APPENDIX J

GROUNDWATER HYDROLOGY

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INTRODUCTION

Groundwater hydrology in CALVIN is discussed in this appendix. Groundwater is treated explicitly in CALVIN, although in a simplified manner. It is fully integrated with surface supplies and water demands. Monthly groundwater hydrology for the period of study (1922-93) was generated from Central Valley simulations using the Integrated Ground Surface Water Model (IGSM) and other groundwater analyses, some of which include groundwater models. Data obtained from these sources necessitated post-processing, manipulation, and/or extrapolation to conform to the requirements of CALVIN. Data sources and procedures are discussed in this appendix. The appendix is organized into four topics: (1) general treatment of groundwater in CALVIN, (2) groundwater data, (3) limitations, and (4) future work and possible improvements. Reference to supporting computer files is made. These files can be found in the "Software and Data Appendices" under "Groundwater Hydrology" in the electronic version of the CALVIN project reports.

GENERAL TREATMENT OF GROUNDWATER IN CALVIN

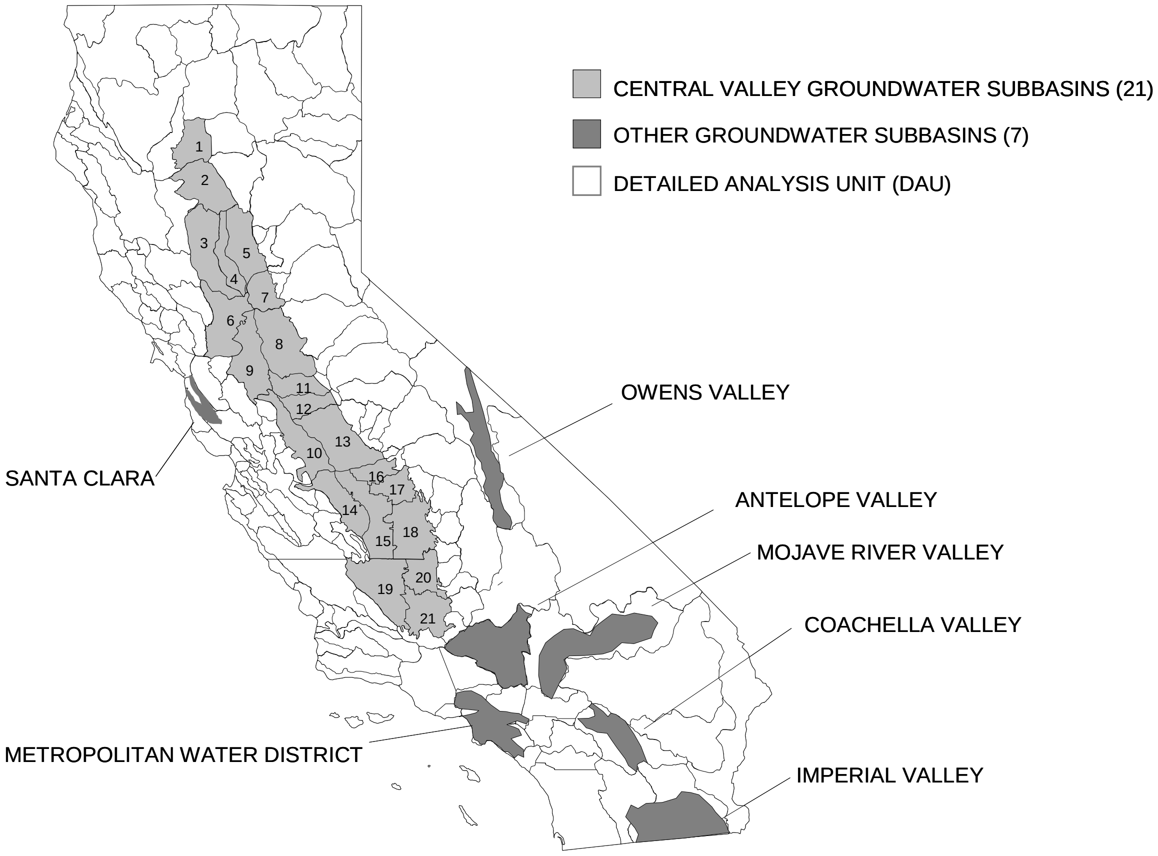
The computational engine used by CALVIN is HEC's Prescriptive Reservoir Model (HEC-PRM). HEC-PRM is a reservoir optimization model (HEC 1999). In CALVIN groundwater is represented as reservoirs. These "underground" reservoirs are treated in the same manner as surface reservoirs. The location of groundwater reservoirs, their interaction with other elements in the model, and data required to generate the groundwater component of CALVIN are presented next.

Location of Groundwater Reservoirs

CALVIN depicts the inter-tied water system of California. Representation of groundwater, thus, is limited to the aquifers that are contained within the Central Valley and seven subbasins outside of the Central Valley. Consequently, groundwater in the far north (north of Redding along the coast and adjacent to Oregon and Nevada), in northern portion of the Bay Area, in the Monterey-Salinas subbasin, and in the southern California desert that abuts Nevada all lie outside the inter-tied system and are not included in the model. Furthermore, groundwater in the San Diego County area was excluded, although it forms part of the inter-tied system. While important locally, groundwater in this area is (a) local in nature, (b) comprised of many small subbasins, and (c) constitutes a small fraction of total water use in the San Diego area. Groundwater in the Metropolitan area of coastal southern California is represented only in a limited and aggregate way because the details, data, and complexity of the many locally operated basins in this region were difficult to obtain and represent in CALVIN.

The groundwater “reservoirs” in CALVIN represent 28 subbasins (GWSB) in the Central Valley, Bay Area, Owens Valley, and Southern California areas (Figure J-1). Of the total, 21 are found in the Central Valley (GW-1 to GW-21) and conform on a one-to-one basis with the Central Valley Production Model (CVPM) subregions described in Appendix A and K. The GWSB in the southern Bay Area (termed GW-SC for Santa Clara) represents groundwater basins in the Santa Clara Valley (those of Santa Clara Valley Water District) and groundwater aquifers in the East Bay managed by Alameda County Water District (Niles Cone basin) and Alameda County Zone 7 (Livermore-Amador Valley basin). In the southeastern Sierra Nevada mountain range, there is a GWSB in Owens Valley (GW-OW). In Southern California there are five GWSBs: Antelope Valley (GW-AV), Mojave River Valley (GW-MJ), Coachella Valley (GW-CH), Imperial Valley (GW-IM), and an amalgamated GWSB that represents only the additional available empty storage space, beyond that currently used by local agencies, in the Metropolitan Water District service area (GW-MWD). Correspondence between CALVIN GWSBs and Department of Water Resources (DWR 1980) subbasins can be found in Annex J-A-1 of this appendix.

Figure J-1. Location of Groundwater Subbasins Modeled in CALVIN



Note: spatial extent of groundwater subbasins is estimated

Groundwater Conceptualization and Interaction with Other Elements in CALVIN

In Figure J-2, schematics are shown of typical components of CALVIN. Schematics of the agricultural and urban sectors are depicted in the top and bottom of this figure. Only the components related to groundwater are discussed here (see the appropriate appendix for other components). Groundwater data required to operate CALVIN consist of (1) GWSB storage volume characteristics, (2) infiltration of agricultural and urban applied water, (3) local inflows (recharge sources excluding agricultural and urban applied water), (4) inter-subbasin flows, (5) artificial recharge facilities and characteristics, and (6) pumping facilities and characteristics. Inter-subbasin flows in the Central Valley have been built into the groundwater inflow hydrology in CALVIN by combining net inter-subbasin flow volumes from CVGSM (Central Valley Ground Surface Water Model) results into local GWSB inflows (explained in more detail later).

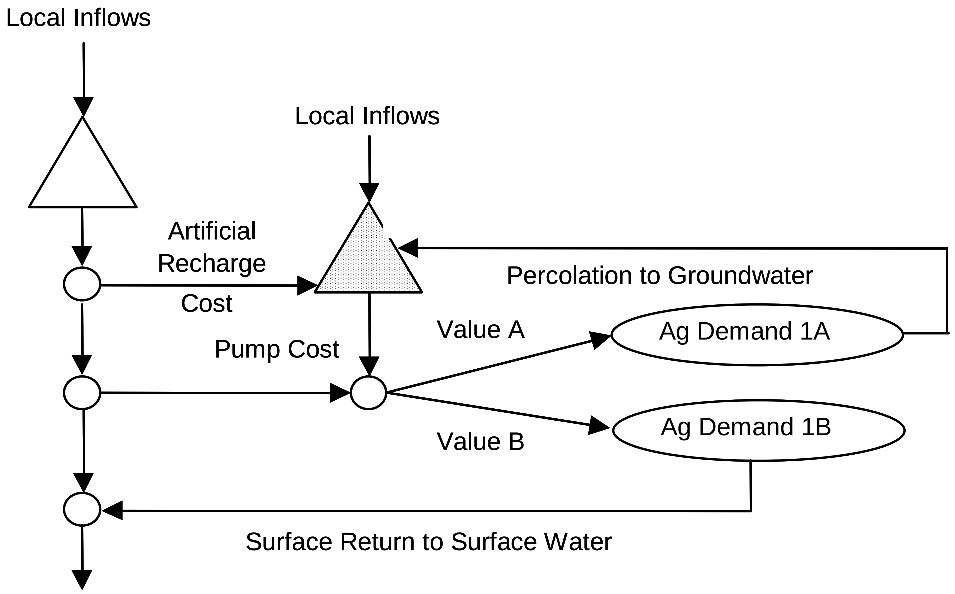
The initial storage volume and total storage capacity of each GWSB are required. Local inflows recharge the GWSBs. Physically, recharge is made up of several water sources. In CALVIN, the configuration is such that infiltration from agricultural and urban applied water is treated differently from all other sources. Infiltration due to applied water (AW) is determined dynamically in the model based on the actual water deliveries to each agricultural and urban region prescribed by CALVIN, and each region's return flow factors (see Appendix K: Irrigation Water Requirements, Appendix 2H: Calibration Process Details, and supporting file *CVGSM Return Flows mark MJed Nov99.xls*). Thus, there is a dynamic link in CALVIN between agricultural and urban regions and their underlying GWSBs to account for deep percolation of AW.

GWSB local inflows are preprocessed, fixed monthly time series of net recharge that are entered directly into CALVIN. They are generally comprised of (a) precipitation deep percolation, (b) stream-aquifer exchanges, (c) canal seepage, (d) lakebed seepage, (e) vertical movement between groundwater layers, (f) boundary flow, (g) inter-subbasin flows, and (h) historical artificial recharge. There are some exceptions to this list of inflow components for some of the GWSBs outside the Central Valley, where construction of inflow time-series depended on sometimes very limited data. Inter-subbasin flows (g) represent the migration of water between different GWSBs in the Central Valley and are currently lumped into local inflows. Information to separate out historical artificial recharge (h) from canal seepage (c) in the data source for the Central Valley groundwater inflows (CVGSM) was very difficult to determine so it is also amalgamated with other components of local inflow, leading to some possible calibration problems (see Appendix 2H: Calibration Process Details). The only recharge source removed from local inflows is percolation of agricultural and urban AW. Development of the data for local inflows in CALVIN is discussed in the next section.

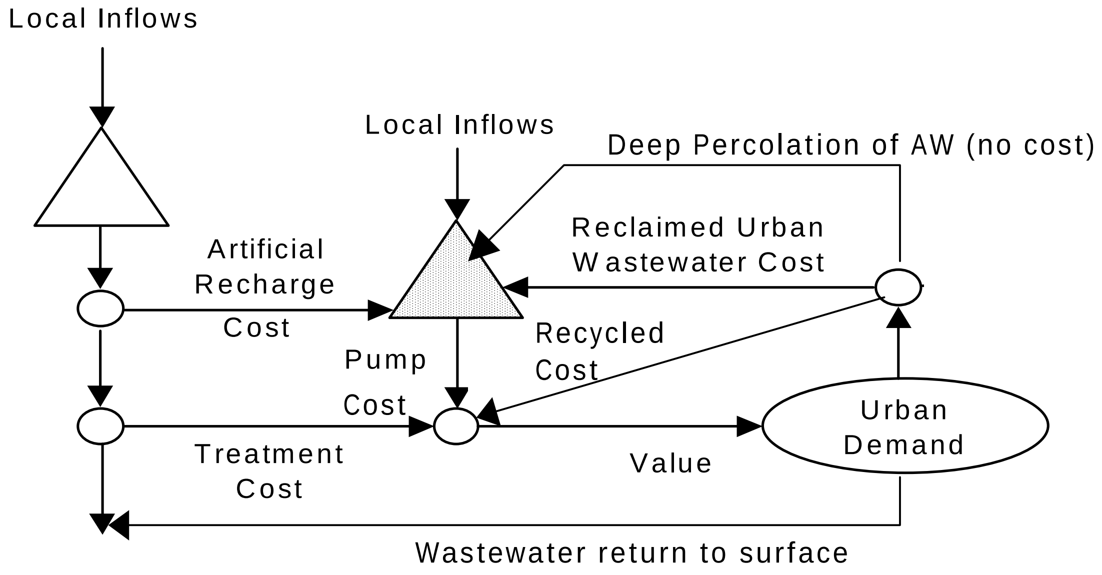
In the current CALVIN formulation, location and capacity of artificial recharge is limited to GWSBs outside the Central Valley. The existing Central Valley recharge facilities (mostly in the Tulare Basin but also some in the vicinity of the San Joaquin River and its tributaries) are not included because historic artificial recharge could not be separated from other components of local groundwater inflow in the data used for CALVIN. The capacities of artificial recharge facilities in CALVIN are based on local agency information (see Appendix H: Infrastructure) and costs of recharge are limited to variable operation and maintenance (O&M) costs (see Appendix G: Operating Costs).

Figure J-2. Groundwater Interaction with Other Elements in CALVIN

Agricultural Sector



Urban Sector



Notes:
1. Triangles represent reservoirs. Groundwater reservoirs are shaded. Arrows indicate links (possible flow lines).
2. Calibration nodes are not depicted in the schematics.
3 In the current formulation of CALVIN, inter-subbasin flow between groundwater subbasins is included in the local inflows.

Groundwater is extracted from the subbasins through pumping. Maximum pumping capacities are required for each subbasin, as is the cost of pumping. Costs for pumping in agricultural areas reflect the O&M of pumping facilities. Groundwater pumped for urban use may incur additional costs associated with different pumped and treatment conditions. Presently, urban groundwater treatment is limited to chlorination. Further explanations can be found in Appendix G: Operating Costs.

Groundwater Data

Groundwater data required in CALVIN is summarized in Table J-1. Procedures used to generate the data for CALVIN are discussed in the next sections. Further steps and calculations of data preparation can be found in supporting files of the "Software and Data Appendices" of the project reports.

The approach to prepare groundwater data for CALVIN differed for subbasins within and outside the Central Valley. In the Central Valley, groundwater data was readied by pre- and post-processing data and results from the Central Valley Ground Surface Water Model (CVGSM) No Action Alternative (NAA) (USBR 1997). Outside of the Central Valley, no single source provided sufficient information to generate data for all subbasins. Consequently, different sources were combined and used to generate the necessary groundwater data for CALVIN, including precipitation records, water resources planning reports, and computer simulations.

Table J-1. Groundwater Data Required by CALVIN for each GWSB

Item	Data for CALVIN	Items Needed to Produce Input Data
1	Initial and total storage capacity (volume)	Areal extent of GWSB, surface elevation, depth to groundwater, depth of available (i.e. useable) groundwater, and specific yield
2	Percolation of agricultural or urban applied water	Soil zone water balance accounting with itemized components (applied water, precipitation, direct runoff, runoff, ET, consumptive use, deep percolation) or derived estimate of average percentage of applied water that deep percolates to groundwater
3	Local inflows	Groundwater balance accounting with itemized components (precipitation deep percolation, stream-aquifer exchanges, canal seepage, lakebed seepage, vertical movement between aquifer layers, and boundary flows) or amalgamated estimate of average recharge and its variability for these components
4	Inter-subbasin flows	Flux between subbasins (presently lumped into local inflows for each subbasin)
5	Artificial recharge	Capacity and cost (historical artificial recharge in the Central Valley is presently lumped in local inflows)
6	Pumping	Capacity and cost

CENTRAL VALLEY GROUNDWATER HYDROLOGY AND RELATED DATA

CVGSM is a special application of the Integrated Ground Surface Water Model (IGSM) to the Central Valley of California. The IGSM is a basin comprehensive planning model that includes groundwater, surface water, groundwater quality, and reservoir operation simulation routines; it is a finite element quasi-three dimensional model capable of simulating several aquifer layers (Montgomery Watson 1995).

