result in very different splits. Detailed calculations and equations can be found in Appendix J and Appendix J-2 (II) (Zikalala et al. 2012). C2VSIM and CVGSM fractions are based on using model outputs and taking fractions of these to represent these splits. C2VSIM's fractions generally have higher return flows to groundwater, which agrees with CVHM, whose methods are based on taking the averages of fractions of surface water runoff from irrigation for each subregion from CVHM input files. Both newer groundwater models imply more irrigation return flow is to groundwater throughout the Central Valley.

**Table 3.1: Agricultural Return Flow Splits to Groundwater**

| Subregion | C2VSIM | CVHM | CVGSM (1997) |
|---|---|---|---|
| | GW | GW | GW |
| 1 | 0.28 | 0.99 | 0.45 |
| 2 | 1.00 | 0.98 | 0.69 |
| 3 | 0.60 | 0.97 | 0.60 |
| 4 | 0.99 | 0.96 | 0.12 |
| 5 | 0.72 | 0.97 | 0.59 |
| 6 | 0.98 | 0.97 | 0.37 |
| 7 | 1.00 | 0.98 | 0.42 |
| 8 | 0.93 | 0.98 | 0.14 |
| 9 | 1.00 | 0.96 | 0.74 |
| 10 | 0.94 | 0.95 | 0.21 |
| 11 | 0.94 | 0.97 | 0.65 |
| 12 | 0.94 | 0.96 | 0.22 |
| 13 | 0.97 | 0.97 | 0.25 |
| 14 | 1.00 | 0.92 | 1.00 |
| 15 | 1.00 | 0.94 | 0.30 |
| 16 | 0.84 | 0.98 | 0.13 |
| 17 | 1.00 | 0.97 | 0.42 |
| 18 | 1.00 | 0.96 | 0.99 |
| 19 | 1.00 | 0.97 | 1.00 |
| 20 | 0.82 | 0.97 | 0.59 |
| 21 | 1.00 | 0.96 | 0.94 |

Agricultural Reuse Amplitudes

As mentioned in Chapter 2, the non-reuse amplitude is 1 (no reuse) for all CVHM regions, neglecting local tailwater reuse. For CVGSM, the reuse fractions were a direct output in the model, but as seen in Table 3.2, amplitudes were quite high for reuse. When these amplitudes were used for the original CALVIN groundwater, they were some of the first to be adjusted (decreased significantly) during calibration, as discussed in the Chapter 4. In C2VSIM, the reuse amplitudes were calculated by summing the applied water and reused water and dividing that net sum by the applied water for the 1980 to 2003 time period. These values in Table 3.2 are significantly smaller than the earlier CVGSM values and seem fairly close to CVHM.

**Table 3.2: Agricultural Reuse Amplitudes & Applied Water Return Flow Fractions**

| Subregion | Agricultural Reuse Amplitude | | | Agricultural Return Flow Fraction | | |
|---|---|---|---|---|---|---|
| | C2VSIM | CVHM | CVGSM | C2VSIM | CVHM | CVGSM |
| 1 | 1 | 1 | 1.32 | 0.47 | 0.26 | 0.39 |
| 2 | 1 | 1 | 1.26 | 0.14 | 0.27 | 0.29 |
| 3 | 1.086 | 1 | 1.28 | 0.20 | 0.17 | 0.35 |
| 4 | 1.001 | 1 | 1.21 | 0.14 | 0.21 | 0.35 |
| 5 | 1.049 | 1 | 1.283 | 0.21 | 0.2 | 0.37 |
| 6 | 1.001 | 1 | 1.08 | 0.06 | 0.23 | 0.28 |
| 7 | 1 | 1 | 1.3 | 0.25 | 0.23 | 0.45 |
| 8 | 1.003 | 1 | 1.23 | 0.12 | 0.25 | 0.33 |
| 9 | 1 | 1 | 1.21 | 0.09 | 0.22 | 0.21 |
| 10 | 1.003 | 1 | 1.33 | 0.20 | 0.21 | 0.4 |
| 11 | 1.005 | 1 | 1.272 | 0.22 | 0.23 | 0.43 |
| 12 | 1.004 | 1 | 1.18 | 0.16 | 0.24 | 0.34 |
| 13 | 1.002 | 1 | 1.18 | 0.12 | 0.21 | 0.27 |
| 14 | 1 | 1 | 1.22 | 0.18 | 0.13 | 0.26 |
| 15 | 1 | 1 | 1.21 | 0.12 | 0.24 | 0.27 |
| 16 | 1.015 | 1 | 1.18 | 0.28 | 0.19 | 0.45 |
| 17 | 1 | 1 | 1.17 | 0.13 | 0.2 | 0.27 |
| 18 | 1 | 1 | 1.25 | 0.18 | 0.21 | 0.31 |
| 19 | 1 | 1 | 1.21 | 0.03 | 0.23 | 0.29 |
| 20 | 1.014 | 1 | 1.17 | 0.10 | 0.19 | 0.3 |
| 21 | 1 | 1 | 1.25 | 0.10 | 0.19 | 0.32 |

### Applied Water Return Flow Fractions

Table 3.2 shows that Agricultural Return Flow Fractions for CVHM and C2VSIM are generally lower than those of CVGSM. C2VSIM's fractions are calculated as the total applied water not consumptively used divided by the total applied water, where the terms used were determined following the calculations for Agricultural Return Flow Split. CVHM's values were determined by using the published composite efficiency values (evapotranspiration of applied water, ETAW) per region as discussed in Chapter 2 (Return Flow % = 1-ETAW %). CVGSM's return flow fractions are based on CVGSM NAA output data (Return Flow % = 1 – On-farm Efficiency %). DWR Bulletin 160-98 also had efficiencies published at the time, and they were generally higher than those from the CVGSM output, resulting in lower return flow fractions. So that was a primary basis for adjusting the CVGSM return flow fractions when calibrating the groundwater system in CALVIN in 2001. The calibration steps taken for the current update CALVIN are discussed in Chapter 4.

External Flows

External flows are entered into CALVIN for each subregion as a source time series. Some external flow terms were directly extracted from results files of the groundwater models, but a few required some calculations, as discussed below. Overall, the average annual external flows for C2VSIM and CVHM seem to follow a similar trend throughout the regions when comparing the 1980-1993 time period, which can be seen in Table 3.3 and Figure 3.1.

**Table 3.3: Average Annual (1980-1993) Net External Flows (TAF/yr)**

| Subregion | C2VSIM[a] | CVHM[b] |
|---|---|---|
| 1 | 16.5 | 6.8 |
| 2 | 342.8 | 406.1 |
| 3 | 0.5 | 30.9 |
| 4 | 75.9 | 23.2 |
| 5 | 199.6 | 64.2 |
| 6 | 250.4 | 453.5 |
| 7 | 224.8 | 186.2 |
| 8 | 613.9 | 685.8 |
| 9 | 116.8 | 446.1 |
| 10 | 146.1 | 30.0 |
| 11 | 49.9 | 19.8 |
| 12 | 119.9 | 57.9 |
| 13 | 529.6 | 564.2 |
| 14 | 391.1 | 260.4 |
| 15 | 815.1 | 1117.0 |
| 16 | 65.6 | -8.8 |
| 17 | 226.2 | 197.9 |
| 18 | 257.5 | 564.3 |
| 19 | 493.3 | 409.7 |
| 20 | 180.8 | 20.9 |
| 21 | 389.5 | -63.9 |
| SAC TOTAL | 1841.2 | 2302.9 |
| SJ TOTAL | 845.5 | 671.8 |
| TL TOTAL | 2819.1 | 2497.5 |
| CV TOTAL | 5505.8 | 5472.2 |

[a] C2VSIM averages are based on adjusted flows for 1980-1993
[b] CVHM averages based on 1980-1993, same as Table 2.5

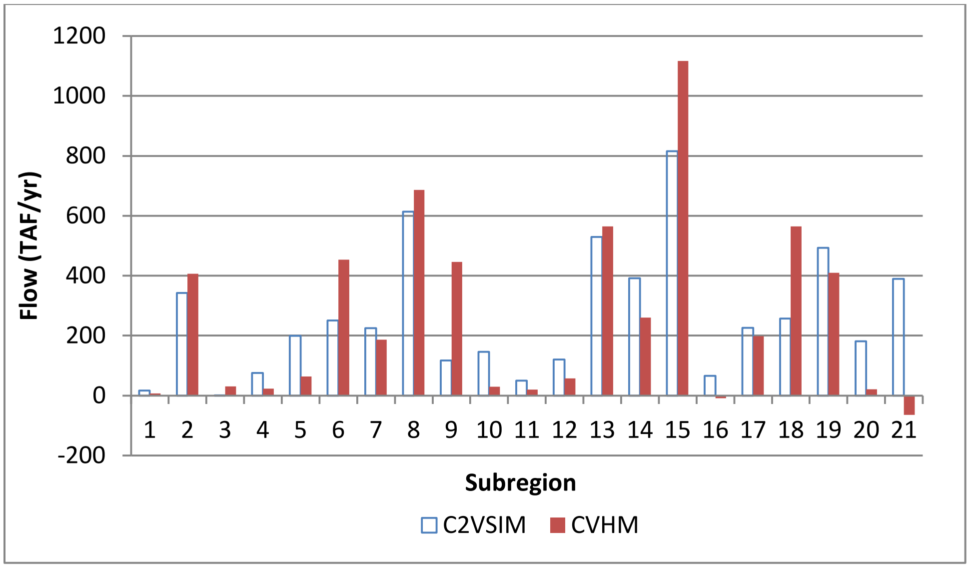


**Figure 3.1: 1980-1993 Average Annual Net External Flows**

The time period annual averages used to represent the models' external flows in CALVIN (1921-2009 for C2VSIM, 1980-1993 for CVHM, and 1921-1990 for CVGSM) are shown in Table 3.3a; these are the values that were input in CALVIN when comparing between models. These different time period-based external flows were used for each of the models because they were considered to be the best representation of updated land use and infrastructure. The CVGSM values are based on the entire time period of the CALVIN model run because that is what was used in the previous version of CALVIN. As seen in Table 3.3a, the average annual external flows for CVGSM are much larger than that of C2VSIM and CVHM. The newer models generally have more terms than CVGSM because the newer models break down the different terms more explicitly and it was decided to include all the time series terms to the external flow term so that a mass balance could be achieved. The breakdown yearly averages of each of the flows that comprise the net external flows averages are presented below in Tables 3.3b-d.

**Table 3.3a: Average Annual Net External Flow Averages (TAF/yr)**

| Subregion | C2VSIM[a] | CVHM[b] | CVGSM[c] |
|---|---|---|---|
| 1 | 28.2 | 6.8 | 1.6 |
| 2 | 176.8 | 406.1 | 402.5 |
| 3 | -8.9 | 30.9 | 8.9 |
| 4 | -95.5 | 23.2 | 260.6 |
| 5 | 66.9 | 64.2 | 144.2 |
| 6 | 180.4 | 453.5 | 367.1 |
| 7 | 168.2 | 186.2 | 277.5 |
| 8 | 401.5 | 685.8 | 747.4 |
| 9 | 84.8 | 446.1 | 13.7 |
| 10 | 72.2 | 30.0 | 296.1 |
| 11 | -1.3 | 19.8 | -158.8 |
| 12 | 48.7 | 57.9 | 155.1 |
| 13 | 344.1 | 564.2 | 863.1 |
| 14 | 278.2 | 260.4 | 308.6 |
| 15 | 594.2 | 1117.0 | 1160.8 |
| 16 | 51.2 | -8.8 | 279.7 |
| 17 | 95.8 | 197.9 | 359.7 |
| 18 | 262.9 | 564.3 | 483.7 |
| 19 | 368.0 | 409.7 | 162.2 |
| 20 | 100.8 | 20.9 | 220.0 |
| 21 | 289.7 | -63.9 | 387.2 |
| SAC TOTAL | 1002.4 | 2302.9 | 2223.5 |
| SJ TOTAL | 463.7 | 671.8 | 1155.5 |
| TL TOTAL | 2040.7 | 2497.5 | 3361.9 |
| CV TOTAL | 3506.8 | 5472.2 | 6740.9 |

[a] C2VSIM averages are based on adjusted flows for1921-2009
[b] CVHM averages based on 1980-1993
[c] CVGSM averages based on 1921-1993

Table 3.3b shows the Interbasin and Boundary Flows. Both terms are direct time series output results from the models or their post-processors. CVGSM shows a major problem with the interbasin flows because the net sum of the terms is not zero. Since interbasin flows are only the flows between basins, and not flows from outside the model boundary, the net sum of interbasin flows between regions should equal zero if a proper mass balance is to be represented. Although C2VSIM and CVHM have significant differences in their representation of interbasin flows, their overall totals are zero. This is a good example of the differences that arise between C2VSIM and CVHM due to their different methods and assumptions, but still achieve a mass balance. The Boundary Flows show significant differences between the three models.

### Table 3.3b: Average Annual External Flows – Interbasin and Boundary Flows (TAF/yr)

| Subregion | Interbasin Flows | | | Boundary Flows | | |
|---|---|---|---|---|---|---|
| | C2VSIM[a] | CVHM[b] | CVGSM[c] | C2VSIM[a] | CVHM[b] | CVGSM[c] |
| 1 | 25.7 | -312.1 | -28.2 | 84.0 | 0 | 0 |
| 2 | -26.8 | 44.2 | 11.7 | 132.0 | 0 | 114.1 |
| 3 | -18.5 | -225.8 | -72.8 | 45.6 | 0 | 14.4 |
| 4 | 49.4 | 558.6 | 115.1 | 0.0 | 0 | 0 |
| 5 | -7.6 | -184.9 | -74.6 | 17.5 | 0 | 83.7 |
| 6 | -24.3 | -47.2 | 85.0 | 25.0 | 0 | -9.2 |
| 7 | -9.9 | 19.4 | -3.2 | 75.3 | 0 | 62.5 |
| 8 | 91.7 | 50.3 | 278.9 | 111.7 | 0 | 22 |
| 9 | -18.1 | 237.7 | -127.4 | 13.8 | -90.5 | -16.1 |
| 10 | -83.9 | -79.9 | -42.3 | 28.8 | 0 | 73.7 |
| 11 | -60.4 | -54.9 | -118.0 | 0.0 | 0 | 0 |
| 12 | -1.4 | -73.4 | -14.8 | 0.0 | 0 | 25.1 |
| 13 | 73.2 | -0.8 | 184.8 | 0.0 | 0 | 70.2 |
| 14 | 72.6 | 85.2 | -119.5 | 0.0 | 0 | 0 |
| 15 | 266.3 | 621.8 | -1483.8 | -53.4 | 0 | 15.1 |
| 16 | -106.9 | -196.1 | 160.2 | 7.8 | 0 | 54.2 |
| 17 | -62.5 | -176.8 | 48.1 | 3.9 | 0 | 6.8 |
| 18 | -150.8 | -20.1 | 72.8 | 23.5 | 0 | 67.7 |
| 19 | 56.1 | 212.2 | -128.0 | 4.1 | 0 | 234.1 |
| 20 | -110.7 | -164.4 | 86.9 | 49.2 | 0 | 85.4 |
| 21 | 46.9 | -292.9 | -361.4 | 52.1 | 0 | 58.6 |
| SAC TOTAL | 61.6 | 140.1 | 184.5 | 504.9 | -90.5 | 271.4 |
| SJ TOTAL | -72.6 | -209.0 | 9.7 | 28.8 | 0.0 | 169.0 |
| TL TOTAL | 11.0 | 68.8 | -1724.7 | 87.2 | 0.0 | 521.9 |
| CV TOTAL | 0.0 | 0.0 | -1530.5 | 620.9 | -90.5 | 962.3 |

[a] C2VSIM averages are based on adjusted flows for1921-2009
[b] CVHM averages based on 1980-1993
[c] CVGSM averages based on 1921-1993

Table 3.3c shows groundwater-surface water (GW/SW) interaction from streams and lakes, and deep percolation of precipitation. GW/SW interaction from streams and lakes are direct outputs from the models or their post-processors. As can be seen in the table, CVHM does not represent GW/SW interaction from lakes (a small matter for the current Central Valley). Overall, the differences for GW/SW interaction from streams vary widely. And since this term is a direct output from the models, no adjustments were made here. This is another good example showing the differences between models and their representation of surface water and groundwater interaction.

The deep percolation from precipitation terms for C2VSIM and CVGSM are calculated in similar methods following the calculations for agricultural return flow splits. CVHM calculation of this term is based on the farm net recharge output and evapotranspiration splits. This term is significantly higher for CVHM than C2VSIM and CVGSM, likely largely due to the calculation method. The precipitation input data for C2VSIM and CVHM were compared and confirmed to be very similar. So this difference in deep percolation from precipitation between the two models is likely due to both the CALVIN term calculation methods and the methods in the groundwater models themselves. These differences are substantial, especially for the Sacramento Valley.

**Table 3.3c: Average Annual External Flows - Deep Percolation from Streams, Lakes, & Precipitation (TAF/yr)**

| Subregion | GW/SW Interaction: streams | | | GW/SW Interaction: lakes | | | DP from Precipitation | | |
|---|---|---|---|---|---|---|---|---|---|
| | C2VSIM[a] | CVHM[b] | CVGSM[c] | C2VSIM[a] | CVHM[b] | CVGSM[c] | C2VSIM[a] | CVHM[b] | CVGSM[c] |
| 1 | -235.3 | -131.5 | -77.6 | 0 | 0 | 0 | 137.3 | 440.2 | 107.4 |
| 2 | -73.1 | -293.1 | 46.6 | 0 | 0 | 0 | 134.4 | 631.4 | 223.7 |
| 3 | -161.0 | -234.0 | -38.1 | 0 | 0 | 0 | 87.8 | 613.5 | 95.7 |
| 4 | -323.1 | -533.4 | 102.0 | 0 | 0 | 0 | 101.7 | 260.6 | 43.5 |
| 5 | -190.7 | -213.3 | -18.4 | 0 | 0 | 0 | 144.8 | 690.1 | 148.3 |
| 6 | 45.2 | 13.8 | 201.5 | 0 | 0 | 0 | 109.0 | 556.4 | 74.7 |
| 7 | 9.1 | -42.9 | 158.3 | 0 | 0 | 0 | 61.7 | 278.0 | 45.7 |
| 8 | 64.7 | 84.8 | 373.2 | 0 | 0 | 0 | 121.2 | 546.4 | 71.5 |
| 9 | -3.1 | 551.8 | 15.3 | 0 | 0 | 0 | 84.0 | 263.2 | 141.9 |
| 10 | -127.3 | 38.2 | 140.3 | 0 | 0 | 0 | 101.7 | 158.0 | 44.0 |
| 11 | -180.0 | -102.3 | -324.8 | 0 | 0 | 0 | 78.8 | 180.7 | 153.8 |
| 12 | -133.6 | 20.7 | 21.7 | 0 | 0 | 0 | 62.8 | 137.5 | 36.1 |
| 13 | -34.9 | 125.3 | 388.9 | 0 | 0 | 0 | 163.9 | 350.6 | 92.5 |
| 14 | 0.0 | 5.6 | 0.0 | 0 | 0 | 352.7 | 45.6 | 100.5 | 51.3 |
| 15 | -231.8 | 177.6 | 125.6 | -53.4 | 0 | 2311.4 | 91.1 | 177.4 | 41.0 |
| 16 | 12.3 | 35.0 | 0.0 | 0 | 0 | 0 | 80.0 | 106.4 | 16.6 |
| 17 | -23.0 | 174.8 | 144.2 | 0 | 0 | 0 | 112.3 | 159.7 | 61.0 |
| 18 | -33.5 | 106.9 | 125.1 | 0 | 0 | 0 | 105.5 | 217.6 | 91.3 |
| 19 | -160.5 | 0.0 | 0 | 0 | 0 | 0 | 46.1 | 93.7 | 51.3 |
| 20 | 26.5 | 19.3 | 0 | 0 | 0 | 0 | 61.7 | 62.2 | 36.3 |
| 21 | 80.5 | 107.2 | 205.4 | -6.7 | 0 | 389.2 | 46.1 | 79.3 | 75.7 |
| SAC TOTAL | -867.3 | -797.8 | 762.8 | 0 | 0 | 0 | 981.9 | 4279.9 | 952.4 |
| SJ TOTAL | -475.8 | 81.9 | 226.1 | 0 | 0 | 0.0 | 407.3 | 826.8 | 326.4 |
| TL TOTAL | -329.4 | 626.4 | 600.3 | -60.1 | 0 | 3053.3 | 588.5 | 996.7 | 424.5 |
| CV TOTAL | -1672.6 | -89.6 | 1589.2 | -60.1 | 0 | 3053.3 | 1977.6 | 6103.4 | 1703.3 |

[a] C2VSIM averages are based on adjusted flows for1921-2009
[b] CVHM averages based on 1980-1993
[c] CVGSM averages based on 1921-1993

Table 3.3d shows the subsidence, diversion losses to groundwater (gains to groundwater), and losses from groundwater. For C2VSIM and CVHM, subsidence results are directly from model outputs or from post-processors. There seems to be some trends between the two models for subsidence, but CVHM generally has more subsidence gains to the basin than C2VSIM. No subsidence term was used from CVGSM.

Diversion losses to groundwater, or conveyance seepage flows, are a loss from the surface water irrigation or conveyance system, which is a gain to the groundwater basin. CVHM does not explicitly represent this term but it is accounted for when calculating the crop efficiencies, which is discussed in Chapter 2 and in Appendix 1. This term is an input to CVGSM and is reported in C2VSIM's result post-processor. Estimated canal losses have decreased over time, as seen from time series data for the individual regions. It is unlikely that an up-to-date model like C2VSIM would suggest higher diversion losses over time so the likely reason there are more diversion losses from canals represented in C2VSIM than CVGSM could be that CVGSM was somehow underestimating diversion water that was being lost to the groundwater basins.

Tile drain outflow represents the practice of removing excess water from upper layers of some groundwater basins. Of the 3 models, this is only represented in C2VSIM and only in regions 10 and 14.

Evapotranspiration losses from groundwater are a time series output from CVHM (from FB_Details.OUT). This term is not included in external flows for CALVIN since the non-recoverable (and recoverable) losses are accounted for by an amplitude on the surface water side. This was necessary for CVHM due to the methods used to calculate some of the other terms in CVHM. Evapotranspiration losses needed to be subtracted in the net external flows for CVHM because terms like the deep percolation from precipitation have significantly higher flows to the groundwater basins because the evapotranspiration losses are accounted for separately as its own term, which does not seem to be the case for C2VSIM or CVGSM. CALVIN and C2VSIM represent evapotranspiration losses and conveyance losses as a fraction on the surface water side, and these are discussed and tabulated in Appendix 5. This is another reason CVHM was not ultimately used for the update project because trying to account for this difference would have required more changes to CALVIN's basic framework (CALVIN's surface water loss fractions would all need to be changed to 1 to indicate no non-recoverable or recoverable losses on the surface water side for CVHM). Although the loss on the surface water side is accounted for by the loss fraction in C2VSIM and CVGSM, the recoverable loss from the surface water as a gain to the groundwater side needs to be added back to the system. Since the CALVIN network does not represent this directly, the external flows term includes that recoverable loss from surface water as a gaining flow to the groundwater system.

**Table 3.3d: Average Annual External Flows – Subsidence, Diversion Gains, and Losses from Groundwater (TAF/yr)***

| Subregion | Subsidence[1] | | | Diversion Losses to GW (Gains) | | | Tile Drain Outflow | Evapo-transpiration Loss |
|---|---|---|---|---|---|---|---|---|
| | C2VSIM[a] | CVHM[b] | CVGSM[c] | C2VSIM[a] | CVHM[b] | CVGSM[c] | C2VSIM[s] | CVHM[b] |
| 1 | -0.02 | 18.27 | 0 | 16.5 | 0 | 0 | 0 | -8.0 |
| 2 | 0.01 | 23.61 | 0 | 10.4 | 0 | 6.4 | 0 | 0 |
| 3 | 0.78 | 1.69 | 0 | 36.5 | 0 | 9.7 | 0 | -124.5 |
| 4 | 0.90 | -0.37 | 0 | 75.6 | 0 | 0 | 0 | -262.2 |
| 5 | 0.00 | 0.05 | 0 | 103.0 | 0 | 5.2 | 0 | -227.8 |
| 6 | 5.13 | -0.33 | 0 | 20.2 | 0 | 15.1 | 0 | -69.3 |
| 7 | 0.01 | 7.56 | 0 | 32.0 | 0 | 14.2 | 0 | -75.8 |
| 8 | 0.05 | 5.07 | 0 | 12.1 | 0 | 1.8 | 0 | -0.7 |
| 9 | 0.11 | -0.60 | 0 | 8.1 | 0 | 0 | 0 | -515.5 |
| 10 | 42.35 | 15.11 | 0 | 141.4 | 0 | 80.4 | -30.8 | -101.4 |
| 11 | 0.01 | 0.57 | 0 | 160.2 | 0 | 130.2 | 0 | -4.3 |
| 12 | 0.02 | 2.20 | 0 | 120.9 | 0 | 87 | 0 | -29.2 |
| 13 | 9.21 | 92.70 | 0 | 132.6 | 0 | 126.7 | 0 | -3.6 |
| 14 | 128.39 | 69.07 | 0 | 33.2 | 0 | 24.1 | -1.5 | 0 |
| 15 | 78.99 | 140.19 | 0 | 496.5 | 0 | 151.5 | 0 | 0 |
| 16 | 0.14 | 45.87 | 0 | 57.8 | 0 | 48.7 | 0 | 0 |
| 17 | 0.25 | 40.29 | 0 | 64.8 | 0 | 99.6 | 0 | 0 |
| 18 | 70.69 | 259.94 | 0 | 247.5 | 0 | 126.8 | 0 | 0 |
| 19 | 43.97 | 103.84 | 0 | 378.2 | 0 | 4.8 | 0 | 0 |
| 20 | 46.59 | 103.96 | 0 | 27.5 | 0 | 11.4 | 0 | 0 |
| 21 | 48.77 | 42.43 | 0 | 22.0 | 0 | 19.7 | 0 | 0 |
| SAC TOTAL | 7.0 | 54.9 | 0 | 314.4 | 0 | 52.4 | 0 | -1283.7 |
| SJ TOTAL | 51.6 | 110.6 | 0 | 555.2 | 0 | 424.3 | -30.8 | -138.5 |
| TL TOTAL | 417.8 | 805.6 | 0 | 1327.4 | 0 | 486.6 | -1.5 | 0 |
| CV TOTAL | 476.4 | 971.1 | 0 | 2196.9 | 0 | 963.3 | -32.3 | -1422.2 |

*Positive values are flows into the groundwater basin and negative values are flows out of the basin.

[1] Subsidence for CVHM was actually the Interbed storage, which includes subsidence but is not entirely subsidence alone.

[a] C2VSIM averages are based on adjusted flows for1921-2009

[b] CVHM averages based on 1980-1993

[c] CVGSM averages based on 1921-1993

Although both C2VSIM and CVHM seem to represent Central Valley groundwater much better than the older CVGSM, there are still significant differences between the new, improved models, implying some level of uncertainty in the general understanding of Central Valley groundwater.

Pumping Terms

The pumping capacities and pumping depths are shown in Table 3.4. The pumping capacities for C2VSIM and CVHM are the maximum values of pumping for the period1980-1993. CVGSM capacities are the maximum monthly pumping for the period 1922-1990. If pumping volume is greater than 100 TAF, capacity is set to 110% of maximum value; otherwise, capacity is set to 105% of maximum value. The values shown in Table 3.4 do not include the correction factor.

The pumping depths for C2VSIM and CVHM were explicitly calculated using the heads from the input files. CVGSM depths to groundwater were not available for the previous CALVIN study so the depths to groundwater were pieced together from analyses for the Draft CVPIA PEIS (USBR 1997). Since there was some uncertainty in the C2VSIM and CVHM calculations and DWR measured groundwater level data exists, measured static water level was assumed to be the most appropriate and accurate set of data to be used for the CALVIN groundwater update (Appendix 2).

**Table 3.4: Pumping Capacities and Depths**

| **Subregion** | **Pumping Capacity (TAF/month)** | | | **Pumping Depth (ft)** | | | |
|---|---|---|---|---|---|---|---|
| | C2VSIM | CVHM | CVGSM | C2VSIM | CVHM | Old CALVIN | DWR* |
| 1 | 7.2 | 2.3 | 18.9 | 175 | 153 | 130 | 71 |
| 2 | 93.2 | 354.7 | 145.9 | 144 | 43 | 120 | 40 |
| 3 | 175.8 | 4.4 | 162.8 | 104 | 63 | 100 | 27 |
| 4 | 109.2 | 2.4 | 105.2 | 17 | NA | 60 | 16 |
| 5 | 240.1 | 25.1 | 214.9 | 35 | 14 | 75 | 27 |
| 6 | 85.7 | 181.8 | 141 | 64 | 57 | 70 | 25 |
| 7 | 120.5 | 73.8 | 87.3 | 95 | 19 | 95 | 40 |
| 8 | 185.6 | 474.5 | 198.5 | 148 | 17 | 110 | 90 |
| 9 | 43.9 | 90 | 67.1 | 30 | 43 | 80 | 24 |
| 10 | 185.2 | 7.9 | 188.5 | 80 | 73 | 60 | 17 |
| 11 | 64.9 | 22.8 | 47.5 | 54 | 22 | 75 | 47 |
| 12 | 86.9 | 19 | 73.2 | 48 | 42 | 90 | 68 |
| 13 | 225.8 | 524.5 | 277.1 | 108 | 113 | 125 | 75 |
| 14 | 221.1 | 214.8 | 317 | 373 | 176 | 350 | 235 |
| 15 | 335.3 | 1066.5 | 388.5 | 73 | 36 | 210 | 93 |
| 16 | 61.8 | 32.1 | 55.2 | 59 | 123 | 130 | 57 |
| 17 | 152.6 | 275.5 | 145.1 | 145 | 80 | 130 | 34 |
| 18 | 238.4 | 570.8 | 332.3 | 180 | 186 | 200 | 80 |
| 19 | 213.7 | 471.2 | 163 | 407 | 165 | 310 | 139 |
| 20 | 125.3 | 162.2 | 103 | 429 | 366 | 310 | 298 |
| 21 | 265.6 | 113.3 | 217.4 | 592 | 250 | 310 | 191 |

* Average Measured Groundwater Level Data

Constraining a minimum pumping rate would ideally help represent parts of the Central Valley that exclusively depend on groundwater. However, none of the models seemed to have sufficiently detailed calibrations to provide such insights.

### Storage Terms

Table 3.5 shows the storage related terms. The storage values for C2VSIM are output by the results post-processor. The maximum storage capacity was set by taking the maximum storage at any time from 1980-2003. For C2VSIM, the initial storage was set to be the storage at the end of 2005. CVHM's storage terms are calculated by using the maximum effective storage for the maximum capacity (maximum value minus minimum value for 1980-1993) and the effective storage based on September 2003 (September 2003 storage minus minimum value for 1980-1993). CVGSM storage capacities were extracted directly from the model output, as with C2VSIM.

