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Updating the CALVIN Hydro-Economic Optimization Model of California: *Central Valley Groundwater*

Heidi Chou, Prudentia Zikalala, Christina R. Buck, Jay R. Lund, Josué Medellín-Azuara

Abstract Updates are being made to Central Valley groundwater in CALVIN, a hydro-economic model of California's intertied water supply and delivery system. These updates reflect better estimates of water demands, groundwater availability, and local water management opportunities. This poster focuses on updating 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. Two CALVIN update projects, using the DWR and USGS groundwater models, are underway to improve groundwater representation including basin inflows, reuse, return flows, capacities, and pumping costs. These sub-projects will result in a CALVIN model with updated groundwater representation based on C2VSIM and CVHM. This poster shows a preliminary comparison of these sub-projects and a summary comparison between the DWR and USGS models.

CALVIN Background

CALVIN, the CALifornia Value Integrated Network model is an economic-engineering optimization model of California's water system, covering 92% of California's population and 88% of the irrigated crop area (Jenkins et al. 2001). The model uses a network flow optimization solver 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. Since CALVIN is a system engineering model, groundwater levels are not represented as in a groundwater model; groundwater volumes are modeled instead (Draper et al. 2003). To update the groundwater representation in CALVIN, newer information from more detailed and dedicated groundwater models are employed. Currently, CALVIN's groundwater representation is 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).

Central Valley groundwater basins in CALVIN are represented by the Central Valley Production Model (CVPM) subregions (subbasins) as shown in Figure 1. C2VSIM and CVHM use the same subregion index for groundwater basins, allowing direct comparisons of data and results.

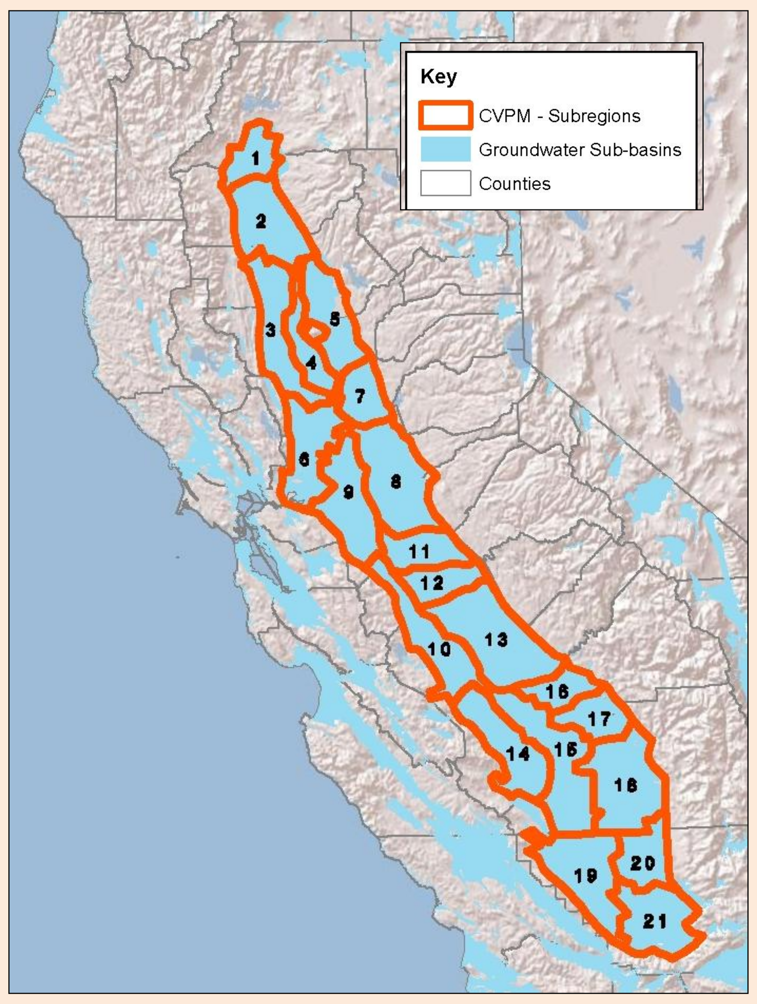

Figure 1: Groundwater Subbasins Modeled in CALVIN

California Groundwater Modeling Efforts

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 (CDWR 2011). The United States Geological Survey (USGS) also developed a groundwater model for the Central Valley using MODFLOW and published its development in 2009 (Faunt et al. 2009). These two models, C2VSIM and CVHM, have been studied extensively to draw data and results for improving CALVIN's groundwater representation.