The model was originally developed in 1976 at the University of California, Los Angeles and has undergone several revisions, presently maintained by Montgomery Watson in conjunction with the U.S. Bureau of Reclamation (USBR).

A calibrated CVGSM served as the basis to evaluate groundwater impacts in the Draft Central Valley Programmatic Improve Act Programmatic Environmental Impact Statement (CVPIA PEIS) (USBR 1997). CVGSM formulation and calibration have been documented by James M. Montgomery (1990) and Montgomery Watson (1995). The Draft CVPIA PEIS is part of the assessment required by the Central Valley Project Improvement Act (CVPIA) of 1992. Many different alternatives were evaluated in the Draft CVPIA PEIS. A preferred alternative was identified which constituted a combination of items of different alternatives (USBR 1999).

During the first phase of the CALVIN development, results of the preferred alternative were not available publicly. Furthermore, no specific alternative is assured of implementation since it is subject to public comment and approval by many agencies. Moreover, any modification of CVP operation likely will require coordination with the CALFED Bay-Delta process. Thus, data prepared for CALVIN made use of the Draft CVPIA PEIS NAA – the No Action Alternative. The NAA is based on projections of conditions that would occur if the alternatives were not implemented and operation of CVP facilities continued as foreseen without implementation of the CVPIA. It also includes reasonable and certain facilities that would be constructed by federal, state, and local agencies without implementation of the alternatives. Descriptions of what is included in the NAA are contained in the Draft CVPIA PEIS (USBR 1997). As part of the Final PEIS (USBR 1999), the NAA was revisited to make some minor corrections to surface water deliveries modeled in CVGSM. The revised final NAA runs (RNAA) produced some minor differences in groundwater balances largely in the southern portion of the Central Valley (see Annex J-A-2). These differences were deemed to be very small and groundwater data in CALVIN derived from CVGSM continues to be based on the 1997 NAA simulation run.

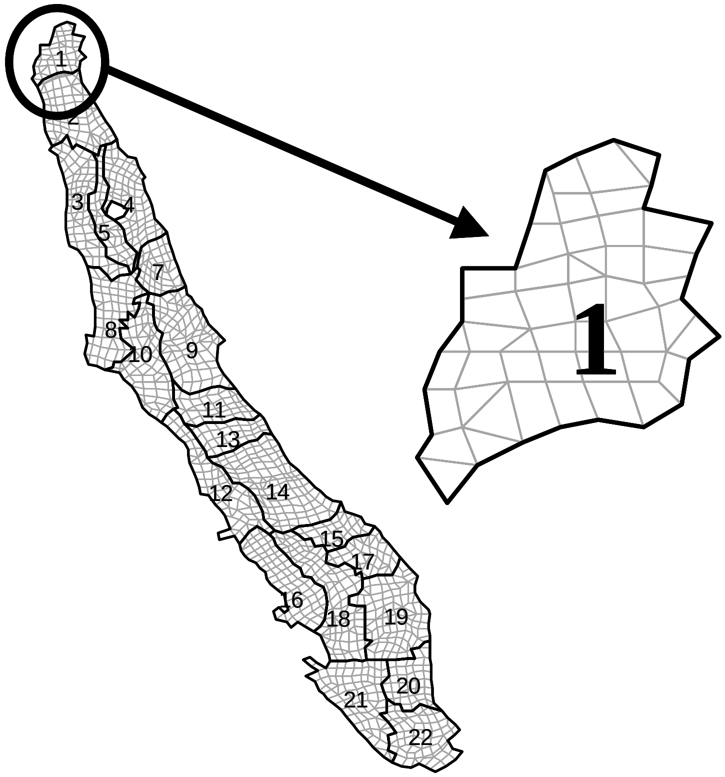
The 21 GWSBs in the Central Valley correspond on a one-to-one basis with CVPM regions. No changes were made to data in the CVGSM NAA simulation. However, modifications were made to files contained on the CD-ROM (USBR 1997) so that when rerun CVGSM reported information on a monthly basis (it is yearly on the CD-ROM), output was grouped according to CVPM subregions, and flux (flow) reported between CVPM subregions. The data required for CALVIN (identified in Table J-1) are discussed in succession. At the conclusion of the discussion, a summary of groundwater characteristics is presented.

Storage

Initial storage level and total storage capacity of the Central Valley GWSBs were determined by pre- and post-processing CVGSM data files. It was necessary to preprocess the majority of the data since CVGSM computes some values internally. Also, initial and total useable storage values are not reported directly by CVGSM in the format required by CALVIN. Thus, the effort to determine storage characteristics for CALVIN was a matter of executing some of the internal computations externally, in addition to making adjustment for CALVIN input requirements. CVGSM files used in preparation of CALVIN data are listed in Table J-A-2 of the Annex.

As explained, groundwater basins area represented as “underground” reservoirs in CALVIN. Their characteristics are determined by aggregating the finite elements defined in CVGSM into the corresponding GWSBs (Figure J-2). Each finite element is made up of three or more nodes, and the Central Valley aquifer is modeled as three soil layers (Figure J-3). At each node: (i) surface elevation (supporting file *CNJSTRA1.DAT*), (ii) layer thickness (supporting file *CNJSTRA1.DAT*), and (iii) initial groundwater levels (supporting file *CNJIN90.NEA*) are available (CVGSM NAA simulation files). Furthermore, (iv) the surface area of each finite element (supporting file *CNJOUT1.OUT*) is computed in Pass 1 of the simulation. Last, (v) specific yield (supporting file *CNJPARM.DAT*) is available at each node that defines the larger areal extensions (polygons) that encompass many finite elements in CVGSM. The polygons do not conform to the 21GWSBs in CALVIN (Figure J-4). Together these five characteristics were used to determine storage in the GWSBs. Specific yield calculations are carried out internally (using a parametric grid) in CVGSM and are not reported in output files. The first step to determine storage was to compute average specific yield in each polygon by simply averaging the specific yield values of the nodes defining each polygon (i.e. SY1 = (SYN1.1 + SYN.1.2 + SYN1.3 + SYN1.4)/4, where SY1 is the specific yield of polygon 1 and N1.1 is node 1 of polygon 1) (see supporting file *Storage yield.xls*).

Figure J-2. Finite Elements and Groundwater Subbasins in CVGSM

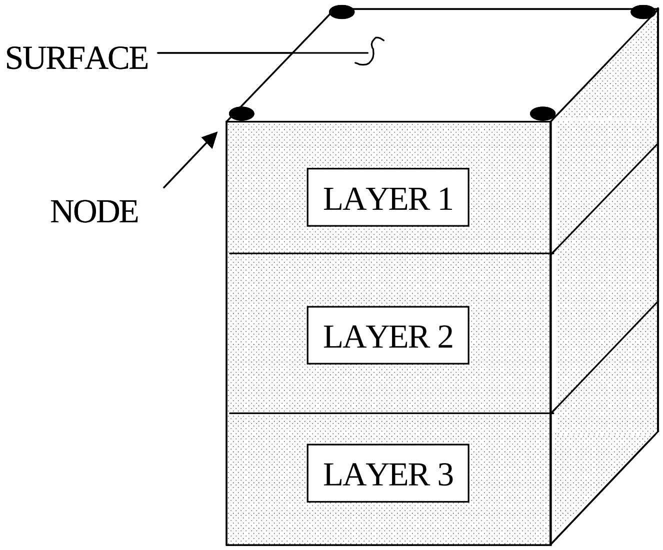


Next the specific yield in each finite element was determined by overlaying the specific yield polygons over the CVGSM elements (Figure J-4); assignment of specific yields to individual elements was carried out according to spatial overlay. This assignment was completed using AutoCAD, ArcView, and ArcInfo. Specific yield polygons were plotted in AutoCAD from coordinates contained in CVGSM (CVPIA PEIS file *CNJPARM.DAT*). These specific yield polygons were imported into ArcView. The USBR prepared a GIS coverage of the CVGSM finite element grid. Assignment of specific yield values to each finite element was completed by spatial analysis in ArcInfo using the specific yield polygon and CVGSM finite element coverage.

Source: Montgomery Watson 1995.

The CVGSM finite grid consists of three soil layers. Layers are defined based on different soil characteristics, such as different specific yields. Available (i.e., useable) water was considered only in the upper two layers of the model. In general, groundwater contained in the third layer is considered unfit for use - principally due to salinity.

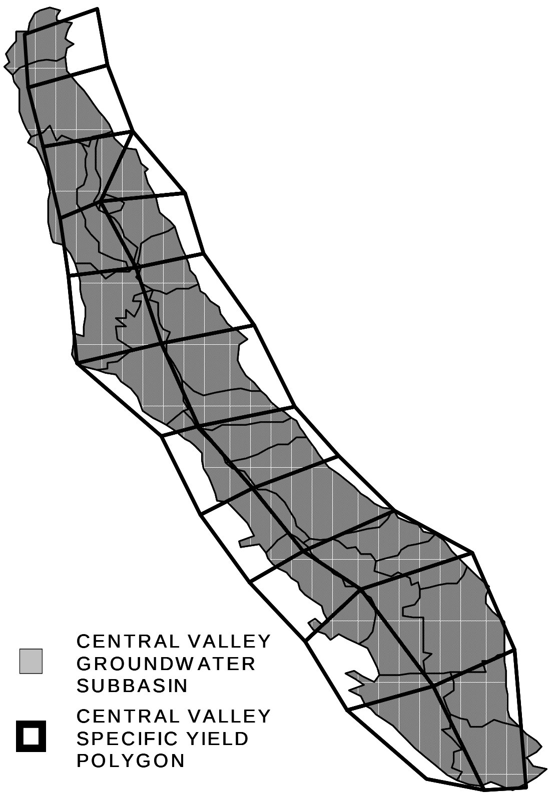
Figure J-3. Finite Elements and Layers in CVGSM



Source: Montgomery Watson 1995.

Surface elevations, groundwater levels, and layer depths are known at nodes. Average values for each finite element of (1) surface elevation, (2) groundwater level, (3) layer 1 depth, and (4) layer 2 depth, and (5) depth to water table were computed by averaging the node values for each finite element (Figure J-5).

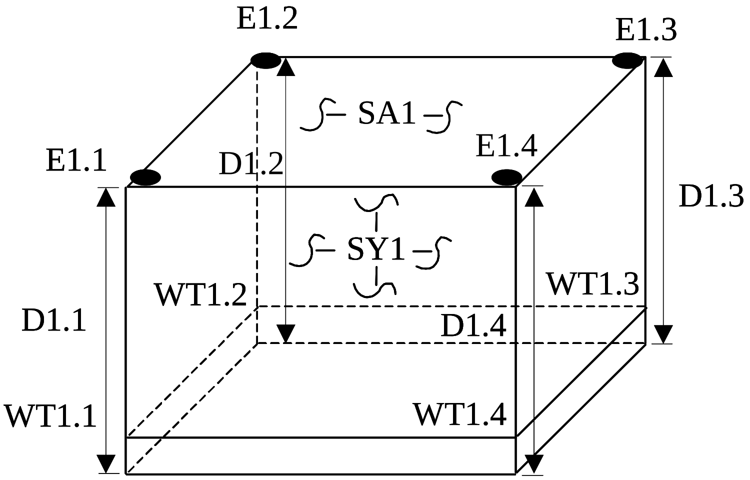
Figure J-4. Specific Yield Polygons and Groundwater Subbasins in CVGSM



Initial storage, consequently, was computed by multiplying the surface area of a finite element by the average depth (or partial depth) of the layer in which water is stored and average specific yield in each layer (Area x Average Depth x Specific Yield, see Table J-2). Total storage required an additional step to make the same calculation for the volume in the finite element above the water table. Lastly, initial storage and total capacity for each GWSB reservoir were computed by summing the individual values for all the finite elements in each subbasin (Table J-2, see supporting file *Element Calcs.xls*).

Sources: Montgomery Watson 1995; USBR 1997, CVPIA PEIS CVGSM NAA file *CNJPARM.DAT*.

Figure J-5. Storage Volume Calculations - Example of One Layer of Finite Element



E	Elevation
D	Depth (of layer)
SA	Surface Area
SY	Specific Yield
WT	Water Table (Elevation)
1.1	Layer.Node

Sources: Calculations - *Element Calcs.xls*; Data - USBR 1997 *CNJSTRA1.DAT*, *CNJIN90.NEA*, *CNJOUT1.OUT*, and *CNJPARM.DAT*.

Table J-2. Storage Volume Calculations

Item	Parameter	Computation
1	Average Depth of Finite Element	(D1.1 + D1.2 + D1.3 + D1.4) / 4 (Depth - *CNJSTRA1.DAT*)
2	Finite Element Storage Volume *	SA1 x Average Depth x SY1 * (Surface Area - *CNJOUT1.OUT;* Specific Yield - parametric grid in *CNJPARM.DAT*, summarized in supporting file *Storage.xls*.) * Note: This computation is carried out for (i) Layer 1 and (ii) Layer 2.
3	Groundwater Subbasin Total Storage Volume	Σ (Finite Element Storage Volumes within Groundwater Subbasin) (see supporting file *Element Calcs.xls*)
4	Average Depth of Initial Saturated Volume in Finite Element	[(D1.1 - (E1.1 - WT1.1)) + (D1.2 - (E1.2 - WT1.2)) (D1.3 - (E1.3 - WT1.3)) + (D1.4 - (E1.4 - WT1.4))] / 4 ** (Depth and Surface Elevation - *CNJSTRA1.DAT*; Water Table Elevation - *CNJIN90.NEA*;) ** Note: In the spreadsheet *Element Calcs.xls*, there is a check to determine whether the water table lies in the first or second layer so that this equation is computed when the water table is in the first layer. There is an accompanying computation for the second layer.
5	Finite Element Initial Storage Volume ***	SA1 x Average Saturated Depth x SY1 *** *** Note: This computation is carried out for (i) Layer 1 (if saturated volume present) and (ii) Layer 2.
6	Groundwater Subbasin Initial Storage Volume	Σ (Finite Element Initial Storage Volumes within Groundwater Subbasin) (see supporting file *Element Calcs.xls*)

Source: Calculations in supporting files: *Storage.xls* and *Elements Calcs.xls* of “Software and Data Appendices” in CALVIN report files; Data - USBR 1997 CVGSM NAA simulation input and output files.

There are some underlying assumptions in these computations. The first is that the GWSBs are composed of unconfined aquifers. The aquifer system in the Central Valley is unconfined, with the exception of the west side of the San Joaquin Valley. In the San Joaquin Valley, a confining Concoran clay layer is present (Bertoldi et al 1991; Page 1991). However, the assumption of an unconfined aquifer in the GWSBs where Concoran clay is present is not an incorrect assertion. Within the conceptualized limits of the GWSBs in the west side of the San Joaquin Valley, there are areas that are not confined. Furthermore, the vertical movement of groundwater in all of the Central Valley (including the west side of the San Joaquin Valley) has been artificially enhanced by irrigation wells. When not pumping, these wells permit vertical flow between permeable layers within the aquifer system (Bertoldi et al 1991). The second assumption is that soil above the initial water table has not compacted permanently and storage is possible with the yield characteristics specified in CVGSM.