Actual groundwater storage capacity in California is unknown and is not accurately measureable at this time. The California DWR Groundwater Bulletin 118 estimates that the groundwater storage capacity for the whole state can be anywhere between 850 million acre-feet (MAF) to 1.3 billion acre-feet. The C2VSIM results for maximum storage are a much larger estimate of groundwater storage, since the sum total for just the Central Valley exceeds the Bulletin's estimates for the whole state. CVHM's storage seems comparable to the estimates presented in the Groundwater Bulletin. It is important to have a reasonable initial storage since CALVIN does not model water levels, but change in storage; the initial storage is essentially a reference starting point. But ultimately, when considering CALVIN results, the change in storage results could be applied to any initial storage so long as there is still water available in the basin.

Overdraft is estimated directly from the change in storage values for CVHM and C2VSIM. The storage change per month is summed over a long time period and divided by the number of years in that time period to get the average annual storage change for that time period. C2VSIM's average was based on 1980-2009 (29 years) and CVHM's average was based on 1980-1993 (13 years). Then this yearly storage change value is multiplied by 72 years to estimate total change in storage for 72 years. Positive values indicate overdraft and negative values indicate recharge to groundwater. CVGSM storage change was estimated for Table 3.5 by subtracting the initial storage from the ending storage from the model output.

As seen in the change in storage region totals at the bottom of Table 3.5, the differences are large in the Sacramento region, with CVHM showing overall gain to the groundwater storage and C2VSIM showing 12 MAF of overdraft. The estimated overdraft for the San Joaquin region also differs widely between the three models, with CVGSM being 8 MAF less than CVHM, and CVHM 4 MAF less than C2VSIM. The total Central Valley modeled overdraft from 1921-1993 are close for C2VSIM and CVHM, at 80 MAF, which is significantly less in CVGSM, at about 28 MAF. The largest difference in magnitude of overdraft between the three models is the Tulare region. If only the San Joaquin and Tulare regions were totaled, CVHM would have 20 MAF more overdraft than C2VSIM, but with the addition of 8 MAF of groundwater inflow modeled in CVHM's Sacramento region, C2VSIM and CVHM have very close total Central Valley estimated overdraft values. Given the variability in groundwater use and recharge, estimates of overdraft are also quite variable with different method used for long term averaging. Additional overdraft scenarios and calculation methods will be discussed in Chapter 5.

**Table 3.5: Maximum Storage Capacity, Initial Storage, and Change in Storage (TAF)**

| Subregion | Maximum Storage Capacity | | | Initial Storage | | | Change in Storage from 1921-1993* | | |
|---|---|---|---|---|---|---|---|---|---|
| | C2VSIM | CVHM | CVGSM | C2VSIM | CVHM | CVGSM | C2VSIM | CVHM | CVGSM |
| 1 | 38,510 | 19,543 | 5,448 | 38,447 | 16,346 | 1902 | -990 | 3,045 | 128 |
| 2 | 136,757 | 33,133 | 24,162 | 136,494 | 19,031 | 24,905 | -882 | 3,077 | 601 |
| 3 | 133,958 | 22,782 | 22,127 | 132,687 | 10,350 | 31,526 | 939 | -773 | -200 |
| 4 | 61,622 | 15,730 | 15,362 | 60,728 | 8,552 | 16,750 | 220 | -1,257 | -231 |
| 5 | 92,020 | 23,850 | 24,399 | 91,113 | 16,587 | 29,285 | 656 | -311 | 991 |
| 6 | 175,719 | 34,350 | 22,864 | 174,968 | 11,683 | 34,169 | -307 | -3,457 | 1,871 |
| 7 | 58,484 | 12,190 | 12,270 | 56,539 | 10,180 | 14,448 | 5,330 | 1,032 | -2,143 |
| 8 | 193,433 | 31,153 | 32,842 | 190,665 | 12,230 | 38,110 | 7,836 | 1,595 | 6,090 |
| 9 | 139,752 | 81,528 | 23,395 | 139,472 | 18,419 | 33,723 | -362 | -11,323 | -2,730 |
| 10 | 91,920 | 20,844 | 29,250 | 90,210 | 11,311 | 72,159 | 3,155 | 251 | -1,264 |
| 11 | 59,302 | 10,704 | 15,543 | 58,838 | 4,905 | 22,157 | 592 | 289 | 2,201 |
| 12 | 43,510 | 16,651 | 13,919 | 42,602 | 3,683 | 19,687 | 1,737 | -723 | 966 |
| 13 | 142,508 | 48,168 | 47,484 | 138,216 | 33,636 | 53,506 | 9,656 | 10,756 | -26 |
| 14 | 181,001 | 32,789 | 65,235 | 178,840 | 32,789 | 120,766 | 6,831 | 9,495 | 5,312 |
| 15 | 313,759 | 38,000 | 90,978 | 309,643 | 22,341 | 145,888 | 2,977 | 12,555 | 79 |
| 16 | 64,915 | 27,274 | 11,650 | 64,696 | 27,274 | 13,739 | 257 | 9,435 | 6,359 |
| 17 | 98,836 | 31,370 | 13,942 | 97,214 | 24,960 | 12,820 | 3,561 | 9,142 | 306 |
| 18 | 322,480 | 58,956 | 59,544 | 321,375 | 58,956 | 59,454 | -11,063 | 20,349 | 6,828 |
| 19 | 147,060 | 28,006 | 68,266 | 141,750 | 28,006 | 77,268 | 13,526 | 7,256 | -2 |
| 20 | 141,457 | 20,229 | 40,814 | 137,073 | 20,229 | 27,178 | 11,937 | 6,654 | -773 |
| 21 | 351,327 | 58,804 | 81,622 | 341,142 | 58,699 | 88,838 | 27,903 | 5,611 | 4,007 |
| SAC TOTAL | 1,030,255 | 274,260 | 182,869 | 1,021,114 | 123,377 | 232,622 | 12,441 | -8,372 | 4,377 |
| SJ TOTAL | 337,241 | 96,367 | 106,196 | 329,867 | 53,536 | 167,509 | 15,140 | 10,572 | 1,876 |
| TL TOTAL | 1,620,834 | 295,428 | 432,051 | 1,591,732 | 273,254 | 545,951 | 55,930 | 80,497 | 22,116 |
| CV TOTAL | 2,988,329 | 666,055 | 721,116 | 2,942,713 | 450,167 | 946,082 | 83,511 | 82,697 | 28,369 |

*Positive values represent overdraft and negative values represent gains to groundwater.

Urban Return Flow

As mentioned above, CVHM includes urban land use in the calculation of the farm efficiencies. C2VSIM and CVGSM include urban return flows separately so a return flow fraction can be calculated. C2VSIM simulates land use processes within the urban areas including groundwater pumping and surface water supply to meet urban demand, urban water supply shortage or surplus, and flow in excess of demand is returned to surface water bodies or to groundwater. In urban areas, a *Rootzone budget output* file tabulates monthly volumes of precipitation, runoff, applied water to urban regions, net return flow of applied water to surface water, and water that goes to the unsaturated zone as deep percolation. The algorithms for separating infiltration of applied water from the total monthly volume infiltrated and calculation of total return flows to SW and GW are similar to that described above. Calculated fractions show that for the Sacramento region, all water returned from urban regions returns to SW, whereas for the San Joaquin and Tulare regions all of the return flow infiltrates to GW. As seen in Table 3.6, C2VSIM representation of urban return flow fraction varies widely across all regions.

**Table 3.6: Urban Return Flow Fractions**

| Subregion | Urban Return Flow to GW | | Urban Return Flow to SW | | Total Urban Return Flow | |
|---|---|---|---|---|---|---|
| | C2VSIM | CVGSM | C2VSIM | CVGSM | C2VSIM | CVGSM |
| 1 | 0 | 0.501 | 0.496 | 0 | 0.496 | 0.501 |
| 2 | 0.001 | 0.522 | 0.521 | 0 | 0.522 | 0.522 |
| 3 | 0.001 | 0.503 | 0.495 | 0 | 0.496 | 0.503 |
| 4 | 0.001 | 0.504 | 0.497 | 0 | 0.498 | 0.504 |
| 5 | 0.001 | 0.515 | 0.508 | 0 | 0.509 | 0.515 |
| 6 | 0.004 | 0.533 | 0.524 | 0 | 0.528 | 0.533 |
| 7 | 0.002 | 0.006 | 0.519 | 0.53 | 0.521 | 0.536 |
| 8 | 0.002 | 0.005 | 0.532 | 0.522 | 0.534 | 0.527 |
| 9 | 0.001 | 0.524 | 0.524 | 0 | 0.525 | 0.524 |
| 10 | 0.455 | 0.528 | 0 | 0 | 0.455 | 0.528 |
| 11 | 0.477 | 0.537 | 0 | 0 | 0.477 | 0.537 |
| 12 | 0.474 | 0.528 | 0 | 0 | 0.474 | 0.528 |
| 13 | 0.464 | 0.526 | 0 | 0 | 0.464 | 0.526 |
| 14 | 0.452 | 0.512 | 0 | 0 | 0.452 | 0.512 |
| 15 | 0.449 | 0.51 | 0 | 0 | 0.449 | 0.51 |
| 16 | 0.476 | 0.005 | 0 | 0.516 | 0.476 | 0.521 |
| 17 | 0.471 | 0.522 | 0 | 0 | 0.471 | 0.522 |
| 18 | 0.468 | 0.528 | 0 | 0 | 0.468 | 0.528 |
| 19 | 0.448 | 0.512 | 0 | 0 | 0.448 | 0.512 |
| 20 | 0.5 | 0.518 | 0 | 0 | 0.5 | 0.518 |
| 21 | 0.465 | 0.005 | 0 | 0.514 | 0.465 | 0.519 |

## Conclusions

CVHM and C2VSIM are up-to-date groundwater models whose methods and results have been reviewed and confirmed to be significant improvements from previous Central Valley groundwater models (i.e., CVGSM). Both new groundwater models have been designed and built with added detail to represent Central Valley groundwater hydrology and management practices. Both models are also undergoing improvements and updates. Although there are many differences between the models' methods and results, both can be useful for water managers and planners. The benefits and drawbacks of each model are subjective to the users of the model and what the models are being used for. Dogrul et al. 2011 discusses the differences of the theory, approaches, and features of the two models. Schmid et al. 2011 compares the models using a common hypothetical example.

For this CALVIN groundwater representation update, C2VSIM was used primarily because the model period for C2VSIM (1921-2009) matches the model period for CALVIN (1921-1993). It would have been possible to use CVHM (1961-2003), but a thoroughly estimated hydrology match would have been needed to extend CVHM's data back to 1921 in order for CVHM results to be used for the CALVIN external flows term. Another benefit was that since C2VSIM is essentially an updated and improved version of CVGSM, many of the calculation methods used in the past remained relevant. C2VSIM also had all the terms previously represented in CALVIN plus some updates, whereas CVHM sometimes combined some representation of CALVIN required terms in other areas and there was some doubt associated with the methods used to split these back out to CALVIN terms. However, throughout this project, there was much valuable correspondence with USGS regarding the uses of CVHM for CALVIN and many of the components that were difficult to calculate or not present in this version of CVHM will be present in future versions. Future updates to CALVIN groundwater should re-visit the idea of using CVHM for groundwater representation. CVHM is based on the widely used MODFLOW and many of the results in the current version are comparable with other studies (i.e. storage results) and physical measurements. The CVHM calculated terms and results were largely considered when calibrating the C2VSIM inputs to updated CALVIN; Chapter 4 discusses some of these considerations and presents the results of the updated CALVIN model.

# CHAPTER 4

# CALVIN with Updated Groundwater Representation

As discussed in the last chapter, the updated CALVIN groundwater representation is based primarily on C2VSIM. Another update that affects groundwater management is Delta pumping constraints, which are updated based on CALSIM II 2009 results (DWR 2011). This chapter presents the final terms used in CALVIN, discusses the calibration process, shows CALVIN network improvements, and compares the updated CALVIN with the previous version.

## Updated CALVIN

The previous chapter compared the input terms between the groundwater models. However, C2VSIM had additional components that were not directly accounted for in CVHM and/or CVGSM. Table 4.1 shows the C2VSIM terms required to achieve a mass balance and used for the updated CALVIN model. Figure 4.1 is a schematic of the flows and interactions of these terms in the groundwater system in the updated CALVIN network. This schematic is similar to the flow interaction diagram in Chapter 1, but has some differences and also includes the nodes and links as in the updated CALVIN network. The schematic shows the hidden nodes, which are used in the model to separate the shadow value of the diversion from the shadow value of the delivery. This schematic does not show the calibration flow term since calibration flows were small and ultimately were not included. This schematic also includes artificial recharge, which was not previously explicit in the CALVIN groundwater system. Along with artificial recharge, some network improvements and simplifications were made by adding a few hidden nodes, and these changes are shown in red in the schematic.

Table 4.1: Groundwater Data Required by Updated CALVIN

| Item | Data for CALVIN | Data type |
|---|---|---|
| 1 | Agricultural return flow split (GW & SW) | Fraction (1a+1b=1) |
| 2 | Internal reuse | Amplitude (≥1) |
| 3 | Return flow of total applied water | Amplitude (<1) |
| 4 | External flows | Monthly time series |
| 4-1 | Inter-basin flows | Monthly time series |
| 4-2 | Deep percolation from streams & lakes | Monthly time series |
| 4-3 | Deep percolation from precipitation | Monthly time series |
| 4-4 | Boundary inflow | Monthly time series |
| 4-5 | Subsidence | Monthly time series |
| 4-6 | Gains from diversions (conveyance seepage) | Monthly time series |
| 4-7 | Non-recoverable losses | Monthly time series |
| 5 | Groundwater pumping capacity (maximum & minimum) | Number value |
| 6 | Pumping lift (for pumping cost) | Number value & Cost ($) |
| 7 | Initial Storage | Number value |
| 8 | Ending Storage | Number value |
| 9 | Storage capacity (maximum & minimum) | Number value |
| 10 | Artificial Recharge Operation Cost | Cost ($) |
| 11 | Artificial Recharge Rate | Amplitude (<1) |
| 12 | Urban return flow | Amplitude (<1) |

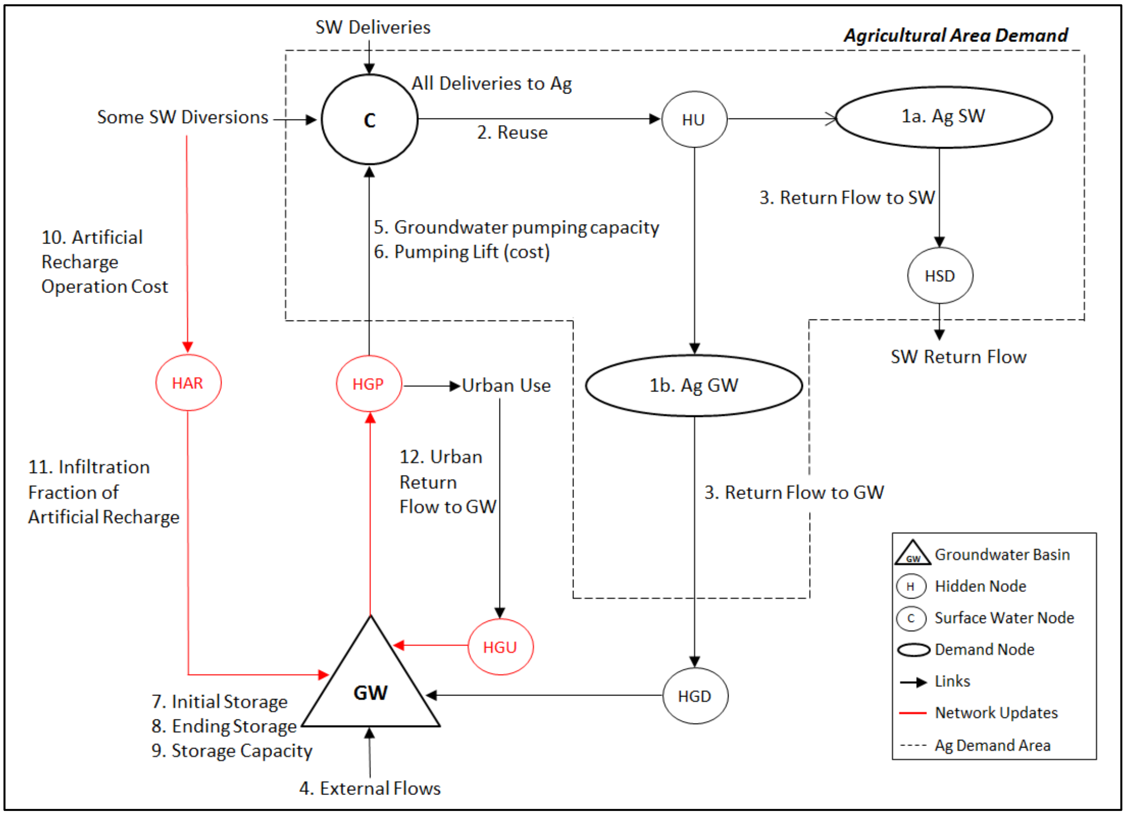


Figure 4.1 Updated CALVIN Groundwater Schematic

## Network & Schematic Improvements

The schematic included the addition of the hidden nodes to simplify the direct groundwater interaction. The previous version of CALVIN had multiple pumping links and urban return flow links connected with the groundwater basins. Adding node “HGP” provides a link from groundwater which represents total pumping from the groundwater basin. From HGP, pumping is split between agricultural pumping and urban pumping. Similarly, the previous CALVIN had multiple urban return flows returning to the groundwater basin, and now combines return flows at “HGU” before returning to the aquifer. The link between HGU and the groundwater basin is the total urban return flow. Since C2VSIM represents artificial recharge for basins 13, 15-21, nodes and links for artificial recharge were added for those basins. A detailed description of the schematic updates is provided in Appendix 3.

## Updated CALVIN & Old CALVIN Input Comparisons

The tables in this section compare the updated, calibrated CALVIN model and the CALVIN model prior to this groundwater update project. Table 4.2 shows the run numbers and a description of each run. Updated CALVIN will be referred to as “UPDATED CALVIN” and the previous version will be called “OLD CALVIN.” These comparison tables will show and discuss the final values used for UPDATED CALVIN. A summary of the calibration process and reasons for some adjustments from the original C2VSIM inputs is discussed below.

**Table 4.2: UPDATED CALVIN and OLD CALVIN**

| Run Name | Run Number | Description |
|---|---|---|
| “OLD CALVIN” | R17I03 | The results from this run are discussed in Bartolomeo 2011. This is the “base” model for the groundwater update project. |
| “UPDATED CALVIN” | S07I14 | This is the final calibrated run based primarily on C2VSIM groundwater terms and a hybrid CALSIM II-OLD CALVIN-based delta pumping & exports constraints. |

### Agricultural Return Flow, Reuse, and Total Applied Water Return Flow

Table 4.3 shows the Agricultural Return Flow to Groundwater fractions, the Reuse amplitudes, and the Total Applied Water Return Flow amplitudes. There are significant differences between old and UPDATED CALVIN for all three of these terms. UPDATED CALVIN has generally higher return flows to groundwater and lower reuse amplitudes. Many of the OLD CALVIN terms here were adjusted from the CVGSM based values in the groundwater calibration project from 2001. Details of why those earlier adjustments were made can be found in Appendix J and O (Jenkins 2001).

For the UPDATED CALVIN columns, the values adjusted during calibration are shown in bold italics and red. These particular values were adjusted based on comparisons with CVHM results and consideration of how reasonable the C2VSIM calculated value was. A summary of the calibration changes is in the calibration section below.

**Table 4.3: UPDATED CALVIN Return Flow to Groundwater, Reuse, and Applied Water Return Flow**

| Subregion | Split Ag Return Flow to GW Fraction | | Reuse Amplitude | | Applied Water Return Flow Amplitude | |
|---|---|---|---|---|---|---|
| | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN* | OLD CALVIN |
| 1 | 0.28 | 0.44 | 1 | 1 | 0.47 | 0.32 |
| 2 | 1 | 0.77 | 1 | 1 | ***0.26*** | 0.26 |
| 3 | 0.6 | 0.78 | 1.086 | 1.05 | 0.2 | 0.28 |
| 4 | 0.99 | 0.18 | 1.001 | 1.13 | 0.14 | 0.21 |
| 5 | 0.72 | 0.74 | 1.049 | 1.06 | 0.21 | 0.283 |
| 6 | 0.98 | 1 | 1.001 | 1.32 | ***0.12*** | 0.08 |
| 7 | 1 | 0.55 | 1 | 1.08 | 0.25 | 0.3 |
| 8 | 0.93 | 0.21 | 1.003 | 1.1 | 0.12 | 0.23 |
| 9 | 1 | 0.7 | 1 | 1.1 | ***0.1*** | 0.21 |
| 10 | 0.94 | 0.26 | 1.003 | 1.05 | 0.2 | 0.33 |
| 11 | 0.94 | 1 | 1.005 | 1.04 | 0.22 | 0.272 |
| 12 | 0.94 | 0.38 | 1.004 | 1.1 | ***0.18*** | 0.18 |
| 13 | 0.97 | 0.34 | 1.002 | 1.1 | ***0.13*** | 0.18 |
| 14 | 1 | 1 | 1 | 1 | 0.18 | 0.22 |
| 15 | 1 | 0.4 | 1 | 1.05 | 0.12 | 0.21 |
| 16 | 0.84 | 0.31 | 1.015 | 1.1 | 0.28 | 0.18 |
| 17 | 1 | 0.61 | 1 | 1.1 | 0.13 | 0.17 |
| 18 | 1 | 1 | 1 | 1 | 0.18 | 0.25 |
| 19 | 1 | 1 | 1 | 1 | 0.03 | 0.21 |
| 20 | 0.82 | 0.99 | 1.014 | 1.07 | 0.1 | 0.17 |
| 21 | 1 | 1 | 1 | 1 | 0.1 | 0.25 |

* Red Bold Italics indicate values adjusted during calibration

## External Flows

Table 4.4 shows the average annual net external flows for UPDATED CALVIN and OLD CALVIN, along with the original C2VSIM flow averages since this term was adjusted significantly for many basins. Specifically, the external flow time series term that was adjusted was groundwater-surface water interaction from streams. Differences in stream exchanges before and after 1951 are due to the change in aquifer levels and therefore changes in surface-groundwater interactions. Stream-aquifer connections have changed over time so streams that may have gained water from aquifers before 1951 have reversed to losing water to aquifers. If the historical time series of stream-aquifer flows was used, there would likely have been a million acre-feet per year of water that was not accounted for correctly in the Central Valley. As a result, streamflow exchanges before 1951 were adjusted based on if the annual average difference for subregions was above 50 TAF/yr. Adjusted subregions are 2, 4, 5, 6, 9, 11, 13, 15, 18, 19 and 21 (shown in bold italics and red in Table 4.4). To maintain mass balance of water available within the subregion, the difference between historical and adjusted stream inflows was accounted for in the depletion areas of respective subregions or as depletions or accretions to major streams in these subregions. A more detailed description of this adjustment is in Appendix 4.

Effectively, the C2VSIM external flow values are used; some of the water was just moved from the external flows term to the depletions and accretions to account for the changes in aquifer levels after 1951. Overall, UPDATED CALVIN has much less external flows entering the groundwater system than OLD CALVIN's external flows entering the groundwater system. The individual flows that summed to be net external flows are discussed in Chapter 3.

As mentioned in the previous chapter, C2VSIM represents evapotranspiration losses as a surface water loss fraction so it is not accounted for in the external flows time series. More details on the C2VSIM surface loss fractions can be found in Appendix 5.

**Table 4.4: Net External Flow Averages Compared (TAF/yr)**

| Subregion | UPDATED CALVIN* | C2VSIM | OLD CALVIN (CVGSM) |
|---|---|---|---|
| 1 | 28 | 28 | 2 |
| 2 | ***235*** | 177 | 403 |
| 3 | -9 | -9 | 9 |
| 4 | ***-68*** | -96 | 261 |
| 5 | ***91*** | 67 | 144 |
| 6 | ***225*** | 180 | 367 |
| 7 | 168 | 168 | 278 |
| 8 | 402 | 402 | 747 |
| 9 | ***134*** | 85 | 14 |
| 10 | 72 | 72 | 296 |
| 11 | ***29*** | -1.3 | -159 |
| 12 | 49 | 49 | 155 |
| 13 | ***365*** | 344 | 863 |
| 14 | 278 | 278 | 309 |
| 15 | ***688*** | 594 | 1161 |
| 16 | 51 | 51 | 280 |
| 17 | 96 | 96 | 360 |
| 18 | ***241*** | 263 | 484 |
| 19 | ***424*** | 368 | 162 |
| 20 | 101 | 101 | 220 |
| 21 | ***322*** | 290 | 387 |
| SAC TOTAL | ***1206*** | 1002 | 2224 |
| SJ TOTAL | ***515*** | 464 | 1156 |
| TL TOTAL | ***2201*** | 2041 | 3362 |
| TOTAL | ***3922*** | 3507 | 6741 |

* Red Bold Italics indicate values adjusted during calibration

Pumping Terms

Table 4.5 shows the pumping related terms (capacity, depth, and unit costs) for CALVIN (UPDATED and OLD). The maximum pumping values from C2VSIM were used as pumping constraints except for a few regions (shown in bold italics and red). These exceptions were increased during calibration because it was found that the maximum pumping constraints were being hit often, and when comparing the C2VSIM maximum pumping capacities with CVHM, C2VSIM's maximum pumping values were significantly lower, indicating that the actual maximum could be larger.

Pumping depths and costs were not adjusted in the calibration phase. Since the data is based on average measured DWR groundwater level data, those pumping depths were used to calculate the pumping cost. Adjustments were made to the pumping costs to reflect year 2008 economic dollars. Details of the how pumping costs were calculated can be found in Appendix 2.

**Table 4.5: UPDATED CALVIN Pumping Terms Comparison**

| Subregion | Maximum Pumping (TAF/month) | | Pumping Depth (feet) | | Pumping Cost[1] ($) | |
|---|---|---|---|---|---|---|
| | UPDATED CALVIN* | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN |
| 1 | 7.2 | 20.76 | 71 | 130 | $ 23.59 | $ 30.00 |
| 2 | 93.2 | 153.23 | 40 | 120 | $ 15.82 | $ 28.20 |
| 3 | 175.8 | 170.98 | 27 | 100 | $ 11.93 | $ 23.80 |
| 4 | 109.2 | 110.47 | 16 | 60 | $ 9.33 | $ 16.00 |
| 5 | 240.1 | 225.65 | 27 | 75 | $ 11.93 | $ 18.80 |
| 6 | 85.7 | 148.06 | 25 | 70 | $ 11.93 | $ 18.20 |
| 7 | 120.5 | 96.02 | 40 | 95 | $ 23.07 | $ 28.80 |
| 8 | 185.6 | 208.38 | 90 | 110 | $ 31.89 | $ 28.60 |
| 9 | ***50*** | 73.77 | 24 | 80 | $ 11.93 | $ 20.40 |
| 10 | 185.2 | 197.88 | 17 | 60 | $ 9.07 | $ 15.60 |
| 11 | 64.9 | 52.21 | 47 | 75 | $ 19.45 | $ 20.60 |
| 12 | 86.9 | 80.56 | 68 | 90 | $ 24.89 | $ 23.60 |
| 13 | 225.8 | 290.96 | 75 | 125 | $ 25.93 | $ 30.00 |
| 14 | 221.1 | 332.85 | 235 | 350 | $ 69.22 | $ 76.40 |
| 15 | 335.3 | 407.88 | 93 | 210 | $ 30.08 | $ 46.60 |
| 16 | 61.8 | 60.76 | 57 | 130 | $ 19.70 | $ 29.80 |
| 17 | 152.6 | 152.39 | 34 | 130 | $ 16.07 | $ 31.60 |
| 18 | ***300*** | 348.95 | 80 | 200 | $ 27.48 | $ 45.20 |
| 19 | 213.7 | 171.1 | 139 | 310 | $ 44.85 | $ 68.40 |
| 20 | 125.3 | 108.1 | 298 | 310 | $ 84.00 | $ 67.20 |
| 21 | 265.6 | 228.31 | 191 | 310 | $ 59.37 | $ 69.60 |

* Red Bold Italics indicate values adjusted during calibration

[1] Note that UPDATED CALVIN pumping costs are based on year 2008$ dollars and OLD CALVIN costs are based on year 2000$ dollars

## Storage Terms

The storage terms are shown in Table 4.6. The values in the table reflect the maximum, initial, ending, and average annual change in storage for the 72 year time period for water years 1921-1993.

For UPDATED CALVIN, the maximum storage constraint was not actually used in the final run since the initial and ending storages were set to simulate overdraft. The initial storage values were set based on C2VSIM initial storage values. The ending storages were set based on the calculated overdraft/change in storage discussed in Chapter 3, with some calibration adjustments. The change in storage calculated for the OLD CALVIN run was based on the initial storage minus the ending storage. The initial and ending storages for OLD CALVIN differ from the original groundwater calibration based on CVGSM, due to other CALVIN calibrations in the past 10 years.

As can be seen in the storage change numbers, there is some agreement that much more overdraft occurs in the Tulare basin than the other two Central Valley basins. The ending storages for UPDATED CALVIN that were adjusted from C2VSIM's calculated overdraft for the regions are shown in bold italics. Reasons behind this adjustment will be discussed in the next section.

In general, estimates of long-term overdraft vary widely, as such calculations are quite sensitive to the selection of periods, durations, and flows over wet and dry periods.

