Supporting Information S1

S1: SVIHM Soil Water Budget Model: Updates to Foglia et al. (2013a,b)

The following updates were made to the Soil Water Budget Model (SWBM) described in Foglia et al. (2013):

- crop coefficient for alfalfa: Kc = 0.9 (instead of 0.94)
- root zone depth for alfalfa = 8 ft (instead of 4 ft)
- water application efficiency on alfalfa and grain for center pivot and wheel line irrigation: AE = 100% (instead of 90% for CP and 75% for WL)
- introduced soil water depletion factor for alfalfa and grain: 15 % for center pivot, 5% for wheel line
- updated regression to evaluate the tributary streamflow data using most recent available data
- updated interpolation of precipitation values
- revised rules applied to assign irrigation type and water sources (see details at http://www.water.ca.gov/landwateruse/lusrvymain.cfm) under some specific missing data conditions for land use alfalfa, grain, or pasture:
    - irrigation type is "unknown": irrigation type is assumed to be wheel line
    - water source is "unknown": water source is assumed to be groundwater
    - water source is "dry" or "sub"-irrigated: no additional irrigation occurs

For pasture and grain, the Kc values were not adjusted. For pasture, there was no adjustment in irrigation efficiency. The table below compares the water budget results presented by Foglia et al. (2013) with the results from the updated SWBM.

Table S1. Comparison of average simulated annual water budget terms averaged over the 21 year period between the initial water budget (top, Foglia et al., 2013) and the updated, adjusted soil water budget model results (bottom). All calculations assume that the water table is below the root zone.

inches/yr	Crop ET	Actual ET	Irrigation	SW Irrigation	GW Pumping	Recharge	Area(ha)
Alfalfa	42.0	40.1	33.1	4.1	29.0	14.6	5,622
Grain	16.2	16.1	14.1	2.1	11.9	18.4	803
Pasture	40.0	33.9	29.7	20.8	9.0	17.2	4,819
ET / noIRR	11.2	10.8	0.0	0.0	0.0	10.8	8,249
noET / noIRR	0.0	0.0	0.0	0.0	0.0	21.5	686

inches/yr	crop ET	Actual ET	Irrigation	SW Irrigation	GW Pumping	Recharge	Area (ac)
Alfalfa	39.2	36.8	21.5	2.8	18.7	6.3	13,893
Grain	16.1	16.1	10.3	1.6	8.7	10.6	1,985
Pasture	38.2	34.8	26.0	20.5	5.5	11.6	11,909
ET / noIRR	14.0	11.0	0.0	0.0	0.0	10.8	20,383
noET / noIRR	0.0	0.0	0.0	0.0	0.0	21.6	1,695
acft / yr	crop ET	Actual ET	Irrigation	SW Irrigation	GW Pumping	Recharge	Area (ac)
Alfalfa	45,384	42,605	24,871	3,207	21,665	7,294	13,893
Grain	2,663	2,663	1,707	263	1,444	1,753	1,985
Pasture	37,910	34,536	25,791	20,351	5,440	11,512	11,909
ET / noIRR	23,780	18,684	-	-	-	18,345	20,383
noET / noIRR	-	-	-	-	-	3,051	1,695

S2: SVIHM Model Development

The model domain is discretised into 50 x 50 m cells, resulting in a total of 880 rows and 420 columns. Two layers were included in order to capture vertical fluxes associated with groundwater-surface-water interactions. Due to the basin geometry, the bottom layer is not laterally expanding as much as the top layer (Figure 1).