Percolation of Applied Water

The percentage of applied water (AW) from agricultural and urban water use that is not depleted (deep percolates to usable groundwater or returns to the surface water system) and related efficiencies were initially determined from DWR estimates (see Appendix B-1: Urban Representation, and Appendix K: Irrigation Water Requirements). Due to model formation of HEC-PRM and goals in CALVIN to reflect the interaction between surface and groundwater dynamically, it was necessary to separate percolation of AW from surface return flows and from other sources of percolation in the CVGSM data. Total deep percolation to each GWSB in the Central Valley is summarized in the CVGSM NAA output file *SOIL2A_Y.NEA* (CVPIA PEIS CD-ROM Disk 2, 1997). In this output file, a soil-water budget is tabulated for agricultural, urbanized, and native vegetation areas in each GWSB on a monthly basis. Agricultural land monthly water accounting consists of precipitation (RAIN), precipitation runoff (D.R), irrigation (IRRIG), irrigation runoff (RETURN), crop consumptive use (C.U.), evapotranspiration (E.T.), and total percolation (PERC.). Urban land monthly water accounting consists of precipitation (RAIN), precipitation runoff (D.R.), urban water use (W.U.), urban surface return flows (RETURN), evapotranspiration (E.T.), and total percolation (PERC.) (see Table J-3 for definitions). Also required is the partition of urban water use for indoor versus outdoor application in each month (see Table J-4). The indoor fraction of urban water use (labeled in Table J-3 as "**i.w.u.**") is given along with the return destination for this water (either to surface water or to groundwater) in the input file *CNJPARM.DAT* (see parameters URINDR and IURIND). 100% of indoor urban water use is routed to surface return in four subbasins: GW-7 (Sacramento), GW-8 (Sacramento), GW-16 (Fresno), and GW-21 (Bakersfield). In all other subbasins, all indoor urban water use is considered to eventually percolate to groundwater in CVGSM and is included in the PERC term of the soil balance for urban land.

Separation of percolation contributed by precipitation on agricultural lands from that due to agricultural AW in the monthly soil budget CVGSM results (*SOIL2A_Y.NEA)* was determined by first computing the amount of irrigation applied water that percolates (IRRIG minus RETURN minus C.U.) and then subtracting this from total percolation (PERC) to get precipitation percolation on agricultural lands in each month of the CVGSM simulation (1922-1990).

Separation of percolation contributed by precipitation on urban lands from that due to urban water use required computing separately the amount of indoor urban water use that percolates

(Indoor W.U. minus RETURN) and the amount of outdoor urban water use that percolates. The latter requires first calculating the available precipitation for percolation (RAIN minus D.R.) and the available outdoor urban water use available for precipitation (outdoor W.U.) and the adjusted percolation (PERC minus the amount of indoor water use that percolates). Then the amount of outdoor water use that percolates is estimated as the ratio of (outdoor W.U.) to (outdoor W.U. plus available precipitation for percolation) times the adjusted percolation. Precipitation percolation on urban lands is then calculated as (PERC minus the sum of the amount of indoor urban water use that percolates plus the amount of outdoor urban water use that percolates). The procedures for computing applied water percolation in agricultural and urban areas are summarized in Table J-5.

Table J-3. CVGSM Soil Budget Terms Used to Calculate Applied Water Percolation

Agricultural and Urban Terms	Definition
Rain[a]	Precipitation in inches over each land use area.
Irrigation (IRRIG)[a]	Irrigation applied water in inches applied to agricultural area.
Urban Water Use (W.U.)[b]	Urban water supply in inches applied to urbanized land[b]
Consumptive Use (C.U.)[a]	Amount of irrigation applied water consumptively used to satisfy evapotranspiration or soil moisture deficits up to field capacity.[a]
Evapotranspiration (E.T.)[a]	"Actual" evapotranspiration of plants; it is dependent on soil moisture conditions.[a]
Direct Runoff (D.R.)[a]	Direct runoff due to rainfall.[a]
Indoor Fraction of W.U. (i.w.u.)	Monthly varying fixed fraction of Urban Water Use that is indoors, from CVGSM NAA input file *CNJPARM.DAT* (see Table J-4)
Return Flow (RETURN)[a]	Surface water return flow from agricultural applications (such as tailwater, field runoff, etc.) or from urban water use (set equal to indoor use when there is a centralized wastewater collection and treatment system; the monthly volume of urban indoor water use is computed as a monthly varying fixed fraction of total urban water use)[b]
Percolation (PERC.)[a]	Percolation to groundwater as a result of rainfall and irrgation applied water for agricultural areas[a], and as a result of rainfall and urban outdoor water use in urban areas[b] unless there is no urban surface return flow, in which case it includes 100% of urban indoor use as well[b].

Source: As defined in [a]Montgomery Watson 1995 and [a]additionally by examination of and deduction from CVGSM data files and documentation in the CVPIA PEIS (USBR 1997) and water balance in the soil budget files.

Table J-4. Indoor Fraction of Urban Water Use in CVGSM

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.00	1.00	0.60	0.50	0.45	0.40	0.40	0.40	0.40	0.50	0.70	0.80

Source: USBR 1997, CVGSM NAA input file *CNJPARM.DAT*, parameter URINDR. Note that the same fraction is used in all areas of the Central Valley.

Table J-5. Calculation of Precipitation Percolation and Partitioning of Agricultural and Urban Return Flows to Surface and Groundwater for CALVIN

CVGSM NAA Output Data for each CVPM region from *SOIL2A_Y.NEA* (USBR 1997): **RAIN, IRRIG., W.U., C.U., E.T., D.R.** (from precipitation), **RETURN** (from applied water), and **PERC**. (see Table J-3) and monthly fraction indoor urban water use (**i.w.u.**)
Agricultural Calculations
1) Percolation of Irrigation Applied Water = **IRRIG.** – **C.U.** – **RETURN**
2) Percolation from Precipitation on Agricultural Lands = **PERC** – [**IRRIG.** – **C.U.** – **RETURN]**
3) CVPM-wide Agricultural Application Efficiency = **C.U. / IRRIG.**
4) Fraction of Agricultural Return Flow to Groundwater = [**IRRIG.** – **C.U.** – **RETURN**] / [**IRRIG. – C.U.**]

5) Fraction of Agricultural Return Flow to Surface water = **RETURN /** [**IRRIG. – C.U.**]
Urban Calculations
1) Precipitation Available for Percolation = **RAIN – D.R.**
2) Outdoor Urban Water Use Available for Percolation = [1- **i.w.u.**] x **W.U.**
3) Adjusted Percolation = **PERC.** – [**i.w.u.** x **W.U.** – **RETURN**]
4) Percolation of Outdoor Urban Water Use = Adjusted Percolation x { (1- **i.w.u.**) x **W.U.** / [**RAIN** – **D.R.** + (1- **i.w.u.**) x **W.U.**] }
5) Percolation from Precipitation on Urban Lands = Adjusted Percolation – Percolation of Outdoor Urban Water Use
6) CVPM-wide Urban Application Return Flow = [**RETURN** + Percolation of Outdoor Urban Water Use] / **W.U.**
7) Fraction of Urban Return Flow to Groundwater =[Percolation of Outdoor Urban Water Use + (**i.w.u.** x **W.U.** – **RETURN**)] / **W.U.** 8) Fraction of Urban Return Flow to Surface Water = **RETURN / W.U.**

Notes: In the table, items in bold are values from *SOIL2A_Y.NEA* or from *CNJPARM.DAT*. Source: Calculations in supporting files of the CALVIN report: *Soil WB Cals mark 1-7.xls*, *Soil WB Cals mark 8-14.xls*; dated 11/08/1999, and *Soil WB Cals mark 15-21 edMJ 080900.xls*, dated 08/10/2000.

CVPM-wide agricultural application efficiencies that occur CVGSM and the split between surface runoff and deep percolation of irrigation applied water from these soil budget computations are presented in Table J-6 (irrigation deep percolation volumes derived from these computations are used to calibrate groundwater in CALVIN as described in Appendix 2H: Calibration Process Details). Comparative values from DWR (1998) are also presented in Table J-6. In CALVIN the DWR irrigation efficiencies are applied to return flows, while the volume of deep percolation of irrigation applied water is used along with the volume of irrigation application, to calibrated the surface water/groundwater split of the non-consumptive portion of irrigation water.

Table J-6. CVGSM Efficiencies and Agricultural Partition for CALVIN Return Flows

GWSB	Return Flow Surface (taf/yr)	Return Flow GW (taf/yr)	Ag Area Partition % Surface Return	Ag Area Partition % GW Return	CVGSM Application Efficiency	DWR Application Efficiency[a]	Difference DWR – CVGSM Efficiency
GW-1	26.0	21.4	0.55	0.45	0.61	0.68	0.07
GW-2	57.2	128.5	0.31	0.69	0.71	0.74	0.03
GW-3	225.3	338.5	0.40	0.60	0.65	0.67	0.02
GW-4	304.7	41.6	0.88	0.12	0.65	0.67	0.02
GW-5	254.4	371.3	0.41	0.59	0.63	0.66	0.03
GW-6	140.8	81.9	0.63	0.37	0.72	0.68	-0.04
GW-7	124.5	91.2	0.58	0.42	0.55	0.63	0.08
GW-8	267.2	43.9	0.86	0.14	0.67	0.68	0
GW-9	60.1	172.0	0.26	0.74	0.79	0.70	-0.09
GW-10	564.3	146.2	0.79	0.21	0.60	0.62	0.02
GW-11	124.7	236.1	0.35	0.65	0.57	0.69	0.12
GW-12	198.5	54.6	0.78	0.22	0.66	0.73	0.07
GW-13	352.6	116.8	0.75	0.25	0.73	0.73	0
GW-14	0.0	415.7	0.00	1.00	0.74	0.78	0.04
GW-15	388.8	168.6	0.70	0.30	0.73	0.74	0.01
GW-16	172.5	27.9	0.86	0.14	0.55	0.73	0.18
GW-17	119.5	86.6	0.58	0.42	0.73	0.74	0.01
GW-18	5.6	606.4	0.01	0.99	0.69	0.75	0.06
GW-19	0.0	280.4	0.00	1.00	0.71	0.79	0.08

GW-20	80.4	117.2	0.41	0.59	0.70	0.76	0.06
GW-21	22.5	373.0	0.06	0.94	0.68	0.75	0.07
TOTAL	3,490	3,920	0.15	0.17	0.68		

Sources: Calculated from CVPEIS NAA *SOIL2A_Y.NEA* (USBR 1997); summarized in *CVPM Return Flows mark Mjed Nov99.xls* and [a] DWR 1998.

This percentage split on return flows defines the corresponding division of the CVPM agricultural demands (i.e. 1A and 1B in Figure J-2). The split is required due to limitations of the network flow algorithm of HEC-PRM, the computational engine of CALVIN. Either a loss or gain factor is permitted on a flow link connecting two nodes, meaning that flow from one source cannot be partitioned to more than one destination when using the loss or gain factor (HEC 1999). One link can represent a flow line between the agricultural area and one return flow destination, whereas physically there are two destinations - either (1) surface water or (2) groundwater. The partition of a single agricultural area in two demand areas (with equal marginal values of water for equal percentages of demand) allows dynamic modeling of return flows to surface water and groundwater. Thus, the artificial division of the agricultural areas was created to overcome HEC-PRM limitations while attempting to capture the physical interaction of return flows. Appendix K: Irrigation Water Requirements contains further discussion of efficiencies, and in Appendix 2H: Calibration Process Details further discusses the causes of differences between CVGSM and DWR effective irrigation efficiencies in context of calibrating CALVIN.

Urban return flow fractions and the partition to surface and groundwater of these return flows as computed from CVGSM are provided in Table J-7. These are used in CALVIN, however, groundwater return flows that are extremely small in GW-7, 8, 16, and 21 are ignored and all urban return flows in these basins are routed to surface water.

Table J-7. Urban Return Flow Fraction and Partition from CVGSM NAA

GWSB	Return Flow Surface (taf/yr)	Return Flow GW (taf/yr)	Portion Return to Surface	Portion Return to GW	Total Urban Return Flow Fraction
GW-1	0.0	44.7	0.0	0.501	0.501
GW-2	0.0	32.3	0.0	0.522	0.522
GW-3	0.0	7.7	0.0	0.503	0.503
GW-4	0.0	2.7	0.0	0.504	0.504
GW-5	0.0	43.4	0.0	0.515	0.515
GW-6	0.0	47.7	0.0	0.533	0.533
GW-7	232.0	2.7	0.530	0.006	0.536
GW-8	169.5	1.5	0.522	0.005	0.526
GW-9	0.0	62.6	0.0	0.524	0.524
GW-10	0.0	14.9	0.0	0.528	0.528
GW-11	0.0	90.9	0.0	0.537	0.537
GW-12	0.0	41.5	0.0	0.528	0.528
GW-13	0.0	53.2	0.0	0.526	0.526
GW-14	0.0	9.6	0.0	0.512	0.512
GW-15	0.0	22.5	0.0	0.510	0.510
GW-16	141.9	1.3	0.516	0.005	0.520
GW-17	0.0	39.2	0.0	0.522	0.522
GW-18	0.0	71.8	0.0	0.528	0.528
GW-19	0.0	4.0	0.0	0.512	0.512

GW-20	0.0	16.2	0.0	0.518	0.518
GW-21	91.7	1.0	0.514	0.005	0.519
TOTAL	635	611	0.268	0.258	0.526

Sources: Calculated from CVPEIS NAA *SOIL2A_Y.NEA* (USBR 1997); summarized in *CVPM Return Flows mark Mjed Nov99.xls*.

Local Inflows

Local inflows to GWSBs represent net aquifer recharge from all sources except from agricultural and urban applied water, which is modeled dynamically. Consequently, local inflows correspond to recharge from (1) precipitation (derived as described above in text and Table J-5 when separating applied water percolation, from the output file *SOIL2A_Y.NEA*), and recharge from (2) streams/rivers, (3) canals and historic artificial recharge, (4) lakebed seepage, (5) vertical movement between layers, (6) net inter-subbasin flows, and (7) subsurface boundary flows (taken directly from the output file *GW2A_Y.NEA*). These data are pre-processed to develop the inflow time series for each of the Central Valley GWSBs modeling in CALVIN. Boundary flows refer to groundwater movement that crosses the exterior boundaries (limits of area that are modeled) in CVGSM.

In addition to percolation from precipitation on agricultural and urban lands (described above), there is additional precipitation percolation from undeveloped land in each CVPM region that must be added to that from computed from developed land. On undeveloped areas of the subbasin, all percolation reported in CVGSM in the Soil Balance for these lands is due to precipitation and added to the precipitation percolation volumes from agricultural and urban lands to develop the inflow.

Local inflows also implicitly include artificial recharge that is part of current historical operations. These volumes are inseparable from canal seepage in the “Recharge” component of the CVGSM output provided in file *GW2A_Y.NEA*. Maintaining artificial recharge as part of local inflows creates several problems for calibration of agricultural demands and groundwater parameters in CALVIN (see Appendix 2H: Calibration Process Details).

Table J-8 provides a summary of each component of local inflows as derived from CVGSM output files for the period 1922-1990.

Table J-8. Average Annual Inflows to GW from CVGSM for the 1920-1990 Period (taf/yr)

GWSB	Precip. Perc.	Streams	Recharge (Canals & AR)	Bedrock/ Lakebeds	Boundary Flow	Subsurface Inflow	Total Net Inflow
GW-1	107.4	-77.6	0.0	0.0	0.0	-28.2	1.6
GW-2	223.7	46.6	6.4	0.0	114.1	11.7	402.4
GW-3	95.7	-38.1	9.7	0.0	14.4	-72.8	8.8
GW-4	43.5	102.0	0.0	0.0	0.0	115.1	260.6
GW-5	148.3	-18.4	5.2	0.0	83.7	-74.6	144.1
GW-6	74.7	201.5	15.1	0.0	-9.2	85.0	367.0
GW-7	45.7	158.3	14.2	0.0	62.5	-3.2	277.6
GW-8	71.5	373.2	1.8	0.0	22.0	278.9	747.4
GW-9	141.9	15.3	0.0	0.0	-16.1	-127.4	13.7
GW-10	44.0	140.3	80.4	0.0	73.7	-42.3	296.2
GW-11	153.8	-324.8	130.2	0.0	0.0	-118.0	-158.7
GW-12	36.1	21.7	87.0	0.0	25.1	-14.8	155.0
GW-13	92.5	388.9	126.7	0.0	70.2	184.8	863.1

GW-14	51.3	0.0	24.1	352.7	0.0	-119.5	308.7
GW-15	41.0	125.6	151.5	2,311.4	15.1	-1,483.8	1,160.9
GW-16	16.6	0.0	48.7	0.0	54.2	160.2	279.7
GW-17	61.0	144.2	99.6	0.0	6.8	48.1	359.6
GW-18	91.3	125.1	126.8	0.0	67.7	72.8	483.8
GW-19	51.3	0.0	4.8	0.0	234.1	-128.0	162.2
GW-20	36.3	0.0	11.4	0.0	85.4	86.9	220.1
GW-21	75.7	205.4	19.7	389.2	58.6	-361.4	387.2
TOTAL	1,703	1,589	963	3,053	962	-1,531	6,741

Source: Precipitation percolation extracted from CVGSM NAA output file *SOIL2A_Y.NEA* (see CALVIN supporting files *Soil WB Cals mark 1-7.xls*, *Soil WB Cals mark 8-14.xls*; dated 11/08/1999, and *Soil WB Cals mark 15-21 edMJ 080900.xls*, dated 08/10/2000). Other components taken directly from results reported in CVGSM NAA output file *GW2A_Y.NEA*. These values are summarized from CALVIN supporting file *GW Local Inflows mark altern crMJ 08102000.xls*.