Using MODFLOW and the FMP, CVHM simulates major groundwater and surface water processes in the Central Valley for the 21 water-balance regions for water years 1962 to 2003. 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 (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 2009. The model uses a 3-layered, 1392 element, finite element grid that overlays the entire Central Valley. More information on C2VSIM can be found in Brush et al. (2008) and CDWR (2011).

CALVIN Groundwater Parameters

Using model inputs and outputs from C2VSIM and CVHM, CALVIN input parameters were developed. Terms extracted from the simulation models and input to CALVIN for each groundwater sub-basin (GWSB) are shown in Table 1. A schematic describing the terms and how groundwater interacts in CALVIN is shown in Figure 2.

Table 1: 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	Inter-basin flows	Monthly time series
5	External flows	Monthly time series
5-1	Stream Leakage	Monthly time series
5-2	Deep percolation from precipitation	Monthly time series
5-3	Boundary inflow	Monthly time series
5-4	Conveyance seepage	Monthly time series
6	Lower-bound groundwater pumping (minimum)	Number value
7	Upper-bound groundwater pumping (maximum)	Number value
8	Representative depth to groundwater (pumping lift)	Number value
9	Storage capacity terms (minimum, maximum, initial, ending)	Number values (4)
10	Non-recoverable conveyance loss (calibration term)	Amplitude (<1)

The agricultural return flow split term separates return flows (not consumptively used) to surface water from those that more directly recharge groundwater. Agricultural return flows are a large source of recharge for Central Valley aquifers, especially south of the Delta. This term defines the fraction of agricultural return flow to surface water (1a) and to groundwater (1b).

The internal reuse term represents the portion of return flow that is "reused" on a farm for irrigation, sometimes called "tail water reuse".

The return flow of gross applied water applies to return flow to both surface water and groundwater. This term is estimated using information on irrigation efficiencies, or evapotranspiration of applied water. This parameter is compared between the C2VSIM, CVHM, and CVGSM (CALVIN) in Table 2 in the next section.

Inter-basin flow is net groundwater flow between subregions and is input to CALVIN as a monthly time series for each subregion.

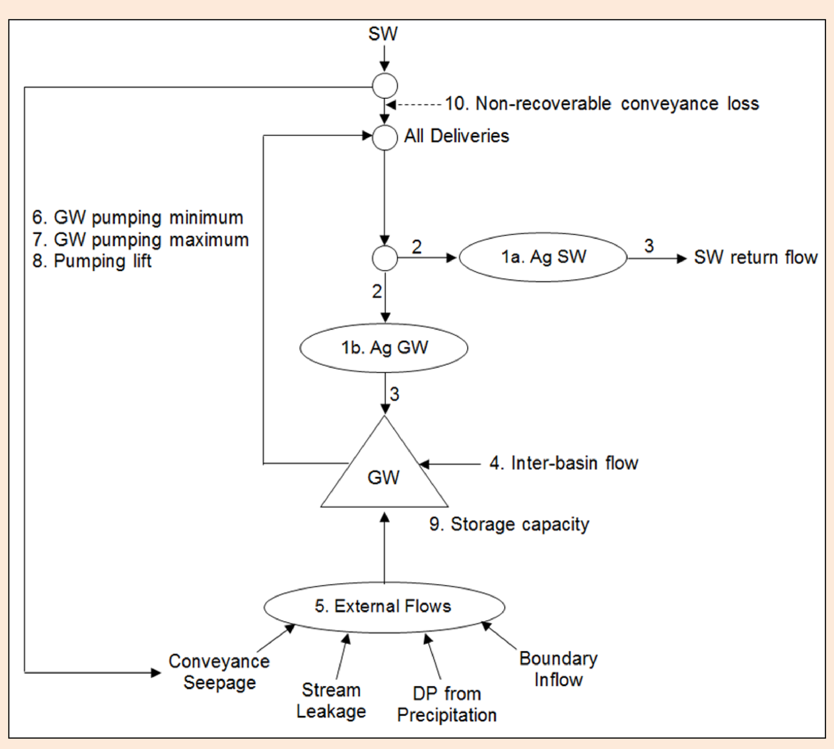

Figure 2: Flows and Interactions in CALVIN Groundwater Sub-basins

External flows include several source flows into and out of each groundwater subregion, excluding return flow from urban areas and agricultural applied water. These flows include groundwater-surface water interactions of streams (stream leakage), deep percolation from precipitation, boundary inflows, and conveyance seepage. The sum of these individual time series comprise the External Flows monthly time series input to CALVIN.