**Table 4.6: UPDATED CALVIN Storage Terms and Overdraft**

| **Subregion** | **Maximum Storage Capacity (TAF/mo)** | | **Initial Storage (TAF/mo)** | | **Ending Storage* (TAF/mo)** | | **Average Annual Storage Change for 1921-1993 (TAF/yr)**[1] | |
|---|---|---|---|---|---|---|---|---|
| | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN* | OLD CALVIN | UPDATED CALVIN | OLD CALVIN |
| 1 | 38,510 | 5,448 | 38,447 | 1,902 | 39,437 | 1,774 | -13.8 | 1.8 |
| 2 | 136,757 | 24,162 | 136,494 | 11,843 | ***136,494*** | 11,242 | ***0.0*** | 8.3 |
| 3 | 133,958 | 22,127 | 132,687 | 13,345 | 131,748 | 13,545 | 13.0 | -2.8 |
| 4 | 61,622 | 15,362 | 60,728 | 10,350 | 60,508 | 10,581 | 3.1 | -3.2 |
| 5 | 92,020 | 24,399 | 91,113 | 15,552 | 90,457 | 14,561 | 9.1 | 13.8 |
| 6 | 175,719 | 22,864 | 174,968 | 17,948 | 175,275 | 16,077 | -4.3 | 26.0 |
| 7 | 58,484 | 12,270 | 56,539 | 10,025 | 51,209 | 12,168 | 74.0 | -29.8 |
| 8 | 193,433 | 32,842 | 190,665 | 22,366 | 182,829 | 16,276 | 108.8 | 84.6 |
| 9 | 139,752 | 23,395 | 139,472 | 17,744 | 139,834 | 20,474 | -5.0 | -37.9 |
| 10 | 91,920 | 29,250 | 90,210 | 22,213 | 87,055 | 23,477 | 43.8 | -17.6 |
| 11 | 59,302 | 15,543 | 58,838 | 10,948 | 58,246 | 8,747 | 8.2 | 30.6 |
| 12 | 43,510 | 13,919 | 42,602 | 10,380 | 40,865 | 9,414 | 24.1 | 13.4 |
| 13 | 142,508 | 47,484 | 138,216 | 31,143 | 128,560 | 31,169 | 134.1 | -0.4 |
| 14 | 181,001 | 65,235 | 178,840 | 51,075 | 172,009 | 45,763 | 94.9 | 73.8 |
| 15 | 313,759 | 90,978 | 309,643 | 70,494 | 306,666 | 70,415 | 41.3 | 1.1 |
| 16 | 64,915 | 11,650 | 64,696 | 6,359 | 64,439 | 0 | 3.6 | 88.3 |
| 17 | 98,836 | 13,942 | 97,214 | 7,311 | 93,653 | 7,005 | 49.5 | 4.3 |
| 18 | 322,480 | 59,544 | 321,375 | 40,775 | ***321,375*** | 33,947 | ***0.0*** | 94.8 |
| 19 | 147,060 | 68,266 | 141,750 | 43,085 | 128,224 | 43,087 | 187.9 | 0.0 |
| 20 | 141,457 | 40,814 | 137,073 | 22,630 | 125,136 | 23,403 | 165.8 | -10.7 |
| 21 | 351,327 | 81,622 | 341,142 | 51,595 | ***324,302*** | 47,588 | ***233.9*** | 55.7 |
| SAC TOTAL | 1,030,255 | 182,869 | 1,021,113 | 121,075 | 1,008,673 | 116,698 | 172.8 | 60.8 |
| SJ TOTAL | 337,240 | 106,196 | 329,866 | 74,684 | 314,726 | 72,807 | 210.3 | 26.1 |
| TL TOTAL | 1,620,835 | 432,051 | 1,591,733 | 293,324 | 1,535,804 | 271,208 | 776.8 | 307.2 |
| TOTAL | 2,988,330 | 721,116 | 2,942,712 | 1,902 | 2,859,203 | 909,908 | 1159.8 | 394.0 |

* Red Bold Italics indicate values adjusted during calibration

[1] Positive values represent overdraft and negative values represent gains to groundwater.

Artificial Recharge

In C2VSIM, subregions 13, and 15-21 manage their groundwater supplies with artificial recharge of imported or local surface water. Artificial recharge flows to groundwater are reported as C2VSIM diversions and are described in the simulation application's *CVdivspec.dat* file, which specifies diversions for spreading and destination subregions for infiltration facilities. In C2VSIM, spreading facilities have a recoverable fraction of 0.95 (an assumed infiltration rate). The groundwater budget output file has a "Recharge" term, which includes both diversion losses and water from spreading facilities. To separate artificial recharge volumes from the total recharge volume, an infiltration rate of 0.95 was applied to monthly diversion volumes for surface water diversions for spreading, where diversions for spreading are listed in Table 4.7. Monthly volumes of Diversion times 0.95 was taken as recharge from spreading facilities and was therefore separated from the total recharge term for subregions 13, and 15-21. Figure 4.1 shows the added nodes and links (in bold italics and red) that represent this artificial recharge addition to the CALVIN network. Artificial recharge was not explicitly represented in OLD CALVIN; historical artificial recharge was included in select inflows.

**Table 4.7: Surface Water Diversion for Spreading**

| C2VSIM Source Node | Destination Subregion | Artificial Recharge Infiltration Rate | Non-recoverable Losses | Description |
|---|---|---|---|---|
| 84 | 13 | 0.95 | 0.05 | Chowchilla R riparian SR13 Spreading |
| 74 | 13 | 0.95 | 0.05 | Fresno R riparian SR13 Spreading |
| 28 | 15 | 0.95 | 0.05 | Kings R Main Stem to SR15 Spreading |
| 43 | 15 | 0.95 | 0.05 | Kings R North Fork to SR15 Spreading |
| 37 | 15 | 0.95 | 0.05 | Kings R South Fork to SR15 Spreading |
| 52 | 15 | 0.95 | 0.05 | Kings R Fresno Slough to SR15 Spreading |
| 24 | 16 | 0.95 | 0.05 | Kings R to Fresno ID SR16 Spreading |
| Import | 16 | 0.95 | 0.05 | Friant-Kern Canal to SR16 Spreading |
| 25 | 17 | 0.95 | 0.05 | Kings R to Consolidated ID SR17 Spreading |
| 25 | 17 | 0.95 | 0.05 | Kings R to Alta ID SR17 Spreading |
| Import | 17 | 0.95 | 0.05 | Friant-Kern Canal to SR17 Spreading |
| 420 | 18 | 0.95 | 0.05 | Kaweah R Partition A to SR18 Spreading |
| 422 | 18 | 0.95 | 0.05 | Kaweah R Partition B to SR18 Spreading |
| 422 | 18 | 0.95 | 0.05 | Kaweah R Partition C to SR18 Spreading |
| 420 | 18 | 0.95 | 0.05 | Kaweah R Partition D to SR18 Spreading |
| 426 | 18 | 0.95 | 0.05 | Kaweah R to Corcoran ID SR18 Spreading |
| 18 | 18 | 0.95 | 0.05 | Tule R riparian to SR18 Spreading |
| Import | 18 | 0.95 | 0.05 | Friant-Kern Canal to SR18 Spreading |
| 7 | 19 | 0.95 | 0.05 | Kern R to SR19 Spreading |
| Import | 19 | 0.95 | 0.05 | California Aqueduct to SR19 Spreading |
| Import | 19 | 0.95 | 0.05 | Friant-Kern Canal to SR19 Spreading |
| 2 | 20 | 0.95 | 0.05 | Kern R to SR20 Spreading |
| Import | 20 | 0.95 | 0.05 | Friant-Kern Canal to SR20 Spreading |
| Import | 20 | 0.95 | 0.05 | Cross-Valley Canal to SR20 Spreading |
| 3 | 21 | 0.95 | 0.05 | Kern River to Subregion 21B spreading |
| 4 | 21 | 0.95 | 0.05 | Kern River to Subregion 21C spreading |
| Import | 21 | 0.95 | 0.05 | California Aqueduct to SR21 Spreading |
| Import | 21 | 0.95 | 0.05 | Friant-Kern Canal to SR21 Spreading |
| Import | 21 | 0.95 | 0.05 | Cross-Valley Canal to SR21 Spreading |

Table 4.8 shows the annual average historical artificial recharge per C2VSIM simulation and operation costs of artificial recharge facilities updated from OLD CALVIN artificial recharge costs. These are calculated to reflect operating costs for these agricultural groundwater recharge activities, which limit facility operations and the opportunity cost of land used for recharge basins.

**Table 4.8: Artificial Recharge Operation Costs**

| Subregion | CALVIN Link | Diversions for Spreading | Average Annual Artificial Recharge (TAF/yr) | Operating Cost ($/AF)[1] |
|---|---|---|---|---|
| 13 | HAR13_GW-13 | Chowchilla R riparian & Fresno R riparian | 4 | 6.5 |
| 15 | HAR15_GW15 | Kings R | 138 | 6.5 |
| 16 | HAR15_GW16 | Kings R & Friant-Kern Canal | 24 | 6.5 |
| 17 | HAR15_GW17 | Kings R & Friant-Kern Canal | 23 | 6.5 |
| 18 | HAR15_GW18 | Kaweah R, Tule R riparian & Friant-Kern Canal | 178 | 6.5 |
| 19 | HAR15_GW19 | California Aqueduct, Kern R and Friant-Kern Canal | 79 | 6.5 |
| 20 | HAR15_GW20 | Kern R, Friant-Kern Canal & Cross-Valley Canal | 66 | 6.5 |
| 21 | HAR15_GW21 | Kern R, California Aqueduct, Friant-Kern Canal & Cross Valley Canal | 208 | 6.5 |

[1] OLD CALVIN cost (5 $/AF) converted to 2008 dollars

## Urban Return Flow

The urban return flow fractions used for UPDATED CALVIN are based on C2VSIM's representation of urban return flow, as discussed in Chapter 3 (Table 3.6). These can be compared with the urban return flow fractions for OLD CALVIN, which are from CVGSM (also shown in Table 3.6).

## Agricultural Water Demands

Along with updating the input terms related to CALVIN groundwater, agricultural demands were also updated. Results from an improved and updated Statewide Agricultural Production Model – SWAP (Howitt et al. 2012) were used for UPDATED CALVIN's agricultural demands. Table 4.9 shows agricultural demands for OLD CALVIN and UPDATED CALVIN. The differences in the water delivery targets can be attributed to improvements made in SWAP crop production model in that some CVPM regions (3, 10, 14, 15, 19 and 21) were further discretized for better representation. A detailed description of SWAP is in Howitt et al. 2012.

Table 4.9 shows that overall net demand target for UPDATED CALVIN is slightly lower. Generally, this could imply that decreased shortages in deliveries can be expected in UPDATED CALVIN. The calibration steps were based primarily on determining if shortages reflected in the results of each run were "true" shortages or if a specific calculated input term caused the shortage, such as local capacity constraints, leading to scarcities even in very wet years. The calibration process to reduce these "untrue" shortages is discussed in the next section.

**Table 4.9: Average Annual Agricultural Water Delivery Targets (TAF/yr)**

| Agricultural Demand Area | OLD CALVIN | UPDATED CALVIN |
|---|---|---|
| CVPM 1 | 126 | 139 |
| CVPM 2 | 497 | 473 |
| CVPM 3 | 2,196 | 1,315 |
| CVPM 4 | 956 | 884 |
| CVPM 5 | 1,313 | 1,485 |
| CVPM 6 | 619 | 732 |
| CVPM 7 | 429 | 413 |
| CVPM 8 | 802 | 737 |
| CVPM 9 | 926 | 1,208 |
| CVPM 10 | 919 | 1,403 |
| CVPM 11 | 855 | 777 |
| CVPM 12 | 772 | 760 |
| CVPM 13 | 1,506 | 1,679 |
| CVPM 14 | 1,358 | 1,129 |
| CVPM 15 | 1,701 | 1,828 |
| CVPM 16 | 345 | 368 |
| CVPM 17 | 797 | 739 |
| CVPM 18 | 1,759 | 2,119 |
| CVPM 19 | 887 | 842 |
| CVPM 20 | 829 | 640 |
| CVPM 21 | 1,195 | 999 |
| SAC TOTAL | 7,864 | 7,386 |
| SJ TOTAL | 4,052 | 4,620 |
| TL TOTAL | 8,871 | 8,664 |
| TOTAL | 20,787 | 20,670 |

During the calibration phase of OLD CALVIN in 2001, it was found that there was too much excess water in the system, so a calibration outflow was needed for CALVIN to have reasonable results. These calibration outflows were constrained time series that dumped water from the C delivery node (shown in Figure 4.1) before reaching the demand nodes, effectively increasing water use. Table 4.10 shows these averaged annual calibration flows from the 2001 calibration. These calibration flows were a primary reason CALVIN needed to be updated.

Table 4.10: Average Annual Old CALVIN Calibration Outflow (TAF/yr)

| Subregion | Calibration Outflow |
|---|---|
| 1 | 5 |
| 2 | 0 |
| 3 | 0 |
| 4 | 63 |
| 5 | 114 |
| 6 | 259 |
| 7 | 46 |
| 8 | 33 |
| 9 | 0 |
| 10 | 389 |
| 11 | 242 |
| 12 | 16 |
| 13 | 247 |
| 14 | 0 |
| 15 | 0 |
| 16 | 194 |
| 17 | 62 |
| 18 | 0 |
| 19 | 216 |
| 20 | 23 |
| 21 | 170 |
| SAC TOTAL | 520 |
| SJ TOTAL | 894 |
| TL TOTAL | 665 |
| TOTAL | 2,079 |

## Calibration Summary

The results presented in the sections above for UPDATED CALVIN reflect the already calibrated values (shown in bold italics). This section discusses and summarizes calibration adjustments made to the original C2VSIM inputs.

### Calibration Steps

The previous section compared UPDATED CALVIN and OLD CALVIN. This calibration section discusses the key differences between these two successfully calibrated runs. Table 4.11 presents those runs, their numbers, and a description of the runs. Starting with OLD CALVIN as a base, the newly calculated C2VSIM-based input terms were used for the “UPDATED CALVIN C2VSIM Base” run. The model solves, but the shortages were quite high in unusual ways, indicating some possibly “untrue” localized scarcity. Calibration adjustments were made for different terms in runs S07I05-S07I08 to try to minimize unrealistic scarcity. Run S07I08 is called “UPDATED CALVIN Old Delta” since it is the successfully calibrated CALVIN run with updated groundwater representation based primarily on C2VSIM, but does not include the updated Delta term constraints. Calibration adjustments were made for Delta terms in runs S07I08-S07I14. UPDATED CALVIN represents the final, calibrated run with all updates, including the updated Delta terms.

**Table 4.11: CALVIN Calibration Runs**

| Run Name | Run Number | Description |
|---|---|---|
| "UPDATED CALVIN C2VSIM Base" | S07I05 | The results from this run are based primarily on C2VSIM inputs as originally calculated prior to any calibration changes (external flows adjustment is included). Delta terms are based on OLD CALVIN. |
| "UPDATED CALVIN Old Delta" | S07I08 | This is the final calibrated run based primarily on C2VSIM groundwater terms with Delta terms based on OLD CALVIN. |
| "UPDATED CALVIN" | S07I14 | This is the final calibrated run based primarily on C2VSIM groundwater terms and a hybrid CALSIM II-OLD CALVIN-based delta pumping & exports constraints. |

The calibration process was essentially split into two parts: 1) the calibration of CALVIN based on C2VSIM input terms (from UPDATED CALVIN C2VSIM Base to UPDATED CALVIN Old Delta), and 2) the calibration of the new Delta exports and pumping constraints (from UPDATED CALVIN Old Delta to UPDATED CALVIN). The section below summarizes the changes made in the entire calibration process, discussing the base calibration first, then the Delta terms calibration. A detailed description of the entire calibration process can be found in Appendix J(2) (Zikalala et al. 2012).

### UPDATED CALVIN C2VSIM Base Calibration

Table 4.12 shows the resulting annual average shortages (scarcities) for the major runs. As can be seen between the UPDATED CALVIN C2VSIM Base run and the UPDATED CALVIN Old Delta run, there are significant decreases in scarcities in regions 2, 4, 6, and 18. Small decreases occur in regions 9, 12, 13, 20, and 21. These reductions in shortages are due to adjusting surface water diversion capacities, amplitudes for return flows, maximum pumping capacities, and calculated overdraft. These adjustments were made based on examining the results from each run and determining what term or factor might be causing that region to have unrealistic shortages, particularly shortages in very wet years caused by localized capacity constraints and amplitudes. Dual values for node conveyances to the subregions were considered to assess if the capacities or upper bounds were realistic for the physical system. Values that were not believed to represent "true" groundwater or capacity conditions were adjusted; these adjustments were based on comparisons with CVHM results or measured data. The shortages for each run (S07I05-S07I08) and the changes made between runs are described in more detail in Appendix J(2).

## Table 4.12: Average Annual Agricultural Water Scarcity Comparison

| Agricultural Demand Area | CALVIN Schematic Demand Node | CALVIN Delivery Link | Annual Average Water Shortages (TAF/yr) | | | |
|---|---|---|---|---|---|---|
| | | | OLD CALVIN* | UPDATED CALVIN C2VSIM Base | UPDATED CALVIN Old Delta | UPDATED CALVIN |
| CVPM 1 | Ag-GW | HU1-CVPM 1G | 0.0 | 0.7 | 0.8 | 1.0 |
| | Ag-SW | HU1-CVPM 1S | 0.0 | 0.4 | 0.7 | 1.1 |
| CVPM 2 | Ag-GW | HU2-CVPM 2G | 0.0 | 189.0 | 0.0 | 0.0 |
| | Ag-SW | HU2-CVPM 2S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 3 | Ag-GW | HU3-CVPM 3G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU3-CVPM 3S | 15.0 | 0.0 | 0.0 | 0.0 |
| CVPM 4 | Ag-GW | HU4-CVPM 4G | 0.0 | 70.7 | 0.0 | 0.0 |
| | Ag-SW | HU4-CVPM 4S | 0.0 | 1.7 | 0.0 | 0.0 |
| CVPM 5 | Ag-GW | HU5-CVPM 5G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU5-CVPM 5S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 6 | Ag-GW | HU6-CVPM 6G | 0.0 | 45.5 | 7.3 | 28.5 |
| | Ag-SW | HU6-CVPM 6S | 0.0 | 1.2 | 0.5 | 0.5 |
| CVPM 7 | Ag-GW | HU7-CVPM 7G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU7-CVPM 7S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 8 | Ag-GW | HU8-CVPM 8G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU8-CVPM 8S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 9 | Ag-GW | HU9-CVPM 9G | 0.0 | 8.3 | 0.1 | 12.7 |
| | Ag-SW | HU9-CVPM 9S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 10 | Ag-GW | HU10-CVPM 10G | 0.0 | 48.4 | 48.7 | 51.4 |
| | Ag-SW | HU10-CVPM 10S | 0.0 | 3.3 | 3.4 | 3.5 |
| CVPM 11 | Ag-GW | HU11-CVPM 11G | 0.0 | 0.3 | 0.3 | 0.7 |
| | Ag-SW | HU11-CVPM 11S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 12 | Ag-GW | HU12-CVPM 12G | 0.0 | 25.4 | 22.6 | 23.4 |
| | Ag-SW | HU12-CVPM 12S | 22.0 | 1.6 | 1.1 | 1.5 |
| CVPM 13 | Ag-GW | HU13-CVPM 13G | 0.0 | 75.9 | 74.5 | 74.9 |
| | Ag-SW | HU13-CVPM 13S | 0.0 | 2.4 | 2.3 | 2.4 |
| CVPM 14 | Ag-GW | HU14-CVPM14G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU14-CVPM14S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 15 | Ag-GW | HU15-CVPM15G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU15-CVPM15S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 16 | Ag-GW | HU16-CVPM16G | 0.0 | 7.8 | 8.0 | 13.3 |
| | Ag-SW | HU16-CVPM16S | 0.0 | 2.6 | 2.6 | 2.7 |
| CVPM 17 | Ag-GW | HU17-CVPM17G | 0.0 | 33.6 | 33.6 | 34.8 |
| | Ag-SW | HU17-CVPM17S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 18 | Ag-GW | HU18-CVPM18G | 0.0 | 151.0 | 107.6 | 106.0 |
| | Ag-SW | HU18-CVPM18S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 19 | Ag-GW | HU19-CVPM19G | 0.0 | 0.0 | 0.0 | 0.0 |
| | Ag-SW | HU19-CVPM19S | 0.0 | 0.0 | 0.0 | 0.0 |
| CVPM 20 | Ag-GW | HU20-CVPM20G | 0.0 | 25.5 | 22.1 | 21.9 |
| | Ag-SW | HU20-CVPM20S | 0.0 | 5.3 | 4.8 | 4.9 |
| CVPM 21 | Ag-GW | HU21-CVPM21G | 0.0 | 42.6 | 39.9 | 38.6 |
| | Ag-SW | HU21-CVPM21S | 0.0 | 0.0 | 0.0 | 0 |
| **Sacramento** | | | **15.0** | **317.5** | **9.4** | **43.8** |
| **San Joaquin** | | | **22.0** | **157.3** | **152.9** | **157.8** |
| **Tulare** | | | **0.0** | **268.4** | **218.6** | **222.3** |
| **Central Valley Total** | | | **37.0** | **743.2** | **380.9** | **423.8** |

*Note that OLD CALVIN had different SWAP targets

Since the surface water loss fractions were changed in this update, the surface water diversion capacities were examined more closely for the regions with significant shortages. Table 4.13 shows the changes made to the upper bound conveyance capacity for the surface water diversions and reasons for the adjustments. In most cases, the surface water loss amplitudes (discussed in Appendix 5) are lower for UPDATED CALVIN, indicating higher surface water losses so the upper bound capacities were increased to compensate for greater losses. The link that represents surface water diversion recoverable and non-recoverable losses comes after the link that the upper bound capacity is on in the CALVIN network. To better represent the "true" upper bound capacity, the upper bound capacities were increased so that when the flow reaches the link with the associated surface water loss, the original upper bound capacity could still be delivered.

**Table 4.13: Surface Water Diversion Capacity Calibration Adjustments**

| Subregion | CALVIN SW Diversion Link | Upper Bound Capacity (TAF/month) | | Source or Reason for Adjustment |
|---|---|---|---|---|
| | | OLD CALVIN | UPDATED CALVIN | |
| 2 | D77-HSU2D77 | 12.7 | 29.7 | USBR website |
| | C1-HSU2C1 | 1.8 | 1.98 | Compensation for increased SW losses |
| | C11-HSU2C11 | 0.7 | 1.03 | C2VSIM |
| | HSU2C9-C6 | 26.4 | 29.3 | C2VSIM |
| 4 | D30-HSU4D30 | 194.1 | 236 | Compensation for increased SW losses |
| 6 | C314_HSU6C314 | 32.1 | 34 | Compensation for increased SW losses |
| | C16_HSUC16 | 36.3 | 38.5 | Compensation for increased SW losses |
| | C21_HSUC21 | 40.5 | 42.9 | Compensation for increased SW losses |
| 12 | D645-HSU12D645 | 5.4 | 5.94 | Compensation for increased SW losses |
| | D649-HSU12D649 | 12.2 | 13.42 | Compensation for increased SW losses |
| | D662-HSU12D662 | 107.1 | 117.81 | Compensation for increased SW losses |
| | D664-HSU12D664 | 2 | 2.2 | Compensation for increased SW losses |
| | D699-HSU12D699 | 4.5 | 4.95 | Compensation for increased SW losses |
| 13 | D645-HSU13D645 | 111.4 | 122.54 | Compensation for increased SW losses |
| | D649-HSU13D649 | 4.3 | 4.73 | Compensation for increased SW losses |
| | D634-HSU13D634 | 42.9 | 47.19 | Compensation for increased SW losses |
| | D624-HSU13D634 | 57.2 | 62.92 | Compensation for increased SW losses |
| | D694-HSU13D694 | 0.5 | 0.55 | Compensation for increased SW losses |
| 18 | C56-HSU18C56 | 179.6 | 197.56 | Compensation for increased SW losses |
| | C58-HSU18C58 | 23.1 | 25.41 | Compensation for increased SW losses |

Calibration adjustments also were made to the C2VSIM calculated groundwater terms. Table 4.14 compares the final values used for UPDATED CALVIN and the original C2VSIM calculated values. These adjustments were not all made in just one run at one time; the changes were made throughout runs S07I05-S07I08 (discussed in detail in Appendix J(II) (Zikalala et al. 2012)).

The first column of Table 4.14 shows adjustments for total applied water return flow amplitudes. These amplitudes were increased to allow more water to return to the groundwater basins. The increases for this term were mostly justified based on comparisons with CVHM return flow amplitudes (Table 3.2).

The maximum pumping capacities were adjusted for regions 9 and 18. This was done because there were large shortages that seemed unreasonable for those regions. Additionally, maximum pumping was being reached even during normal water years and comparisons of the maximum pumping capacity for those regions with CVHM values indicated that they could be higher (Table 3.4).

Change in storage values were adjusted for regions 1, 18, and 21 because the C2VSIM-based calculations of storage change did not seem to reflect physically likely storage changes in those regions. Increased groundwater storage for regions 2 and 18 just did not seem realistic, so they were adjusted to have no storage change. Considering region 21’s physical area, the C2VSIM calculated overdraft of 27,903 TAF seemed too high and unlikely to be true. So rather than eliminate region 18’s recharge to groundwater, that addition of groundwater was accounted for in region 21 instead. Although this doesn’t follow conventional calibration methods, regions 18 and 21 are both in the Tulare region, so making this adjustment seemed reasonable, from an overall Tulare basin perspective; the total overdraft for the Tulare region based on C2VSIM is not affected. Additionally, when compared with CVHM’s region 21 calculated overdraft of 5,611 TAF, the UPDATED CALVIN value is much closer than the C2VSIM calculated value.

**Table 4.14: Adjustments to Groundwater Terms**

| Subregion | Total Applied Water Return Flow Amplitude | | Maximum Pumping Capacity (TAF/month) | | Overdraft (TAF) | |
|---|---|---|---|---|---|---|
| | C2VSIM | UPDATED CALVIN | C2VSIM | UPDATED CALVIN | C2VSIM | UPDATED CALVIN |
| 2 | 0.14 | 0.26 | - | - | -990 | 0 |
| 6 | 0.06 | 0.12 | - | - | - | - |
| 9 | 0.09 | 0.10 | 43.9 | 50 | - | - |
| 12 | 0.16 | 0.18 | - | - | - | - |
| 13 | 0.12 | 0.13 | - | - | - | - |
| 18 | - | - | 238.4 | 300 | -11063 | 0 |
| 21 | - | - | - | - | 27903 | 16840 |

Note that “-“ just indicates that no changes were made for that term for that region.

The adjustments discussed above allowed for about an average annual 360 TAF of localized scarcities to be removed from the system, as seen in Table 4.12 when comparing shortages between UPDATED CALVIN C2VSIM Base and UPDATED CALVIN Old Delta. Adjustments were made until it was obvious that regardless of reasonable adjustments, the scarcities would remain, implying real scarcity in those regions not due to unrealistic local constraints. UPDATED CALVIN Old Delta was used as a base case for the next part of the update project – updates to Delta terms.

UPDATED CALVIN Delta Exports and Pumping Calibration

Table 4.15 compares the input constraints that affect the Delta. The major pumping plants for the Delta are Banks and Tracy Pumping Plants. For this update, the Tracy pumping upper-bound constraint was left as it was in OLD CALVIN; the CALSIM II Tracy pumping constraint had comparable maximums as the constraints used in OLD CALVIN. The Banks upper-bound pumping constraint used for UPDATED CALVIN is a hybrid of CALSIM II 2009 results (DWR 2011) and OLD CALVIN's constraints. Although CALSIM's complex Delta flow restrictions would be a better representation of real Delta exports than OLD CALVIN's constraints, using CALSIM results alone as constraints would be too inflexible and would result in optimization infeasibilities. The hybrid version was used so that the final Banks pumping constraint is updated to be more comparable with CALSIM II 2009 results while still being able to achieve feasible results through CALVIN's optimization methods.

A cumulative distribution was plotted for CALSIM II's Banks pumping constraint and it was determined that the maximum of 465 TAF was a reasonable maximum to use for the new constraint. Then, in order to bring OLD CALVIN's Banks upper-bound to a lower value, any value for pumping for OLD CALVIN that exceeded the 465 TAF maximum was set to 465 TAF. It appeared that every value was greater than 465 TAF so 465 TAF was used to be the Banks constraint, with adjustments for number of days per month.

The Required Delta Outflow is a constrained minimum flow in CALVIN. The constraint used for UPDATED CALVIN was based on both CALSIM II 2009 and OLD CALVIN. At every month, the maximum value for Delta Export Outflow between CALSIM II 2009 and OLD CALVIN was used as the constraint for UPDATED CALVIN. This results in UPDATED CALVIN having a larger annual average Delta Export Outflow constraint.

**Table 4.15: Delta Pumping Constraints and Minimum Delta Outflow**

| Model | Banks Pumping Upper-bound Constraint | | Tracy Pumping Upper-bound Constraint | | Total Delta Pumping Upper-bound Constraint | | Minimum Delta Outflow | |
|---|---|---|---|---|---|---|---|---|
| | Annual Average (TAF/yr) | Maximum (TAF/mo) | Annual Average (TAF/yr) | Maximum (TAF/mo) | Annual Average (TAF/yr) | Maximum (TAF/mo) | Annual Average (TAF/yr) | Maximum (TAF/mo) |
| UPDATED CALVIN | 5475 | 465 | 2169 | 283 | 7644 | 748 | 6314 | 1713 |
| CALSIM II 2009 | 2593 | 472 | 3331 | 283 | 5924 | 755 | 4944 | 1320 |
| OLD CALVIN | 6158 | 523 | 2169 | 283 | 8327 | 806 | 5593 | 1713 |

Table 4.12 shows that shortages for UPDATED CALVIN are higher than that of UPDATED CALVIN Old Delta. This is expected because in an attempt to have pumping capacity constraints and Delta exports be closer in comparison to CALSIM II 2009, there is less pumping and more required Delta outflow in UPDATED CALVIN than in OLD CALVIN (and UPDATED CALVIN Old Delta). As seen in the results, when the Delta terms were updated, there was more scarcity in the Sacramento region, which also agrees with the idea of more export outflow and lower pumping.

Table 4.16 shows the results from the CALVIN run for the Banks Pumping Plant and Tracy Pumping Plant. Although new constraints were used, the total annual average Delta pumping remained very close in comparison between the two models. This is interesting considering that UPDATED CALVIN has more Delta required outflow, and a tighter constraint for Banks pumping plant. This indicates that the upper bound constraint is reached more often in the Banks pumping plant in UPDATED CALVIN.

**Table 4.16: Average Annual Delta Pumping Results (TAF/yr)**

| | UPDATED CALVIN | OLD CALVIN | CALSIM II 2009 |
|---|---|---|---|
| Banks Pumping | 4,383 | 4,906 | 2,984 |
| Tracy Pumping | 942 | 462 | 2,496 |
| Total Delta Pumping | 5,325 | 5,368 | 5,479 |

## UPDATED CALVIN Results

This section presents and discusses the major run results for UPDATED CALVIN and compares them with OLD CALVIN's results.

### Targets, Deliveries, and Scarcities

Table 4.17a shows the agricultural targets, deliveries and shortages for the model results. As mentioned before, the targets are different between the models because results from an updated version of SWAP were used to define water delivery targets for UPDATED CALVIN. One major problem with OLD CALVIN was that 2 million acre-feet of calibration flows out of the system were needed to have reasonable results, indicating that there was generally too much inflow in the system. With too much water in the system, scarcity is likely to be small, as seen in the last column of Table 4.17a. The scarcities for UPDATED CALVIN, though larger, are more reasonable and seem to better represent actual water scarcity, and omit the earlier 2 MAF/yr of calibration demands. The updated model has a much better physical basis.