Extension of Record

The period of record simulated in CVGSM (1922-1990) lacks three years (1991-1993) that are analyzed in CALVIN. Data from CVGSM was extended through 1993 for CALVIN by using results from similar years within the simulation period 1922-1990. Precipitation records were used find similar years within the 1922-1990 period to match years 1991, 1992, and 1993. Annual precipitation served as the basis for matching years. In CVGSM, composite precipitation in an element is determined by weighting several different precipitation gages (Montgomery Watson 1995). For matching years based on annual precipitation here, only one gage (with the highest weight) per subbasin was utilized. The precipitation gage used to match years and the matching years for extending the groundwater inflow data are presented in Table J-9.

Inter-subbasin Flows

Physically, the Central Valley is made up of several large aquifers. North of the Delta, groundwater generally flows toward the Delta. From just north of Tulare to the Delta, groundwater flow tends to be northerly toward the Delta. Groundwater in the far southern Central Valley flows inward toward the old lakebed in the Tulare Basin (Bertoldi et al, 1991). However, local conditions, such as intensive pumping or high river flows, can modify the general flow trends. Originally, we attempted to represent inter-subbasin flows in the Central Valley directly with CALVIN links and data extracted from CVGSM. However, flux flow between GWSBs (*CPEF_Y.NEA*, *CPEF_YL2.NEA*, and *CPEF_YL3.NEA*) could not be reconciled with the groundwater balance for each GWSB reported by CVGSM in output file *GW2A_Y.NEA*. As a result, this methodology was abandoned in favor of leaving net inter-subbasin flows lumped with local inflows, as reported in *GW2A_Y.NEA*. The procedure used in trying to generate the inter-subbasin flows for separate representation is documented in the Annex in case the use of inter-subbasin links is contemplated in the future.

Table J-9. Precipitation Gage Used and Matching Years for Extending GW Inflow Data

GWSB	Precipitation Gage	Gage No. in CVGSM	Match for 1991	Match for 1992	Match for 1993
GW-1	Redding (7300)	1	1933	1990	1938
GW-2	Orland (6506)	3	1966	1979	1980
GW-3	Colusa (1948)	5	1932	1923	1958
GW-4	Colusa (1948)	5	1932	1923	1958
GW-5	Marysville (5385)	6	1945	1948	1958

GW-6	Winters (9742)	7	1974	1975	1925
GW-7	Sacramento (7633)	8	1948	1923	1956
GW-8	Camp Pardee (1428)	10	1926	1954	1938
GW-9	Lodi (5032)	9	1990	1984	1967
GW-10	Los Banos (5120)	31	1949	1957	1956
GW-11	Modesto (5738)	12	1990	1979	1941
GW-12	Merced (5532)	13	1990	1948	1938
GW-13	Merced (5532)	13	1990	1948	1938
GW-14	Kettleman (4536)	32	1925	1922	1922
GW-15	Kettleman (4536)	32	1925	1922	1922
GW-16	Fresno WSO AP (3257)	17	1945	1962	1938
GW-17	Fresno WSO AP (3257)[a]	17[a]	1945	1962	1938
GW-18	Visalia (9367)	21	1965	1963	1980
GW-19	Button Willow (1244)	27	1973	1933	1978
GW-20	Button Willow (1244)[b]	27[b]	1973	1933	1978
GW-21	Bakersfield (442)	28	1925	1975	1952

Source: USBR 1997, *CNJCHRC.DAT*; summarized in CALVIN supporting file *Precip Gage Matches.xls.*

Notes: [a] Gage 19 (Orange Grove 6476) corresponds to the highest weighted gage, but records were not available for the period 1991-3. Gage 17 (Fresno WSO AP 3257) corresponds to the second highest weighted gage. [b] Gage 24 (Delano 2346) corresponds to the highest weighted gage, but there are several missing records during the period 1991-3. Gage 27 (Button Willow 1244) corresponds to the second highest weighted gage.

Pumping Characteristics in the Central Valley

Pumping characteristics required in CALVIN are monthly pumping capacity and pumping costs. Pumping capacities in the Central Valley were estimated separately for the agricultural and urban portions of pumping reported in the CVGSM NAA simulation (see output file *GW2A_Y.NEA).* In some urban cases, installed well capacity was available directly from local agency sources. In other cases where urban areas depend only on groundwater pumping, other assumptions were made. Details about capacity and costs assumptions for pumping in CALVIN are discussed next.

Agricultural Pumping Capacity

The monthly pumping rates for each GWSB in the Central Valley are reported in the CVGSM NAA output file *GW2A_Y.NEA* for the simulation period 1922-1990. These values represent aggregate agricultural and urban pumping in each subbasin. A groundwater postprocessor exists that reveals the components (agriculture and urban) of groundwater extraction. However, it was not made available for use in CALVIN.

As a result, estimates of monthly urban pumping under the NAA assumptions were first made on the basis of monthly urban demands in each GWSB as reported in CVGSM NAA (file *SOIL2A_Y.NEA*). In all but five GWSBs, urban demands are supplied fully by groundwater so the estimation was relatively straightforward and is believed to be correct. In the remaining five subbasins (1, 7, 8, 16, and 21), the portion of urban demand supplied by surface water had to be determined from other sources, including the CVGSM NAA surface water diversion file *CNJDVSP2.NDA* (see CALVIN supporting file *CVGSM Diversions 2 edMJ 10192000.xls*). Estimated monthly urban pumping for each GWSB under the CVGSM NAA was then subtracted from total pumping reported in *GW2A_Y.NEA* to get monthly agricultural pumping. The monthly agricultural pumping capacity was then assumed to be some small percentage greater than the maximum monthly pumping volume that occurred during the simulation period 1922-

1990. No actual data or information on installed well capacity on farms or in irrigation districts is widely available, as far as we know, to get more accurate estimates of agricultural pumping capacity across the Central Valley. Furthermore, a balance is required between allowing pumping to expand in possible response to changing conditions (installation of new wells by farmers in dry conditions) versus reflection of actual installed capacity. For maximum monthly pumping volumes under 100 taf, the capacity was set equal to 110% of the maximum value. For volumes greater than 100 taf, the capacity was set equal to 105% of the maximum (see CALVIN supporting file *Policy 4a Pumping 081600.xls*). The resultant estimated capacities are reported in Table J-10.

Agricultural Pumping Costs

We assume agriculture pumping occurs near the point of water use. Consequently, agricultural groundwater pumping costs are limited to O&M of pumping facilities, which includes the important component of energy consumption. CALVIN assumes \$0.20 af/ft lift (or equivalently \$0.20 kwh/af) for O&M costs of agricultural pumping. This value represents a current (1999) state-wide average and is applied in CALVIN for the 2020 case analyzed. The value was synthesized from reported energy costs plus an estimate of other O&M costs (CPUC 1998; Curley and Knutsen 1993). The per acre-foot unit cost of groundwater pumping is then computed by multiplying \$0.20 times an estimate of the average pumping head in each GWSB. In the current analyses, fixed pumping cost is used. It is important to note that this assumption presumes constant pumping heads throughout the analyses. When groundwater levels deveiate substantially from those that occur in the CVGSM NAA, the CALVIN fixed head pumping costs could be substantially different from actual costs.

The CVGSM groundwater postprocessor provides groundwater depths of CVGSM runs, but was unavailable for the CALVIN study. Depth to groundwater in 2020 was pieced together from the economic analyses conducted for the Draft CVPIA PEIS (USBR 1997). Three components make up the pumping depth in the Central Valley: (1) pumping lift in 1990, (b) drawdown, and (c) adjustment for 2020 conditions. Pumping lifts were taken from *CESDAT95.GMS* (USBR 1997). These values are not derived from CVGSM runs but rather reflect estimates reported in DWR Bulletin 160 (DWR 1993). Drawdown is contained in *CESDAT95.GSM* (USBR 1997, NAA) and is either 20 or 30 feet. Adjustment for 2020 conditions is found in *NOACTAVC.GMS* (USBR 1997, NAA). The "change in depth" was used, as opposed to "dry" or "wet conditions". This change represents the difference in pumping lift estimated from CVGSM between existing conditions and the NAA runs. The values of each component, total pumping head, and O&M pumping cost are presented in Table J-10. Further discussion of pumping costs is included in Appendix G: Operating Costs.

Table J-10. Estimated Agricultural Pumping Costs and Capacity in the Central Valley

GWSB	Pumping Depth in 1990[a] ft	Drawdown[a] Ft	Adjustment for 2020 Conditions[c] ft	Pumping Head ft	Pumping Cost[d] \$/af	Pumping Capacity[e] taf/mo
GW-1	130	20	0	150	30.0	20.76
GW-2	120	20	1	141	28.2	153.23
GW-3	100	20	-1	119	23.8	170.98
GW-4	60	20	0	80	16.0	110.47
GW-5	75	20	-1	94	18.8	225.65
GW-6	70	20	1	91	18.2	148.06

GW-7	95	30	19	144	28.8	96.02
GW-8	110	30	3	143	28.6	208.38
GW-9	80	20	2	102	20.4	73.77
GW-10	60	20	-2	78	15.6	197.88
GW-11	75	30	-2	103	20.6	52.21
GW-12	90	30	-2	118	23.6	80.56
GW-13	125	30	-5	150	30.0	290.96
GW-14	350	30	2	382	76.4	332.85
GW-15	210	30	-7	233	46.6	407.88
GW-16	130	30	-11	149	29.8	60.76
GW-17	130	30	-2	158	31.6	152.39
GW-18	200	30	-4	226	45.2	348.95
GW-19	310	30	4	344	68.4	171.1
GW-20	310	30	-4	336	67.2	108.1
GW-21	310	30	8	348	69.6	228.31

Source: CVGSM and CVPM NAA input and output files from CVPIA PEIS (USBR 1997). See also Table G-1 in Appendix G: Operating Costs. Notes: [a] from file CESDAT95.GMS; [c] from file NOACTAVC.GMS; [d] at $0.20/af per foot of lift; [e] see CALVIN supporting file *Policy 4a Pumping 081600.xls* for details.

Urban Pumping Capacity and Costs

Maximum limits on urban pumping and costs, on the other hand, were estimated or identified from state and local agency water resources reports in most cases (see CALVIN supporting files in the urban appendix sub-folders such as *Reg1 to 4 Urban documentation.doc*). Costs were used as cited in the reports, despite the fact that some figures may include capital costs that are not supposed to be included in CALVIN. Data sources and estimated values for urban pumping costs and capacities are reported in Table J-11. Further discussion of urban pumping costs is contained in Appendix G: Operating Costs.

Table J-11. Urban Pumping Costs and Capacities in the Central Valley

GWSB	Sources	Urban Destination	Cost $/af	Capacity taf/mo
GW-1 to GW-6; GW-8 to GW-15; GW-17 to GW-21	see Appendix B-1: Urban Representation	Fixed M&I withdrawals from GWSB to “CVPM# Urban” node	None	None
GW-7	McCormack 1998 and DWR 1994, Volume 1, p. 150, Table 6-6. Capacity based on current use.	Greater Sacramento Urban Area	57	31.3
GW-8	McCormack 1998 and DWR 1994, Volume 1, p. 150, Table 6-6. Capacity based on current use (15.5 taf/mo), adjusted upward to eliminate shortages during calibration.	Greater Sacramento Urban Area	55	17.5
GW-8	DWR 1994, Volume 1, p. 150, Table 6-6. Capacity based on current use (9.6 taf/mo), adjusted upward to eliminate shortages during calibration.	Stockton	70	10
GW-16	DWR 1994, Volume 1, p. 150, Table 6-6. Capacity based on current use (28.3 taf/mo), unrestricted for 2020 population growth.	Fresno	80	Unlimited
GW-21	DWR 1994, Volume 1, p. 150, Table 6-6. Capacity based on current use (22.6 taf/mo), adjusted upward to eliminate shortages during calibration.	Bakersfield	128	33

Notes: a In the majority of the Central Valley, urban pumping is not modeled economically but rather as fixed extractions from groundwater subbasins. Thus, urban pumping cost is not reflected in these areas. See Appendix B-1 for further discussion.

GROUNDWATER HYDROLOGY AND RELATED DATA OUTSIDE THE CENTRAL VALLEY

Seven GWSBs outside of the Central Valley are included in CALVIN. In general, comprehensive groundwater models, like the CVGSM in the Central Valley, do not exist, are not available to the public, nor encompass the period of record examined in CALVIN. Thus, CALVIN data for subbasins outside of the Central Valley do not rely on a single source. Rather, many water resource reports, modeling efforts, precipitation records, and assumptions are used to generate the required data. In the Annex, methods and calculations for each subbasin are presented. It should be noted that our level of confidence in data in CALVIN for GWSBs outside the Central Valley is less that for CVGSM-generated data for GWSBs in the Central Valley. Refinements and revisions to these data should be considered as studies are completed and made publicly available.

Following the same outline as in the Central Valley, the six groundwater-related data components required to run CALVIN (storage characteristics, percolation of applied agricultural and urban water, local inflows, inter-subbasin flows, artificial recharge characteristics, and pumping characteristics) are discussed for each GWSB outside of the Central Valley. Under each component a summary of the data sources and data preparation method is presented.

Storage

A variety of methods were used to estimate storage characteristics in different GWSBs. In many cases values were taken directly from DWR and other reports. In other cases, values were extrapolated and extended. Extrapolations were employed to encompass the entire basin modeled in CALVIN from values reported for a portion of the subbasin. Also, assumptions were made regarding storage above the current water table. All of these methods are very simple and can introduce errors into CALVIN. Provided that there are not large fluctuations in storage in these GWSBs in CALVIN runs, these likely errors should not unduly compromise CALVIN results. Sources and methods are summarized in Table J-12.

Table J-12. Storage Characteristics and Sources for GWSBs Outside the Central Valley

GWSB	Sources	Details and Assumptions
GW-SC	ACWD 1995; SCVWD 1996; Zone7 1998.	Initial storage from combining ACWD (1995), p. ES-8 (empty), SCVWD (1996), Appendix K (200 taf), and Zone 7, web page (full =225 taf), totaling 425 taf. Storage capacity from ACWD (1995), p. ES-8 (30 taf), SCVWD (1996) Appendix K (400 taf), and Zone 7, web page (225 taf), totaling 655 taf.
GW-OW	DWR 1994; Danskin 1988; Guyman and Yen 1988;	Initial storage from Hardt 1980 p. 39-40 (30,000 taf). The upper bound (total storage) in CALVIN is currently set at 100,000 taf, effectively unrestricted, but ending storage set to initial to prevent long-term depletion or mining. Note that DWR 1994 indicates that useable storage is unknown.