The model boundary is similar but not identical to the storage units delineated by Mack (1958), classifying alluvium with differing hydrogeological properties. The boundaries of the alluvium were instead delineated by the exclusion of steep topographic gradients, exceeding 4 degrees. The analysis was based on the National Elevation Data (NED) digital elevation model (Gesch 2007). For validation, aerial images from the 2005 National Agriculture Imagery Program (NAIP) were used to further adjust the lateral extent of the alluvium in the Scott Valley. The spatial extent of the lower aquifer system boundary was established using available information from geologic maps, borehole logs obtained from the California Department of Water Resources, cross sections (S.S. Papadopulos & Associates 2012) (California State Water Resources Control Board 1975), and digital elevation data (Watershed Sciences 2010) (Gesch 2007) (Gesch, Oimoen, et al. 2002). In some wells near the center of the valley, a thick clay layer was located above the bedrock; this clay was not included in alluvial aquifer thickness (S.S. Papadopulos & Associates 2012).

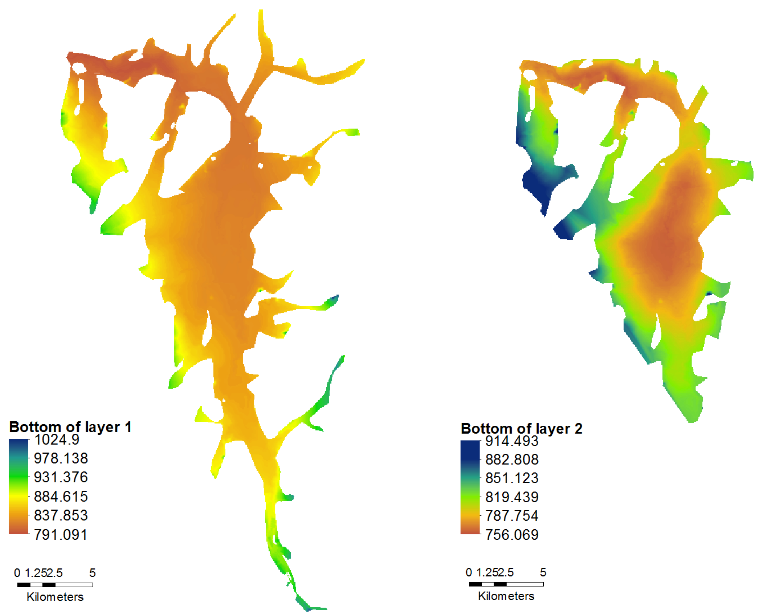

Figure S1. Bottom elevation and extent of the top layer (left) and the lower layer (right): elevation is in meter a.s.l.

The upper layer of the model has uniform thickness of 15.24 meters (50 ft), with the lower layer having variable thickness depending on the depth to bedrock. Cell thickness in the lower layer tends to increase towards the centre of the valley, with a maximum thickness of 60.9 meters between Etna and Fort Jones.

The integrated model simulates groundwater and surface-water conditions from October 1st, 1990 through September 30th, 2011 using monthly stress periods and daily time steps. The first month represents a steady state condition with subsequent months stressed by factors determined through the soil water budget model.

S3: SVIHM Model: Boundary Conditions

Mountain Front Recharge

Runoff and snowmelt from surrounding hills and mountains drain into the Scott Valley mainly through a network of tributary streams, but also as surface runoff and subsurface flow along the model boundaries. Here, we used the mountain front recharge estimates reported by S.S. Papadopulos and Associates (2012). The estimates are based on precipitation, topography, and stream gauging data in 13 sub-watersheds adjacent to the Scott Valley. In SVIHM, MFR boundary conditions (i.e., a specified flux) are implemented using the MODFLOW WEL package. MFR is assumed to be inactive during the summer months, June to September.

GW Recharge and Evapotranspiration

Groundwater recharge was estimated using the SWBM, with daily groundwater recharge fluxes averaged to monthly values. Recharge is calculated for each of the 2119 land use polygons as a flux per unit area and applied to the top of the highest active cell in the model using the recharge (RCH) package.

ET rates were primarily calculated using the SWBM for all non-urban areas within the Scott Valley based on the same land use polygons as recharge (Foglia et al., 2013b). In areas where the water table was expected to be close to land surface (e.g., near streams), ET was calculated within SVIHM using the Evapotranspiration Segments (ETS) package (Harbaugh et al., 2000). This was done because the SWBM does not simulate direct uptake of shallow groundwater from the aquifer by plants. The area affected by this is relatively small compared with the total area simulated in the model, and does not significantly alter the water budget.