## Table 4.17a: UPDATED CALVIN and OLD CALVIN Agricultural Targets, Deliveries, and Scarcities (TAF/yr)

| **CALVIN Delivery Link** | **Target** | | **Delivery** | | **Scarcity** | |
|---|---|---|---|---|---|---|
| | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN |
| HU1-CVPM1G | 38.9 | 55.6 | 37.9 | 55.6 | 1.0 | 0.0 |
| HU1-CVPM1S | 100.0 | 70.7 | 98.8 | 70.7 | 1.1 | 0.0 |
| HU2-CVPM2G | 473.4 | 382.4 | 473.4 | 382.4 | 0.0 | 0.0 |
| HU2-CVPM2S | 0.0 | 114.2 | 0.0 | 114.2 | 0.0 | 0.0 |
| HU3-CVPM3G | 789.2 | 1713.1 | 789.2 | 1713.1 | 0.0 | 0.0 |
| HU3-CVPM3S | 526.2 | 483.2 | 526.2 | 468.2 | 0.0 | 15.0 |
| HU4-CVPM4G | 875.1 | 172.1 | 875.1 | 172.1 | 0.0 | 0.0 |
| HU4-CVPM4S | 8.9 | 784.0 | 8.9 | 784.0 | 0.0 | 0.0 |
| HU5-CVPM5G | 1069.5 | 971.3 | 1069.5 | 971.3 | 0.0 | 0.0 |
| HU5-CVPM5S | 415.9 | 341.2 | 415.9 | 341.2 | 0.0 | 0.0 |
| HU6-CVPM6G | 716.9 | 619.0 | 688.4 | 619.0 | 28.5 | 0.0 |
| HU6-CVPM6S | 14.7 | 0.0 | 14.2 | 0.0 | 0.5 | 0.0 |
| HU7-CVPM7G | 413.1 | 235.9 | 413.1 | 235.9 | 0.0 | 0.0 |
| HU7-CVPM7S | 0.0 | 193.0 | 0.0 | 193.0 | 0.0 | 0.0 |
| HU8-CVPM8G | 685.3 | 168.4 | 685.3 | 168.4 | 0.0 | 0.0 |
| HU8-CVPM8S | 51.6 | 633.4 | 51.6 | 633.4 | 0.0 | 0.0 |
| HU9-CVPM9G | 1207.5 | 648.4 | 1194.9 | 648.4 | 12.7 | 0.0 |
| HU9-CVPM9S | 0.0 | 277.9 | 0.0 | 277.9 | 0.0 | 0.0 |
| HU10-CVPM10G | 1318.8 | 238.9 | 1267.4 | 238.9 | 51.4 | 0.0 |
| HU10-CVPM10S | 84.2 | 680.1 | 80.6 | 680.1 | 3.5 | 0.0 |
| HU11-CVPM11G | 730.4 | 855.4 | 729.6 | 855.4 | 0.7 | 0.0 |
| HU11-CVPM11S | 46.6 | 0.0 | 46.6 | 0.0 | 0.0 | 0.0 |
| HU12-CVPM12G | 714.8 | 293.3 | 691.4 | 293.3 | 23.4 | 0.0 |
| HU12-CVPM12S | 45.6 | 478.5 | 44.1 | 456.5 | 1.5 | 22.0 |
| HU13-CVPM13G | 1629.0 | 512.1 | 1554.1 | 512.1 | 74.9 | 0.0 |
| HU13-CVPM13S | 50.4 | 994.0 | 48.0 | 994.0 | 2.4 | 0.0 |
| HU14-CVPM14G | 1129.0 | 1357.7 | 1129.0 | 1357.7 | 0.0 | 0.0 |
| HU14-CVPM14S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU15-CVPM15G | 1828.0 | 680.5 | 1828.0 | 680.5 | 0.0 | 0.0 |
| HU15-CVPM15S | 0.0 | 1020.7 | 0.0 | 1020.7 | 0.0 | 0.0 |
| HU16-CVPM16G | 309.0 | 106.9 | 295.7 | 106.9 | 13.3 | 0.0 |
| HU16-CVPM16S | 58.9 | 237.9 | 56.1 | 237.9 | 2.7 | 0.0 |
| HU17-CVPM17G | 738.6 | 486.3 | 703.8 | 486.3 | 34.8 | 0.0 |
| HU17-CVPM17S | 0.0 | 310.9 | 0.0 | 310.9 | 0.0 | 0.0 |
| HU18-CVPM18G | 2119.4 | 1759.5 | 2013.4 | 1759.5 | 106.0 | 0.0 |
| HU18-CVPM18S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU19-CVPM19G | 841.8 | 886.7 | 841.8 | 886.7 | 0.0 | 0.0 |
| HU19-CVPM19S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU20-CVPM20G | 525.0 | 820.5 | 503.1 | 820.5 | 21.9 | 0.0 |
| HU20-CVPM20S | 115.2 | 8.3 | 110.4 | 8.3 | 4.9 | 0.0 |
| HU21-CVPM21G | 999.3 | 1195.4 | 960.7 | 1195.4 | 38.6 | 0.0 |
| HU21-CVPM21S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sacramento | 7386 | 7864 | 7342 | 7849 | 44 | 15 |
| San Joaquin | 4620 | 4052 | 4462 | 4030 | 158 | 22 |
| Tulare | 8664 | 8871 | 8442 | 8871 | 222 | 0 |
| Central Valley Total | 20670 | 20787 | 20246 | 20750 | 424 | 37 |

Table 4.17b shows the urban targets, deliveries, and scarcities. As seen in the table, there are no differences between OLD CALVIN and UPDATED CALVIN in the Central Valley. Slight differences between the models in deliveries and scarcities can be seen in Southern California. Since the differences in urban deliveries are very small in comparison to the agricultural deliveries, the rest of this chapter will focus on the differences that apply to the agricultural side of the models.

**Table 4.17b: UPDATED CALVIN and OLD CALVIN Urban Targets, Deliveries, and Scarcities (TAF/yr)**

| **CALVIN Delivery Region** | **Target** | | **Delivery** | | **Scarcity** | |
|---|---|---|---|---|---|---|
| | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN |
| Sacramento | 1609 | 1609 | 1609 | 1609 | 0.3 | 0.3 |
| San Joaquin | 1571 | 1571 | 1571 | 1571 | 0.0 | 0.0 |
| Tulare | 1284 | 1284 | 1279 | 1279 | 5.1 | 5.1 |
| Central Valley Total | 4464 | 4464 | 4459 | 4459 | 5.4 | 5.4 |
| Southern California | 6840 | 6840 | 6648 | 6649 | 192.1 | 190.5 |

Water Deliveries and Recharge

Total water deliveries include water pumped from the ground and surface water deliveries. The first two columns of Table 4.18 show the groundwater pumping and surface water deliveries. The targets are different between the two runs (as shown in Table 4.17), but it is still useful to compare the total pumping and total surface water deliveries. As seen in groundwater pumping column, UPDATED CALVIN pumps over 2 MAF less groundwater than OLD CALVIN. Similarly on the surface water side, UPDATED CALVIN uses over 2.5 MAF more surface water than OLD CALVIN. This is due mostly to the successful removal of 2 MAF/yr of calibration demands present in OLD CALVIN.

With smaller total deliveries, it could be expected that the groundwater return flow is also smaller for UPDATED CALVIN. However, UPDATED CALVIN has additional representation of artificial recharge in the Tulare region. Interestingly, when considering total recharge to the groundwater basins for UPDATED CALVIN, it sums to be more recharge than in OLD CALVIN.

**Table 4.18: Average Annual Groundwater Pumping, Surface Water Deliveries, Groundwater Return Flow, and Artificial Recharge Results (TAF/yr)**

| Subregion | GW Pumping | | SW Deliveries | | GW Return Flow | | Artificial Recharge |
|---|---|---|---|---|---|---|---|
| | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN | OLD CALVIN | UPDATED CALVIN |
| 1 | 39 | 41 | 98 | 86 | 18 | 18 | - |
| 2 | 145 | 410 | 328 | 86 | 123 | 99 | - |
| 3 | 109 | 463 | 1207 | 1719 | 158 | 480 | - |
| 4 | 12 | 274 | 872 | 682 | 123 | 36 | - |
| 5 | 227 | 391 | 1258 | 921 | 225 | 275 | - |
| 6 | 171 | 394 | 532 | 225 | 69 | 50 | - |
| 7 | 125 | 44 | 289 | 384 | 103 | 71 | - |
| 8 | 462 | 627 | 275 | 175 | 82 | 39 | - |
| 9 | 78 | 31 | 1117 | 896 | 119 | 136 | - |
| 10 | 305 | 299 | 1044 | 620 | 253 | 79 | - |
| 11 | 65 | 0 | 711 | 855 | 161 | 233 | - |
| 12 | 106 | 142 | 629 | 607 | 124 | 53 | - |
| 13 | 610 | 849 | 992 | 657 | 202 | 92 | 29 |
| 14 | 599 | 600 | 530 | 758 | 203 | 299 | - |
| 15 | 916 | 1,261 | 912 | 441 | 219 | 143 | 27 |
| 16 | 24 | 235 | 327 | 110 | 83 | 19 | 0 |
| 17 | 213 | 301 | 490 | 496 | 91 | 83 | 90 |
| 18 | 793 | 812 | 1221 | 947 | 362 | 440 | 302 |
| 19 | 601 | 298 | 241 | 589 | 25 | 186 | 0 |
| 20 | 215 | 211 | 399 | 618 | 50 | 139 | 0 |
| 21 | 177 | 602 | 783 | 593 | 96 | 299 | 1 |
| Sacramento | 1,368 | 2,675 | 5,974 | 5,174 | 1,020 | 1,203 | - |
| San Joaquin | 1,086 | 1,290 | 3,376 | 2,740 | 740 | 456 | - |
| Tulare | 3,539 | 4,319 | 4,903 | 4,552 | 1,131 | 1,608 | 449 |
| Total CV | 5,993 | 8,284 | 14,254 | 12,466 | 2,891 | 3,267 | 449 |

### Change in Storage

CALVIN does not model actual storage capacities, but models the change in storage volume. The initial storage, as mentioned earlier, is an input term to CALVIN and is essentially just a reference starting point for the model. CALVIN outputs actual storage values, but they are relative to the set initial storage. For these models, change in storage has to be compared rather than the model output for storage since the initial storages differ between models. The changes in storage were calculated based on the model run output storage values for each region. Figures 4.2 - 4.4 show the change in storage by Central Valley region (Sacramento, San Joaquin, and Tulare) for UPDATED CALVIN and OLD CALVIN. Sacramento is the sum of Regions 1-9, San Joaquin is the sum of Regions 10-13, and Tulare is the sum of regions 14-21. Negative change in storage values indicate overdraft.

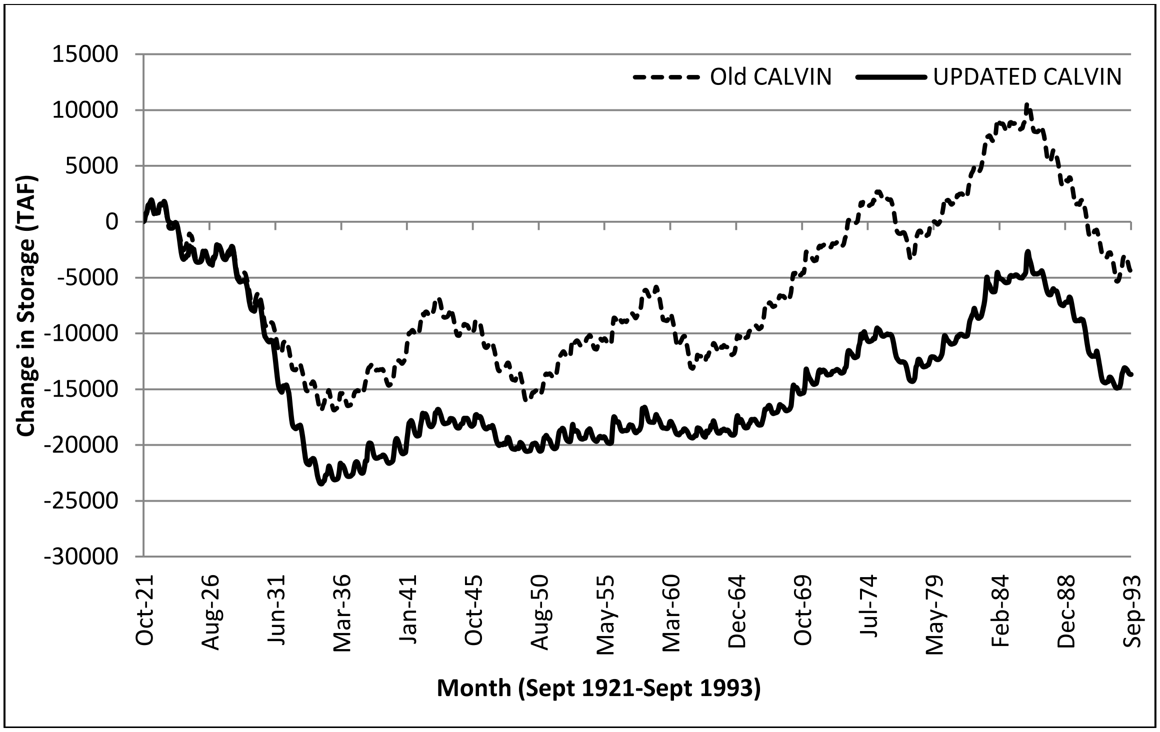


Figure 4.2: UPDATED CALVIN Sacramento Region (Basins 1-9) Change in Storage

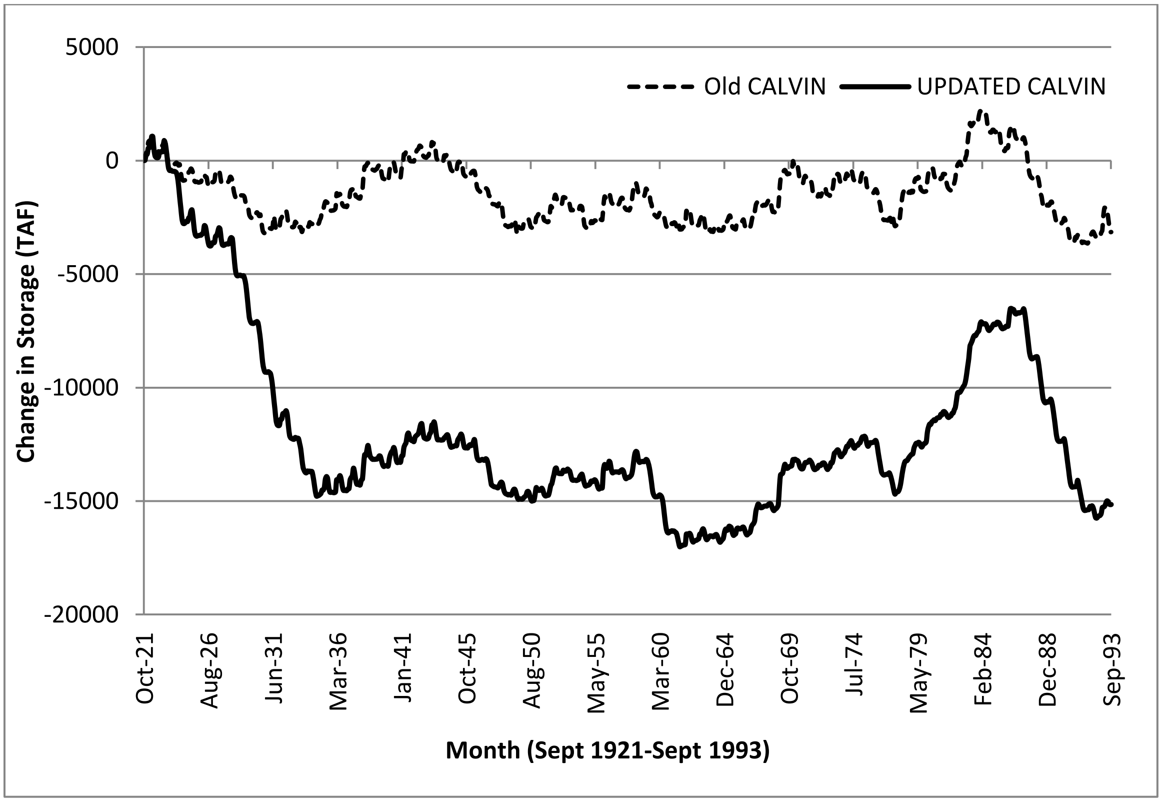


Figure 4.3: UPDATED CALVIN San Joaquin Region (Basins 10-13) Change in Storage

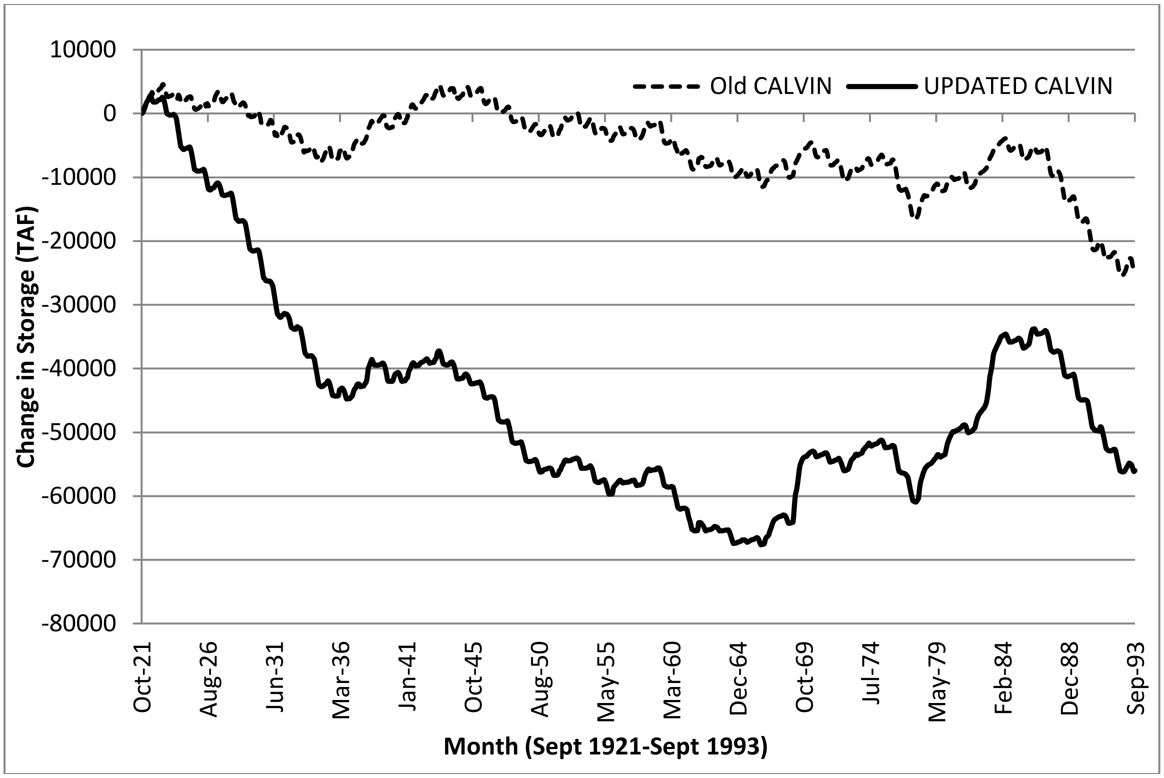


**Figure 4.4: UPDATED CALVIN Tulare Region (Basins 14-21) Change in Storage**

For all three Central Valley regions, UPDATED CALVIN has more overdraft overall than OLD CALVIN, agreeing more with both C2VSIM and CVHM. Change in Storage for both CALVIN models follow similar trends that agree with seasonal variations and year types, but UPDATED CALVIN's changes are greater and have more overdraft. These change in storage results help confirm the scarcity results in Table 4.16. Considering the Tulare region, scarcities were much higher for UPDATED CALVIN, and as can be seen in Figure 4.4, the overdraft difference is large. This also falls into line with the impression that OLD CALVIN had too much water in the system and its representation of groundwater was not always reasonable. The overdraft implied by UPDATED CALVIN agrees better with other studies on overdraft in the Central Valley, including CVHM's representation. Chapter 5 will discuss some different overdraft scenarios and their effects on the Central Valley.

## System Costs

Many changes were made to UPDATED CALVIN, so the system's overall costs were affected. Table 4.19 shows the average annual system costs. The only changes to operating cost values for this update project were the groundwater pumping lift costs and the added artificial recharge costs; all other operating costs were not changed. These changes are reflected in the costs in the table. Scarcity costs are directly related to the scarcity estimates (Table 4.17), but follow seasonal patterns of demands and availability.

UPDATED CALVIN has overall lower pumping costs in the Central Valley, agreeing with Table 4.5, with lower pumping lifts and costs for UPDATED CALVIN. Surface water and other operating costs are not affected much. UPDATED CALVIN's artificial recharge adds an average annual $3 million/year in average costs. OLD CALVIN has much lower scarcity costs because there was much less scarcity in that version of CALVIN (Table 4.17). Overall, UPDATED CALVIN has about an annual average of $40 million (4%) less system costs than OLD CALVIN.

**Table 4.19: Average Annual Central Valley System Costs ($millions/yr)**

| **Costs** | **UPDATED CALVIN** | **OLD CALVIN** |
|---|---|---|
| Groundwater Pumping | 361 | 450 |
| Surface Water Pumping | 426 | 427 |
| Artificial Recharge | 3 | 0 |
| Other[1] | 294 | 264 |
| **Central Valley Operating Costs*** | **$1,084** | **$1,141** |
| Scarcity Costs | 21 | 4 |
| **Central Valley System Costs** | **$1,105** | **$1,145** |

[1] Other costs include: treatment, recycled water, and desalination.

*Total Operating Costs does not include hydropower benefits.

## Results Summary

Table 4.20 summarizes the average annual results for the Central Valley (Regions 1-21) for UPDATED CALVIN. The percent differences from OLD CALVIN are also presented. Overall, UPDATED CALVIN has lower targets and lower deliveries; UPDATED CALVIN pumps 28 percent less groundwater and delivers14 percent more surface water than OLD CALVIN. This decreased pumping is a direct effect of the new input terms for UPDATED CALVIN. With the new groundwater representation, the scarcity for UDPATED CALVIN is 10 times that of OLD CALVIN, which better represents actual water scarcity in the Central Valley. Total Delta pumping is slightly lower in UPDATED CALVIN, but Tracy pumping for UPDATED CALVIN is more than two times that of OLD CALVIN; this increase in Tracy pumping is due to the lower Banks pumping constraint in UPDATED CALVIN. For total groundwater recharge, there is a 2 percent increase for UPDATED CALVIN, primarily due to the addition of artificial recharge representation. Total Central Valley overdraft for UPDATED CALVIN is nearly three times the amount of overdraft in OLD CALVIN; this new overdraft value is comparable with CVHM total overdraft ((Faunt et al. 2009) and DWR's Bulletin 118's estimated values (DWR 2003). Total system costs are 4% less for UPDATED CALVIN than OLD CALVIN.

**Table 4.20: Updated CALVIN Summary – Average Annual Results**

| Results | OLD CALVIN | UPDATED CALVIN | |
|---|---|---|---|
| | Annual Average (TAF/yr) | Annual Average (TAF/yr) | % Difference |
| Total Central Valley Agricultural Target | 20,787 | 20,670 | -1% |
| Total Central Valley Agricultural Delivery | 20,750 | 20,246 | -2% |
| Agricultural GW Pumping | 8,284 | 5,992 | -28% |
| Agricultural SW Delivery | 12,466 | 14,254 | +14% |
| Total Central Valley Agricultural Scarcity | 37 | 424 | +1046% |
| Total Delta Pumping | 5,368 | 5,325 | -1% |
| Banks Pumping | 4,906 | 4,383 | -11% |
| Tracy Pumping | 462 | 942 | +104% |
| Total GW Recharge | 3,267 | 3,338 | +2% |
| Total Central Valley Return Flow | 3,267 | 2,889 | -12% |
| Total Central Valley Artificial Recharge | 0 | 449 | +100% |
| Total Central Valley Overdraft | 394 | 1,160 | +194% |
| Total Central Valley System Costs | $1,145 | $1,105 | -4% |

## Conclusions

This update project has greatly improved several aspects of CALVIN groundwater. First, schematic improvements were made to simplify the flows in and out of each CVPM groundwater basin. And overall, Central Valley groundwater representation in CALVIN has been greatly improved.

Many of the problems associated with OLD CALVIN's groundwater representation could be attributed to the problems with CVGSM (LaBolle 2003). Models like CALVIN can help inform water management decisions for a wide range of conditions. However, conditions are constantly changing so timely updates are needed to maintain the usefulness of the model. The inputs to CALVIN need to come from a trusted source or model that represents actual, or at least reasonable water and water use conditions. C2VSIM's groundwater representation is much more explicit and reasonable than the older CVGSM. However, C2VSIM results are not always close in comparison with other groundwater models (i.e. CVHM). With different representations and results, groundwater input terms to CALVIN can be very different and would overall represent groundwater very differently. It is important to remember this when considering UPDATED CALVIN results; errors and discrepancies in the C2VSIM groundwater model also carry over into CALVIN's groundwater representation. Nonetheless, this project provides a more accurate and up-to-date representation of Central Valley groundwater in CALVIN.

# CHAPTER 5

## Groundwater Overdraft in California’s Central Valley

This chapter discusses an application of the updated CALVIN model to three groundwater overdraft cases in California’s Central Valley. Overdraft is defined as a negative change in groundwater storage from the beginning to end of the model period. The comparison of study results shows potential effects of different levels of overdraft and confirms that the model is behaving well. All three model cases use the updated CALVIN model as a base and result in feasible solutions. Increasing Delta exports and surface water use are the primary adaptations to ending overdraft (aided by artificial recharge). Greater agricultural scarcity is the second adaptation.

### Background

Groundwater overdraft occurs when groundwater extraction exceeds recharge over a long period. In California, few statewide regulations currently exist on groundwater extraction and water users commonly turn to groundwater use when demands cannot be met by surface water supplies. Continued overdraft of groundwater basins gradually depletes groundwater availability and can be environmentally detrimental (i.e. subsidence, increased nitrate leaching, and water quality degradation). Despite these negative consequences, some areas continue to pump groundwater at unsustainably high rates. Using a hydro-economic optimization model like CALVIN to study overdraft shows not only the basic, physical water system effects (i.e. effects on Delta pumping and recharge), but also some economic effects. CALVIN was previously used in a case study of the Tulare Basin that examined the economic effects of different management strategies to end overdraft in that basin (Harou and Lund 2007). Similar to the Tulare Basin case study, this overdraft study examines the economic effects of different overdraft scenarios. However, the 2007 Tulare Basin study had cases based on different management options for ending overdraft, whereas the study presented here uses different groundwater models’ results to represent overdraft and compare those to a case without overdraft. This approach provides insight for managing overdraft in the Central Valley and also illustrates the consequences of remaining uncertainties in groundwater availability in the Central Valley.

### Case Description

Of the three overdraft cases (Table 5.1), the first case is the “Base” updated CALVIN run with overdraft largely based on C2VSIM. In the “No Overdraft” case, no overdraft is allowed; all basin ending storage values were set to the basins’ initial storage values. The “Higher Overdraft” case is a CVHM-C2VSIM-based overdraft scenario. Initially, there was a CVHM-based overdraft case, but since CVHM has major differences in groundwater representation of the Sacramento Valley (discussed in Chapter 3), there would not be a feasible CALVIN result based solely on CVHM overdraft results without new calibration. Instead, a semi-CVHM overdraft case was created using the updated CALVIN overdraft for subregions 1-9 (Sacramento region) and using the typically higher CVHM overdraft for subregions 10-21 (San Joaquin and Tulare regions).

**Table 5.1: Overdraft Cases Description**

| Case Name | Run Number | Case Description |
|---|---|---|
| Base | S07I14 | UPDATED CALVIN with overdraft based on C2VSIM with calibration adjustments. (1.2 MAF/yr Valley-wide). |
| No Overdraft | S07I14a | No overdraft (initial storage = ending storage). |
| Higher Overdraft | S07I14b | Overdraft for subregions 1-9 are the same as UPDATED CALVIN. Greater Overdraft for subregions 10-21 is based on CVHM. (1.45 MAF/yr Valley-wide). |

Table 5.2 presents the total overdraft and average annual overdraft (1921-1993) per subregion for each case. Higher Overdraft is based on CVHM calculated overdraft for the San Joaquin and Tulare regions. CVHM has slightly less overdraft than the Base case in the San Joaquin region, but has significantly more overdraft in the Tulare region. Comparing the Central Valley totals with the Base run, the No Overdraft case has 84 MAF less groundwater available for use over the 72 years and the Higher Overdraft case allows 20 MAF more groundwater to be used over the 72 years. The results from these runs are presented and discussed below.

**Table 5.2: 1921 – 1993 Overdraft Cases***

| Subregion | Base | | No Overdraft | | Higher Overdraft | |
|---|---|---|---|---|---|---|
| | Total (72 years) | Annual Average (TAF/yr) | Total (72 years) | Annual Average (TAF/yr) | Total (72 years) | Annual Average (TAF/yr) |
| 1 | -990 | -14 | 0 | 0 | -990 | -14 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 939 | 13 | 0 | 0 | 939 | 13 |
| 4 | 220 | 3 | 0 | 0 | 220 | 3 |
| 5 | 656 | 9 | 0 | 0 | 656 | 9 |
| 6 | -307 | -4 | 0 | 0 | -307 | -4 |
| 7 | 5,330 | 74 | 0 | 0 | 5,330 | 74 |
| 8 | 7,836 | 109 | 0 | 0 | 7,836 | 109 |
| 9 | -362 | -5 | 0 | 0 | -362 | -5 |
| 10 | 3,155 | 44 | 0 | 0 | 251 | 3 |
| 11 | 592 | 8 | 0 | 0 | 289 | 4 |
| 12 | 1,737 | 24 | 0 | 0 | -723 | -10 |
| 13 | 9,656 | 134 | 0 | 0 | 10,756 | 149 |
| 14 | 6,831 | 95 | 0 | 0 | 9,495 | 132 |
| 15 | 2,977 | 41 | 0 | 0 | 12,555 | 174 |
| 16 | 257 | 4 | 0 | 0 | 9,435 | 131 |
| 17 | 3,561 | 49 | 0 | 0 | 9,142 | 127 |
| 18 | 0 | 0 | 0 | 0 | 20,349 | 283 |
| 19 | 13,526 | 188 | 0 | 0 | 7,256 | 101 |
| 20 | 11,937 | 166 | 0 | 0 | 6,654 | 92 |
| 21 | 16,840 | 234 | 0 | 0 | 5,611 | 78 |
| Sacramento | 13,323 | 185 | 0 | 0 | 13,323 | 185 |
| San Joaquin | 15,140 | 210 | 0 | 0 | 10,572 | 147 |
| Tulare | 55,930 | 777 | 0 | 0 | 80,497 | 1,118 |
| Central Valley Total | 84,393 | 1,172 | 0 | 0 | 104,392 | 1,450 |

*Positive values represent a depletion of storage over time and negative values represent gains to groundwater over time.

## CALVIN Study Results

This section discusses the results from this study. First, the average annual scarcities and water deliveries are presented, followed by a discussion of the recharge differences. Next, the time series for storages for each region are compared in plots, showing the differences in storage over time between the cases. Then the willingness-to-pay values, scarcity costs, and operating costs are tabulated and discussed. Finally, a summary table of the average annual results with the percent differences between the results for the different cases is presented.

### Water Scarcity and Deliveries

Water scarcity is defined as the amount of target water delivery not supplied by the model to meet demands. These results are shown in Table 5.3. Ending overdraft increases water shortages statewide because there is not enough available surface water to meet all demands if groundwater is not overdrafted. As expected, the No Overdraft case has nearly double the water scarcity of the Base case and the Higher Overdraft case has less scarcity than the Base case.