GWSB	Sources	Details and Assumptions
	Hardt 1980; LA 1990.	
GW-AV	DWR 1994; Durbin 1978; Templin 1995.	Initial storage from DWR 1994, Volume 1, p. 88 (20,000 taf). Total storage capacity is assumed to be equal to existing estimated storage per DWR 1994. This assumption disregards potential storage area above the current water table. At the same time, it should be noted that aquifer storage above the current water table has been compromised by land subsidence (6.0 ft from 1926-92, with about 4.7 ft occurring after 1957 (Ikehara and Phillips, 1994, Table 8, as cited in Templin 1995, p. 63.) The upper bound (total storage) in CALVIN is currently set at 100,000 taf, effectively unrestricted, but ending storage set to initial to prevent long-term depletion or mining.
GW-MJ	DWR 1994; MBAW 1998.	Initial storage from DWR 1994, Volume 1, p. 88 (4,370 taf). The upper bound (total storage) in CALVIN is currently set at 100,000 taf, effectively unrestricted, but ending storage set to initial to prevent long-term depletion or mining.
GW-CH	DWR 1994; CVWD 1998.	Initial storage from DWR 1994, Volume 1, p. 88 (3,600 taf). The upper bound (total storage) in CALVIN is currently set at 100,000 taf, effectively unrestricted, but ending storage set to initial to prevent long-term depletion or mining.
GW-IM	DWR 1994; Montgomery Watson 1996.	Initial storage from Montgomery Watson 1996 Imperial County IGSM, p. A-63 (93,000 taf). As opposed to the CVGSM where usable water was defined as contained in the first two layers, in this case computer files were not available to distinguish different layers so that total volume was used as reported in the water budget output. Thus, this accounting incorporates all layers as defined by the modelers. Much of water in storage in this GWSB is poor quality. In fact, much of the groundwater in Imperial County subbasin is not suitable for drinking water purposes or irrigation (Montgomery Watson 1996), including a large portion of groundwater underlying the Imperial Irrigation District. Two small agricultural communities in the Borrego and Sand Hill areas do use groundwater, with additional limited pumping in the Coyote area. The GW-IM incorporates all of the aquifer into one GWSB. The upper bound (total storage) in CALVIN is currently set at 100,000 taf, effectively unrestricted, but ending storage set to initial to prevent long-term depletion or mining.
GW-MWD	MWD 1996	Local groundwater is not explicitly modeled in CALVIN but rather supplies from this source are included in the pre-processed time series of local supplies supplied by MWD (see supporting *Adjusted MWD Demands.xls*). Initial storage (750 taf) is assumed to be half of identified extra storage in the MWD service area. Storage capacity is equal to extra storage identified in MWD, Volume 2, p. 4-11 (1,450 taf).

Percolation of Applied Agricultural Water

Outside of the Central Valley, only two subbasins were modeled dynamically, linking agricultural deliveries to groundwater recharge from applied water: (i) Imperial Valley and (ii) Coachella Valley. In the Imperial Valley, Montgomery Watson (1996) completed a groundwater analysis of Imperial County, applying the Integrated Ground Surface Model (IGSM) to Imperial County. The simulation includes a period of 21 years. A similar process as that used for the CVGSM data was undertaken to separate percolation of agricultural AW from precipitation percolation (see supporting file *Imperial IGSM Phase 1.xls*). These calculations are annual since only annual data contained in the report were available, not actual computer modeling files. From the 21 years of simulation, a single, average value for irrigation efficiency and percolation of agricultural AW was extracted for use in CALVIN (*Imperial IGSM.xls*).

For the CVGSM Central Valley data, initially computations of percolation of applied water were carried out based on the premise that crop water demand could be equally satisfied by water from precipitation or agriculture. In the present formulation, this assumption was changed so that crop water demand is first satisfied by precipitation. The Imperial Valley calculations have not been updated to reflect the modified assumption. For consistency, the Imperial GWSB groundwater hydrology should be recomputed. The percentage of percolation will change somewhat with recalculation due to the modified water balance assumption. Nevertheless, the modified computational approach should not significantly affect results in CALVIN Region 5 (Southern California) since GW-IM is not a significant source of applied water.

In Coachella Valley (GW-CH), the irrigaton efficiency and portion of applied water that percolates was assumed based upon CVGSM values in the southern portion of the Central Valley (USBR 1997), in Imperial Valley (Montgomery Watson 1996), and the annual *Engineer's Report* for Coachella Valley (CVWD 1998). A groundwater modeling effort was completed in the northwest portion of the Coachella Valley in 1998 for the Coachella Valley Water District. However, this model is presently not available to the public, and information was not provided for use in the CALVIN study. Inclusion of data from this model, naturally, will improve estimates of efficiencies and other characteristics of the Coachella subbasin.

Local Inflows

Local inflows in GWSBs outside the Central Valley are not detailed by components as in CVGSM NAA output, with the exception of Owens Valley and Imperial Valley. Thus, generally local inflows are lumped totals representing contributions from several different sources.

In general, water budget estimates and precipitation records were used to generate groundwater inflows for the 73-year period of record in CALVIN. In Santa Clara (South Bay Area), Antelope Valley, Mojave River Valley, and Coachella Valley subbasins (Group 1), only one (an average) or several annual recharge values (dry, average, wet) were available. In Owens Valley and Imperial Valley (Group 2), water budgets were tabulated during 20 and 21-year periods, respectively. Precipitation data were used to estimate annually varying magnitudes and monthly patterns of recharge in all basins (based on a few annual total recharge values). Thus, a major assumption is that the magnitude and monthly recharge pattern follow precipitation patterns.

In Group 1 subbasins the magnitude and distribution of precipitation (after normalizing the average precipitation to average recharge) were employed to estimate monthly recharge. An example calculation for Antelope Valley is provided in the Annex (J.A.xxx). Calculations of inflow for all Group 1 subbasins are contained in CALVIN supporting file *Precip SC Master Final.xls*.

In Owens Valley and Imperial Valley (Group 2), a linear regression relationship was developed between annual precipitation and annual recharge in each area. Total annual recharge during years without water budget tabulations was determined using the regression relationship (see supporting files *Owens Final.xls* and *Imperial Phase 1.xls*). Monthly distribution of recharge for all years was determined by the percentage of annual precipitation during a particular month (*Owens Final.xls and Imperial Phase 1.xls*), as was carried out with Group 1. Often, it was not possible to locate continuous precipitation records at one gage within the subbasins for the period of record in CALVIN. In such cases, other precipitation gages within the proximity of the principal gage were used. The values of supplemental precipitation gages were normalized to the principal gage to avoid any distortions in magnitude. Distributional differences of varied precipitation gages were incorporated into local inflow recharge, however. Data sources, precipitation gages used, and method are summarized in Table J-13. Precipitation records were obtained from sources that compile long-term records, like the United States Historical Climatology Network (USHCN) Serial Temperature and Precipitation Data. Nevertheless, there are some records located on metallic tapes that can be requested from the United States Geological Survey that were not used, but may provide extensions to some of the more limited records used. However, the impact of making the precipitation records more consistent may have a negligible impact on CALVIN performance.

As commented upon in the preceding sections, local inflow hydrology to the Imperial County GWSB is based on calculations carried out in the first phase of CALVIN, which were subsequently changed. The partition of percolation data into agricultural and precipitation portions from the Imperial County IGSM results produced a series of annual percolation quantities from precipitation (*Imperial IGSM Phase 1.xls*). A linear regression was computed to correlate annual percolation from precipitation with annual precipitation (*Imperial Phase 1.xls*). Recalculation of percolation from precipitation based on the modified method (see Table J-5) will alter the linear regression results used to extrapolate the GW-IM inflow data for CALVIN. However, the magnitude of any change is not expected to be large nor have much if any impact on final results.

Inter-subbasin Flows

Each of the subbasins outside the Central Valley is isolated and configured such that there is no movement between them. Thus, there are no inter-subbasin flows in GWSBs outside the Central Valley.

Table J-13. Local Inflow Data and Computations for GWSBs Outside the Central Valley

GWSB	Sources	Method
GW-SC	ACWD 1995; SCVWD 1996; Zone7 1998.	Average annual recharge from ACWD (1995), 5 taf; SCVWD (1996), pp.5-8, 5-12, 112 taf; and Zone 7 (1998), web page, 20 taf; total avg. 137 taf, and estimated wet 254 taf, and dry 80 taf. These estimates include urban applied water percolation recharge. Precipitation: Santa Clara (7912) 1931-1947; San Jose (7821) 1948-93. Annual recharge magnitude and monthly pattern extrapolated from precipitation with single annual recharge estimate ((see CALVIN supporting file *Santa Clara Inflows corrected MJ 07072000.xls* in the Surface Water Hydrology Appendix folders; Further documentation in supporting file *Reg1 to 4 Urban documentation.doc*).
GW-OW	DWR 1994; Danskin 1988; Guyman and Yen 1988; Hardt 1980;	20-year record (1970-1989) of recharge from LA (1990), pp. 151-2, 154-8, and 165-6. The water budgets were post-processed to remove artificial recharge, percolation from applied agricultural water, and the lake (see supporting file *Owens Final.xls*). (79 to 250 taf/yr). <check, doesn't match file in Software and Data Appendices, see Table J-A-1> Precipitation: Independence (4232) Oct 1921:Sep 1993 (see supporting file

	LA 1990.	*Precip SC Master Final.xls*). Linear regression between modified annual recharge and annual precipitation and monthly distribution based on precipitation pattern (see supporting file *Owens Final.xls*).
GW-AV	DWR 1994; Durbin 1978; Templin 1995.	Average annual recharge from Templin 1995, p. 63. A range of estimates from previous studies cited in Templin. The average of this range was adopted for use in CALVIN (49 taf/yr). Precipitation: Tejon Ranch (8839) Oct 1921:Aug 1932; Palmdale (6624) Sep 1932:Sep 1993. Annual recharge magnitude and monthly distribution based on precipitation with single annual recharge estimate (see supporting file *Precip SC Master Final.xls*).
GW-MJ	DWR 1994; MBAW 1998.	Average annual recharge from DWR 1994, Volume 1, p. 88 (72 taf/yr). Precipitation: Tejon Ranch (8839) Oct 1921:Oct 1932; Palmdale (6624) Nov 1933:Mar 1939; Barstow Apr 1939:Mar 1980; Palmdale (6624) Apr 1939:Sep 1993. Annual recharge magnitude and monthly distribution based on precipitation with single annual recharge estimate (see supporting file *Precip SC Master Final.xls*).
GW-CH	DWR 1994; CVWD 1998.	Average annual recharge extrapolated from DWR 1994, Volume 1, p. 88 (33 taf/yr in CVWD area is extrapolated to 128 taf/yr for entire groundwater subbasin). Precipitation: Indio (4259) Oct 1921:May1982, Jul 1985:Oct 1987, Feb 1988: Sep 1993; Tejon Ranch (8839) Nov 1987:Jan 1988, Jan 1992, Aug 1991; Sep 1990. Annual recharge magnitude and monthly distribution based on precipitation with single annual recharge estimate (see supporting file *Precip SC Master Final.xls*). <see Table J-A-1, doesn't match 72 year average>
GW-IM	DWR 1994; Montgomery Watson 1996.	21-year record (1970-1990) of recharge from Montgomery Watson 1996 - calculated in a similar manner as described for the Central Valley (see supporting file *Imperial IGSM Phase 1.xls*). Precipitation: Brawley (1048) Oct 1921:Sep 1993 (see supporting file *Precip SC Master Final.xls*). Linear regression to estimate annual recharge from annual precipitation (see supporting file *Imperial Phase 1.xls*). Monthly distribution based on precipitation pattern (see *Imperial Phase 1.xls*).
GW-MWD	DWR 1994; MWD 1996.	GWSB represents additional empty storage space in local area basins that could be used for additional conjunctive use operations (1450 taf). Thus, no additional local inflows are modeling since these basins' yield is already included in the pre-prossed local supplies to each of the three MWD urban demand areas in CALVIN (see supporting file *Adjusted MWD Demands.xls*)

Pumping Characteristics Outside the Central Valley

Pumping characteristics required in CALVIN for GWSBs outside the Central Valley include monthly pumping capacity and pumping costs.

Agricultural Capacity and Costs

Agricultural pumping outside the Central Valley in CALVIN occurs in Coachella Valley and Imperial Valley. In addition, in Owens Valley groundwater pumping to augment flows in the Owens River (with ultimate destination the city of Los Angeles) is classified as agricultural pumping in CALVIN. The maximum monthly pumping capacity in Coachella Valley was obtained from an amalgamation of state reports (DWR 1975; DWR 1994) and the *Engineer's Report* (CVWD, 1998) with modification to reflect the entire basin. The values for maximum monthly pumping capacity in the Imperial Valley comes from the Imperial County IGSM (Montgomery Watson 1996), determined in a similar manner as in the Central Valley from

CVGSM data. Last, in Owens Valley, the maximum monthly pumping capacity was determined from water budgets (LA 1990).

Pumping costs were based on $0.20/af per foot of lift, as in the Central Valley. Approximate depth to groundwater was ascertained through review of water resources reports and some groundwater well records. This last item was assessed quickly and could be readdressed in a more thorough manner in the future. Table J-14 summarizes the agricultural pumping costs and capacity values in CALVIN for GWSBs outside of the Central Valley.

Table J-14. Agricultural Pumping Costs and Capacities Outside the Central Valley

GWSB	Source and Description	Agricultural Destination	Cost $/taf	Pumping Capacity taf/mo
GW-SC	---	None	---	---
GW-OW	Cost - rough estimate of pumping head from some DWR well records and Danskin (1988), p. 22-23. Capacity - DWR (1994), Volume 1, p. 86. Based on total annual volume limit agreement between Los Angeles Department of Water and Power and Inyo County.	Owens River	20	10
GW-MJ	---	None	---	---
GW-AV	---	None	---	---
GW-CH	CVWD (1998), p. 33-36, 38, 44. Cost - rough estimate from pumping head. Pumping capacity - rough estimate based on total pumping, with distribution 75% urban and 25% agriculture.	Coachella Valley	40	5
GW-IM	Montgomery Watson (1996) and review of some DWR individual well records. Cost - rough estimate from pumping head. Pumping capacity from p A-63.	Borrego, Coyote, and Sand Hills	25	5
GW-MWD	---	None	---	---

Urban Pumping Capacity and Costs

Maximum limits on urban pumping and costs were identified from state and local water resources reports. No external calculations were executed besides aggregating reported values for each groundwater subbasin and / or destination. Costs were estimated as cited in the reports. Effort was made to only include operational costs (pumping, local collection (not urban distribution), and chlorination). However, it is possible that some of these costs include capital costs that should not be included in CALVIN. Costs are documented in further detail in Appendix G: Operating Costs, and further discussion of urban inputs in CALVIN is provided in Appendix B-1: Urban Representation, and in CALVIN supporting files *Reg1 to 4 Urban documentation.doc*, *Sacarea.doc*, and *Reg 5 Urban Documentation.doc*. Table J-15 summarizes the data and sources for urban pumping costs and capacities outside the Central Valley.

Table J-15. Urban Pumping Costs and Capacities Outside the Central Valley

GWSB	Source	Destination	Cost $/taf	Pumping Capacity taf/mo
GW-SC	Cost - DWR 1994, Volume 1, p. 150, Table 6-6. Limit – see supporting file *Reg1 to 4 Urban documentation.doc*. Original estimate of 35.8 taf/mo reduced to 30.5 taf/mo to keep GW supply	SCVWD, Oak Flat, & Alameda Co.	85	30.5

	at no more than 50% of total supply			
GW-OW	----	None	---	---
GW-MJ	CALVIN study estimates. Cost - rough estimate based on pumping head plus an increase to account for treatment cost.	Mojave River Valley	35	Unlimited. Cost and long-term recharge (i.e., no GW mining allowed) determine use. No information on 2020 pumping capacity in these high population growth areas.
GW-AV	CALVIN study estimates. Cost - rough estimate based on pumping head plus a factor increase to account for treatment cost.	Antelope Valley	70	
GW-CH	CALVIN study estimates. Cost - rough estimate based on pumping lift of 250 ft (CVWD web site, 1999.	Coachella Valley	50	
GW-MWD	Cost - rough estimate based on pumping head. Capacity - MWD 1996 Volume 2, p. 4-11.	Central MWD Urban Area	30	146

ARTIFICIAL RECHARGE FACILITIES

Data requirements to represent artificial recharge facilities and operations in CALVIN include maximum monthly capacity of recharge facilities, supply sources and their conveyance capacities, and unit costs. Artificial recharge programs occur formally in the San Joaquin Valley, in the Bay Area, and in Southern California subbasins. Encouraging runoff infiltration and other minor works to facilitate incidental recharge exist in many areas in California. Local conjunctive use projects are plentiful (NHI 1998). Because it was generally difficult to get data on local operations, particularly those of irrigation districts, only larger formal projects involving specific contracts for imported water or those of major urban agencies, are currently represented in CALVIN. This is a limitation, in particular since many less formal local operations in part of the San Joaquin River and Tulare Basin involve significant volumes of CVP Friant Unit water supplies and affect water balance on tributary rivers in these regions.

Other GWSBs have been identified and promoted for possible conjunctive use projects (CALFED 1998, 2000; DWR 1997; DWR 1998b; NHI 1998; USBR 1995 and 1997). Artificial recharge facilities (links) can be located in other GWSBs in subsequent phases of the project, when characteristics of proposed facilities and operations are known.