Irrigation Ditches

A number of irrigation ditches run along the boundary of the Scott Valley for gravity delivery of water diverted from the Scott River. Of the diversions identified in the Scott Valley adjudication decree (CSWRCB, 1980), the Farmers Ditch and Scott Valley Irrigation District (SVID) Ditch were considered most relevant to the SVHIM due to their associated areas and flow allotment. Farmer’s Ditch services an area of 5 km^2 from diversion 183 (SSPA, 2012, CSWRCB, 1980), while the SVID ditch is used to irrigate 20.7 km^2 from a diversion 223 located between French and Etna Creeks. Loss rates for Farmer’s and SVID ditches have been measured at 0.76 m3/d per meter (0.5 cfs per mile) and 1.52 m3/day per meter (1 cfs per mile), respectively (CDWR, 1991). Seepage rates are simulated using the WEL package and assumed constant in time.

Representation of surface water/groundwater interactions

In addition to two major irrigation ditches (Farmer’s Ditch and Scott Valley Irrigation District Ditch), SVIHM simulates surface water/groundwater interactions between the aquifer and the Scott River, including major tributary streams (Shackleford, Mill, Kidder, Oro Fino, Moffett, Patterson, Etna, Crystal, Johnson, Clark’s, Miner’s and French Creeks). A user-defined distribution of the height of the stream water column along the stream network (MODFLOW “RIV” package, Harbaugh et al., 2000) is used to simulate the interactions between groundwater and surface-water in SVIHM_RIV. In contrast, SHIVM_SFR uses a surface water flow modelling approach (MODFLOW "SFR" package, Prudic et al., 2004) to compute local stream water height. Local stream water height is critical to determining the local (50 m scale) interaction between the stream and groundwater.

Streambed elevations of the Scott River and tributaries were extracted from 10 meter DEM (National Elevation Dataset) and LiDAR data (Watershed Sciences, 2010) in conjunction with aerial imagery to digitize the thalweg (Foglia et al., 2013a). Stream depth for each SFR cell is determined in SVIHM using the Gauckler-Manning-Strickler formula, assuming that the stream bed is wide and rectangular. A roughness coefficient of 0.03 was used for all segments of the Scott River. Inflows to each tributary at the model boundary are defined by the streamflow regression model representing flows from the upper watershed (Foglia et al., 2013b Supplementary Materials). The regression did not include Crystal, Johnson, and Miner's Creek; in SVIHM_SFR inflow values for these creeks represent an estimated monthly average flow. Scott River inflow in the southern portion of the model is the sum of East Fork and South Fork Scott River flows.

Initial riverbed conductance was chosen based on field observations of aquifer hydraulic conductivity and adjusted during the calibration process. Due to the availability of flow observations at the USGS station near Fort Jones, and at the SRCD (Siskiyou County RCD) stations located above Serpa Lane and at Young's Dam, the Scott River was divided into three reaches. A fourth conductance term was used for all tributaries and the tailings area of the Scott River (Figure S2). Because of the various assumptions used to calculate groundwater-surface water interaction, it is essential to evaluate and adjust these parameters during the calibration. All four conductance terms were calibrated, even though the conductance of the tributaries showed little importance in the sensitivity analysis.

In SVIHM_SFR, diversions to the Farmer's and SVID ditches are 13900 m^3/d and 43200 m^3/d, respectively, representing the ditch losses to groundwater at their respective diversion points. However, surface water irrigation deliveries from these ditches and all other ditches in the Scott Valley are summarily diverted at the head of each tributary, at the model boundary.