**Table 5.3: Overdraft Study Results – Average Annual Agricultural Water Scarcities (TAF/yr)**

| CALVIN Delivery Link | Base | No Overdraft | Higher Overdraft |
|---|---|---|---|
| HU1-CVPM1G | 1.0 | 1.8 | 0.8 |
| HU1-CVPM1S | 1.1 | 2.2 | 0.6 |
| HU2-CVPM2G | 0.0 | 19.5 | 0.0 |
| HU2-CVPM2S | 0.0 | 0.0 | 0.0 |
| HU3-CVPM3G | 0.0 | 0.0 | 0.0 |
| HU3-CVPM3S | 0.0 | 0.0 | 0.0 |
| HU4-CVPM4G | 0.0 | 16.5 | 0.0 |
| HU4-CVPM4S | 0.0 | 0.2 | 0.0 |
| HU5-CVPM5G | 0.0 | 0.0 | 0.0 |
| HU5-CVPM5S | 0.0 | 0.0 | 0.0 |
| HU6-CVPM6G | 28.5 | 31.3 | 8.0 |
| HU6-CVPM6S | 0.5 | 0.7 | 0.5 |
| HU7-CVPM7G | 0.0 | 11.3 | 0.0 |
| HU7-CVPM7S | 0.0 | 0.0 | 0.0 |
| HU8-CVPM8G | 0.0 | 55.0 | 0.0 |
| HU8-CVPM8S | 0.0 | 4.4 | 0.0 |
| HU9-CVPM9G | 12.7 | 41.4 | 0.0 |
| HU9-CVPM9S | 0.0 | 0.0 | 0.0 |
| HU10-CVPM10G | 51.4 | 55.9 | 51.4 |
| HU10-CVPM10S | 3.5 | 3.9 | 3.4 |
| HU11-CVPM11G | 0.7 | 9.5 | 0.3 |
| HU11-CVPM11S | 0.0 | 0.6 | 0.0 |
| HU12-CVPM12G | 23.4 | 26.1 | 23.3 |
| HU12-CVPM12S | 1.5 | 1.8 | 1.5 |
| HU13-CVPM13G | 74.9 | 141.0 | 74.9 |
| HU13-CVPM13S | 2.4 | 4.5 | 2.3 |
| HU14-CVPM14G | 0.0 | 0.0 | 0.0 |
| HU14-CVPM14S | 0.0 | 0.0 | 0.0 |
| HU15-CVPM15G | 0.0 | 65.9 | 0.0 |
| HU15-CVPM15S | 0.0 | 0.0 | 0.0 |
| HU16-CVPM16G | 13.3 | 15.1 | 0.4 |
| HU16-CVPM16S | 2.7 | 2.9 | 2.7 |
| HU17-CVPM17G | 34.8 | 36.9 | 35.0 |
| HU17-CVPM17S | 0.0 | 0.0 | 0.0 |
| HU18-CVPM18G | 106.0 | 204.0 | 103.3 |
| HU18-CVPM18S | 0.0 | 0.0 | 0.0 |
| HU19-CVPM19G | 0.0 | 0.0 | 0.0 |
| HU19-CVPM19S | 0.0 | 0.0 | 0.0 |
| HU20-CVPM20G | 21.9 | 25.9 | 21.6 |
| HU20-CVPM20S | 4.9 | 5.7 | 4.8 |
| HU21-CVPM21G | 38.6 | 47.3 | 36.9 |
| HU21-CVPM21S | 0.0 | 0.0 | 0.0 |
| Sacramento | 44 | 184 | 10 |
| San Joaquin | 158 | 243 | 157 |
| Tulare | 222 | 404 | 205 |
| Central Valley Total | 424 | 831 | 372 |

Table 5.4 compares the average annual Delta pumping for the three cases. Of the 1.2 MAF annual averaged reduction of overdraft in the No Overdraft case (compared to the Base case), approximately 0.4 MAF of that reduction becomes greater scarcity (Table 5.3) and the rest of the reduction is made up by higher Delta exports. For the system to maintain the Delta outflow requirement (discussed in Chapter 4) and have no reductions to southern California water supply, nearly 0.8 MAF/year more water is pumped from the Delta. So to account for the 1.2 MAF of water not available due to having no overdraft supplies in the No Overdraft case, there is 0.4 MAF of increased water scarcity in the Central Valley and 0.8 MAF increased Delta exports. And as expected, when comparing the Base case with the Higher Overdraft case, the increased supply from higher overdraft decreases Delta pumping and water scarcity.

**Table 5.4: Overdraft Study Results – Average Annual Delta Exports (TAF/yr)**

| | Base | No Overdraft | Higher Overdraft |
|---|---|---|---|
| Banks Pumping | 4,383 | 4,470 | 4,283 |
| Tracy Pumping | 942 | 1,614 | 726 |
| Total Delta Pumping | 5,325 | 6,084 | 5,009 |

Table 5.5 shows average annual groundwater pumping and surface water deliveries. The No Overdraft case significantly reduces average annual groundwater pumping and increases surface water deliveries. Even with the increased surface water use, there is still much scarcity. The Higher Overdraft case has more groundwater pumping, less surface water reliance, and less scarcity.

**Table 5.5: Overdraft Study Results – Average Annual Agricultural Water Deliveries (TAF/yr)**

| Subregion | GW Pumping | | | SW Deliveries | | | Total Deliveries | | |
|---|---|---|---|---|---|---|---|---|---|
| | Base | No Overdraft | Higher Overdraft | Base | No Overdraft | Higher Overdraft | Base | No Overdraft | Higher Overdraft |
| 1 | 39 | 53 | 39 | 98 | 82 | 98 | 137 | 135 | 137 |
| 2 | 145 | 140 | 145 | 328 | 314 | 328 | 473 | 454 | 473 |
| 3 | 109 | 96 | 109 | 1,207 | 1,220 | 1,207 | 1,316 | 1,315 | 1,315 |
| 4 | 12 | 7 | 12 | 872 | 861 | 872 | 884 | 867 | 884 |
| 5 | 227 | 218 | 227 | 1,258 | 1,267 | 1,258 | 1,485 | 1,485 | 1,485 |
| 6 | 171 | 175 | 173 | 532 | 524 | 550 | 703 | 700 | 723 |
| 7 | 125 | 100 | 125 | 289 | 302 | 288 | 414 | 402 | 413 |
| 8 | 462 | 389 | 472 | 275 | 289 | 265 | 737 | 677 | 737 |
| 9 | 78 | 80 | 79 | 1,117 | 1,086 | 1,128 | 1,195 | 1,166 | 1,208 |
| 10 | 305 | 260 | 264 | 1,044 | 1,083 | 1,084 | 1,349 | 1,343 | 1,348 |
| 11 | 65 | 55 | 61 | 711 | 712 | 715 | 776 | 767 | 777 |
| 12 | 106 | 82 | 72 | 629 | 651 | 664 | 735 | 733 | 736 |
| 13 | 610 | 488 | 623 | 992 | 1,046 | 979 | 1,602 | 1,534 | 1,602 |
| 14 | 599 | 504 | 636 | 530 | 625 | 493 | 1,129 | 1,129 | 1,129 |
| 15 | 916 | 889 | 1049 | 912 | 873 | 779 | 1,828 | 1,762 | 1,828 |
| 16 | 24 | 53 | 144 | 327 | 297 | 221 | 351 | 350 | 365 |
| 17 | 213 | 159 | 242 | 490 | 543 | 462 | 703 | 702 | 704 |
| 18 | 793 | 784 | 1023 | 1,221 | 1,132 | 993 | 2,014 | 1,915 | 2,016 |
| 19 | 601 | 413 | 514 | 241 | 429 | 328 | 842 | 842 | 842 |
| 20 | 215 | 49 | 142 | 399 | 560 | 472 | 614 | 609 | 614 |
| 21 | 177 | 257 | 29 | 783 | 695 | 934 | 960 | 952 | 962 |
| Sacramento | 1,368 | 1,257 | 1,382 | 5,974 | 5,945 | 5,994 | 7,342 | 7,202 | 7,376 |
| San Joaquin | 1,086 | 885 | 1,021 | 3,376 | 3,492 | 3,442 | 4,462 | 4,377 | 4,463 |
| Tulare | 3,538 | 3,108 | 3,778 | 4,903 | 5,152 | 4,681 | 8,441 | 8,260 | 8,459 |
| Central Valley Total | 5,992 | 5,249 | 6,181 | 14,254 | 14,589 | 14,117 | 20,246 | 19,839 | 20,298 |

Table 5.6 shows the average annual urban water deliveries and scarcities. Similar to the results comparison between OLD CALVIN and UPDATED CALVIN, the differences in overdraft cases do not affect urban deliveries in the Central Valley. Slight differences can be seen in the deliveries in Southern California. The No Overdraft case results in a higher scarcity total in Southern California whereas the higher overdraft case results in a slightly lower total scarcity in Southern California. Since differences in urban deliveries are non-existent in the Central Valley and small for Southern California, the rest of this chapter will focus on comparisons of agricultural related aspects of the models.

**Table 5.6: Overdraft Study Results – Average Annual Urban Water Deliveries and Scarcities (TAF/yr)**

| CALVIN Delivery Region | Delivery | | | Scarcity | | |
|---|---|---|---|---|---|---|
| | Base | No Overdraft | Higher Overdraft | Base | No Overdraft | Higher Overdraft |
| Sacramento | 1609 | 1608 | 1608 | 0.3 | 0.3 | 0.3 |
| San Joaquin | 1571 | 1571 | 1571 | 0 | 0.0 | 0.0 |
| Tulare | 1279 | 1279 | 1279 | 5.1 | 5.1 | 5.1 |
| Central Valley Total | 4459 | 4458 | 4458 | 5.4 | 5.4 | 5.4 |
| Southern California | 6648 | 6645 | 6648 | 192.1 | 194.8 | 191.8 |

### Recharge

Table 5.7 shows the average annual return flows and artificial recharge flows to groundwater for each region. Considering just groundwater return flow, the No Overdraft case has less return flow to groundwater and the Higher Overdraft case has slightly more return flow to groundwater. The smaller return flow to groundwater in the No Overdraft case is due to overall decreased delivered water to meet the agricultural demand (hence the increased scarcity); less water delivered proportionally reduces agricultural return flows to groundwater.

The artificial recharge result shows one way that overdraft is detrimental to the overall water system. The No Overdraft case increases use of artificial recharge, an action that should be encouraged and is effective in maintaining groundwater storage overtime. However, maintaining and using artificial recharge is generally more expensive in the short term. CALVIN has a link cost for using artificial recharge. The No Overdraft case drives the system to increase use of artificial recharge capabilities since there is a shortage of water and the no overdraft condition in the groundwater basins needs to be maintained. This conjunctive use approach helps allow more groundwater to be used because it is replenished artificially when surface water is abundant. This allows scarcity to be less than total reductions in available water supply due to the no overdraft constraint (met by increased surface water use and increased Delta exports). In contrast, the Higher Overdraft case reduces use of artificial recharge since it can meet more demands through pumping (the economically cheaper option) and is not required to maintain a condition of no overdraft. Considering that these artificial recharge facilities and capabilities are assumed to be in place for all three cases, general increased use of artificial recharge should be encouraged. This agrees with the results from Harou and Lund (2007), where ending overdraft significantly increases the economic value of additional recharge capacity and when there is overdraft, less artificial recharge occurs since maintaining groundwater storage levels is not a constraint. Adding artificial recharge capacity can help lower the cost of ending overdraft. However, if there is enough available supply from (over)pumping groundwater and nothing to require users to recharge water back to the groundwater basins, it is more economical in the short term to just pump more water and return less to the ground (in real practice and in the CALVIN model). Although it may be more economical in the short term to continue over-pumping groundwater, continued overdraft of groundwater basins will eventually increase pumping costs due to higher depths to groundwater as well as environmental problems. Increased pumping lift over time is not represented in CALVIN.

Considering total recharge to groundwater (groundwater return flow + artificial recharge), the No Overdraft case has the highest recharge of the three cases. In CALVIN, this higher recharge is needed to maintain the no overdraft constraint because the solver will do what satisfies constraints and results in the smallest overall cost, driven primarily by meeting demands since shortage costs are high. CALVIN will maximize the amount of water returned to the ground so that groundwater pumping can increase to levels that fall within the no overdraft constraint.

**Table 5.7: Overdraft Study Results – Recharge flows to Groundwater (TAF/yr)**

| Subregion | GW Return Flow | | | Artificial Recharge | | | Total Recharge to GW | | |
|---|---|---|---|---|---|---|---|---|---|
| | Base | No Overdraft | Higher Overdraft | Base | No Overdraft | Higher Overdraft | Base | No Overdraft | Higher Overdraft |
| 1 | 18 | 17 | 18 | - | - | - | 18 | 17 | 18 |
| 2 | 123 | 118 | 123 | - | - | - | 123 | 118 | 123 |
| 3 | 158 | 158 | 158 | - | - | - | 158 | 158 | 158 |
| 4 | 123 | 120 | 123 | - | - | - | 123 | 120 | 123 |
| 5 | 225 | 225 | 225 | - | - | - | 225 | 225 | 225 |
| 6 | 69 | 69 | 71 | - | - | - | 69 | 69 | 71 |
| 7 | 103 | 100 | 103 | - | - | - | 103 | 100 | 103 |
| 8 | 82 | 76 | 82 | - | - | - | 82 | 76 | 82 |
| 9 | 119 | 117 | 121 | - | - | - | 119 | 117 | 121 |
| 10 | 253 | 253 | 253 | - | - | - | 253 | 253 | 253 |
| 11 | 161 | 159 | 161 | - | - | - | 161 | 159 | 161 |
| 12 | 124 | 124 | 124 | - | - | - | 124 | 124 | 124 |
| 13 | 202 | 193 | 202 | 29 | 49 | 27 | 231 | 242 | 229 |
| 14 | 203 | 203 | 203 | - | - | - | 203 | 203 | 203 |
| 15 | 219 | 211 | 219 | 27 | 50 | 27 | 246 | 261 | 246 |
| 16 | 83 | 82 | 86 | 0 | 48 | 0 | 83 | 130 | 86 |
| 17 | 91 | 91 | 91 | 90 | 80 | 41 | 181 | 171 | 132 |
| 18 | 362 | 345 | 363 | 302 | 311 | 250 | 664 | 656 | 613 |
| 19 | 25 | 25 | 25 | 0 | 0 | 0 | 25 | 25 | 25 |
| 20 | 50 | 50 | 50 | 0 | 0 | 0 | 50 | 50 | 50 |
| 21 | 96 | 95 | 96 | 1 | 28 | 1 | 97 | 123 | 97 |
| Sacramento | 1,020 | 999 | 1,023 | - | - | - | 1,020 | 999 | 1,023 |
| San Joaquin | 740 | 729 | 741 | 29 | 49 | 27 | 769 | 778 | 768 |
| Tulare | 1,129 | 1,103 | 1,135 | 420 | 516 | 318 | 1,549 | 1,619 | 1,453 |
| Total Central Valley | 2,889 | 2,831 | 2,899 | 449 | 566 | 345 | 3,338 | 3,397 | 3,244 |

### Storage

Figures 5.1 – 5.3 show the storages by Central Valley region (Sacramento, San Joaquin, and Tulare) for the three cases. All cases' storages follow similar trends that agree with seasonal variations and year types, but the no overdraft case ensures that the initial storage equals the ending storage. Comparing the Base case with the Higher Overdraft case, the Sacramento region is very similar since it has the same representation; the slight decreases in storage in the Sacramento region for the Higher Overdraft case can be attributed to some water from the north being sent to the south to supply demands.

As seen in Figure 5.2, the Higher Overdraft case actually has less overdraft in the San Joaquin region (it was called the Higher Overdraft case since overall Central Valley overdraft is higher). Figure 5.3 shows the large differences in the overdraft allowances in the Tulare region between the cases. All cases in each region have the same initial storage in the figures below.

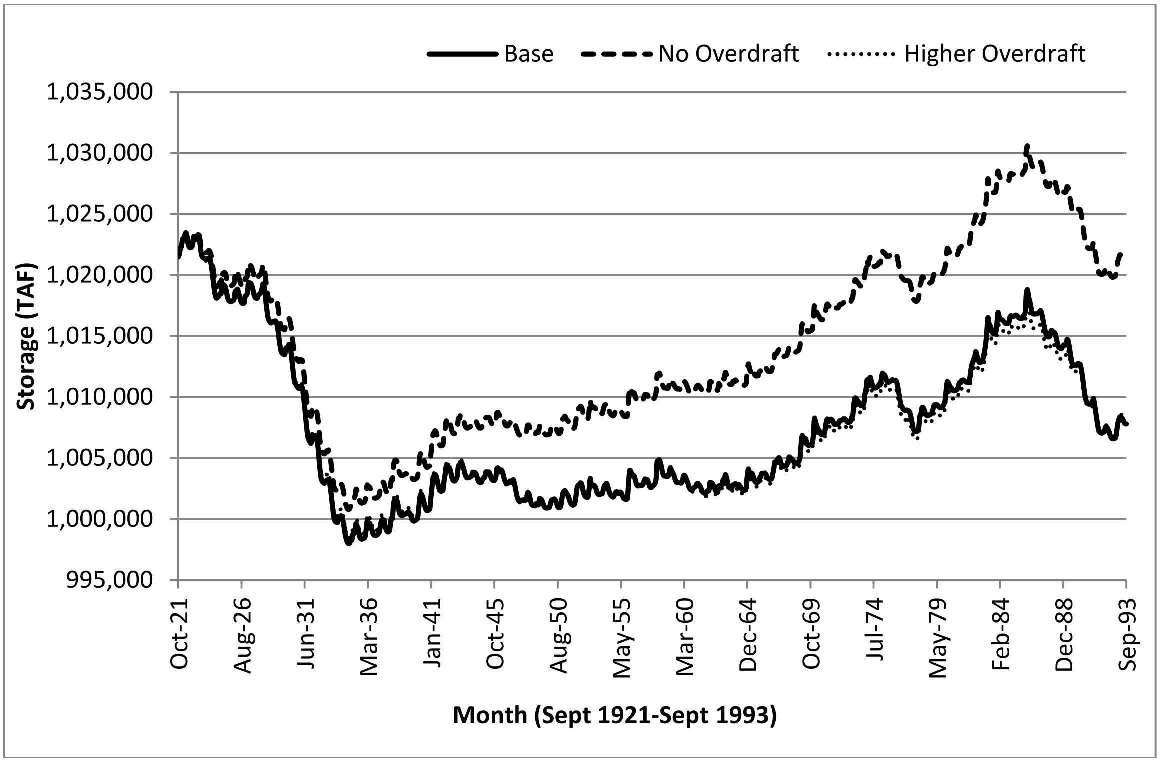


**Figure 5.1: Overdraft Study Results – Sacramento Region (Basins 1-9) Storage**

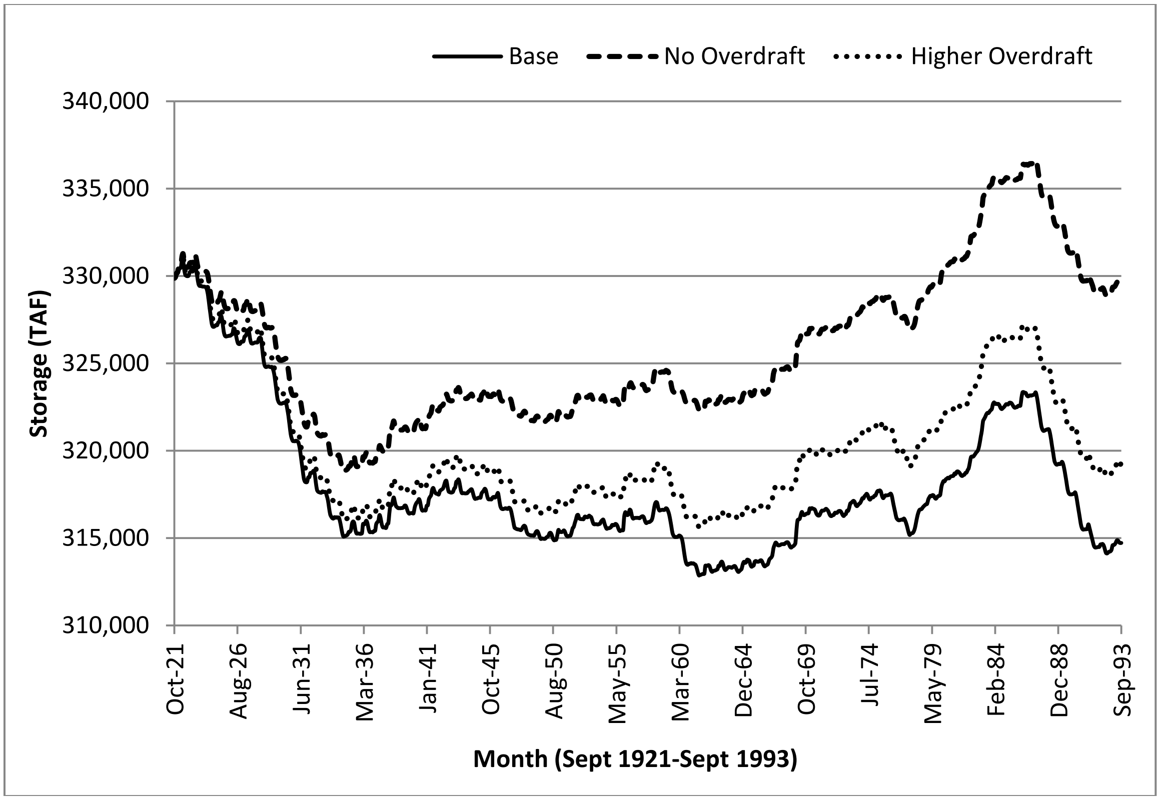


**Figure 5.2: Overdraft Study Results – San Joaquin Region (Basins 10-13) Storage**

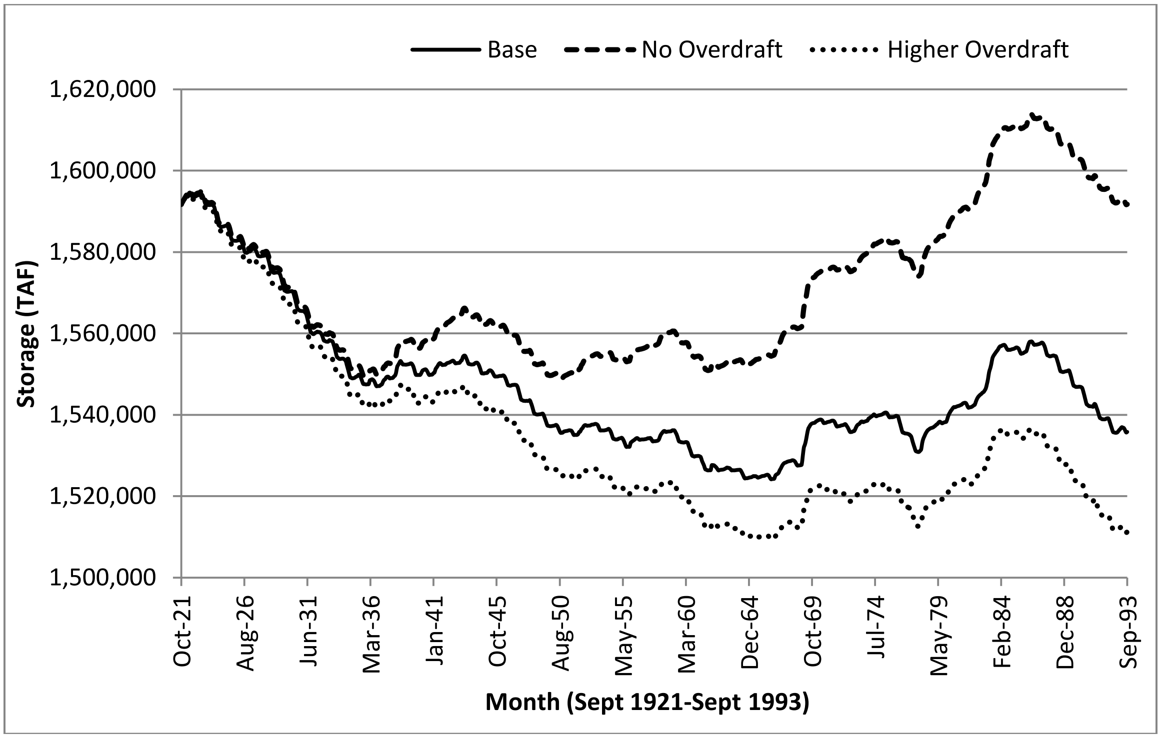


**Figure 5.3: Overdraft Study Results –Tulare Region (Basins 14-21) Storage**

### Willingness-to-pay and Scarcity Costs

The average annual marginal willingness-to-pay (WTP) and scarcity costs are presented in Table 5.8. Marginal WTP reflects what demand areas with shortages would be willing to pay for an additional acre-foot of water; demand areas without scarcity, by definition, have no marginal WTP. Marginal WTP is estimated as the slope of the economic benefit function at the delivered water quantity. Each unit of water goes to the demand area with the highest WTP, if possible, ensuring that the highest value uses are supplied first when possible.

The No Overdraft case has a higher marginal WTP compared to the other two cases because less water is available, creating more scarcity. Comparing the two cases that allow overdraft, the Base case has a higher marginal WTP than the Higher Overdraft case since the Base case has higher scarcities with less available water, and would be willing to pay more for additional water.

Scarcity costs are directly related to the scarcity estimates (Table 5.3), but seasonal variations follow seasonal patterns of demands and availability. Overall, the No Overdraft case has the highest scarcity cost and the Higher Overdraft case has the lowest. The next section compares the Central Valley system costs, including operating costs.

### Table 5.8: Overdraft Study Results – Average Annual Marginal Central Valley Agricultural Willingness-to-pay and Scarcity Costs

| **CALVIN Delivery Link** | **Base** | | **No Overdraft** | | **Higher Overdraft** | |
|---|---|---|---|---|---|---|
| | Marginal WTP ($/AF) | Scarcity Cost (million US $ /yr) | Marginal WTP ($/AF) | Scarcity Cost (million US $ /yr) | Marginal WTP ($/AF) | Scarcity Cost (million US $ /yr) |
| HU1-CVPM1G | 142 | 0.04 | 283 | 0.10 | 115 | 0.03 |
| HU1-CVPM1S | 68.3 | 0.05 | 126 | 0.09 | 36.3 | 0.03 |
| HU2-CVPM2G | 0.4 | 0.0 | 244 | 0.89 | 0.0 | 0.0 |
| HU2-CVPM2S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU3-CVPM3G | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU3-CVPM3S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU4-CVPM4G | 2.5 | 0.0 | 154 | 0.72 | 0.36 | 0.0 |
| HU4-CVPM4S | 22.2 | 0.0 | 137 | 0.01 | 6.44 | 0.0 |
| HU5-CVPM5G | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU5-CVPM5S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU6-CVPM6G | 176 | 1.15 | 252 | 1.27 | 55.1 | 0.32 |
| HU6-CVPM6S | 145 | 0.02 | 238 | 0.03 | 131 | 0.02 |
| HU7-CVPM7G | 0.0 | 0.0 | 177 | 0.46 | 0.0 | 0.0 |
| HU7-CVPM7S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU8-CVPM8G | 0.0 | 0.0 | 590 | 4.16 | 0.0 | 0.0 |
| HU8-CVPM8S | 8.6 | 0.0 | 628 | 0.34 | 0.54 | 0.0 |
| HU9-CVPM9G | 37.6 | 0.46 | 175 | 1.49 | 0.0 | 0.0 |
| HU9-CVPM9S | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| HU10-CVPM10G | 240 | 2.01 | 288 | 2.19 | 241 | 2.01 |
| HU10-CVPM10S | 270 | 0.14 | 339 | 0.15 | 254 | 0.13 |
| HU11-CVPM11G | 6.5 | 0.04 | 106 | 0.49 | 2.17 | 0.01 |
| HU11-CVPM11S | 0.5 | 0.0 | 117 | 0.03 | 0.0 | 0.00 |
| HU12-CVPM12G | 208 | 0.85 | 249 | 0.95 | 202 | 0.85 |
| HU12-CVPM12S | 188 | 0.05 | 262 | 0.06 | 192 | 0.05 |
| HU13-CVPM13G | 343 | 3.49 | 762 | 10.7 | 346 | 3.49 |
| HU13-CVPM13S | 363 | 0.11 | 802 | 0.34 | 356 | 0.11 |
| HU14-CVPM14G | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU14-CVPM14S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| HU15-CVPM15G | 0.0 | 0.0 | 430 | 5.35 | 0.0 | 0.0 |
| HU15-CVPM15S | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 |
| HU16-CVPM16G | 362 | 0.64 | 428 | 0.73 | 6.05 | 0.02 |
| HU16-CVPM16S | 385 | 0.13 | 467 | 0.14 | 377 | 0.13 |
| HU17-CVPM17G | 467 | 1.53 | 527 | 1.62 | 468 | 1.54 |
| HU17-CVPM17S | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| HU18-CVPM18G | 537 | 4.74 | 1101 | 14.8 | 501 | 4.62 |
| HU18-CVPM18S | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| HU19-CVPM19G | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| HU19-CVPM19S | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |
| HU20-CVPM20G | 677 | 1.7 | 836 | 2.0 | 659 | 1.67 |
| HU20-CVPM20S | 610 | 0.38 | 758 | 0.44 | 590 | 0.37 |
| HU21-CVPM21G | 669 | 3.03 | 834 | 3.71 | 632 | 2.90 |
| HU21-CVPM21S | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Region | Max WTP ($/AF) | Total Scarcity Cost (million US $ /yr) | Max WTP ($/AF) | Total Scarcity Cost (million US $ /yr) | Max WTP ($/AF) | Total Scarcity Cost (million US $ /yr) |
| Sacramento | 176 | 2 | 628 | 10 | 131 | 0 |
| San Joaquin | 363 | 7 | 802 | 15 | 356 | 7 |
| Tulare | 677 | 12 | 1100 | 29 | 658 | 11 |
| Central Valley | 677 | 21 | 1100 | 53 | 658 | 18 |

Operating Costs

The different overdraft cases affect operating costs throughout the Central Valley. Table 5.9 shows the average annual operating costs and Central Valley system costs. The No Overdraft case has lower groundwater pumping costs than the other two cases. This is expected since there is less groundwater pumpage in the No Overdraft case (Table 5.5). The Higher Overdraft case has slightly higher groundwater pumping costs, not reflected in the table due to rounding. As expected, the No Overdraft case has higher surface water pumping costs than the Base case, and the Higher Overdraft case has less surface water pumping costs. Since there is little difference between the groundwater pumping costs of the Base case and the Higher overdraft case, the operating cost results indicate that pumping just a little more groundwater to meet demands is cheaper than using additional surface water. Artificial recharge costs are highest for the No Overdraft case and lowest for the Higher Overdraft case. Total operating costs are highest for the Base case, followed by the No Overdraft case, and then the Higher Overdraft case.

Overall, when also considering the scarcity costs, the No Overdraft case has the highest system costs. Although there are increases in the use of surface water and artificial recharge in the No Overdraft case, their capacities are unable to overcome all reductions in water availability, resulting in larger scarcities and thus larger scarcity costs. The Higher Overdraft case has the lowest system and operating costs, indicating that being able to pump more groundwater is still more economical than pumping less groundwater. If artificial recharge capacities could be increased or if there were higher costs for pumping groundwater (i.e. a tax, policy, or increased lifts represented), then pumping less and reducing overdraft might be economical. With no regulations on groundwater use and not considering the environmental and long-term effects of overdraft, CALVIN results show that it is more economically beneficial to overdraft groundwater to meet demands as best as possible, rather than pump less or end overdraft, if overdraft has no additional cost.