Central Valley Artificial Recharge in CALVIN

In the current formulation of CALVIN, there are no formal recharge facilities represented in the Central Valley because of the problems separating out artificial recharge volumes from other inflow components in the CVGSM groundwater hydrology data. Thus historic artificial recharge is included already in pre-defined inflows. Base Case surface diversions, where possible were corrected to remove these flows, but usually were not corrected except thru the calibration process (see Appendix 2H: Calibration Process Details). The Kern Water Bank and other recharge efforts in the southern Central Valley (overlapping GWSBs 19, 20, and 21) possess a maximum monthly capacity of approximately 70 taf per month (DWR 1989). Other recharge facilities belonging to irrigation districts in the Friant Unit are estimated at about 450-500 taf/year capacity (See Table 2H-8 in Appendix 2H; USBR Friant Unit Water Needs Analysis, USBR 2000) and are thought to overlap several GWSBs: 13, 16, 18, 20, and 21. In some alternative investigations, CALVIN runs (see Matthew D. Davis' Masters Thesis work) to explore greater conjunctive use, a capacity of 30 taf/mo is allocated to GW-18, with 10 taf/mo allocated to each of GW-15, 19, 20, and 21.

Table J-16. Artificial Recharge in GWSBs outside the Central Valley

GWSB	Source	Method
GW-SC	ACWD 1995; SCVWD 1996; Zone7 1998.	Artificial recharge from ACWD (1995) is assumed ≈15 taf/year; SCVWD (1996), pp.5-8, 5-12, 204 to 157 taf/year; Zone 7 (1998), web page, 10 taf/year), for an estimated monthly maximum limit of 20 taf. See supporting files for more details.
GW-OW	LA 1990	Maximum annual value from water budgets, pp. 165-166, Table 10 (45 taf), distributed (weighted because recharge is not uniform) as a monthly maximum (≈ 8 taf). See also groundwater budget for CALVIN in *Owens Final.xls*.
GW-AV	Templin 1995	Direct recharge is minimal - infiltration from land application with clay layer. Some reclamation for reuse on golf courses. No concrete plans for artificial recharge program. However, this area will change and become highly urbanized by 2020 with no natural watercourse. In the model, no capacity has been assigned.
GW-MJ	DWR 1994; MBAW 1998	Value of 10 taf/mo synthesized from reports, DWR and MBAW. Based on existing and planning pipelines to delivery SWP water to spreading basins in various sections of the Mojave River. See supporting files for more details.
GW-CH	CVWD 1998	Maximum value of 10 taf/mo roughly estimated from current annual total artificial recharge and projected increases in spreading basin capacity from web page reports,.
GW-IM	Montgomery Watson 1996	Maximum value from water budgets from Imperial County IGSM, p. xxxx.
GW-MWD	MWD 1996	Local conjunctive use occurs in many water districts that comprise the service area of MWD. This is not explicitly modeled in CALVIN. Additional empty storage of 1.45 MAF in these local basins is identified for additional active recharge and conjunctive use (p. 4-11).

Source: See CALVIN supporting files *Reg1 to 4 Urban documentation.doc* and *Reg 5 Urban Documentation.doc* in the urban-related appendix folders, and other files in the Groundwater-related appendix folders (Matthew Davis' work).

Bay Area and Southern California GWSB Artificial Recharge in CALVIN

Urban artificial recharge links in CALVIN are represented in the Bay Area (for Santa Clara Valley Water District, Alameda County Water District, and Alameda County Zone 7) and in Southern California (MWDSC, Mojave Water Agency, Hi Desert Water District, Coachella Valley Water District, and Desert Water Agency). Artificial recharge facilities are also contemplated in other GWSBs outside of the Central Valley and are included in CALVIN usually with zero capacity to estimate the marginal value of proposed facilities. Table J-16 identifies the data source used to estimate the capacity of artificial recharge facilities in each GWSB outside the Central Valley.

Artificial Recharge Costs

Artificial recharge costs represent O&M of spreading basins and related works and the opportunity cost of occupied land. The assumed cost in rural areas without extensive works for CALVIN is $5/af. Artificial recharge spreading facilities in urban areas and in rural areas with extensive works are assumed to cost $10/af in CALVIN. These two values represent preliminary estimates that should be revisited in subsequent phases of data development for the model.

Proposed revised values, based on more recent information are given in Table J-17. It was difficult to determine accurate and site-specific values because (1) most studies / estimates present lumped recharge costs, which can include factors other than O&M (capital cost, opportunity costs of alternative water etc.) and (2) estimating the opportunity cost of land is difficult and beyond the scope of our work.

Table J-17. Proposed Revisions to Artificial Recharge Costs in CALVIN

GWSB	CALVIN AR Cost	Proposed Revised Cost	Facility/Location	Facility Capacity	Data Source
GWSB 1 to 21[a]	$5/af	$10/af	Agricultural spreading basins operated by irrigation districts using agricultural water	0	
GWSB 1 to 21	$10/af	$10/af	Urban spreading basins operated by urban water agencies, for proposed facilities	0	
GW-MWD	$10/af	$10/af	Ventura County spreading operations,	45 taf/yr	1
GW-SC	$10/af	$50/af	Santa Clara Valley reservoirs + spreading operations	90 taf/yr	1
GW-MWD	$10/af	$20-25/af	Orange County spreading	200 taf/yr	1
GW-MWD	$10/af	$20/af	Los Angeles spreading	120 taf/yr	1
GW-MWD	$10/af	$100/af	Los Angeles injection	30 taf/yr	1
GW-MJ, GW-CH	$10/af	$20/af	Based on revised GW-MWD operating costs for urban AR	See Table J-13	
GW-OW, GW-IM, GW-AV	$5/af	$10/af	Proposed future alternatives	0	

Source: 1: Eric G. Reichard, USGS San Diego Office, personal communication, October 5, 1999. Notes: [a] current agricultural recharge links in CALVIN only in GW-21 for Semitropic (D851&D852_GW-21) and other elements of the Kern Water Bank (D855&D857_GW-21), but capacity is set to zero in the Base Case and Unconstrained Alternatives.

In the case where treated wastewater is used to directly recharge an aquifer (reclamation recharge), an incremental wastewater treatment cost is assessed of $33/af in addition to the $5 or $10/af spreading basin operating cost. The incremental cost reflects the difference between treatment of effluent for discharge to a water body (which is required at wastewater treatment plants and not included in the model) and treatment of wastewater used as direct recharge to groundwater (cost estimates from Richard et al, 1992). Presently, the only cases where reclamation artificial recharge is modeled in CALVIN are in the Santa Clara urban demand area (T19_C316), Mojave urban demand area (T32_GW-MJ), and Coachella urban demand area (T11_C145). Appendix G contains further discussion of artificial recharge costs.

LIMITATIONS

There are several observations and/or limitations of the groundwater component of CALVIN. The prominent observations concern: (1) existing data, (2) configuration of groundwater, (3) consistency of data sources, (4) precision of data sources, (5) groundwater costs, (6) dynamic interaction between surface and groundwater, and (7) interaction between adjacent GWSBs in the Central Valley.

Existing Data

New hydrology was not developed specifically for CALVIN. Data consisted of information obtained from published reports and existing models by the USBR, DWR, and local water agencies, as described in previous section. Hydrologic data does not exist for all of the GWSBs for the time period analyzed in CALVIN. As a consequence, existing hydrology was manipulation to create data for the entire period of record. Hence, CALVIN incorporates all of the assumptions and errors that are part of the original data as well as additional assumptions and any errors in the data manipulation used to extend existing data for the full period represented in CALVIN.

Consistency Between Sources

Another important observation is the lack of consistency between sources used to generate surface and groundwater data. First, much of the surface water hydrology and the water resources system infrastructure in CALVIN are based upon DWRSIM, while groundwater hydrology, local accretion flows, and Base Case deliveries in CALVIN are based on CVGSM (the NAA simulation). CVGSM makes use of surface water diversion data generated from two surface water models developed by the USBR: PROSIM and SANJASM. The hydrology that feeds DWRSIM and the USBR surface models and, thus, CVGSM can differ somewhat. Thus, there may be some inconsistency incorporated into CALVIN by utilizing source models with differing hydrology. The CALVIN calibration identifies some of these inconsistencies and problems with data sources.

Second, part of the background calculations that contribute to DWRSIM are depletion analyses computed for Depletion Study Areas (DSA) computed by DWR. The DSA depletion analyses were developed over time, as was DWRSIM. Hence, the initial formulation, with a focus only on changes in surface water resources, has been transformed to consider a more complex system. As a result these tools have become more complicated and more difficult to interpret with time[1]. In the DSA depletion analysis, groundwater is not fully separated from historic surface water resources nor accounted for dynamically. The DSA water balances are used as part of the input to DWRSIM. Thus, there are underlying assumptions about groundwater usage and availability built into DWRSIM and its hydrology. In CALVIN, on the other hand, surface and groundwater are tracked explicitly, with a partial, dynamic linkage between applied agricultural and urban water and groundwater. There is concern that by using DWRSIM's surface hydrology and reservoir operations in the Base Case and CVGSM's groundwater hydrology and deliveries, there may be some water balance problems in CALVIN ultimately requiring a full calibration of the model as presented in Appendix 2H.

Accuracy of Data Sources

There is a marked difference in the quality of data sources for groundwater in the Central Valley compared to subbasins outside the Central Valley. Groundwater hydrology in the Central Valley draws upon results from the Central Valley Ground Surface Water Model (CVGSM). Development of CVGSM was an involved process with much effort that has resulted in a higher degree of accuracy and detail (within the bounds of the accuracy of a simulation model) in general than groundwater hydrology outside of the Central Valley. Some criticism has been

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[1] DWR is in the process of developing a successor to DWRSIM - CALSIM. Eventually the new model may serve as water resources model for both DWR and USBR.

levied at the model due to lack of dynamic calibration. Nonetheless, it is the best effort to date and serves as reference for planning water allocation in the Central Valley. Furthermore, the period of record simulated in the CVGSM (1922-1990) is nearly the entire record optimized in CALVIN. Groundwater data from CVGSM was extended through 1993 by repeating simulation results from years within the period 1922-1990 based matching precipitation. Obviously, the precision of the last three years of records used in CALVIN in the Central Valley is less than the period 1922-1990, which makes use of records generated directly from simulation results.

The CVGSM groundwater data had to be manipulated to partition deep percolation volumes reported in the output into (a) precipitation and (b) agricultural applied water for CALVIN. This calculation also serves to partition agricultural demand areas in two pathways to enable modeling return flows to both surface and groundwater destinations. Thus, disaggregating CVGSM deep percolation introduces a potential distortion to the data prepared for CALVIN.

Groundwater hydrology data developed outside of the Central Valley is much less abundant and precise. In most of these basins, water balance estimates from 1 to 21 years were extrapolated to cover the 72-year period of record of CALVIN, as described. A major assumption is that the magnitude and monthly distribution of annual groundwater recharge is highly correlated with precipitation. Because precipitation data were not available in each subbasin for the entire period of record needed for CALVIN, precipitation records for the full 72 years sometime had to be developed by using data from several different gages. Use of different gages in the same subbasin introduces some inconsistency in developing a recharge pattern, but may be less important that the underlying estimates of recharge and the assumption of good correlation with precipitation.

The accuracy of annual recharge estimates in each basin varied. In Antelope Valley, Coachella Valley, Mojave River Valley, and Santa Clara (South Bay Area) subbasins, usually only one or several annual average recharge values were available for developing the 72-year inflow time series for CALVIN from precipitation records. Consequently, the reliability of groundwater inflows for these subbasins is less certain than those in the Central Valley.

In Owens and Imperial Valleys, water budgets were available for a period of consecutive years. Thus, in Owens Valley and Imperial Valley, the precision of the data developed for CALVIN is based on more extensive estimates of recharge that permit using a more statistically rigorous approach to extrapolating the existing recharge record for CALVIN. While less reliable than the data from the CVGSM, these subbasins' inflow data in CALVIN should be more reliable than the other subbasins outside the Central Valley.

As better information becomes available, the groundwater hydrology can be updated. There is at least one groundwater modeling effort (Coachella Valley) that was not available for use in CALVIN. Moreover, DWR is presently in the process of collating and updating groundwater information throughout the state to release and updated groundwater bulletin in 2002.

Conceptualization of Groundwater in CALVIN

The conceptualization of groundwater in CALVIN introduces some limitations in modeling and some caution for interpreting CALVIN results. Treating groundwater subbasins as lumped reservoirs is largely required to fit the network flow programming-based computational engine that runs CALVIN (HEC-PRM). Potential problems arise from the inability to dynamically link (1) surface and groundwater and (2) hydraulically connected subbasins.

While surface and groundwater are explicitly modeled in CALVIN, there is incomplete dynamic linkage between the two due to limitations in the HEC-PRM solution code. A partial dynamic link is established though return flows of recharge as a percentage of applied water (both agricultural and urban) and through artificial recharge links. All other sources of inflow/outflow to GWSBs and any inter-subbasin flows in the Central Valley are pre-processed as fixed inputs to CALVIN. Thus, there is no dynamic link between surface streams and groundwater to represent stream-aquifer interactions and between basins to represent inter-subbasin flows when storage levels between basins differ.

Stream-aquifer exchanges and inter-subbasin flows in the Central Valley are based on the CVGSM No Action Alternative (NAA) and the conditions in streams, rivers, canals, lakebeds and groundwater basins that occur during the 69 years of that simulation. Conditions arising from the prescribed operations in each CALVIN optimization will likely differ from those that occur in CVGSM NAA. In areas of CALVIN where conditions are substantially different, the true groundwater inflows may be substantially different from those taken from CVGSM NAA. By forcing CALVIN to begin and end each 72-year optimization with the same groundwater storage levels as those in CVGSM NAA, groundwater storage conditions cannot differ greatly from those in the NAA. In other cases, if CALVIN is allowed to mine groundwater basins beyond NAA levels, there is the potential for significant differences in operational and storage conditions for these subbasins and the need to look closely at possible distortions created by the pre-processed groundwater inflows taken from CVGSM NAA. For example, if a subbasin is drawn down in CALVIN more than in the CVGSM NAA, actual inter-subbasin flow and net stream-aquifer flux would change. In CALVIN this aspect would not be properly reflected. It is possible, even when beginning and ending groundwater storage levels are constrained in CALVIN, that adjacent subbasins experience substantially different depths to groundwater than under the CVGSM NAA as a result of more groundwater use in one subbasin during a comparable period. Over time, in reality, different depths would tend to equilibrate, subject to limitations in the flow rate between adjacent subbasins in the Central Valley. With some knowledge of the Darcy flux rates between adjacent subbasins, CALVIN groundwater storage results could perhaps be post-processed to evaluate the potential magnitude of distortions in inter-subbasin flows that result from using pre-processed CVGSM NAA data.

The USBR is currently in the process of selecting and performing analysis of a preferred operational alternative that consists of portions of several of the CVPIA PEIS alternatives analyzed. Since there is no dynamic link between local inflows and operation of the system, care must be followed when selecting the data source for local groundwater inflows. Presently, the NAA was used because no alternative was clearly identified as the one that would be implemented for the CVPIA.

Groundwater Pumping Costs

Another limitation is that presently in CALVIN groundwater pumping costs are represented as fixed head costs at projected 2020 groundwater levels. In the Base Case model that is limited by environmental and physical constraints, and pumping replicates the CVGSM NAA levels, fixed head pumping is a satisfactory assumption. It is possible, but computationally very expensive and more data intensive, to model dynamic head in HEC-PRM. It requires some reconfiguration of cost curves and will likely extend run times extensively.

FUTURE REFINEMENTS TO GROUNDWATER COMPONENT OF CALVIN

Several future directions are identified for improvement and/or extending the groundwater component of CALVIN. Many of these try to address limitations presented above. The most important issues are: (1) comparison of total water in the system between USBR and DWR estimates, (2) evaluation of the No Action Alternative as the best source of data for CALVIN, (3) improvements to the characterization of GWSBs outside of the Central Valley, (4) revision of preliminary pumping and artificial recharge operating costs, and (5) representation of minimum groundwater pumping for agriculture in the Central Valley.

Total Water

In subsequent phases of the project, comparison of total water in the system between USBR and DWR work should be investigated further. Special attention should be given to address inconsistencies in the estimates of local surface hydrology in the Central Valley, and reconcile groundwater and surface water balances as discussed in other appendices. In the present phase of the project, much effort was expending in trying to reconcile differing hydrologies between the two agencies. The calibration process was an important part of addressing this issue (Appendix 2H). Additional work likely will be required to improve and / or settle water balance issues in subsequent phases of CALVIN development and use.