Pumping/Wells

GW extraction through pumping wells is simulated with the WEL package. The pumping rate is specified for each stress period independent of groundwater head in the cell. The location of pumping wells in the model coincides with those used in the SWBM and is based on well logs and local field inspection. The well logs used to determine well locations are the same as those used to determine aquifer thickness and geology. Of the over 1700 well logs supplied by the CDWR and investigated by Foglia et. al. (2013a), 388 were located within the model boundaries; 192 were domestic wells, 164 irrigation wells and 32 unspecified (Figure S2). Groundwater pumping from domestic wells was not included in this version of the model due to the small extraction volume relative to agricultural pumping in the valley. Irrigation well pumping rates for each stress period were determined by the SWBM in order to meet the irrigation requirements of each land use polygon. One pumping well can supply water to more than one land use polygon, but each land use polygon takes water from exactly one well – that closest to the polygon centroid. It is likely that the number of wells used is overrepresented since some wells may have replaced older wells rather than put into service in addition to the older well. However, the volume of water extracted is in accordance with the SWBM. The WEL package does not allow for the specification of a certain filter depth, rather the water extracted is extracted from the cell as a whole. Here, all of the wells are assumed to pump from the top model layer.

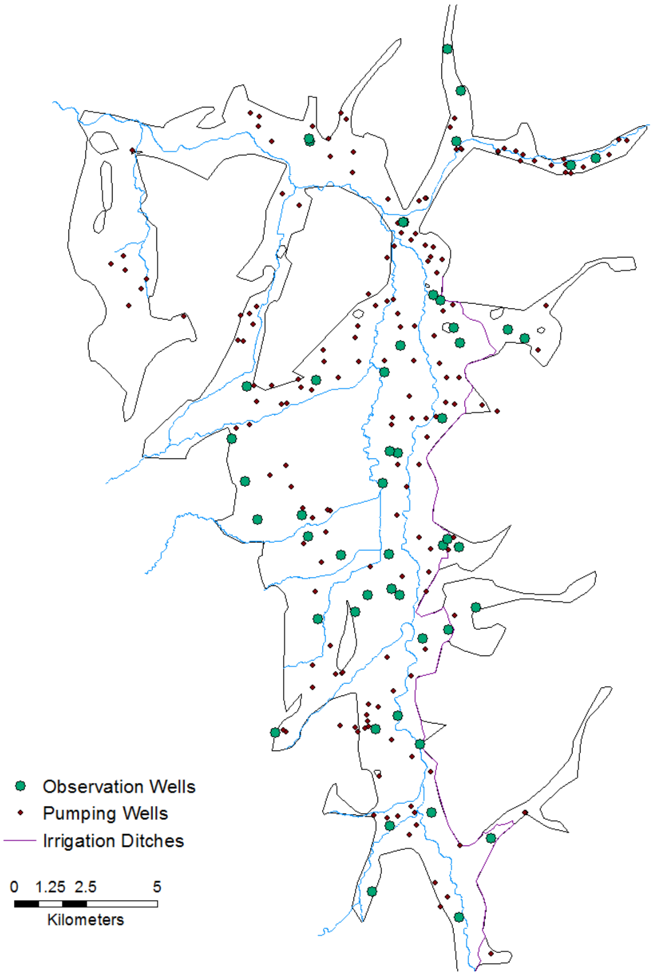

Figure S2. Location of observation wells, pumping wells and irrigation ditches

S4: Model Parameters

Parameters

Both versions of SVIHM have the same boundary conditions, zonation and discretisation. Table S2 presents the list of the parameters included in the sensitivity analysis and calibration with their initial values. Extensive sensitivity analysis and calibration has been carried out and detailed results are presented in Tolley et al. (in preparation).

Table S2 Parameters used in SVIHM.