Depth to groundwater ("pumping depth" or "pumping lift") is used in CALVIN to establish agricultural pumping costs. CALVIN assumes a fixed cost per foot of lift for each subregion; these calculated costs are used as model inputs. Water level data for the Central Valley was obtained from DWR. The year 2000 was chosen to establish a representative pumping lift. Information on the calculations and methods used to determine these parameters, as well as a comparison of these parameters between CVGSM (CALVIN), C2VSIM and CALVIN can be found in Chou (MS Thesis 2012).

Model Comparison: Return Flow Fractions and Deliveries

Potential Consumptive Use of Applied Water (Potential CUAW) is the applied water needed for optimal agricultural conditions where crop production is controlled by maintaining ET rates at their potential levels, soil moisture losses to deep percolation are minimized, and the minimum soil moisture requirements are met. Consumptive use depends on soil type, crop type, and climatic data. Return flow, deep percolation, and losses from conveyance structures of the irrigation system are considered to be part of the irrigation water that goes to non-consumptive uses. C2VSIM and CVHM fractions shown in Table 2 represent fraction of return flow and deep percolation in total applied water.

Separate CALVIN models, based on CVHM and C2VSIM, have been developed. These models are run for water years 1980-1993 since this is the time period of overlap between the three models. A comparison of preliminary results of water deliveries (groundwater, surface water, and net total) for each subregion without calibration is shown in Table 3.

Groundwater pumping data is not readily available in many areas of California. C2VSIM and CVHM data are useful for estimating stresses on groundwater resources and understanding changes in groundwater for the management of this resource as well as surface water. Historical water deliveries met by pumping are 31%, 32% and 49% of use for C2VSIM and 52%, 25%, 50% of use for CVHM for the Sacramento, San Joaquin, and Tulare regions, respectively.

Table 2: Return Flow Fraction of Applied Water

Subregion	C2VSIM[1]	CVHM[2]	CVGSM[3]
1	0.47	0.26	0.33
2	0.14	0.27	0.23
3	0.20	0.17	0.31
4	0.14	0.21	0.32
5	0.21	0.2	0.35
6	0.06	0.23	0.32
7	0.25	0.23	0.41
8	0.12	0.25	0.34
9	0.09	0.22	0.31
10	0.20	0.21	0.32
11	0.22	0.23	0.33
12	0.16	0.24	0.3
13	0.12	0.21	0.29
14	0.18	0.13	0.22
15	0.12	0.24	0.28
16	0.28	0.19	0.28
17	0.13	0.2	0.26
18	0.18	0.21	0.27
19	0.03	0.23	0.25
20	0.10	0.19	0.26
21	0.10	0.19	0.26

[1]Description of these calculations can be found in Zikalala (ongoing research).
[2]Description of these calculations can be found in Chou 2012; Faunt et al. 2009.
[3]Description of these calculations can be found in Jenkins et al. 2001.

Table 3: 1980-1993 Average Annual Water Deliveries

Subregion	C2VSIM Deliveries (TAF/yr)			CVHM Deliveries (TAF/yr)		
	Net GW	Net SW	Total Deliveries	Net GW	Net SW[1]	Total Deliveries
1	30	171	201	49	70	119
2	322	186	508	542	132	674
3	96	1340	1436	32	652	684
4	136	617	752	6	74	80
5	332	1085	1417	62	401	463
6	238	354	593	414	368	782
7	347	435	782	201	256	457
8	710	167	877	843	257	1100
9	118	925	1044	284	112	395
10	332	1014	1346	45	948	993
11	163	740	903	74	632	706
12	185	552	737	59	432	491
13	755	781	1536	816	908	1724
14	540	978	1517	588	914	1502
15	1140	1004	2143	1837	736	2573
16	170	458	628	184	292	476
17	385	346	732	495	398	893
18	593	1027	1620	1288	789	2077
19	639	390	1030	725	488	1214
20	447	344	790	273	721	994
21	1013	566	1579	183	1150	1333
Sacramento	**2330**	**5281**	**7611**	**2433**	**2321**	**4754**
San Joaquin	**1435**	**3087**	**4522**	**993**	**2921**	**3914**
Tulare	**4927**	**5112**	**10039**	**5573**	**5487**	**11060**
Central Valley Total	**8692**	**13480**	**22172**	**8999**	**10730**	**19729**

[1]CVHM Net SW includes the sum of agricultural SW deliveries from CVHM and urban SW deliveries from C2VSIM

Model Comparison: Mass Balances

Table 4 shows the historical (1980-1993) groundwater balance for the C2VSIM and CVHM models. Average annual external flows for both models include: stream exchanges, boundary inflow, deep percolation of precipitation and interbasin flows. C2VSIM flows include lake exchanges, bypass losses, diversion losses, canal leakage and direct recharge to groundwater.