No Action Alternative

The CVGSM NAA is used in the present CALVIN formulation. It represents the No Action Alternative, as opposed to altered operational regimes contemplated by the USBR and CALFED working groups. The NAA represents continuance of CVP and SWP operations as they currently exist. With CVPIA, Bay-Delta Accords, and the evolving CALFED ROD it is unlikely that NAA operations will be continued. Nevertheless, in terms of modeling, the NAA can be representative of groundwater hydrology. In the Base Case, CALVIN was calibrated to so that groundwater behavior tracked closely the behavior simulated in CVGSM NAA. In essence, this meant that groundwater was not unduly mined but rather remained approximately at present day volumes. When examining other configurations and alternatives, assumptions about groundwater mining may be different from those in the CALVIN Base Case. Thus, the task is to assure that groundwater hydrology properly matches assumptions that would occur under different prescriptions dictated by CALVIN alternatives. One important check will be to compare groundwater subbasin storage levels that result in CALVIN with the CVGSM NAA simulation used to develop the inflow data. If further CVGSM simulations of agreed upon operations changes are made, revised groundwater inflow data for CALVIN can be developed from the CVGSM results, following the methods presented in this appendix. As a last note, if CVGSM simulations are extended beyond 1990, these data should be used instead of repeating matching years for the period 1990-93.

GWSBs Outside the Central Valley

As discussed, the availability and accuracy of groundwater data outside the Central Valley is less than in the Central Valley. Without additional groundwater modeling efforts in these subbasins by third parties, characterization of the subbasins in CALVIN will continue to be based on sometimes very limited data. Groundwater models have been developed for Coachella Valley and Imperial County but are not of public record. Public release of computer data files from these modeling efforts that could yield data to provide a better characterization of subbasin hydrology in these areas. The Coachella Valley characterization is likely the worst of the GWSBs in CALVIN, as information from a very limited portion of the subbasin area was extrapolated to the whole subbasin.

Revisit Groundwater Operational Costs

Several groundwater operational costs can be revisited in subsequent phases of the project. First, efforts should be invested in refining urban groundwater pumping costs to be sure they only reflect the variable portion of groundwater supply and are specific to the urban demand areas modeled. Currently urban pumping costs represent region-wide averages. Second, operational costs related to recharge in CALVIN are preliminary. Reported artificial recharge costs often include other costs, including capital costs and sometimes incorporate contractual costs of water supplied or replaced. More investigation is required to improve estimates, including getting site-specific costs. Finally, groundwater pumping costs based on dynamic head could be developed. Dynamic head costs would also permit more refined evaluation of alternative operational scenarios, such as groundwater banking, conjunctive use, and/or mining.

Minimum Groundwater Pumping

In some areas of each CVPM agricultural region, agriculture has no access to surface water supplies that are used in that region. In these parts of the region, farming depends fully on groundwater and some minimum pumping rate should be imposed in each CVPM region in CALVIN to represent this portion of demand that is served only by groundwater. Currently, under unconstrained alternatives greater use of surface water occurs in wet years, sometimes beyond the ability of the existing surface distributions system to deliver this water to individual farms in the CVPM region. A minimum pumping rate would more realistically reflect the limitations of the surface distribution system in supplying agricultural water in the region.

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ANNEX TO APPENDIX J

Table J-A-1. Summary of Groundwater Subbasin Characteristics

GWSB	Initial Storage (taf)	Storage Capacity (taf)	CVGSM % AG AW to GW (%)	CVGSM % AG AW to SW (%)	CVGSM AG Basin Efficiency (%)	Local Inflow Min. (taf/yr)	Local Inflow Max. (taf/yr)	Local Inflow Ave. (taf/yr)
GW-1	1902	5448	0.175	0.213	0.613	-62.4	88.3	1.9
GW-2	11843	24162	0.198	0.088	0.714	140.6	827.6	402.7
GW-3	13345	22127	0.213	0.142	0.645	-116.1	264.7	11.7
GW-4	10350	15362	0.042	0.311	0.646	152.7	460.9	263.1
GW-5	15552	24399	0.220	0.151	0.630	8.1	337.5	144.9
GW-6	17948	22864	0.103	0.177	0.719	256.5	504.9	365.7
GW-7	10025	12270	0.190	0.259	0.551	177.2	427.8	278.0
GW-8	22366	32842	0.046	0.279	0.675	586.2	1065.8	747.4
GW-9	17744	23395	0.152	0.053	0.794	-181.2	344.2	13.2
GW-10	22213	29250	0.083	0.321	0.595	127.2	727.4	299.2
GW-11	10948	15543	0.282	0.149	0.570	-313.3	81.0	-157.3
GW-12	10380	13919	0.074	0.269	0.657	53.2	269.6	156.9
GW-13	31143	47484	0.067	0.202	0.731	523.4	1634.3	872.1
GW-14	51075	65235	0.257	0	0.743	-74.6	1563.0	314.6
GW-15	70494	90978	0.083	0.191	0.726	835.5	2495.7	1167.3
GW-16	6359	11650	0.062	0.384	0.554	167.7	565.7	278.1
GW-17	7311	13942	0.113	0.156	0.731	209.8	792.0	358.7
GW-18	40775	59544	0.309	0.003	0.688	176.9	1428.0	484.8
GW-19	43085	68266	0.291	0	0.709	-67.8	463.9	166.9
GW-20	22630	40814	0.180	0.123	0.697	83.6	429.2	219.4
GW-21	51595	81622	0.305	0.018	0.677	219.3	905.2	390.4
GW-SC	425	655	---	---	---	62.2	277.0	130.0
Old GW-SC ?						65.5	291.9	137.0
GW-OW	30000	100000	---	---	---	45.3	87.9	59.6
Old GW-OW ?						113.3	333.4	178.14
GW-AV	20000	100000	---	0	0.6 [a]	5.6	113.4	48.73
GW-MJ	4370	100000	---	0	0.6 [a]	21.0	155.7	70.41
GW-CH	3600	100000	0.06 [b]	0.26 [b]	0.6 [a] / 0.68 [b]	15.6	470.5	138.86
GW-IM	93000	100000	0	0.32 [b]	0.68 [b]	16.5	714.9	192.2
GW-MWD	750	1450	---	---	---	---	---	---

Note: --- No value - not applicable. [a] urban applied water value (from DWR Bulletin 160-93, 1993), otherwise value in this column is for agricultural applied water. [b] See supporting file *Reg5 Interim Ag Demands Documentation.doc*

Table J-A-1. Continued

GWSB	Principal Precipitation Gage in GWSB	Ag. Pump Max. Capacity taf/mo	Urban Pump Max. Capacity taf/mo	Ag Pump Cost $/af	Urban Pump Cost $/af	Recharge Capacity taf/mo	Recharge Cost $/af
GW-1	Redding (7300)	20.76	---	30.0	---	---	---
GW-2	Orland (6506)	153.23	---	28.2	---	---	---
GW-3	Colusa (1948)	170.98	---	23.8	---	---	---
GW-4	Colusa (1948)	110.47	---	16.0	---	---	---
GW-5	Marysville (5385)	225.65	---	18.8	---	---	---
GW-6	Winters (9742)	148.06	---	18.2	---	---	---
GW-7	Sacramento (7633)	96.02	31.3	28.8	57	---	---
GW-8	Camp Pardee (1428)	208.38	17.5[a] / 10[b]	28.6	55[a] / 70[b]	---	---
GW-9	Lodi (5032)	73.77	---	20.4	---	---	---
GW-10	Los Banos (5120)	197.88	---	15.6	---	---	---
GW-11	Modesto (5738)	52.21	---	20.6		---	---
GW-12	Merced (5532)	80.56	---	23.6	---	---	---
GW-13	Merced (5532)	290.96	---	30.0	---	0	5
GW-14	Kettleman (4536)	332.85	---	76.4	---	---	---
GW-15	Kettleman (4536)	407.88	---	46.6	---		---
GW-16	Fresno WSO AP (3257)	60.76	Unlimited	29.8	80.0	0	5
GW-17	Fresno WSO AP (3257)*	152.39	---	31.6	---	---	---
GW-18	Visalia (9367)	348.95	---	45.2	---	0	5
GW-19	Button Willow (1244)	171.1	---	68.4	---	0	5
GW-20	Button Willow (1244)	108.1	---	67.2	---	0	5
GW-21	Bakersfield (442)	228.31	33	69.6	128.0	0	5
GW-SC	San Jose (xxxxx)	---	30.5	---	85	20	10
GW-OW	Independence (4232)	10	---	20	---	15	5
GW-AV	Palmdale (6624)	---	Unlimited	---	70	0	5
GW-MJ	Barstow	---	Unlimited	---	35	10	10
GW-CH	Indio (4259)	5	Unlimited	40	50	10	10
GW-IM	Brawley (1048)	5	---	25	---	0	5
GW-MWD	---	---	146	---	30	45	10

Note: --- No value - not applicable. [a] Sacramento Urban, [b] Stockton Urban

Table J-A-2. Correspondence Between CALVIN and DWR Groundwater Subbasins

	CALVIN	Location	DWR Subbasins from Bulletin 118-80 and Draft Bulletin 118-2000
1	GW-1	Redding Basin	Redding Basin
2	GW-2	Chico Landing to Red Bluff	North portion of Sacramento Valley
3	GW-3	Colusa Trough	Midwest portion of Sacramento Valley
4	GW-4	Chico Landing to Knight's Landing	Central portion of Sacramento Valley
5	GW-5	Lower Feather R. and Yuba R.	Midwest portion of Sacramento Valley
6	GW-6	Sacramento Valley Floor, Cache Cr., Putah Cr., and Yolo Bypass	Southwest portion of Sacramento Valley
7	GW-7	Lower Sacramento R. below Verona	Mideast portion of Sacramento Valley
8	GW-8	Valley Floor east of Delta	Southeast portion of Sacramento Valley, Sacramento County Basin, and north portion of Eastern San Joaquin County Basin
9	GW-9	Sacramento-San Joaquin Delta	Tracy Basin and west portion of Sacramento County Basin
10	GW-10	Valley Floor west of San Joaquin R.	Delta-Mendota Basin
11	GW-11	Eastern San Joaquin Valley above Toulumne R.	Modesto Basin and south portion of Eastern San Joaquin County Basin
12	GW-12	Eastern Valley Floor between San Joaquin R. and Tuolumne R.	Turlock Basin
13	GW-13	Eastern Valley Floor between San Joaquin R. and Merced R.	Merced Basin, Chowchilla Basin, and Madera Basin
14	GW-14	Westland	Westside Basin
15	GW-15	Mid-Valley Area	Tulare Lake Basin and east portion of Kings Basin
16	GW-16	Fresno Area	Northeast portion of Kings Basin
17	GW-17	Kings R. Area	Southeast portion of Kings Basin
18	GW-18	Kaweah R. and Tule R. Area	Kaweah Basin and Tule Basin
19	GW-19	Western Kern County	West portion of Kern County Basin
20	GW-20	Eastern Kern County	Northeast portion of Kern County Basin
21	GW-21	Kern R. Area	South portion of Kern County Basin
22	GW-SC	Southern Bay Area	3 Santa Clara Valley Basins, Niles Cone and Livermore-Amador Valley Basin
23	GW-OW	Owens Valley	Owens Valley
24	GW-AV	Antelope Valley	Antelope Valley
25	GW-MJ	Mojave River Valley	Coyote Lake Valley, Caves Canyon Valley, Middle Mojave River Valley, Upper Mojave River Valley, and Harper Valley (subject to revision)
26	GW-MWD	Scattered in Ventura, Los Angeles and Orange County	See MWDSC (1996)
27	GW-CH	Coachella Valley	Coachella Valley
28	GW-IM	Imperial Valley	Imperial Valley, East Salton Sea Basin, Amos Valley, and Ogilby Valley

Table J-A-3. CVGSM Files Used to Prepare Groundwater Components of CALVIN

No-Action Alternative	Description	Use in Calvin Data Preparation
Pass 1 – Input Files		
CNJ.IN1	Model control file	Not used.
CNJCHRC.DAT	Element characteristic file	Precipitation gage assignments in each subbasin used to match similar precipitation years to extend CALVIN groundwater hydrology through 1991-3 (CVGSM terminates in 1990).
CNJELEM.DAT	Element configuration file	Not used.
CNJLAKE.DAT	Lake configuration data file	Not used.
CNJSTA1.DAT	Stratigraphy data file	Surface elevation and layer thickness used to compute storage.
CNJSTRM.DAT	Stream geometry file	Not used.
CNJXY.DAT	Node x-y coordinate file	Not used.
CNJOUT1.OUT	Pass1 text output file	Surface area used to compute storage.
Pass 2 - Step 2a Input Files		
CNJAGSP2.NEA	Agricultural water demand file	Not used.
CNJBOND.DAT	Boundary condition data file	Not used.
CNJCROP.NEA	Crop acreage data file	Not used.
CNJDVSP2.NDA	Diversion specification file	Used to help determine portion of total pumping for urban use.
CNJET.DAT	Evapotranspiration data file	Not used.
CNJIN22A.NEA	Control input file	Used to specify monthly reporting and to generate flux flows (inter-subbasin flows) between different groundwater subbasins. Note that this option has been turned off and net intersubbasin flows are lumped into local inflows.
CNJIN90.NEA	Initial condition data file	Initial groundwater elevations used to compute storage.
CNJINFL.NDA	Streamflow data file	Not used.
CNJLND.NBA	Land use data file	Not used.
CNJMIN.NDA	Minimum stream flow data file	Not used.
CNJOPER1.N3B	Operations data file	Not used.
CNJOUT1.BIN	Binary input generated by part 1 (pass 1)	Not used.
CNJPARM.DAT	Parameter data file	Percentage of indoor/outdoor water use to compute local inflows. Specific yield polygons used to compute storage.
CNJPRCP1.DAT	Precipitation data file	Not used.
CNJPRNT.N1A	Locations for gw table and strm hydgrph	Not used.
CNJPUMP2.NEA	Pumping data file	Not used.
CNJPUSP.DAT	Pumping specification data file	Not used.

No-Action Alternative	Description	Use in Calvin Data Preparation
CNJSWDV1.NDA	Surface water diversion data file	Used to help determine portion of total pumping for urban use.
CNJURB.N1A	Urban water demand file	Not used.
Output Files		
WU2A_Y.BIN	Budget output (binary)	Used to generate text output files.
DIVDTL2A.BIN	Stream reach budget (binary)	Used to generate text output files.
STRMDT2A.BIN	Diversion detail (binary)	Used to generate text output files.
CNJOUT2.OUT	Standard output file	Not used.
GW2A_Y.NEA	Groundwater budget	Local inflows for groundwater subbasins (all components except for precipitation and exclusion of applied agricultural water); Pumping to calibrate and validate CALVIN (same as WU2A_Y.NEA). Maximum pumping used as pumping limits.
SOIL2A_Y.NEA	Soil moisture budget	Extraction of percolation of applied agricultural water from percolation to compute local inflow from precipitation and generate split in CALVIN agricultural areas due to return flows to either groundwater or surface water; CVGSM basin efficiencies
WU2A_Y.NEA	Land and water use budget	Areas used to convert inches to volumes in soil moisture budget to generate local inflows for groundwater subbasins; Pumping to calibrate and validate CALVIN (same as GW2A_Y.NEA).
STRMDT2A.NEA	Streamflow budget	Not used.

Sources: USBR 1997, CVGSM No Action Alternative.

Table J-A-4. Comparison of Draft and Final CVPIA PEIS CVGSM NAA and RNAA Simulations

<insert table from excel file of summary results>

Inter-subbasin Flows

Physically, the Central Valley is made up of several large aquifers. North of the Delta, groundwater generally flows toward the Delta. From Tulare to the Delta, groundwater flow tends to be northerly toward the Delta. Last, groundwater flows inward toward the old lakebed in the Tulare basin (Bertoldi et al, 1991). However, local conditions, such as intensive pumping or high river flows, can modify the general flow trends.

Since groundwater is represented as independent underground reservoirs, it would be necessary to depict subsurface groundwater movement through inter-subbasin flows. The inter-subbasin flows can be extracted directly from CVGSM NAA output. They can then be pre-processed and entered into the CALVIN model explicitly as fixed exchanges between underground reservoirs.