Comparing total Central Valley costs, the cost of ending overdraft in all Central Valley groundwater basins is at least $23 million/year, assuming that the Base case has good overdraft representation. Without economically-minded re-operation, the actual costs could be much higher. Completely ending overdraft in the Central Valley at one time is not possible, but taking steps towards having less reliance on over-pumping groundwater is. This can be done by improving efficiencies, promoting more recharge (artificial or natural), and conjunctive use, with a side-effect of increasing Delta exports unless agricultural deliveries are decreased. More discussion on viable management options for ending overdraft can be found in Harou and Lund 2007.

**Table 5.9: Overdraft Study Results – Average Annual Central Valley System Costs ($millions/yr)**

| Costs | Base | No Overdraft | Higher Overdraft |
|---|---|---|---|
| Groundwater Pumping | 361 | 315 | 361 |
| Surface Water Pumping | 426 | 460 | 416 |
| Artificial Recharge | 3 | 4 | 2 |
| Other[1] | 294 | 295 | 293 |
| **Total Operating Costs*** | **$1,084** | **$1,074** | **$1,072** |
| Scarcity Costs | 21 | 53 | 18 |
| **Total System Costs** | **$1,105** | **$1,128** | **$1,090** |

[1] Other costs include: treatment, recycled water, and desalination.
*Total Operating Costs does not include hydropower benefits.

### Results Summary

Table 5.10 summarizes the average annual results for the entire Central Valley (Subregions 1-21) for this overdraft study and percent differences from the Base case. Overall, there is less total delivery in the No Overdraft case and more delivery in the Higher Overdraft case, with the largest factor for delivery differences being groundwater pumping. The No Overdraft case pumps 12 percent less groundwater than the base and increases surface water use by 2 percent and artificial recharge by 26 percent, but still nearly doubles scarcity. The Higher Overdraft case pumps more groundwater and uses less surface water, and has less overall scarcity. Delta pumping increases by 14% from the Base case to the No Overdraft case since there is less available groundwater in the No Overdraft case; the opposite effect happens for the Higher Overdraft case (decreased Delta pumping). More artificial recharge to groundwater occurs in the No Overdraft case to allow more use of surface water and even out water availability. The Higher Overdraft case has less artificial recharge since more groundwater is available in this case. Total system and operating costs are highest for the No Overdraft case and lowest for the Higher Overdraft case. The marginal willingness-to-pay for extra water and scarcity costs are highest for the No Overdraft case since that case has the most scarcity.

**Table 5.10: Overdraft Study Summary – Average Annual Results**

| Result (TAF) | Base | No Overdraft | | Higher Overdraft | |
|---|---|---|---|---|---|
| | Avg. Annual | Avg. Annual | % Difference | Avg. Annual | % Difference |
| Total Central Valley Overdraft (TAF/yr) | 1,172 | 0 | -100% | 1,450 | +24% |
| Total Central Valley Delivery (TAF/yr) | 20,246 | 19,839 | -2% | 20,298 | +0.3% |
| GW Pumping (TAF/yr) | 5,992 | 5,249 | -12% | 6,181 | +3% |
| SW Delivery (TAF/yr) | 14,254 | 14,589 | +2% | 14,117 | -1% |
| Total Central Valley Ag. Scarcity (TAF/yr) | 424 | 831 | +96% | 372 | -12% |
| Total Delta Exports (TAF/yr) | 5,325 | 6,084 | +14% | 5,009 | -6% |
| Banks Pumping (TAF/yr) | 4,383 | 4,470 | +2% | 4,283 | -2% |
| Tracy Pumping (TAF/yr) | 942 | 1,614 | +71% | 726 | -23% |
| Total GW Recharge (TAF/yr) | 3,338 | 3,397 | +2% | 3,244 | -3% |
| Return Flow (TAF/yr) | 2,889 | 2,831 | -2% | 2,899 | +0.3% |
| Artificial Recharge (TAF/yr) | 449 | 566 | +26% | 345 | -23% |
| Total System Costs (million $/yr) | 1,105 | 1,128 | +2% | 1,090 | -1% |
| Operating Costs (million $/yr) | 1,084 | 1,074 | -0.9% | 1,072 | -1% |
| Scarcity Cost (million $/yr) | 21 | 53 | +152% | 18 | -14% |
| Maximum WTP ($/AF) | 677 | 1,011 | +49% | 658 | -3% |

## Conclusions

This overdraft study is just one of the many possible applications of the updated CALVIN model. Many other overdraft cases could be explored with Updated CALVIN, but some would require additional calibration. The cases chosen for this study did not need additional calibration and show some basic comparisons between the groundwater models (CVHM and C2VSIM) and a No Overdraft case, providing some policy and operations insights.

As discussed in Chapter 3, CVHM and C2VSIM have many significant differences in representing Central Valley groundwater. The Higher Overdraft case had only differences for Regions 10-21, but these differences affect the entire system, water diversions, and scarcities. This shows how different regional representations can affect system-wide results and how important it is to pick a model with reasonable results as a base.

The No Overdraft case provides some insight into how the system and system costs would change to end overdraft. It implies that an immediate switch to completely ending overdraft would raise costs, but the results also show that improving recharge and increasing Delta exports would reduce increases in water scarcity. Additional artificial recharge evens out surface water availability, allowing for more surface water to be used and for more consistent deliveries between wet and dry years. However, unless there are direct, immediate benefits to the water users or policies that require less over-pumping or more recharge, it is unlikely that water users will take it upon themselves to pay more for a benefit that they don’t immediately see.

Along with giving useful insights for overall groundwater management and policy, this study also confirmed that Updated CALVIN is behaving as it should and that its results make some practical sense.

# CHAPTER 6

# Conclusions

Integrated hydro-economic modeling is useful for examining the benefits and drawbacks of existing or proposed water policies, operations, and plans. However, water conditions, regulation, demands, and estimates are constantly changing, so timely updates are needed to maintain and improve the usefulness of models. New models with new data are constantly being developed, and incorporating newer data can make hydro-economic models, like CALVIN, more useful. In an effort to make the most of available resources and include a reasonable groundwater representation in CALVIN, C2VSIM was primarily used in this groundwater update project. This project provides a more accurate and up-to-date representation of Central Valley groundwater in CALVIN, which can lead to studies investigating the economic impacts of Central Valley groundwater use and provide an additional framework for groundwater policy discussions. The CALVIN improvements from this project are summarized below.

## CALVIN Improvements

Many improvements were made to the CALVIN model. These include updating and improving the model's representation of Central Valley groundwater, updating the Delta pumping constraints to better reflect actual conditions, and improving the model network and schematic to be more explicit and include some artificial recharge. These improvements are summarized in Table 6.1.

**Table 6.1: Improvements to CALVIN**

| **Central Valley** |
|---|
| Updated agricultural demands to match current SWAP estimates |
| Updated existing groundwater term inputs with new, more accurate values |
| Added some new groundwater terms for more detailed representation of the system |
| Eliminated 2 MAF of calibration outflows (from the previous version of CALVIN) |
| Added explicit representation of artificial recharge for some regions in the Tulare Basin |
| **Delta Pumping** |
| Updated Banks Pumping Plant constraint |
| Updated Delta Export Outflow |
| **Network and Schematic** |
| Added artificial recharge nodes and links for some regions in the Tulare Basin |
| Added hidden nodes and links for groundwater pumping |
| Added hidden nodes and links for urban groundwater return flow |

### Central Valley

The updated agricultural demands based on updated SWAP reduced demands by an average of 117 TAF/year. The changes to the agricultural return flow splits, internal reuse amplitudes, applied water return flow amplitudes, external flows, pumping capacities, pumping costs, storage constraints, and urban return flow amplitudes based primarily on C2VSIM significantly changed how CALVIN models water in the Central Valley. The elimination of 2 MAF of calibration outflows strengthens CALVIN because the model now has a tighter and more explicit representation of Central Valley mass balances of water, more reasonable results, and its groundwater interaction is balanced without the additional calibration flows. The addition of explicit artificial recharge representation allows for an important recharge practice to be represented in the model. The groundwater representation in the updated CALVIN model is more explicit and accurate, making the model more useful.

### Delta Pumping

Updates to Delta pumping and outflow were made based on both CALSIM II 2009 and what was previously in CALVIN. Since CALVIN is an optimization model, its Delta pumping and outflows cannot be expected to be the same as a simulation-based model like CALSIM, but incorporating aspects of CALSIM into CALVIN makes CALVIN more relatable to CALSIM and real-life applications.

### Network and Schematic

The improvements made to the CALVIN network simplify the direct interactions with the Central Valley groundwater subbasins. The urban and pumping hidden nodes result in fewer direct flows going in and out of each groundwater subbasin, allowing for easier comparisons of results and mass balances.

## Conclusions from CALVIN Modeling

The updated CALVIN model was used to study how a few different overdraft cases could affect model results, as well as system economics and management. Three cases were examined: the base case, no overdraft, and higher overdraft. These three cases have significantly different results, as expected. With the no overdraft case, water scarcities were highest and drove the system to increase surface water use and artificial recharge to groundwater. Overall system and operating costs were lowest for the highest overdraft scenario, suggesting that being able to pump more groundwater is the more economical option, which agrees with current, real practices.

This study shows immediately ending overdraft in the Central Valley would have high costs and that including and increasing artificial recharge capacities can benefit the overall water system. Currently, overdrafting groundwater is common, with lower costs. However, with groundwater availability decreasing, pumping costs likely increasing, and environmental effects of overdraft worsening, overdraft will be an increasing problem in the future and may have other costs associated with it not included in CALVIN. Options to mitigate overdraft include: increasing recharge use and capacities (artificial and natural), increase in water reuse, more conjunctive use, more surface water use, and decrease in water use and demands. Although there are many possible solutions, many solutions have higher immediate costs and the long-term benefits are unclear or unknown. Unless policies require water users to follow these solutions, groundwater overdraft will likely continue to be a problem in the years to come.

## Limitations and Further Work

"All models are wrong, but some are useful" said George Box (1979).

This CALVIN groundwater update project has improved Central Valley groundwater representation in CALVIN. However, CALVIN is just a model and the models used for this update are just models; they can all be useful, but are not exactly accurate. These models can help draw policy implications and present likely outcomes and effects, but as can be seen in comparisons with measured data and other similar models, there is still much uncertainty in many aspects of these models, albeit probably more accuracy and certainty than most model-free analysis.

Nonetheless, to maintain usefulness, these models should be kept up to date and continue to be improved. This project focused on updating the groundwater in the Central Valley, but CALVIN is a model of California's entire water system and many more improvements can be made. To gain better understanding and insight to the Central Valley water system, the surface water side of CALVIN could use some updates to rim inflows and deliveries, particularly Valley floor accretions and depletions. Additionally, since the CALVIN network was built using software from the early 2000's, new machines are having some problems with CALVIN's network so some updates to the CALVIN software would also be very useful.

As it stands, CALVIN is a unique hydro-economic optimization model of California's water system and has a variety of applications. Using this CALVIN with updated Central Valley groundwater representation for studies related to groundwater in California could provide some useful results. There have been many CALVIN climate change studies, but none that have updated Central Valley groundwater representation. This study examined just a few overdraft scenarios, but it would be interesting to see what the updated CALVIN model would show under more overdraft cases with added climate changes. Looking more into the economic aspects of climate change adaptation or overdraft mitigation in the Central Valley could also provide some useful results. There is always more research that can be done using CALVIN.

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# Appendix 1

## CVHM Groundwater Term Calculations

This appendix presents some of the different approaches taken when calculating the CALVIN groundwater parameters. The parameters presented as “CVHM” (and in bold) are primarily calculations results from the Zonebudget post-processor; this was the version ultimately used to represent CVHM and the methods are described in Chapter 2. Other versions of these calculations include results from FB_details.OUT and other input files, but these were not chosen to represent CVHM since it involved using terms from different post-processors that did not result in mass balance. However, these calculations still reflect reasonable methods to calculate these terms so some descriptions and results are summarized below.

**Table 2.2: CVHM Datasets (from Chapter 2)**

| Dataset name | Description |
|---|---|
| CVHM Historical ZB (1980-1993)<br>“CVHM” | Based on historical CVHM run using Zonebudget post-processor; averages based on 1980-1993. |
| CVHM Historical (1980-2003)<br>“CVHM Hist 1980-2003” | Based on historical CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1980-2003. |
| CVHM Historical (1961-2003)<br>“CVHM Hist” | Based on historical CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1961-2003. |
| CVHM 2000 Land Use (1961-2003)*<br>“CVHM 2000” | Based on an updated 2000 land use CVHM run using a combination of FB_details.OUT and Zonebudget; averages are based on 1961-2003. |

*Note that this run had obvious problems in some of the Tulare Basin regions so the results from this run were ultimately not used for any formal comparison.

### Agricultural Return Flow Split

Different approaches were explored to calculate this term. This was the original approach:

Fraction to SW= RUN/(RUN+DP)
Fraction to GW= DP/(RUN+DP)

Where RUN and DP are part of the Farm Balance found in FB_DETAILS.OUT.

RUN = Overland runoff out of the farm
DP = Deep percolation out of the farm

However, both RUN and DP include precipitation and applied water. CVHM does not separate precipitation out as a separate component to either runoff or deep percolation, as was previously done by the CVGSM model (Direct Runoff was runoff due to rainfall alone). So the above equation is not strictly agricultural return flows, but total return flow.

Since applied water and precipitation are outputs in the CVHM model, a ratio was used to estimate the runoff from applied water and runoff from precipitation.

Applied Water = NRD-in + SRD-in + WELLS-in

Consumptive Use = COMPOSITE EFFICIENCY (%) x Applied Water

Runoff from Applied Water = RUN x [Applied Water / (Applied Water + Precipitation)]

Deep percolation of Applied Water =
Applied Water – Consumptive Use – Runoff from Applied Water

Fraction of Agricultural Return Flow to GW =
Deep percolation of Applied Water / [Applied Water – Consumptive Use]

Fraction of Agricultural Return Flow to SW =
Runoff from Applied Water / [Applied Water – Consumptive Use]

NRD-in = Non-routed deliveries into the farm
SRD-in = Semi-routed deliveries into the farm
WELLS-in = Groundwater well pumping deliveries into the farm
COMPOSITE EFFICIENCY = see term #3 below

The results for return flow to groundwater and return flow to surface water are tabulated below. The “CVHM” set shown in bold is the dataset that was used in the final comparisons.

**Table A1.1: Agricultural Return Flow Fractions to Groundwater and Surface Water**

| Subregion | **CVHM** | | Hist CVHM (1980-2003) | | Hist CVHM | | CVHM 2000 | |
|---|---|---|---|---|---|---|---|---|
| | **GW** | **SW** | GW | SW | GW | SW | GW | SW |
| 1 | **0.99** | **0.01** | 0.65 | 0.35 | 0.65 | 0.35 | 0.64 | 0.36 |
| 2 | **0.98** | **0.02** | 0.72 | 0.28 | 0.73 | 0.27 | 0.7 | 0.30 |
| 3 | **0.97** | **0.03** | 0.75 | 0.25 | 0.76 | 0.24 | 0.75 | 0.25 |
| 4 | **0.96** | **0.04** | 0.68 | 0.32 | 0.68 | 0.32 | 0.05 | 0.95 |
| 5 | **0.97** | **0.03** | 0.71 | 0.29 | 0.72 | 0.28 | 0.63 | 0.37 |
| 6 | **0.97** | **0.03** | 0.75 | 0.25 | 0.76 | 0.24 | 0.74 | 0.26 |
| 7 | **0.98** | **0.02** | 0.69 | 0.31 | 0.70 | 0.30 | 0.67 | 0.33 |
| 8 | **0.98** | **0.02** | 0.82 | 0.18 | 0.82 | 0.18 | 0.83 | 0.17 |
| 9 | **0.96** | **0.04** | 0.79 | 0.21 | 0.80 | 0.20 | 0.82 | 0.18 |
| 10 | **0.95** | **0.05** | 0.83 | 0.17 | 0.83 | 0.17 | 0.84 | 0.16 |
| 11 | **0.97** | **0.03** | 0.76 | 0.24 | 0.78 | 0.22 | 0.77 | 0.23 |
| 12 | **0.96** | **0.04** | 0.72 | 0.28 | 0.74 | 0.26 | 0.73 | 0.27 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | **0.97** | **0.03** | 0.84 | 0.16 | 0.85 | 0.15 | 0.86 | 0.14 |
| 14 | **0.92** | **0.08** | 0.88 | 0.12 | 0.84 | 0.16 | 0.89 | 0.11 |
| 15 | **0.94** | **0.06** | 0.92 | 0.08 | 0.91 | 0.09 | 0.9 | 0.10 |
| 16 | **0.98** | **0.02** | 0.91 | 0.09 | 0.91 | 0.09 | 0.92 | 0.08 |
| 17 | **0.97** | **0.03** | 0.86 | 0.14 | 0.87 | 0.13 | 0.87 | 0.13 |
| 18 | **0.96** | **0.04** | 0.90 | 0.10 | 0.90 | 0.10 | 0.89 | 0.11 |
| 19 | **0.97** | **0.03** | 0.93 | 0.07 | 0.93 | 0.07 | 0.92 | 0.08 |
| 20 | **0.97** | **0.03** | 0.94 | 0.06 | 0.93 | 0.07 | 0.94 | 0.06 |
| 21 | **0.96** | **0.04** | 0.93 | 0.07 | 0.92 | 0.08 | 0.93 | 0.07 |

### Agricultural Reuse

This version of CVHM did not “reuse” water on a farm for repeated irrigation. 1 was used for all regions for this term, indicating no reuse.

### Return Flow of Total Applied Water

**Table A1.2: Return Flow Fraction of Total Applied Water**

| Subregion | Composite Efficiency (ETAW) | | Return Flow (1-ETAW) | |
|---|---|---|---|---|
| | 2000's | 1990's | 2000's | 1990's |
| 1 | 0.74 | 0.76 | **0.26** | 0.24 |
| 2 | 0.73 | 0.75 | **0.27** | 0.25 |
| 3 | 0.83 | 0.82 | **0.17** | 0.18 |
| 4 | 0.79 | 0.78 | **0.21** | 0.22 |
| 5 | 0.8 | 0.8 | **0.2** | 0.2 |
| 6 | 0.77 | 0.77 | **0.23** | 0.23 |
| 7 | 0.77 | 0.77 | **0.23** | 0.23 |
| 8 | 0.75 | 0.78 | **0.25** | 0.22 |
| 9 | 0.78 | 0.79 | **0.22** | 0.21 |
| 10 | 0.79 | 0.8 | **0.21** | 0.2 |
| 11 | 0.77 | 0.78 | **0.23** | 0.22 |
| 12 | 0.76 | 0.77 | **0.24** | 0.23 |
| 13 | 0.79 | 0.8 | **0.21** | 0.2 |
| 14 | 0.87 | 0.86 | **0.13** | 0.14 |
| 15 | 0.76 | 0.76 | **0.24** | 0.24 |
| 16 | 0.81 | 0.79 | **0.19** | 0.21 |
| 17 | 0.8 | 0.79 | **0.2** | 0.21 |
| 18 | 0.79 | 0.79 | **0.21** | 0.21 |
| 19 | 0.77 | 0.79 | **0.23** | 0.21 |
| 20 | 0.81 | 0.81 | **0.19** | 0.19 |
| 21 | 0.81 | 0.81 | **0.19** | 0.19 |

### External Flows: Inter-basin Flows

**Table A1.3: Average Annual Inter-basin Flow (TAF/yr)**

| Subregion | **CVHM** | Hist CVHM (1980-2003) | Hist CVHM | CVHM 2000 |
|---|---|---|---|---|
| 1 | **-312.1** | -310.2 | -314.4 | -288.1 |

| | | | | |
|---|---|---|---|---|
| 2 | **44.2** | 32.3 | 41.3 | -10.0 |
| 3 | **-225.8** | -218.4 | -219.6 | -178.8 |
| 4 | **558.6** | 552.3 | 542.1 | 379.6 |
| 5 | **-184.9** | -171.4 | -178.3 | -14.1 |
| 6 | **-47.2** | -55.2 | -22.7 | -121.6 |
| 7 | **19.4** | 36.0 | -10.3 | 101.3 |
| 8 | **50.3** | 60.9 | 49.4 | 0.2 |
| 9 | **237.7** | 205.5 | 249.9 | 220.5 |
| 10 | **-79.9** | -70.2 | -96.9 | -88.7 |
| 11 | **-54.9** | -44.6 | -49.7 | -9.9 |
| 12 | **-73.4** | -80.9 | -72.4 | -88.7 |
| 13 | **-0.8** | -0.3 | 0.1 | 36.7 |
| 14 | **85.2** | 108.7 | 166.1 | 247.1 |
| 15 | **621.8** | 514.9 | 484.2 | 189.9 |
| 16 | **-196.1** | -144.7 | -169.6 | -49.7 |
| 17 | **-176.8** | -179.5 | -153.9 | -176.0 |
| 18 | **-20.1** | -3.4 | -33.5 | -67.7 |
| 19 | **212.2** | 183.9 | 201.8 | 142.3 |
| 20 | **-164.4** | -146.9 | -173.8 | 140.1 |
| 21 | **-292.9** | -268.7 | -239.8 | -364.4 |
| SAC TOTAL | **140.1** | 131.7 | 137.4 | 89.0 |
| SJ TOTAL | **-209.0** | -196.1 | -219.0 | -150.6 |
| TL TOTAL | **68.8** | 64.4 | 81.6 | 61.6 |
| TOTAL | **0.0** | 0.0 | 0.0 | 0.0 |

## External Flows: Stream Leakage

### Table A1.4: Average Annual Stream Leakage (TAF/yr)

| Subregion | **CVHM** | Hist CVHM (1980-2003) | Hist CVHM | CVHM 2000 |
|---|---|---|---|---|
| 1 | -131.5 | -121.1 | -143.8 | -108.5 |
| 2 | -293.1 | -293.3 | -293.6 | -373.1 |
| 3 | -234.0 | -228.5 | -211.1 | -167.7 |
| 4 | -533.4 | -531.6 | -492.1 | -250.7 |
| 5 | -213.3 | -216.1 | -198.5 | -280.8 |
| 6 | 13.8 | 32.7 | 33.8 | 31.2 |
| 7 | -42.9 | -41.8 | -38.0 | -34.1 |
| 8 | 84.8 | 91.6 | 94.7 | 84.9 |
| 9 | 551.8 | 656.0 | 703.6 | 496.9 |
| 10 | 38.2 | 53.7 | 65.0 | 46.1 |
| 11 | -102.3 | -102.0 | -97.7 | -89.2 |
| 12 | 20.7 | 33.8 | 39.4 | 31.8 |
| 13 | 125.3 | 146.1 | 164.0 | 128.4 |
| 14 | 5.6 | 5.9 | 5.5 | 5.5 |
| 15 | 177.6 | 245.7 | 238.3 | 250.9 |

| | | | | |
|---|---|---|---|---|
| 16 | 35.0 | 36.3 | 33.3 | 41.8 |
| 17 | 174.8 | 179.4 | 169.5 | 210.9 |
| 18 | 106.9 | 113.6 | 103.6 | 142.7 |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | 19.3 | 19.7 | 18.8 | 18.8 |
| 21 | 107.2 | 121.8 | 130.4 | 91.8 |
| SAC TOTAL | -797.8 | -652.0 | -545.0 | -601.9 |
| SJ TOTAL | 81.9 | 131.6 | 170.7 | 117.1 |
| TL TOTAL | 626.4 | 722.3 | 699.2 | 762.4 |
| TOTAL | -89.6 | 202.0 | 325.0 | 277.6 |

### External Flows: Deep Percolation from Precipitation

Many different approaches were taken to calculate this term. The final calculations were based on using ratios from output terms in FB_Details.OUT and applying them to the Zonebudget output “Farm Net Recharge.” The older calculations used the ratio from FB_details.OUT and applied it to FB_details.OUT’s DP-out.

Applied Water = NRD-in + SRD-in + WELLS-in

Precipitation = P-in

Deep Percolation = DP-out

Deep Percolation of Precipitation = DP-out x (P-in / (P-in + NRD-in + SRD-in + WELLS-in))

**Table A1.5: Average Annual Deep Percolation from Precipitation (TAF/yr)**

| Subregion | **CVHM** | CVHM Hist (1980-2003) | CVHM Hist | CVHM 2000 |
|---|---|---|---|---|
| 1 | **440.2** | 481.8 | 478.3 | 480.6 |
| 2 | **631.4** | 679.7 | 643.2 | 670.1 |
| 3 | **613.5** | 683.9 | 636.4 | 656.4 |
| 4 | **260.6** | 385.7 | 366.2 | 370.0 |
| 5 | **690.1** | 796.6 | 767.7 | 794.3 |
| 6 | **556.4** | 632.4 | 594.4 | 600.0 |
| 7 | **278.0** | 333.3 | 333.6 | 312.3 |
| 8 | **546.4** | 595.2 | 568.5 | 547.8 |
| 9 | **263.2** | 540.9 | 506.0 | 512.3 |
| 10 | **158.0** | 245.3 | 236.6 | 240.2 |
| 11 | **180.7** | 213.9 | 204.6 | 197.3 |
| 12 | **137.5** | 177.4 | 167.6 | 166.0 |
| 13 | **350.6** | 428.9 | 416.3 | 398.8 |
| 14 | **100.5** | 94.9 | 92.1 | 100.4 |
| 15 | **177.4** | 174.1 | 173.9 | 196.2 |
| 16 | **106.4** | 111.7 | 111.6 | 110.0 |
| 17 | **159.7** | 167.0 | 159.9 | 154.0 |
| 18 | **217.6** | 233.6 | 237.1 | 229.7 |
| 19 | **93.7** | 76.0 | 72.6 | 73.3 |

| | | | | |
|---|---|---|---|---|
| 20 | **62.2** | 58.6 | 57.7 | 54.3 |
| 21 | **79.3** | 91.0 | 82.8 | 62.7 |
| SAC TOTAL | **4279.9** | 5129.6 | 4894.4 | 4943.8 |
| SJ TOTAL | **826.8** | 1065.5 | 1025.1 | 1002.3 |
| TL TOTAL | **996.7** | 1006.8 | 987.7 | 980.6 |
| TOTAL | **6103.4** | 7201.9 | 6907.2 | 6926.7 |

### External Flows: Boundary Inflow

**Table A1.6: Average Annual Boundary Inflow (TAF/yr)**

| Subregion | **CVHM** | CVHM Hist (1980-2003) | CVHM Hist | CVHM 2000 |
|---|---|---|---|---|
| 1 | **0** | 0 | 0 | 0 |
| 2 | **0** | 0 | 0 | 0 |
| 3 | **0** | 0 | 0 | 0 |
| 4 | **0** | 0 | 0 | 0 |
| 5 | **0** | 0 | 0 | 0 |
| 6 | **0** | 0 | 0 | 0 |
| 7 | **0** | 0 | 0 | 0 |
| 8 | **0** | 0 | 0 | 0 |
| 9 | **-90.5** | -134.7 | -102.9 | -130.8 |
| 10 | **0** | 0 | 0 | 0 |
| 11 | **0** | 0 | 0 | 0 |
| 12 | **0** | 0 | 0 | 0 |
| 13 | **0** | 0 | 0 | 0 |
| 14 | **0** | 0 | 0 | 0 |
| 15 | **0** | 0 | 0 | 0 |
| 16 | **0** | 0 | 0 | 0 |
| 17 | **0** | 0 | 0 | 0 |
| 18 | **0** | 0 | 0 | 0 |
| 19 | **0** | 0 | 0 | 0 |
| 20 | **0** | 0 | 0 | 0 |
| 21 | **0** | 0 | 0 | 0 |
| SAC TOTAL | **-90.5** | -134.7 | -102.9 | -130.8 |
| SJ TOTAL | **0.0** | 0.0 | 0.0 | 0.0 |
| TL TOTAL | **0.0** | 0.0 | 0.0 | 0.0 |
| TOTAL | **-90.5** | -134.7 | -102.9 | -130.8 |

### External Flows: Evapotranspiration / Non-recoverable losses

Some of the Agricultural Recharge terms calculated from the Farm Net Recharge terms in Zonebudget are negative. Rather than expressing negative recharge, the negative values were separated out to be the estimated ET losses from groundwater. This was the method used for the final CVHM terms. But the previous versions of the calculations took the time series of EGW-in and TGW-in from FB_Details.OUT, which are evaporation from groundwater and transpiration from groundwater to the farm. These estimated ET values are compared with the ones calculated from the Zonebudget in Table A1.7.

**Table A1.7: Average Annual ET from Groundwater (TAF/yr)**

| Subregion | **CVHM** | CVHM Hist (1980-2003) | CVHM Hist |
|---|---|---|---|
| 1 | **8.0** | 34.4 | 35.8 |
| 2 | **0.0** | 64.9 | 62.6 |
| 3 | **124.5** | 310.3 | 298.6 |
| 4 | **262.2** | 395.1 | 399.7 |
| 5 | **227.8** | 405.6 | 402.6 |
| 6 | **69.3** | 305.2 | 282.4 |
| 7 | **75.8** | 144.0 | 146.5 |
| 8 | **0.7** | 93.1 | 74.5 |
| 9 | **515.5** | 863.9 | 824.6 |
| 10 | **101.4** | 378.4 | 395.3 |
| 11 | **4.3** | 120.0 | 118.7 |
| 12 | **29.2** | 148.5 | 149.4 |
| 13 | **3.6** | 306.6 | 326.0 |
| 14 | **0.0** | 1.6 | 4.0 |
| 15 | **0.0** | 57.1 | 99.5 |
| 16 | **0.0** | 1.3 | 1.4 |
| 17 | **0.0** | 10.8 | 11.5 |
| 18 | **0.0** | 17.2 | 18.6 |
| 19 | **0.0** | 0.8 | 1.5 |
| 20 | **0.0** | 0.0 | 0.0 |
| 21 | **0.0** | 56.2 | 67.5 |
| SAC TOTAL | **1283.7** | 2616.6 | 2527.3 |
| SJ TOTAL | **138.5** | 953.6 | 989.4 |
| TL TOTAL | **0.0** | 145.0 | 203.8 |
| TOTAL | **1422.2** | 3715.2 | 3720.5 |

## Net External Flows

Summing the respective terms from each of the datasets results in the net external flows shown in Table A1.8.