Parameter Name	Description	Value
Kx1	Horizontal hydraulic conductivity of Zone 1	45 m/d[1]
Kx2	Horizontal hydraulic conductivity of Zone2	12 m/d[1]
Kx3	Horizontal hydraulic conductivity of Zone 3	51 m/d[1]
Kx4	Horizontal hydraulic conductivity of Zone 4	20 m/d[1]
Kx5	Horizontal hydraulic conductivity of Zone 5	10 m/d[1]
Kx6	Horizontal hydraulic conductivity of Zone 6	28 m/d[1]
Kx7	Horizontal hydraulic conductivity of Zone 7	1000 m/d
Ss1	Specific storage of Zone 1 in the upper layer	0.00067 m^{-1}[1]
Ss2-6	Specific storage of Zones 2 through 6 in the upper layer	0.00067 m^{-1}[1]
Ss7	Specific storage of zone 7 in the upper aquifer	0.013 m^{-1}
Ssd	Specific storage of the lower layer	5E-7 m^{-1}
Wel1-13	Mountain front recharge from Moffett	2.21 – 97.1 m^3/d
Wel20	Farmers Ditch	41.2 m^3/d
Wel21	SVID Ditch	64.7 m^3/d
Riv1	River conductance between Fort Jones and SRCD station	3600 m^2/d
Riv2	River conductance between SRCD station and Young's Dam	3600 m^2/d
Riv3	River conductance for all triburaties and Tailings	3600 m^2/d
Riv5	River conductance between Young's Dam and tailings	3600 m^2/d
SFR1	Hydraulic conductivity of the Scott River sediments	1 m/d
SFR2	Hydraulic conductivity of ditch diversions	0 m/d
SFR3	Hydraulic conductivity of tributaries and tailings	13 m/d
MAN	Manning's Roughness Coefficient	

[1]After Mack (1958)

Head and Flow observations

Groundwater Head Observations

A total of 2197 groundwater head observations in 50 wells were used in the sensitivity analysis and calibration. The majority of the observations were obtained from a voluntary stakeholder monitoring program, which has collected monthly head observations in private wells throughout the Scott Valley since March 2006. In addition, bi-annual data is available from DWR for five wells located within the model domain, with the oldest measurements dating back to the early 1950s.

River Observations

Three gauges were used to calculate river gain/loss observations for SVIHM_RIV. These observations describe the gain or loss of streamflow along a specified segment. The first segment lies between the Fort Jones USGS station and the SRCD measuring station above Serpa Lane. The second segment is located between Serpa Lane and Young's Dam further upstream. The third segment runs from Young's Dam to the beginning of the tailing area in the southern portion of the valley. Subtracting the downstream flow observation of a segment from the upstream flow observation, the gain/loss of the aquifer to this river segment is calculated in m^3/d. Only observations from August and September and from July to September were used for reaches 1 and 2 respectively (Table S3). During these months the tributary streams are either nearly completely diverted or dry up (Mack, 1958) and the error of gain/loss observations is minimised.

Table S3. River flow observations between flow gages, times during which observations are available and number of observations used.

Flow gages	Time period	Number of Observations
Fort Jones – Above Serpa SRCD	01/08/2008 - 28/09/2011	135
Above Serpa SRCD – Below Young's SRCD	31/07/2008 - 15/08/2009	108

Streamflow Observations

While SVIHM_RIV, which relies on flow differences between gauges with simultaneous measurements, the SVIHM_SFR model can be calibrated against actual discharge observations anytime and anywhere along the stream network allowing for more data to be used (Table S4). For each station, key data were selected based on a criterion for filtering the hydrograph to select each peak and low flow values and all the points in the rising and falling limb using a change in sign of the derivative. Flows have been categorized into high, medium, and low flows (Table S3 and Figure S3).

Table S4. Available flow gauges within the Scott Valley, the total time period of observations and the number of observations used for the SFR model.

Flow gage	Time period	Number of observations used
Above Serpa SRCD	11/08/2008 - 6/09/2011	171
Below Young's SRCD	23/07/2008 - 1/09/2010	240
Fort Jones USGS	01/10/1990 - 30/09/2011	1537
East Fork	30/06/2002 - 30/09/2011	529
French Creek	12/01/2004 -30/09/2011	586
Mill Creek	13/10/2004 – 01/09/2005	53
Shackleford Creek	08/10/2004 - 31/07/2011	472

Figure S3. Observed discharge of the Scott River at the Fort Jones USGS measurement station, and selected observations used for the calibration of the SFR model.

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