To generate inter-subbasin flows from CVGSM, the control file was modified to create an output file with flux (flow) across element faces. Due to dimension limitations, each layer in CVGSM was run separately resulting in three output files that contain flow across element faces (*CPEF_Y.NEA*, *CPEF_YL2.NEA*, and *CPEF_YL3.NEA*). Element faces were specified in the print control data file *CNJPRNT38.N1A*, according to borders of the CVPM subregions (GWSBs). Element faces were added along a common border between two subbasins to generate the inter-subbasin flows. 38 intersubbasin flow paths were identified between the 21 GWSBs in the Central Valley. As with local flows, it was necessary to extend the CVGSM derived data by three years. The same precipitation matches as with local inflows were used.

Another assumption is necessary since matching precipitation years differed between adjacent subbasins. Consequently, to generate inter-subbasin flows in the last three years of the CALVIN model, an average flow was computed based on the two matching years. In HEC-PRM negative flows cannot be expressed (HEC 1999) so that time series flow values must be entered for each flow direction (eg GW-1 to GW-2 and GW-2 to GW-1). The variation of values and matching years are presented on the next page. These inter-subbasins flows, derived as described were inconsistent with other components of each GWSB water balance produced by CVGSM NAA output. In order to avoid major discrepancies with the water balance and accounting of groundwater in the calibration of CALVIN, only those inflow components documented in the output file GW2a_Y.NEA were ultimately used to generate the groundwater inflows in CALVIN with the assumption that inter-subbasin exchanges have already been lumped into the CVGSM components reported in the GW2a_Y.NEA file.

Table J-A-5. Inter-subbasin Configuration, Flows, and Matching Years for Record Duplication

CVGSM Element Flux ID	First GWSB	Second GWSB	Max. Flow First to Second GWSB (taf)	Min. Flow First to Second GWSB (taf)	Ave. Flow First to Second GWSB (taf)	Max. Flow Second to First GWSB (taf)	Min. Flow Second to First GWSB (taf)	Ave. Flow Second First GWSB (taf)	Match First GWSB 1991	Match Second GWSB 1991	Match First GWSB 1992	Match Second GWSB 1992	Match First GWSB 1993	Match Second GWSB 1993
1	GW-1	GW-2	3.5	2.9	3.2	0.0	0.0	0.0	1933	1966	1990	1979	1938	1980
2	GW-2	GW-3	0.0	0.0	0.0	3.8	0.8	1.7	1966	1932	1979	1923	1980	1958
3	GW-2	GW-4	0.4	0.0	0.0	0.8	0.0	0.2	1966	1932	1979	1923	1980	1958
4	GW-2	GW-5	0.0	0.0	0.0	1.0	0.2	0.5	1966	1945	1979	1948	1980	1958
5	GW-3	GW-4	0.0	0.0	0.0	8.9	2.6	7.1	1932	1932	1923	1923	1958	1958
6	GW-4	GW-5	0.1	0.0	0.0	3.0	0.0	1.3	1932	1945	1923	1948	1958	1958
7	GW-3	GW-6	0.6	0.0	0.0	2.0	0.0	0.9	1932	1974	1923	1975	1958	1925
8	GW-4	GW-6	0.1	0.0	0.0	0.5	0.0	0.1	1932	1974	1923	1975	1958	1925
9	GW-5	GW-6	0.4	0.0	0.1	0.1	0.0	0.0	1945	1974	1948	1975	1958	1925
10	GW-5	GW-7	0.0	0.0	0.0	2.7	1.5	2.1	1945	1948	1948	1923	1958	1956
11	GW-6	GW-9	1.6	0.0	0.7	1.5	0.0	0.1	1974	1990	1975	1984	1925	1967
12	GW-6	GW-7	0.0	0.0	0.0	1.3	0.1	0.7	1974	1948	1975	1923	1925	1956
13	GW-7	GW-8	3.1	0.3	2.1	0.0	0.0	0.0	1948	1926	1923	1954	1956	1938
14	GW-8	GW-9	13.1	4.5	9.7	0.0	0.0	0.0	1926	1990	1954	1984	1938	1967
15	GW-9	GW-10	1.9	0.0	0.6	0.6	0.0	0.0	1990	1949	1984	1957	1967	1956
16	GW-9	GW-11	2.7	0.0	1.6	0.0	0.0	0.0	1990	1990	1984	1979	1967	1941
17	GW-8	GW-11	7.1	0.0	1.9	0.1	0.0	0.0	1926	1990	1954	1979	1938	1941
18	GW-10	GW-11	7.1	0.0	1.9	0.1	0.0	0.0	1949	1990	1957	1979	1956	1941
19	GW-11	GW-12	0.0	0.0	0.0	11.9	7.8	9.8	1990	1990	1979	1948	1941	1938
20	GW-10	GW-12	7.1	0.9	3.9	0.0	0.0	0.0	1949	1990	1957	1948	1956	1938
21	GW-12	GW-13	0.0	0.0	0.0	11.7	7.2	9.4	1990	1990	1948	1948	1938	1938
22	GW-10	GW-13	17.5	0.0	0.5	15.2	0.0	1.2	1949	1990	1957	1948	1956	1938
23	GW-10	GW-14	18.3	0.8	4.4	0.0	0.0	0.0	1949	1925	1957	1922	1956	1941
24	GW-10	GW-15	3.6	0.0	0.7	1.6	0.0	0.0	1949	1925	1957	1922	1956	1941
25	GW-13	GW-15	6.2	0.0	1.1	3.1	0.0	0.0	1990	1925	1948	1922	1938	1941
26	GW-13	GW-16	0.0	0.0	0.0	11.8	1.7	7.4	1990	1945	1948	1962	1938	1938
27	GW-14	GW-15	0.0	0.0	0.0	41.2	21.0	28.7	1925	1925	1922	1922	1941	1941
28	GW-15	GW-16	10.2	0.0	0.8	3.6	0.0	0.5	1925	1945	1922	1962	1941	1938
29	GW-16	GW-17	0.0	0.0	0.0	14.2	1.6	6.1	1945	1945	1962	1962	1938	1938
30	GW-15	GW-17	11.4	3.4	6.7	0.0	0.0	0.0	1925	1945	1922	1962	1941	1938
31	GW-17	GW-18	0.0	0.0	0.0	6.8	0.6	5.4	1945	1965	1962	1963	1938	1980
32	GW-15	GW-18	9.8	0.0	4.7	3.4	0.0	0.0	1925	1965	1922	1963	1941	1980

CVGSM Element Flux ID	First GWSB	Second GWSB	Max. Flow First to Second GWSB (taf)	Min. Flow First to Second GWSB (taf)	Ave. Flow First to Second GWSB (taf)	Max. Flow Second to First GWSB (taf)	Min. Flow Second to First GWSB (taf)	Ave. Flow Second First GWSB (taf)	Match First GWSB 1991	Match Second GWSB 1991	Match First GWSB 1992	Match Second GWSB 1992	Match First GWSB 1993	Match Second GWSB 1993
33	GW-15	GW-19	14.4	7.6	11.8	0.0	0.0	0.0	1925	1973	1922	1933	1941	1978
34	GW-18	GW-19	6.0	0.0	3.7	1.9	0.0	0.0	1965	1973	1963	1933	1980	1978
35	GW-18	GW-20	0.2	0.0	0.0	4.1	0.0	0.9	1965	1973	1963	1933	1980	1978
36	GW-19	GW-20	4.7	0.0	2.6	1.3	0.0	0.0	1973	1973	1933	1933	1978	1978
37	GW-19	GW-21	7.0	0.0	2.7	1.3	0.0	0.0	1973	1925	1933	1975	1978	1952
38	GW-20	GW-21	0.0	0.0	0.0	8.6	4.2	5.3	1973	1925	1933	1975	1978	1952

Example of Computing Local Inflows Outside the Central Valley

Antelope Valley

Estimated Average Annual Recharge = 49 TAF

Precipitation Records: Tejon Ranch (8839) Oct 1921:Aug-1932;

Palmdale (6624) Sep-1932:Sep-1993

Average Annual Precipitation of Palmdale = 7.98 in.

Calculations:

[1] Month

[2] Monthly precipitation records. Note, if the precipitation is not the principal gage (i.e. Tejon Ranch in the case of Antelope Valley), only the normalized precipitation is reported and used.

[3] Annual Precipitation = Σ (Monthly Precipitation for the hydrologic year) - computed for reference only.

[4] Monthly Normalized Precipitation = Monthly Precipitation / Average Annual Precipitation

[5] Monthly Local Inflow = Monthly Normalized Precipitation x Estimated Average Annual Local Inflow

[6] Annual Local Inflow = Σ (Monthly Local Inflow for the hydrologic year) - computed for reference only.

Table J.A.5: Example of Local Inflows Outside of the Central Valley

Month [1]	Precip. [2]	Annual Precip. [3]	Normal. Precip. [4]	Local Inflow [5]	Annual Local Inflow [6]
Oct-90	0.22		0.0276	1	
Nov-90	0.01		0.0013	0	
Dec-90	0.00		0.0000	0	
Jan-91	1.20		0.1504	7	
Feb-91	1.11		0.1391	7	
Mar-91	4.17		0.5226	26	
Apr-91	0.00		0.0000	0	
May-91	0.00		0.0000	0	
Jun-91	0.00		0.0000	0	
Jul-91	0.21		0.0263	1	
Aug-91	0.01		0.0013	0	
Sep-91	0.11	7	0.0138	1	43
Oct-91	0.00		0.0000	0	

Month [1]	Precip. [2]	Annual Precip. [3]	Normal. Precip. [4]	Local Inflow [5]	Annual Local Inflow [6]
Nov-91	2.00		0.2506	12	
Dec-91	0.31		0.0388	2	
Jan-92	2.05		0.2569	13	
Feb-92	4.96		0.6216	30	
Mar-92	2.52		0.3158	15	
Apr-92	0.23		0.0288	1	
May-92	0.10		0.0125	1	
Jun-92	0.00		0.0000	0	
Jul-92	0.06		0.0075	0	
Aug-92	0.52		0.0652	3	
Sep-92	0.00	13	0.0000	0	78
Oct-92	0.00		0.0000	0	
Nov-92	3.02		0.3784	19	
Dec-92	0.43		0.0539	3	
Jan-93	7.50		0.9398	46	
Feb-93	4.86		0.6090	30	
Mar-93	0.99		0.1241	6	
Apr-93	0.00		0.0000	0	
May-93	0.00		0.0000	0	
Jun-93	0.37		0.0464	2	
Jul-93	0.00		0.0000	0	
Aug-93	0.00		0.0000	0	
Sep-93	0.00	17	0.0000	0	105

Summary of Groundwater Computations to Prepare Data Input to CALVIN (to be updated and completed)

Central Valley

No.	Item	Source <some of these are old files, and have been updated and revised by Mark Leu and Mimi Jenkins, especially those related to GW inflows in the Central Valley; see main text>
1.a	Initial Storage	Calculated in *Element Calcs.xls* from data in CVGSM.
1.b	Total Storage	Calculated in *Element Calcs.xls* from data in CVGSM.
2.	Percolation of Applied Agricultural Water	Calculated in *Soil WB 1-7.xls*, *Soil WB 8-14.xls, Soil WB 15-21.xls* from data in CVGSM.
3.	Local Inflows	Partially calculated in *Soil WB 1-7.xls*, *Soil WB 8-14.xls, Soil WB 15-21.xls* from data in CVGSM (precipitation and urban return) and other components from *GW2A_Y.NEA* from CVGSM, summarized in *GW Local Inflows CV.xls*.
4.	Intersubbasin Flows	Lumped into local inflows.
5.a	Agricultural Pumping	Maximum pumping in CVGSM, *GW2A_Y.NEA*.
5.b	Urban Pumping	
6.	Artificial Recharge	Identified in DWR 1989.

Outside of the Central Valley

Santa Clara

No.	Item	Source <to be updated; see main text>
1.a	Initial Storage	Identified in ACWCD (1998), SCWCD (1996), and Zone 7 (1998).
1.b	Total Storage	Identified in ACWCD (1998), SCWCD (1996), and Zone 7 (1998).
2.	Percolation of Applied Agricultural Water	No agriculture modeled in Santa Clara groundwater subbasin.
3.	Local Inflows	Calculated in Brian's file from data in ACWCD (1998), SCWCD (1996), and Zone 7 (1998) and local precipitation records.
4.	Intersubbasin Flows	Lumped into local inflows.
5.a	Agricultural Pumping	Maximum pumping in CVGSM, *GW2A_Y.NEA*.
5.b	Urban Pumping	Identified in ACWCD (1998), SCWCD (1996), and Zone 7 (1998).
6.	Artificial Recharge	Identified in ACWCD (1998), SCWCD (1996), and Zone 7 (1998).

Owens Valley

No.	Item	Source <to be checked, see main text>
1.a	Initial Storage	Identified in Hardt et al (1980).
1.b	Total Storage	Assumed to be 100, 000 TAF for modeling purposes.
2.	Percolation of Applied Agricultural Water	Agriculture is not modeled dynamically in Owens Valley.
3.	Local Inflows	Calculated in *Owens Final.xls* from data in LA (1990) and local precipitation records.
4.	Intersubbasin Flows	None.
5.a	Agricultural Pumping	Maximum pumping from LA (1990).
5.b	Urban Pumping	
6.	Artificial Recharge	Identified in DWR 1989.

Antelope Valley

No.	Item	Source
1.a	Initial Storage	Identified in DWR (1994).
1.b	Total Storage	Assumed to be 100,000 for modeling purposes.
2.	Percolation of Applied Agricultural Water	No agriculture modeled in Mojave River groundwater subbasin.
3.	Local Inflows	Calculated in *GW Local Inflows OCV.xls* from data in USGS (1995) and local precipitation records.
4.	Intersubbasin Flows	None.
5.a	Agricultural Pumping	None - area will be urbanized in 2020.
5.b	Urban Pumping	
6.	Artificial Recharge	None modeled.

Mojave Valley

No.	Item	Source
1.a	Initial Storage	Identified in DWR 1994.
1.b	Total Storage	Assumed to be 100,000 for modeling purposes.
2.	Percolation of Applied Agricultural Water	No agriculture modeled in Mojave River groundwater subbasin.
3.	Local Inflows	Calculated in *GW Local Inflows OCV.xls* from data in DWR (1994) and local precipitation records.

4.	Intersubbasin Flows	None.
5.a	Agricultural Pumping	Identified in MRV xx (1998).
5.b	Urban Pumping	Identified in MRV xx (1998)
6.	Artificial Recharge	Identified in MRV xx (1998).

Coachella Valley

No.	Item	Source
1.a	Initial Storage	Identified in DWR 1994.
1.b	Total Storage	Assumed to be 100, 000 for modeling purposes.
2.	Percolation of Applied Agricultural Water	Value assumed based on values in the southern Central Valley and Imperial Valley.
3.	Local Inflows	Identified in xx.
4.	Intersubbasin Flows	None.
5.a	Agricultural Pumping	Identified in CVWD 1998.
5.b	Urban Pumping	
6.	Artificial Recharge	Identified in CVWD 1998.

Imperial Valley

No.	Item	Source
1.a	Initial Storage	Identified in Montgomery Watson 1996.
1.b	Total Storage	Assumed to be 100, 000 for modeling purposes.
2.	Percolation of Applied Agricultural Water	Calculated in Imperial Phase 1.xls.
3.	Local Inflows	Calculated in Imperial Phase 1.xls.
4.	Intersubbasin Flows	None
5.a	Agricultural Pumping	Maximum pumping in Montgomery Watson 1996.
5.b	Urban Pumping	
6.	Artificial Recharge	Identified in DWR 1989.

Metropolitan Water District

No.	Item	Source
1.a	Initial Storage	One half the identified additional storage in the MWD service area (MWD 1996).
1.b	Total Storage	Identified additional storage in the MWD service area (MWD 1996).
2.	Percolation of Applied Agricultural Water	No agriculture modeled in MWD groundwater subbasin.
3.	Local Inflows	Local inflows are not modeled in the MWD service area.
4.	Intersubbasin Flows	None.
5.a	Agricultural Pumping	No agricultural area modeled in MWD groundwater subbasin.
5.b	Urban Pumping	Identified in MWD 1996.
6.	Artificial Recharge	Capacities identified in MWD 1996.