**Table A1.8: Average Annual External Flows (TAF/yr)**

| Subregion | **CVHM** | CVHM Hist (1980-2003) | CVHM Hist | CVHM 2000 |
|---|---|---|---|---|
| 1 | **6.8** | 16.2 | -15.7 | 84.0 |
| 2 | **406.1** | 353.8 | 328.4 | 287.0 |
| 3 | **30.9** | -73.3 | -92.9 | 309.9 |
| 4 | **23.2** | 11.4 | 16.5 | 498.9 |
| 5 | **64.2** | 3.4 | -11.7 | 499.4 |
| 6 | **453.5** | 304.6 | 323.1 | 509.6 |
| 7 | **186.2** | 183.4 | 138.7 | 379.5 |
| 8 | **685.8** | 654.7 | 638.2 | 632.9 |

| | | | | |
|---|---|---|---|---|
| 9 | **446.1** | 403.7 | 532.1 | 1098.9 |
| 10 | **30.0** | -149.8 | -190.7 | 197.6 |
| 11 | **19.8** | -52.7 | -61.5 | 98.2 |
| 12 | **57.9** | -18.2 | -14.7 | 109.1 |
| 13 | **564.2** | 268.1 | 254.4 | 563.9 |
| 14 | **260.4** | 207.8 | 259.7 | 353.0 |
| 15 | **1117.0** | 877.6 | 796.9 | 637.0 |
| 16 | **-8.8** | 2.0 | -26.1 | 102.1 |
| 17 | **197.9** | 156.1 | 164.1 | 188.9 |
| 18 | **564.3** | 326.5 | 288.6 | 304.7 |
| 19 | **409.7** | 259.1 | 272.9 | 215.6 |
| 20 | **20.9** | -68.5 | -97.3 | 213.2 |
| 21 | **-63.9** | -112.1 | -94.1 | -209.9 |
| SAC TOTAL | **2302.9** | 1857.9 | 1856.6 | 4300.1 |
| SJ TOTAL | **671.8** | 47.5 | -12.5 | 968.8 |
| TL TOTAL | **2497.5** | 1648.5 | 1564.7 | 1804.6 |
| TOTAL | **5472.2** | 3553.9 | 3408.8 | 7073.5 |

## Maximum Pumping Capacity

Some of the older calculations use the absolute maximum monthly pumping values from FB_Details.OUT. The final CVHM values used were based on “Farm Wells” from Zonebudget.

**Table A1.8: Agricultural Maximum Monthly Pumping (TAF/month)**

| Subregion | **CVHM** | CVHM Hist (1980-2003) | CVHM Hist | CVHM 2000 |
|---|---|---|---|---|
| 1 | **2.3** | 2.6 | 2.6 | 2.4 |
| 2 | **354.7** | 149.2 | 157.3 | 84.7 |
| 3 | **4.4** | 55.3 | 77.8 | 42.1 |
| 4 | **2.4** | 4.8 | 11.8 | 0.0 |
| 5 | **25.1** | 6.3 | 72.4 | 3.1 |
| 6 | **181.8** | 142.7 | 183.2 | 96.6 |
| 7 | **73.8** | 19.8 | 39.0 | 0.0 |
| 8 | **474.5** | 217.3 | 249.0 | 116.0 |
| 9 | **90.0** | 131.3 | 269.7 | 16.5 |
| 10 | **7.9** | 81.9 | 81.9 | 104.2 |
| 11 | **22.8** | 53.8 | 100.5 | 74.8 |
| 12 | **19.0** | 59.3 | 71.0 | 74.6 |
| 13 | **524.5** | 261.0 | 327.8 | 292.3 |
| 14 | **214.8** | 236.7 | 485.6 | 338.9 |
| 15 | **1066.5** | 430.5 | 436.2 | 432.7 |
| 16 | **32.1** | 52.1 | 108.6 | 60.8 |
| 17 | **275.5** | 157.3 | 178.7 | 148.4 |
| 18 | **570.8** | 377.0 | 448.3 | 361.5 |

| | | | | |
|---|---|---|---|---|
| 19 | **471.2** | 226.2 | 243.6 | 240.5 |
| 20 | **162.2** | 98.9 | 122.5 | 113.0 |
| 21 | **113.3** | 93.5 | 93.5 | 0.0 |

### Representative depth to Groundwater (Pumping Lift)

Before it was decided that DWR 2000 average measured well data would be used to represent depth to groundwater, values were calculated based on CVHM using the following method:

Depth to Groundwater = Lift = GSE – Water Elevation

GSE = Ground surface elevation, used “cvr2_lay1_topm.txt” (from CVHM input, model_arrays folder)

Water Elevation = heads outputted in LIST file

NOTE: the head value given from MODFLOW is actually the average head, and not the effective water level. This would mean that head is actually an overestimate (this is in addition to all the other assumptions). So the calculated lift is an underestimate.

This method was based on using the well indices specified in the FMP file (a CVHM input file) that specifies, by element, where wells are located as of year 2000. For this calculation, an average of 2000 water year heads was used.

An alternative method involved using subregion indices from dwr_subregions file (CVHM input file) – to match, and then extract groundwater elevation at each element. However, this method involved sometimes using subregion elements where a well does not actually exist, or at least was not modeled in CVHM. Using the well indices file was determined to be a better representation since only elements with known, existing wells were used for the calculation.

An issue that arose was that GSE was less than Water Elevation in many elements. Elements where this occurred were excluded from the calculations.

**Table A1.9: Groundwater Pumping Lift (feet)**

| Subregion | CVHM | CVHM 2000 |
|---|---|---|
| 1 | 153 | 154 |
| 2 | 43 | 43 |
| 3 | 63 | 63 |
| 4* | NA | NA |
| 5 | 14 | 14 |
| 6 | 57 | 57 |

| | | |
|---|---|---|
| 7 | 19 | 18 |
| 8 | 17 | 16 |
| 9 | 43 | 43 |
| 10 | 73 | 73 |
| 11 | 22 | 22 |
| 12 | 42 | 43 |
| 13 | 113 | 134 |
| 14 | 176 | 206 |
| 15 | 36 | 55 |
| 16 | 123 | 151 |
| 17 | 80 | 102 |
| 18 | 186 | 230 |
| 19 | 165 | 194 |
| 20 | 366 | 413 |
| 21 | 250 | 276 |

*For this region, all GSE values were less than the water elevation so no value for lift could be calculated.

### Maximum Storage Capacity

The term “Storage” from the Zonebudget was used for all calculations here. Effective storage was calculated for this term to represent the absolute maximum available water. Calculation is as follows:

1. Arbitrarily set the initial storage to a very large number such that the created storage time series is never negative. Used $1\text{x}10^9$.
2. Once storage values are converted from change in storage to storage, the effective storage can be calculated: Absolute Maximum storage – Absolute Minimum Storage (note that the original arbitrarily high number is subtracted out by doing this).

**Table A1.10: Maximum (Effective) Storage (TAF)**

| Subregion | **CVHM Historical (1980-1993)** | CVHM Historical | CVHM 2000 |
|---|---|---|---|
| 1 | **19,543** | 24,969 | 18,984 |
| 2 | **33,133** | 33,133 | 30,105 |
| 3 | **22,782** | 30,291 | 28,094 |
| 4 | **15,730** | 25,993 | 20,348 |
| 5 | **23,850** | 33,887 | 26,713 |
| 6 | **34,350** | 41,230 | 35,657 |
| 7 | **12,190** | 13,308 | 13,030 |
| 8 | **31,153** | 31,153 | 30,177 |
| 9 | **81,528** | 128,968 | 96,095 |
| 10 | **20,844** | 29,718 | 27,502 |

| | | | |
|---|---|---|---|
| 11 | **10,704** | 15,972 | 14,237 |
| 12 | **16,651** | 32,495 | 21,168 |
| 13 | **48,168** | 48,168 | 49,794 |
| 14 | **32,789** | 90,541 | 52,038 |
| 15 | **38,000** | 49,214 | 39,397 |
| 16 | **27,274** | 47,732 | 32,371 |
| 17 | **31,370** | 39,890 | 38,811 |
| 18 | **58,956** | 83,700 | 34,740 |
| 19 | **28,006** | 44,875 | 59,136 |
| 20 | **20,229** | 39,587 | 27,953 |
| 21 | **58,804** | 58,804 | 64,187 |
| SAC TOTAL | **274,260** | 362,934 | 299,203 |
| SJ TOTAL | **96,367** | 126,354 | 112,701 |
| TL TOTAL | **295,428** | 454,344 | 348,633 |
| TOTAL | **666,055** | 943,631 | 760,537 |

### Initial & Ending Storage Capacity

The initial storage was calculated to be the effective initial storage, the maximum amount of water available in September 2003. This was calculated: Storage in 2003-Absolute Minimum storage. The results are shown in Table 14. The initial storage values used for CALVIN here are taken directly from CALVIN model inputs.

**Table A1.11: Initial Storage (TAF)**

| Region | **CVHM Historical (1980-1993)** | CVHM Historical | CVHM 2000 |
|---|---|---|---|
| 1 | **16,346** | 21,773 | 12,908 |
| 2 | **19,031** | 19,031 | 14,355 |
| 3 | **10,350** | 10,350 | 11,244 |
| 4 | **8,552** | 8,552 | 9,989 |
| 5 | **16,587** | 16,587 | 13,656 |
| 6 | **11,683** | 11,683 | 16,066 |
| 7 | **10,180** | 11,297 | 8,185 |
| 8 | **12,230** | 12,230 | 10,565 |
| 9 | **18,419** | 18,419 | 32,512 |
| 10 | **11,311** | 11,311 | 9,344 |
| 11 | **4,905** | 4,905 | 4,435 |
| 12 | **3,683** | 3,683 | 5,518 |
| 13 | **33,636** | 33,636 | 39,214 |
| 14 | **32,789** | 90,541 | 44,445 |
| 15 | **22,341** | 33,555 | 25,833 |
| 16 | **27,274** | 47,732 | 31,158 |
| 17 | **24,960** | 33,480 | 34,051 |

| | | | |
|---|---|---|---|
| 18 | **58,956** | 83,700 | 33,598 |
| 19 | **28,006** | 44,875 | 59,136 |
| 20 | **20,229** | 39,587 | 27,953 |
| 21 | **58,699** | 58,699 | 64,187 |
| SAC TOTAL | **123,377** | 129,922 | 129,481 |
| SJ TOTAL | **53,536** | 53,536 | 58,510 |
| TL TOTAL | **273,254** | 432,170 | 320,361 |
| TOTAL | **450,167** | 615,627 | 508,353 |

Overdraft scenarios were not examined when initially calculating groundwater terms so the CVHM dataset ending storages were just set to the initial storages (no change in storage).

# Appendix 2

## Groundwater Pumping Lift Cost Calculation

Table A2.1 shows the summary calculation for pumping lift cost. The first column presents the DWR 2000 averaged well data. The Technical Note by Buck 2012 (below) describes how the pumping lift depths were determined. Column 2 shows drawdown values used in the previous version of CALVIN (Appendix J). Column 3 is the Pumping Head, which is estimated by summing the drawdown and the pumping lift. Column 4 shows the change in lift values that were used in the previous version of CALVIN, which are used to determine Total Dynamic Head in Column 5. Column 6 is the estimated pumping cost in year 2000 dollars ($.20af/ft). The 2000 costs are then hit with a multiplier (x1.296) to reflect 2008 costs (last column in the table).

**Table A2.1: Estimated Agricultural Pumping Costs**

| Subregion | Estimated Pumping Lift (ft)* | Drawdown (ft) | Pumping Head (ft) | Change in Lift (ft) | Total Dynamic Head (ft) | Pumping Cost, 2000$ ($.20af/ft) | Pumping Cost, 2008$ ($/AF) |
|---|---|---|---|---|---|---|---|
| 1 | 71 | 20 | 91 | 0 | 91 | $ 18.20 | $ 23.59 |
| 2 | 40 | 20 | 60 | 1 | 61 | $ 12.20 | $ 15.82 |
| 3 | 27 | 20 | 47 | -1 | 46 | $ 9.20 | $ 11.93 |
| 4 | 16 | 20 | 36 | 0 | 36 | $ 7.20 | $ 9.33 |
| 5 | 27 | 20 | 47 | -1 | 46 | $ 9.20 | $ 11.93 |
| 6 | 25 | 20 | 45 | 1 | 46 | $ 9.20 | $ 11.93 |
| 7 | 40 | 30 | 70 | 19 | 89 | $ 17.80 | $ 23.07 |
| 8 | 90 | 30 | 120 | 3 | 123 | $ 24.60 | $ 31.89 |
| 9 | 24 | 20 | 44 | 2 | 46 | $ 9.20 | $ 11.93 |
| 10 | 17 | 20 | 37 | -2 | 35 | $ 7.00 | $ 9.07 |
| 11 | 47 | 30 | 77 | -2 | 75 | $ 15.00 | $ 19.45 |
| 12 | 68 | 30 | 98 | -2 | 96 | $ 19.20 | $ 24.89 |
| 13 | 75 | 30 | 105 | -5 | 100 | $ 20.00 | $ 25.93 |
| 14 | 235 | 30 | 265 | 2 | 267 | $ 53.40 | $ 69.22 |
| 15 | 93 | 30 | 123 | -7 | 116 | $ 23.20 | $ 30.08 |
| 16 | 57 | 30 | 87 | -11 | 76 | $ 15.20 | $ 19.70 |
| 17 | 34 | 30 | 64 | -2 | 62 | $ 12.40 | $ 16.07 |
| 18 | 80 | 30 | 110 | -4 | 106 | $ 21.20 | $ 27.48 |
| 19 | 139 | 30 | 169 | 4 | 173 | $ 34.60 | $ 44.85 |
| 20 | 298 | 30 | 328 | -4 | 324 | $ 64.80 | $ 84.00 |
| 21 | 191 | 30 | 221 | 8 | 229 | $ 45.80 | $ 59.37 |

***** Averaged DWR 2000 well data

# Technical Note:

## Pumping Lift from DWR Well Data

By: Christina R. Buck
September 20, 2011
Updated October 10, 2011

### Introduction

An estimated pumping lift for each CVPM region is required for calculating pumping costs in CALVIN. Recent efforts to update the representation of groundwater in CALVIN have explored using the Central Valley Hydrologic Model (CVHM), developed by the United States Geological Survey (USGS), and the California Central Valley Simulation (C2VSIM) model, developed by the Department of Water Resources (DWR), to improve required terms. For estimating pumping lift in CALVIN, it was decided that using measured data of groundwater heads would be best.

The pumping lift is the length (often in feet) that water must be pumped from the water surface in the well to ground surface elevation. DWR monitors water levels throughout the Central Valley typically twice per year, once in the spring and then in the fall. This data provides a snapshot of the head in wells at the time of measurement. This is usually close to the start and end of the irrigation season. A variety of well types make up their monitoring network, including irrigation, domestic, stock, monitoring, industrial, observation, recreation wells and some that are no longer in use. Data from this monitoring effort is available online from the Water Data Library (http://www.water.ca.gov/waterdatalibrary/).

### Method

In CALVIN, one number is used to represent typical pumping lifts in irrigation wells in each sub-region. Therefore, water level data was obtained (by Aaron King, UC Davis Center for Watershed Sciences, Graduate Student) from contacts at DWR. The full data set includes wells in CVPM regions 2 thru 21 from years 1990-2011. Data for CVPM region 1 was obtained separately. The year 2000 was chosen to establish a representative pumping lift.

Data was filtered by year (2000). Measurements were tagged as Spring or Fall measurements based on a cutoff of July (July and earlier being a spring measurement, August and later being a fall measurement). This allowed for calculating the average 2000 spring measurement and fall measurement independently. DWR data includes a number of columns: ground surface elevation, RPWS, GSWS, WSE, etc. Ground Surface Water Surface (GSWS) is the measured distance from the ground surface to the water level in the well. This was the data used to calculate a representative pumping lift.

There are a variety of well types in DWR's monitoring network. Wells in the categories of irrigation, irrigation and domestic, stock, unused irrigation wells, observation, and undetermined were used in the calculation. This served to focus mainly on irrigation related wells while still including enough categories to maintain a good sample size. The distribution of wells with measurements taken in 2000 that were used for the calculation is shown in Figure A2.

Measured water levels indicate the piezometric head in the well and are dependent on the screened intervals of the well. This should be distinguished from the "depth to groundwater" which can refer to the distance below ground surface to the water table. Piezometric head in the wells can be higher or lower than the water table depending on the well screening and aquifer dynamics. For this effort, we want the average pumping lift for irrigation wells in each region, so averaging the GSWS measurements in each region to obtain a representative lift for that area assumes that the sample of measured wells is generally representative of wells in that region.

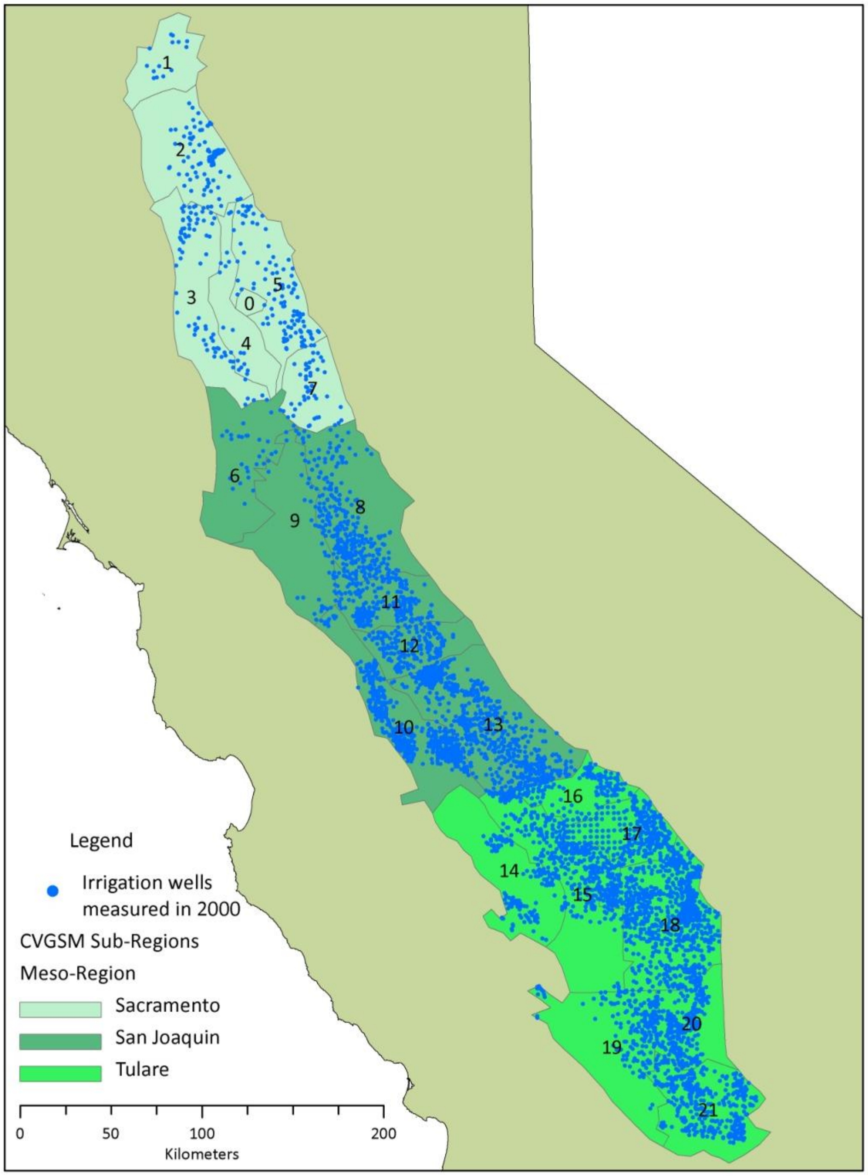
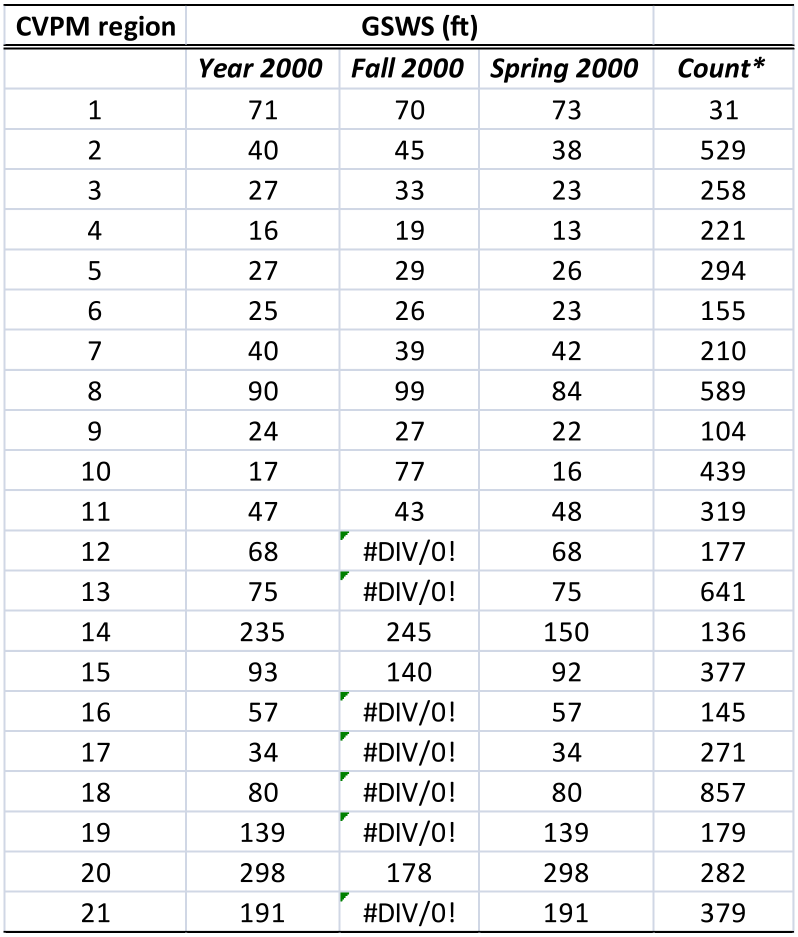


**Figure A2: Distribution of wells measured in 2000 used for the estimate of pumping lift (courtesy of Aaron King)**

Results

Table A1 presents averaged measurements taken any time during year 2000, average of fall and spring measurements, and the total number of measurements used for the year 2000 average (Count).

**Table A1.2: Average GSWS (feet) for measurements taken in 2000, Fall 2000, Spring 2000 and the total count of measurements used for the Year 2000 average**



| CVPM region | GSWS (ft) | | | |
|---|---|---|---|---|
| | *Year 2000* | *Fall 2000* | *Spring 2000* | *Count** |
| 1 | 71 | 70 | 73 | 31 |
| 2 | 40 | 45 | 38 | 529 |
| 3 | 27 | 33 | 23 | 258 |
| 4 | 16 | 19 | 13 | 221 |
| 5 | 27 | 29 | 26 | 294 |
| 6 | 25 | 26 | 23 | 155 |
| 7 | 40 | 39 | 42 | 210 |
| 8 | 90 | 99 | 84 | 589 |
| 9 | 24 | 27 | 22 | 104 |
| 10 | 17 | 77 | 16 | 439 |
| 11 | 47 | 43 | 48 | 319 |
| 12 | 68 | #DIV/0! | 68 | 177 |
| 13 | 75 | #DIV/0! | 75 | 641 |
| 14 | 235 | 245 | 150 | 136 |
| 15 | 93 | 140 | 92 | 377 |
| 16 | 57 | #DIV/0! | 57 | 145 |
| 17 | 34 | #DIV/0! | 34 | 271 |
| 18 | 80 | #DIV/0! | 80 | 857 |
| 19 | 139 | #DIV/0! | 139 | 179 |
| 20 | 298 | 178 | 298 | 282 |
| 21 | 191 | #DIV/0! | 191 | 379 |

*Measurement count for Year 2000

Cells that have #DIV/0! indicate that no data was available during that time or for that area. Spring values tend to be less than fall indicating that water levels in the spring and early summer are closer to the ground surface than by the end of irrigation season. This is due to winter recharge that "refills" the groundwater basin and summer extraction that draws water levels down. In some places where irrigation serves as a major source of recharge, fall levels can be higher than spring levels (example, region 20).

In reality, pumping lift is dynamic and changes between years and within a year. For the purposes of CALVIN, which uses a single number for all time and for each region, Year 2000 values were used because they approximate the overall average of available measured data for groundwater head in wells.

# Appendix 3

## CALVIN Schematic & Network Improvements

Updates to the CALVIN schematic were made to better accommodate components related to groundwater for the agricultural and urban sectors and to facilitate the calibration process. Hidden nodes and nodes for artificial recharge have been added to the PRMNetBuilder network. The following hidden nodes were added:

- Return flow of applied water to surface water from agricultural areas (HSD)
- Return flow of applied water to groundwater for urban areas (HGU)
- Infiltration of surface diversions allocated for spreading-Artificial Recharge (HAR)
- Pumping to all demand areas (HGP)

The added hidden nodes link to physical downstream and upstream nodes and carry amplitude functions that can represent losses. Hidden nodes for pumping (HGP) link groundwater to demand areas and have amplitudes of 1. It is assumed that pumps are located close to the demand areas so that no losses occur.

Hidden nodes for return flow (HGD and HGU) to groundwater for agricultural and urban areas link demand areas to groundwater and have a return flow amplitude representative of fraction of applied water that is returned to the ground. Artificial recharge nodes (HAR) consists of upstream and downstream links such that upstream links to surface water diversions allocated for spreading and carry amplitude that reflect fractions of diverted water that is lost to evaporation and the downstream link is artificial recharge flow to the groundwater basin. Hidden node for return flow to surface water (HSD) for agricultural and urban areas link demand areas to surface water and have return flow amplitude representative of fraction of applied water that is returned to surface water.

Figures A3.1 and A3.2 below show the updated, detailed schematic for agricultural and urban sectors, respectively.

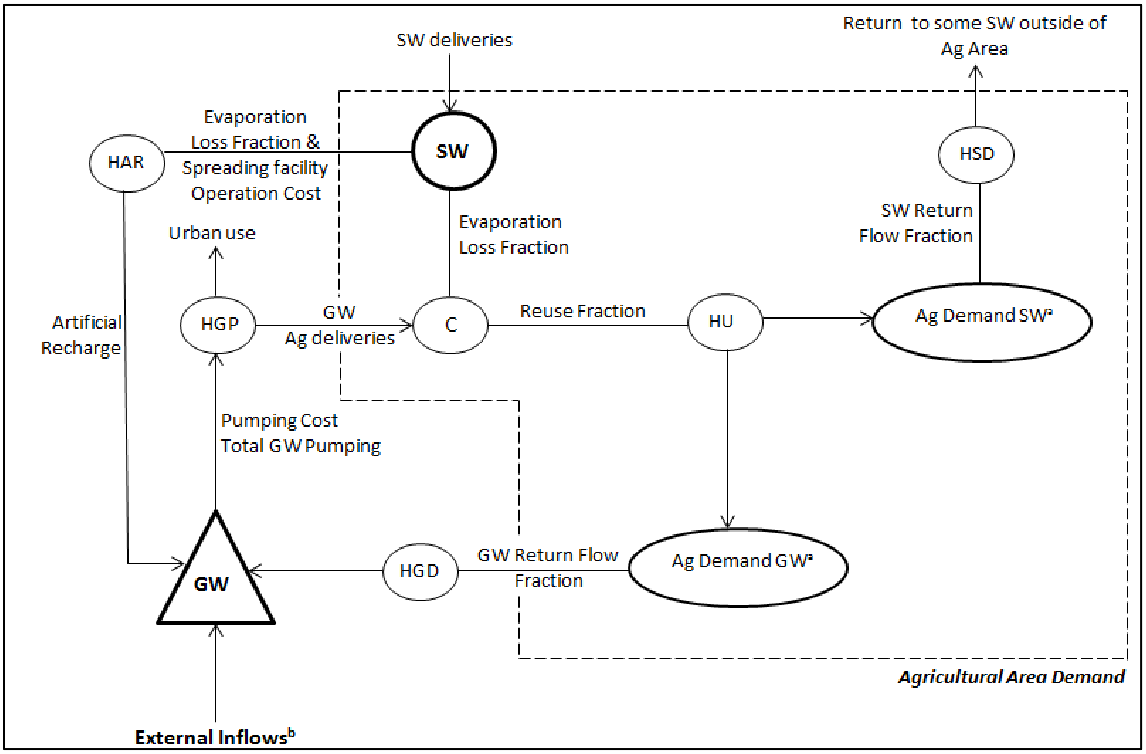


**Figure A3.1: Updated CALVIN Schematic for Agricultural Sector**

*Notes: a) Ag Demand GW represents the non-consumptive use portion of irrigation water that deep percolates to groundwater, and Ag Demand SW represents the portion that returns to surface water systems as tailwater.*
*b) External Inflows represent net monthly time series inflows to groundwater from Streams, Lakes, Deep Percolation of Precipitation, Diversion losses, Boundary Inflows, Interbasin Inflows, Subsidence and Tile Drain Outflows*

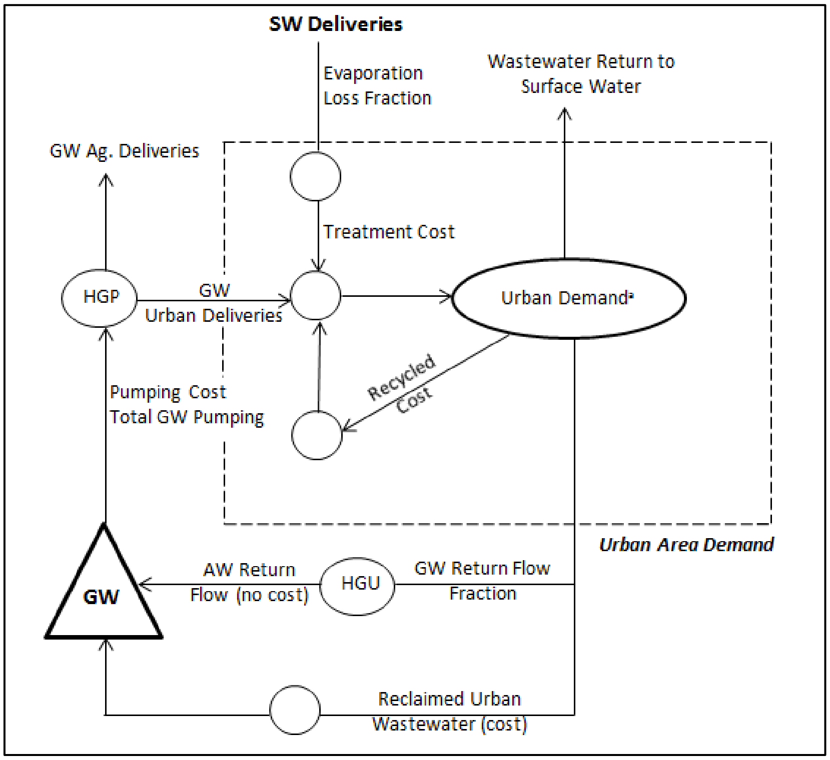


**Figure A3.2: Updated CALVIN Schematic for Urban Sector**

*Notes: a) Urban Demands is represented in CALVIN as Int: CVPM, represent urban demands for water for indoor use and Ext: CVPM is demand for outdoor use, following Bartolomeo (2011).*

# Appendix 4

## C2VSIM Streamflow Adjustments

Differences in streamflow exchange before and after 1951 could be due to the change in aquifer levels and changes in the interactions between surface-groundwater. There are changes in direction and magnitude of flow between groundwater basins and rivers over time so streams that may have been gaining streams before 1951 could have reversed to being losing stream after 1951 or vice versa. Another possibility is that less water goes from groundwater to streams after this time as a result of groundwater depletion and thus smaller stream-aquifer hydraulic connectivity. If the historical time series of streamflows were used, there would likely be a million acre-feet per year of water that may not be accounted for correctly in the Central Valley, which would result in some exaggerated availability of surface water or groundwater.