Direct recharge to groundwater from Recharge basins will be modeled explicitly in final CALVIN, since these are actively managed seepage areas and are therefore a decision variable with management costs. Calibration Flow 1 is the discrepancy in the mass balance per CALVIN flow terms extracted directly from the physical models. For the CVHM-CALVIN terms, all flows in and out of the groundwater basins are accounted for, resulting in the low Calibration Flow 1 values shown in Table 4. For C2VSIM-CALVIN, some flows (i.e. tile drain flows) are not accounted for in the balance and the assumption that water in the unsaturated zone ends up in the saturated zone within a month step affects the estimated deep percolation terms, which results in some higher Calibration Flow 1.

Historical runs for C2VSIM and CVHM model show that on an annual basis, total inflows to groundwater in the Central Valley are larger for CVHM than C2VSIM. Even though historical annual pumping estimated in CVHM is larger than the C2VSIM estimate, CVHM shows less overdraft for the entire valley. The differences in the way the two Central Valley models simulate groundwater budgets indicate different implications for water management. However, given a lack of groundwater data in California, these models remain useful for policy and management studies of groundwater resources.

Table 4: Average Annual Groundwater Mass Balance Comparison[1] (Preliminary Results)

Subregion Number	Net External Flows[2] (taf/yr)		Net Pumping[3] (taf/yr)		Recharge from Applied Water[4] (taf/yr)		Change in Storage[5] (taf/yr)		Calibration Flow 1[6] (taf/yr)	
	C2VSIM	CVHM	C2VSIM	CVHM	C2VSIM	CVHM	C2VSIM	CVHM	C2VSIM	CVHM
1	22	7	30	49	24	0	16	-42	0	0
2	300	406	322	542	34	93	12	-43	0	0.02
3	-12	31	96	32	127	12	18	11	0	0.04
4	45	23	136	6	86	1	-4	17	0	0.08
5	173	64	332	62	140	2	-18	4	0	0.02
6	215	453	238	414	36	8	12	48	0	0.18
7	202	186	347	201	77	1	-67	-14	0	0.05
8	534	686	710	843	79	135	-98	-22	0	0.03
9	85	446	118	284	28	2	6	157	11	3.44
10	117	30	332	45	190	13	-39	-3	-14	0.98
11	67	20	163	74	114	51	-2	-4	-20	0.12
12	85	58	185	59	62	13	-26	10	11	0.88
13	416	564	755	816	212	104	-147	-149	-20	0.86
14	312	260	540	588	110	196	-111	-132	6	0.01
15	768	1117	1140	1837	314	547	-5	-174	53	0.8
16	97	-9	170	184	104	62	-19	-131	-49	0.06
17	159	198	385	495	114	170	-91	-127	20	0.18
18	374	564	593	1288	264	442	11	-283	-33	0.09
19	419	410	639	725	50	215	-110	-101	60	0.07
20	168	21	447	273	114	160	-187	-92	-23	-0.01
21	508	-64	1013	183	67	170	-437	-78	0	0.37
SAC Total	**1564**	**2303**	**2330**	**2433**	**631**	**255**	**-123**	**116**	**11**	**4**
SJ Total	**685**	**672**	**1435**	**993**	**579**	**181**	**-214**	**-147**	**-42**	**3**
TL Total	**2805**	**2498**	**4927**	**5573**	**1138**	**1961**	**-949**	**-1118**	**34**	**2**
Central Valley Total	**5054**	**5472**	**8692**	**8999**	**2348**	**2396**	**-1286**	**-1149**	**3**	**8**

[1]Average Annual values calculated based on water years 1980-1993.
[2]Net External Flows includes all flows excluding recharge from applied water.
[3]Net pumping includes urban and agricultural pumping.
[4]Recharge from Applied Water includes urban and agricultural recharge from applied water.
[5]This term is the average annual change in storage for water years 1980-1993.
[6]Calibration Flow 1 represents the difference between [Net External Flows + Recharge from Applied Water – Pumping] and Change in Storage.

Conclusion

Integrated hydro-economic modeling is useful for examining benefits and drawbacks of existing or proposed state water policies, operations, and plans. However, water conditions, regulation, demands, and estimates are constantly changing, so updates are needed to maintain and improve the usefulness of models. Incorporating newer data should make system models, like CALVIN, more useful. C2VSIM and CVHM are both being used to improve representation of Central Valley groundwater in CALVIN, which can lead to studies investigating the economic impacts of Central Valley groundwater use, aid in assessing the practical limitations of our understanding of Central Valley hydrology, and provide an additional framework for groundwater policy discussions.

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Contact info:
hdchou@ucdavis.edu,
pgzikalala@ucdavis.edu