Because the possible inflated availability, streamflow exchanges before 1951 were adjusted using the annual average difference for subregions above 50 TAF/yr. Adjusted subregions are 2, 4, 5, 6, 9, 11, 13, 15, 18, 19 and 21. In order to maintain mass balance of water available within the subregions, the difference between historical and adjusted stream inflows were accounted for in the depletion areas of respective subregions or as depletions or accretions to major streams in these subregions. Table A4.1 shows monthly flows added or subtracted in the subregion depletion study areas: (-) add to depletion area and (+) subtract from depletion area. Details on depletion areas and how they are used in CALVIN are in the Appendix I (Draper et al. 2000). Table A4.1 also shows depletion and accretion areas and streams corresponding to subregions, as well as nodes per CALVIN network. Depletion and Accretion areas are listed in Appendix I and checked in CALVIN Schematic; stream information is as modeled in C2VSIM - version R356.

**Table A4.1: Adjusted monthly flows to depletion and accretion areas in the Central Valley due to changes in historical streamflow exchanges before 1951**

| Subregion | Depletion Area or Stream | Nodes in CALVIN network | Adjusted monthly inflows (TAF/month) |
|---|---|---|---|
| 2 | 10 | D76a - DA10 Depletion | 11.9 |
| 4 | 15 | D66 - DA15 Depletion | 5.8 |
| 5 | 69 | D37 - DA69 Depletion | 4.9 |
| 6 | 65 | C20 - DA65 Depletion | 9.3 |
| 9 | 55 | D509 - D55 Depletion and Accretion | 10.3 |
| 11 | San Joaquin River to Tuolumne to Stanislaus | D688 - Depletion | 6.4 |
| 13 | Merced River | D643 - Depletion Upper Merced River | 0.2 |
|  |  | D647 - Depletion Lower | 0.3 |

| | | | |
|---|---|---|---|
| | | Merced River | |
| | Chowchilla River | D634 - Depletion Chowchilla River | 0.4 |
| | Fresno River | D624 - Depletion Fresno River | 1.4 |
| | San Joaquin River | D605 - Depletion San Joaquin River | 1.9 |
| 15 | Kings River | C53 - Depletion Kings River | 19.5 |
| 18 | Kaweah River | C89 - Accretion Kaweah River | 0.1 |
| | Tule River | C57 - Accretion Tule River | 4.5 |
| 19 and 21 | Kern River | C97 - Depletion Kern River | 18.2 |

Table A4.2 shows annual average Net External Inflows calculated to be used in CALVIN based on C2VSIM in column 3. The $2^{nd}$ column shows the adjusted values actually used in CALVIN. Columns 4 and 5 show comparisons of average yearly flows under this term from CVHM and CVGSM.

**Table A4.2: Annual Average Net External Inflows in the Central Valley**

| Subregion | Net External Inflows to Groundwater (TAF/yr) | | | |
|---|---|---|---|---|
| | C2VSIM | | | |
| | w/ Adjustments to Streamflow Exchange | w/out Adjustment to Streamflow Exchange | CVHM | CVGSM |
| 1 | 28 | 28 | 6.8 | -96 |
| 2 | 235 | 177 | 406.1 | 189 |
| 3 | -9 | -9 | 30.9 | 77 |
| 4 | -68 | -96 | 23.2 | 227 |
| 5 | 91 | 67 | 64.2 | 6 |
| 6 | 225 | 180 | 453.5 | 302 |
| 7 | 168 | 168 | 186.2 | 242 |
| 8 | 402 | 402 | 685.8 | 686 |
| 9 | 134 | 85 | 446.1 | -118 |
| 10 | 72 | 72 | 30.0 | 262 |
| 11 | 29 | -1 | 19.8 | 303 |
| 12 | 49 | 49 | 57.9 | 129 |
| 13 | 365 | 344 | 564.2 | 781 |
| 14 | 278 | 278 | 260.4 | 267 |
| 15 | 688 | 594 | 1117.0 | 1130 |
| 16 | 51 | 51 | -8.8 | 273 |
| 17 | 96 | 96 | 197.9 | 309 |
| 18 | 241 | 263 | 564.3 | 402 |
| 19 | 424 | 368 | 409.7 | 121 |
| 20 | 101 | 101 | 20.9 | 194 |
| 21 | 322 | 290 | -63.9 | 322 |
| **Sacramento Total** | **1206** | **1002** | 2497.5 | **1515** |

| | | | | |
|---|---|---|---|---|
| **San Joaquin Total** | **515** | **464** | 671.8 | **1474** |
| **Tulare Total** | **2201** | **2041** | 2302.9 | **3017** |
| **Central Valley Total** | **3922** | **3507** | 5472.2 | **6006** |

# Appendix 5

## C2VSIM Surface Water Recoverable and Non-recoverable Losses

Table A5.1shows the C2VSIM surface water recoverable (primarily diversion) and non-recoverable (evaporation and transpiration) losses and how they correspond to CALVIN nodes and links. The 5th column shows the previous version of CALVIN's Recoverable and Non-recoverable loss amplitudes. Column 6 shows the new values used. If a parentheses ( ) is shown, that indicates that amplitude was adjusted to the value inside of the parentheses during the calibration process.

### Table A5.1: Surface Water Recoverable & Non-Recoverable Loss Amplitudes

| C2VSIM Surface Water Diversion Source Node | Subregion | Fraction Non-Recoverable Losses | Land Use | Old CALVIN RL & NRL Amplitude | New CALVIN RL & NRL Amplitude | Diversion Description & CALVIN Nodes & Links for Fraction Update |
|---|---|---|---|---|---|---|
| **Subregion 1** | | | | | | |
| Import | 1 | 0.01 | Ag | | | Whiskeytown and Shasta imports for SR1 Ag |
| | | **0.01** | | **0.97** | **0.96** | **HSU1SR3_C3** |
| Import | 1 | 0.01 | M&I | | | Whiskeytown and Shasta imports for SR1 M&I |
| 206 | 1 | 0.01 | M&I | | | Sacramento River to Bella Vista Conduit SR1 M&I |
| 206 | 1 | 0.01 | M&I | | | Sacramento River Keswick to Red Bluff SR1 M&I |
| | | **0.03** | | **1** | **0.88 (1)** | **T41_Ext: Redding &**<br>**T41_Int: Redding** |
| 206 | 1 | 0.02 | Ag | | | Sacramento River to Bella Vista Conduit SR1 Ag |
| | **1** | **0.02** | | **0.97** | **0.95** | **HSU1D5_C3** |
| 216 | 1 | 0.02 | Ag | | | Sacramento River Keswick to Red Bluff SR1 Ag |
| 212 | 1 | 0.02 | Ag | | | Cow Creek riparian diversions to SR1 Ag |
| 221 | 1 | 0.02 | Ag | | | Battle Creek riparian diversions to SR1 Ag |
| Import | 1 | 0.02 | Ag | | | Cottonwood Creek riparian diversions to SR1 Ag |
| | **1** | **0.08** | | **0.97** | **0.52** | **HSU1D74_C3** |
| **Subregion 2** | | | | | | |
| 234 | 2 | 0.02 | Ag | | | Antelope Creek diversions to Los Molinos MWC SR2 Ag |
| 245 | 2 | 0.02 | Ag | | | Mill Creek to Los Molinos MWC SR2 Ag |
| 258 | 2 | 0.02 | Ag | | | Deer Creek to Los Molinos MWC SR2 Ag |

| | | | | | | |
|---|---|---|---|---|---|---|
| 231 | 2 | 0.02 | Ag | | | Sacramento River diversions to Corning Canal SR2 Ag |
| Import | 2 | 0.02 | Ag | | | Clear Creek riparian diversions to SR2 Ag |
| | | **0.1** | | **0.93** | **0.47 (0.88)** | **HSU2D77_C6** |
| 242 | 2 | 0.02 | Ag | | | Elder Creek riparian diversions SR2 Ag |
| 253 | 2 | 0.02 | Ag | | | Thomas Creek riparian to SR2 Ag |
| 262 | 2 | 0.02 | Ag | | | Sacramento River to SR2 Ag |
| | **2** | **0.06** | | **0.93** | **0.64 (0.88)** | **HSU2C1_C6** |
| 231 | 2 | 0.02 | Ag | | | Sacramento River diversions to the Tehama Colusa Canal to SR2 Ag |
| | **2** | **0.02** | | **0.93** | **0.95** | **HSU2C11_C6** |
| 264 | 2 | 0.02 | Ag | | | Stony Creek to North Canal SR2 Ag |
| Import | 2 | 0.02 | Ag | | | Stony Creek to South Canal from Black Butte Reservoir SR2 Ag |
| | | **0.04** | | **0.93** | **0.88** | **HSU2C9_C6** |
| **Subregion 3** | | | | | | |
| 264 | 3 | 0.02 | Ag | | | Stony Creek to Tehama Colusa Canal and SR3 Ag |
| 231 | 3 | 0.02 | Ag | | | Sacramento River diversions to the Tehama Colusa Canal to SR3 Ag |
| | | **0.04** | | **0.95** | **0.9** | **HSU3C11_C302** |
| 264 | 3 | 0.02 | Ag | | | Stony Creek to Glenn-Colusa Canal and SR3 Ag |
| 261 | 3 | 0.02 | Ag | | | Sacramento River to Glenn Colusa Canal to SR3 Ag |
| 261 | 3 | 0.02 | Refuge | | | Sacramento River to Glenn Colusa Canal to SR3 Refuge (Ag) |
| | | **0.06** | | **0.95** | **0.85** | **HSU3C13_C302** |
| 282 | 3 | 0.02 | Ag | | | Sacramento River to SR3 Ag |
| | | **0.02** | | **0.95** | **0.88** | **HSU3D66_C303** |
| 327 | 3 | 0.02 | Ag | | | Colusa Basin Drain to SR3 Ag |
| 324 | 3 | 0.02 | Refuge | | | Colusa Basin Drain to SR3 Ag |
| | | **0.04** | | **0.95** | **0.76 (0.88)** | **HSU3C305_C303** |
| **Subregion 4** | | | | | | |
| 331 | 4 | 0.02 | Ag | | | Sacramento River to SR4 Ag |
| | | **0.02** | | **0.97** | **0.88** | **HSU4D30_C14** |
| **IN CALVIN: Butte Creek and Little Chico Creek --> SURPLUS DELTA OUTFLOW OR TO NORTH BAY AQUEDUCT TO URBAN NAPA-SOLANO** | | | | | | |
| 285 | 4 | 0.02 | Ag | | | Butte Creek to RD 1004 SR4 Ag |
| 284 | 5 | 0.02 | Ag | | | Butte Creek at Parrott-Phelan Dam to SR5 Ag |

| | | | | | | |
|---|---|---|---|---|---|---|
| 286 | 5 | 0.02 | Ag | | | Butte Creek at Durham Mutual Dam to SR5 Ag |
| 287 | 5 | 0.02 | Ag | | | Butte Creek at Adams and Gorrill Dams to SR5 Ag |
| 291 | 5 | 0.02 | Refuge | | | Butte Creek to Sutter & Butte Duck Clubs to SR5 Ag |
| Import | 5 | 0.02 | Ag | | | Little Chico Creek to SR4 Ag |
| 292 | 4 | 0.02 | Ag | | | Butte Slough to SR4 Ag |
| | | | | | | |
| **Subregion 5: URBAN in CALVIN receives only GW supplies, Yuba receives both GW and SW supplies & Palermo Canal serves Ag** | | | | | | |
| Import | 5 | 0.02 | Ag | | | Tarr Ditch SR5 Ag (55% is used inside the model area) |
| | | **0.02** | | **0.96** | **0.88** | **HSU5C35_C26** |
| Import | 5 | 0.02 | Ag | | | Miocene and Wilenor Canals SR5 Ag |
| Import | 5 | 0.02 | Ag | | | Oroville-Wyandotte ID through Forbestown Ditch SR5 Ag |
| 347 | 5 | 0.02 | Ag | | | Feather River to SR5 Ag (replaced by Thermalito) |
| 347 | 5 | 0.02 | Ag | | | Feather River to SR5 Ag |
| Import | 5 | 0.02 | Ag | | | Bangor Canal SR5 Ag (Miners Ranch Canal) |
| | | **0.08** | | **0.96** | **0.52 (0.88)** | **HSU5C77_C26** |
| Import | 5 | 0.02 | M&I | | | Feather River to Thermalito ID SR5 M&I |
| 352 | 5 | 0.01 | M&I | | | Feather River to Yuba City SR5 M&I |
| Import | 5 | 0.02 | M&I | | | Palermo Canal from Oroville Dam SR5 M&I |
| 351 | 5 | 0.01 | M&I | | | Yuba River to SR5 M&I |
| | | **0.06** | | **1** | **0.82 (1)** | **T61_Ext: Yuba and T61_Int: Yuba** |
| Import | 5 | 0.02 | Ag | | | Thermalito Afterbay to SR5 Ag |
| 358 | 5 | 0.02 | Ag | | | Bear River to Camp Far West ID North Side SR5 Ag |
| | | **0.04** | | **0.96** | **0.76 (0.88)** | **HSU5C80_C26** |
| 351 | 5 | 0.02 | Ag | | | Yuba River to SR5 Ag |
| | | | | **0.96** | **0.88** | **HSU5C83_C26** |
| **Subregion 6** | | | | | | |
| 329 | 6 | 0.02 | Ag | | | Knights Landing Ridge Cut diversions (Baseflow) SR3 Ag |
| 371 | 6 | 0.02 | Ag | | | Sacramento R Rt Bk btwn Knights Landing & Sacramento to SR6 Ag |
| | | **0.04** | | **0.93** | **0.76 (0.88)** | **HSU6C314_C17** |
| 381 | 6 | 0.01 | M&I | | | Sacramento River to West Sacramento SR6 M&I |
| 400 | 6 | 0.02 | M&I | | | Putah South Canal SR6 M&I |
| 413 | 6 | 0.02 | M&I | | | Delta to North Bay Aqueduct to SR6 M&I |

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|---|---|---|---|---|---|---|
| | | **0.05** | | **1** | **0.84 (1)** | **T14_ERes: Napa-Solano, T14_Ind: Napa-Solano and T14_IRes: Napa-Solano** |
| Import | 6 | 0.02 | Ag | | | Cache Creek to SR6 Ag |
| | | | | **0.93** | **0.88** | **HSU6C16_C17** |
| 398 | 6 | 0.02 | Ag | | | Yolo Bypass to SR6 Ag |
| 400 | 6 | 0.02 | Ag | | | Putah South Canal SR6 Ag |
| 404 | 6 | 0.02 | Ag | | | Putah Creek riparian diversions SR6 Ag |
| 413 | 6 | 0.02 | Ag | | | Delta to North Bay Aqueduct to SR6 Ag |
| | | **0.08** | | **0.93** | **0.59 (0.88)** | **HSU6C21_C17** |
| **Subregion 7** | | | | | | |
| 364 | 7 | 0.02 | Ag | | | Feather River to SR7 Ag |
| | | | | **0.93** | **0.88** | **HSU7D42_C34** |
| 358 | 7 | 0.02 | Ag | | | Bear River to Camp Far West ID South Side SR7 Ag |
| 358 | 7 | 0.02 | Ag | | | Bear River to South Sutter WD SR7 Ag |
| Import | 7 | 0.02 | Ag | | | Bear River Canal to South Sutter WD SR7 Ag |
| | | **0.06** | | **0.93** | **0.64 (0.88)** | **HSU7C33_C34** |
| 372 | 7 | 0.02 | Ag | | | Sacramento R Lt Bank btwn Knights Landing & Sacramento to SR7 Ag |
| | | | | **0.93** | **0.88** | **HSU7C67_C34 (Include diversions from Butte Creek & Little Chico)** |
| **Subreigon 8** | | | | | | |
| Import | 7 | 0.01 | M&I | | | Folsom Lake to SR7 M&I |
| 377 | 7 | 0.01 | M&I | | | American R to Carmichael WD SR7 M&I |
| 378 | 7 | 0.01 | M&I | | | American R LB to City of Sacramento SR7 M&I |
| 381 | 8 | 0.01 | M&I | | | Sacramento River Left Bank to City of Sacramento SR8 M&I |
| 375 | 8 | 0.01 | M&I | | | Folsom South Canal to SR8 M&I |
| | | **0.05** | | **1** | **0.76 (1)** | **T4_Ext: Sacramento and T4_Int: Sacramento** |
| 375 | 8 | 0.01 | M&I | | | Folsom South Canal to SR8 M&I |
| | | | | **1** | **0.94 (1)** | **T43_Ext: CVPM8 and T43_Int:CVPM8** |
| Import | 7 | 0.02 | Ag | | | American River to North Fork and Natomas Ditches to SR7 Ag* |
| 375 | 8 | 0.02 | Ag | | | Folsom South Canal to SR8 Ag |
| | | **0.04** | | **0.92** | **0.76 (0.88)** | **HSU8C173_C36** |
| 193 | 8 | 0.02 | Ag | | | Cosumnes R riparian to SR8 Ag |
| | | | | **0.92** | **0.88** | **HSU8C37_C36** |
| Import | 8 | 0.02 | Ag | | | Mokelumne R to SR8 AgS |

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|---|---|---|---|---|---|---|
| 195 | 8 | 0.02 | Ag | | | Mokelumne R to SR8 Ag |
| | | **0.04** | | **0.92** | **0.76 (0.88)** | **HSU8D98_C36** |
| 165 | 8 | 0.02 | Ag | | | Calaveras R to SR8 Ag* |
| *In CALVIN Calaveras diversions are not allocated for SR8 (Calaveras_SR-New Hogan Lake_etc). | | | | | | |
| Central San Joaquin ID from Stanislaus River diversion to CVPM 8 in CALVIN but not in C2VSIM (_C43_HSU8C43_C36_CVPM8 Ag) | | | | | | |
| **Subregion 9** | | | | | | |
| 418 | 9 | 0.02 | Ag | | | Delta to SR9 Ag |
| | | | | **1** | **0.88 (0.93)** | **HSU9D507_C68** |
| Import | 9 | 0.02 | Ag | | | Delta Mendota Canal to Subregion 9 Ag |
| | | | | **1** | **0.93** | **HSU9D521_C68 and HSU9D515_C68** |
| | | | | | | |
| **Subregion 10** | | | | | | |
| 145 | 10 | 0.03 | Ag | | | San Joaquin R riparian (Fremont Ford to Vernalis) SR10 Ag |
| | | | | **0.9** | **0.82** | **HSU10C10_C84** |
| Import | 10 | 0.02 | Ag | | | Delta Mendota Canal to Subregion 10 Ag |
| Import | 10 | 0.02 | Refuge | | | Delta-Mendota Canal to SR10 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU10C30_C84** |
| Import | 10 | 0.02 | Ag | | | Mendota Pool to SR10 Ag |
| Import | 10 | 0.02 | Refuge | | | Mendota Pool to SR10 Refuges (Ag) |
| | | | | **0.9** | **0.82** | **HSU10D731_C84** |
| Import | 10 | 0.02 | Ag | | | O'Neill Forebay to SR10 Ag |
| Import | 10 | 0.02 | Refuge | | | O'Neill Forebay to SR10 Refuges (Ag) |
| | | | | **0.9** | **0.88** | **HSUD803_C84 (IN CALVIN as CA Aqueduct, Harvey Bank Pumping Station, should confirm this)** |
| Import | 10 | 0.02 | Ag | | | San Luis Canal to SR10 Ag |
| Import | 10 | 0.02 | Refuge | | | San Luis Canal to SR10 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU10C85_C84** |
| **Subregion 11** | | | | | | |
| 147 | 11 | 0.03 | Ag | | | Stanislaus R to South San Joaquin Canal to SR11 Ag |
| 147 | 11 | 0.03 | Ag | | | Stanislaus R to Oakdale Canal to SR11 Ag |
| | | **0.06** | | **0.8** | **0.64 (0.82)** | **HSU11D16_C172** |
| 147 | 11 | 0.01 | M&I | | | Stanislaus R to South San Joaquin Canal to SR11 M&I |
| 147 | 11 | 0.01 | M&I | | | Stanislaus R to Oakdale Canal to SR11 M&I |
| 152 | 11 | 0.01 | M&I | | | Stanislaus R riparian to SR11 M&I |
| Import | 11 | 0.01 | M&I | | | Modesto Canal to SR11 M&I |
| 142 | 11 | 0.01 | M&I | | | Tuolumne R RB riparian to SR11 M&I |

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| | | **0.05** | | **1** | **0.7 (1)** | **T45_Ext:CVPM11 and T45_Int:CVPM11** |
| 152 | 11 | 0.03 | Ag | | | Stanislaus R riparian to SR11 Ag |
| | | | | **0.88** | **0.82** | **HSU11D672_C172** |
| Import | 11 | 0.03 | Ag | | | Modesto Canal to SR11 Ag |
| | | | | **0.88** | **0.82** | **HSU11D662_C172** |
| 142 | 11 | 0.03 | Ag | | | Tuolumne R RB riparian to SR11 Ag |
| | | | | **0.88** | **0.82** | **HSU11D664_C172** |
| 145 | 11 | 0.03 | Ag | | | San Joaquin R riparian (Fremont Ford to Vernalis) SR11 Ag |
| | | | | **0.88** | **0.82** | **HSU11D689_C172** |
| **Subregion 12** | | | | | | |
| 142 | 12 | 0.03 | Ag | | | Tuolumne R LB riparian to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU12D664_C45** |
| 142 | 12 | 0.01 | M&I | | | Tuolumne R LB riparian to SR12 M&I |
| 123 | 12 | 0.01 | M&I | | | Merced R Right Bank riparian to SR12 M&I |
| 117 | 12 | 0.01 | M&I | | | Merced R to Merced ID Northside Canal to SR12 M&I |
| Import | 12 | 0.01 | M&I | | | Turlock Canal to SR12 M&I |
| | | **0.04** | | **1** | **0.76 (1)** | **T66_Ext:CVPM12 & T66_Int:CVPM12** |
| Import | 12 | 0.03 | Ag | | | Turlock Canal to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU12D662_C45** |
| 117 | 12 | 0.03 | Ag | | | Merced R to Merced ID Northside Canal to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU12D645_C45** |
| 123 | 12 | 0.03 | Ag | | | Merced R Right Bank riparian to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU12D649_C45** |
| 134 | 12 | 0.03 | Ag | | | San Joaquin R riparian (Fremont Ford to Vernalis) SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU12D699_C45** |
| **Subregion 13** | | | | | | |
| | | | **AG** | **0.9** | **0.94** | **HSU13D606_C46** |
| 123 | 13 | 0.03 | Ag | | | Merced R Left Bank riparian to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU13D649_C46** |
| 117 | 13 | 0.03 | Ag | | | Merced R to Merced ID Main Canal to SR12 Ag |
| | | | | **0.9** | **0.82** | **HSU13D645_C46** |
| Import | 13 | 0.03 | Ag | | | Madera Canal to Chowchilla WD SR13 Ag |
| Import | 13 | 0.03 | Ag | | | Madera Canal to Madera ID SR13 Ag |
| Import | 13 | 0.02 | Ag | | | Madera Canal to SR13 Ag |
| | | **0.05** | | **0.9** | **0.75(0.88)** | **HSU13C72_C46** |
| 84 | 13 | 0.03 | Ag | | | Chowchilla R riparian |

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| | | | | | | SR13 Ag |
| | | | | **0.9** | **0.82** | **HSU13D634_C46** |
| 74 | 13 | 0.03 | Ag | | | Fresno R riparian SR13 Ag |
| | | | | **0.9** | **0.82** | **HSU13D624_C46** |
| 60 | 13 | 0.03 | Ag | | | San Joaquin R riparian (Friant to Gravelly Ford) SR13 Ag |
| 115 | 13 | 0.03 | Ag | | | San Joaquin R riparian (Fremont Ford to Vernalis) SR13 Ag |
| | | | | **0.9** | **0.82** | **HSU13D694_C46** |
| Import | 13 | 0.02 | Ag | | | Delta-Mendota Canal to SR13 Ag |
| Import | 13 | 0.02 | Ag | | | Mendota Pool to SR13 Ag |
| | | **0.04** | | **0.9** | **0.75(0.88)** | **HSU13D731_C46** |
| **Subregion 14** | | | | | | |
| Import | 14 | 0.02 | Ag | | | Mendota Pool to SR14 Ag |
| | | | | **0.9** | **0.82** | **HSU14D608_C91** |
| Import | 14 | 0.02 | Ag | | | San Luis Canal to SR14 Ag |
| Import | 14 | 0.02 | Refuge | | | San Luis Canal to SR14 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU14C92_C91** |
| Import | 14 | 0.01 | M&I | | | San Luis Canal to SR14 M&I |
| | | | | **1** | **0.94** | **D750_Ext:CVPM14** |
| Import | 14 | 0 | Seepage | | | San Luis Canal Seepage Losses SR14 |
| **Subregion 15** | | | | | | |
| 28 | 15 | 0.04 | Ag | | | Kings R Main Stem to SR15 Ag |
| 43 | 15 | 0.04 | Ag | | | Kings R North Fork to SR15 Ag |
| 37 | 15 | 0.04 | Ag | | | Kings R South Fork to SR15 Ag |
| 52 | 15 | 0.04 | Ag | | | Kings R Fresno Slough to SR15 Ag |
| | | | | **0.84** | **0.8** | **HSU15C52_C90** |
| Import | 15 | 0.02 | Ag | | | Mendota Pool to SR15 Ag |
| Import | 15 | 0.02 | Refuge | | | Mendota Pool to SR15 Refuges (Ag) |
| | | | | **0.84** | **0.82** | **HSU15D608_C90** |
| Import | 15 | 0.02 | Ag | | | San Luis Canal to SR15 Ag |
| Import | 15 | 0.02 | Refuge | | | San Luis Canal to SR15 Refuges (Ag) |
| Import | 15 | 0.02 | Ag | | | Friant-Kern Canal to SR15 Ag |
| | | | | **0.84** | **0.93** | **HSU15C49_C90** |
| **Subregion 16** | | | | | | |
| 60 | 16 | 0.03 | Ag | | | San Joaquin R riparian (Friant to Gravelly Ford) SR16 Ag |
| | | | | **0.8** | **0.82** | **HSU16D606_C50** |
| 24 | 16 | 0.03 | Ag | | | Kings R to Fresno ID SR16 Ag |

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| | | | | **0.8** | **0.85** | **HSU16C53_C50** |
| Import | 16 | 0.02 | Ag | | | Friant-Kern Canal to SR16 Ag |
| | | | | **0.8** | **0.93** | **HSU16C49_C50** |
| 60 | 16 | 0.01 | M&I | | | San Joaquin R riparian (Friant to Gravelly Ford) SR16 M&I |
| Import | 16 | 0.01 | M&I | | | Friant-Kern Canal to SR16 M&I |
| | | **0.02** | | **1** | **0.88 (1)** | **T24_Ext: City of Fresno and T24_Int: City of Fresno** |
| **Subregion 17** | | | | | | |
| 25 | 17 | 0.04 | Ag | | | Kings R to Consolidated ID SR17 Ag |
| 25 | 17 | 0.04 | Ag | | | Kings R to Alta ID SR17 Ag |
| | | | | **0.9** | **0.8 (0.88)** | **HSU17C53_C55** |
| Import | 17 | 0.02 | Ag | | | Friant-Kern Canal to SR17 Ag |
| | | | | **0.9** | **0.93** | **HSU17C76_C55** |
| Import | 17 | 0 | Seepage | | | Friant-Kern Canal to SR17 Seepage Loss |
| **Subregion 18** | | | | | | |
| 420 | 18 | 0.03 | Ag | | | Kaweah R Partition A to SR18 Ag |
| 422 | 18 | 0.03 | Ag | | | Kaweah R Partition B to SR18 Ag |
| 422 | 18 | 0.03 | Ag | | | Kaweah R Partition C to SR18 Ag |
| 420 | 18 | 0.03 | Ag | | | Kaweah R Partition D to SR18 Ag |
| 426 | 18 | 0.03 | Ag | | | Kaweah R to Corcoran ID SR18 Ag |
| | | | | **0.9** | **0.83** | **HSU18C56_C60** |
| 18 | 18 | 0.03 | Ag | | | Tule R riparian to SR18 Ag |
| | | | | **0.9** | **0.83** | **HSU18C58_C60** |
| Import | 18 | 0.02 | Ag | | | Friant-Kern Canal to SR18 Ag |
| | | | | **0.9** | **0.93** | **HSU18C688_C60** |
| Import | 18 | 0.01 | M&I | | | Friant-Kern Canal to SR18 M&I |
| | | | | **1** | **0.94 (1)** | **C688_T51 (New supply for 2100 from FKC to CVPM18)** |
| **Subregion 19** | | | | | | |
| 7 | 19 | 0.01 | Ag | | | Kern R to SR19 Ag |
| | | | | **0.9** | **0.92** | **HSU19C73_C100** |
| Import | 19 | 0.02 | Ag | | | California Aqueduct to SR19 Ag |
| Import | 19 | 0.02 | Refuge | | | California Aqueduct to SR19 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU19D847_C100 and HSU19D850_C100** |
| Import | 19 | 0.02 | Ag | | | Friant-Kern Canal to SR19 Ag |
| Import | 19 | 0.02 | Refuge | | | Friant-Kern Canal to SR19 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU19C62_C100** |

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|---|---|---|---|---|---|---|
| Import | 19 | 0.02 | Refuge | | | Cross-Valley Canal to SR19 Refuges (Ag) |
| | | | | **0.9** | **0.93** | **HSU19C74_C100** |
| **Subregion 20** | | | | | | |
| 2 | 20 | 0.03 | Ag | | | Kern R to SR20 Ag |
| | | | | **0.9** | **0.84** | **HSU20C65_C63** |
| Import | 20 | 0.02 | Ag | | | Friant-Kern Canal to SR20 Ag |
| | | | | **0.9** | **0.93** | **HSU20C64_C63** |
| Import | 20 | 0.02 | Ag | | | Cross-Valley Canal to SR20 Ag |
| | | | | **0.9** | **0.93** | **HSU20C74_C63** |
| 2 | 20 | 0.01 | M&I | | | Kern R to SR20 M&I |
| Import | 20 | 0.01 | M&I | | | Friant-Kern Canal to SR20 M&I |
| | | **0.02** | | **1** | **0.88 (1)** | **T53_Int:CVPM20 and T53_Ext:CVPM20** |
| **Subregion 21** | | | | | | |
| 2 | 21 | 0.02 | Ag | | | Kern R to SR21A Ag |
| 3 | 21 | 0.02 | Ag | | | Kern River to Subregion 21B Ag |
| 4 | 21 | 0.02 | Ag | | | Kern River to Subregion 21C Ag |
| | | | | **0.8** | **0.9** | **HSU21C65_C66** |
| Import | 21 | 0.02 | Ag | | | California Aqueduct to SR21 Ag |
| Import | 21 | 0.02 | Ag | | | Friant-Kern Canal to SR21 Ag |
| | | | | **0.8** | **0.93** | **HSU21C689_C66** |
| Import | 21 | 0.02 | Ag | | | Cross-Valley Canal to SR21 Ag |
| | | | | **0.8** | **0.93** | **HSU21C74_C66** |
| Import | 21 | 0.01 | M&I | | | California Aqueduct to SR21 M&I |
| | | | | **1** | **0.94 (1)** | **T28_Int:Bakersfield and T28_Ext:Bakersfield** |