# Supplementary Materials: Characterizing Changes in Streamflow and Sediment Supply in the Sacramento River Basin, California, Using Hydrological Simulation Program—FORTRAN (HSPF)

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## S1. Streamflow and Sediment Data

The daily streamflow and sediment boundary conditions for water years 1958 to 2008 were developed using available continuous streamflow data, locations of large dams, and natural watershed boundaries. Modeled stream reaches represented in the model included the main branch of the Sacramento River and the main contributing tributaries below large dams. Streamflow and sediment data from 42 out of the 288 USGS gages in the study domain were downloaded from the National Water Information System (NWIS) [1], and included records that ranged from four to 120 years for streamflow data and one to 58 years for sediment data (Table S1). Gages with the complete hydrologic record (1958–2008) were used as boundary conditions when located on the model boundary. Other gages located within the domain were used for calibration and validation. Snow water equivalent (SWE) data for snow calibration were collected from the California Data Exchange Center CDEC [2].

Suspended sediment concentrations and loads were available at varying periods for 18 locations in the study area from NWIS [1]. Of the 42 streamgaging stations (Table S1), 19 gages contained sediment data within the model period (1958–2008), with the majority of the data existing in 1975–1980. Various model outputs are available for comparison with the observed data for model calibration. Modeled outputs of suspended sediment concentrations (mg/L) or sediment loads (tons/day) are on a daily time step but can be summed or averaged to monthly or annual time scales. Annual sediment loads, instantaneous samples, and daily discharge or suspended sediment concentration data were used to compare with modeled sediment outputs. Suspended sediment concentrations and sediment loads were calibrated to each gage for the period where data was available.

## S2. Dams

The National Inventory of Dams (NID) [3] dataset is a compilation of state jurisdictional dams used primarily for hazard and risk assessment. The state jurisdictional dams are either 7.6 m in height or higher and exceed 18,500 $m^3$ in storage, or are 1.8 m or higher with more than 62,000 $m^3$ in storage coupled with a high hazard classification [4]. The NID is maintained by the Army Corps of Engineers (USACE). There are 1594 dams in California meeting the NID criteria above, and 471 are located in the Sacramento River watershed. For the purposes of this study, only the larger dams having a significant effect on trapping sediment loads were used to define boundary conditions. A series of criteria were developed to select dams to use as flow boundaries and that allowed negligible sediment to pass downstream. Dams used as boundary conditions in this model were chosen on the basis of sediment trap efficiency and watershed size. Large dams with high sediment trap efficiencies have the greatest contribution to streamflow and the smallest contribution of sediment loads.

**Table S1.** United States Geological Survey stream gaging stations used for model calibration (C), validation (V), and boundary conditions (B). Bold rows indicate gages located on the Sacramento River. Nf = North fork, Mf = Middle fork, Lf = Lower fork, R = River, C = Creek.

| Model Reach Number | USGS Station ID | Gage Name | Drainage Area ($km^2$) | Flow Data (Years) | Calibration/Validation/ Boundary | Sediment Data Available |
|---|---|---|---|---|---|---|
| 1 | 11374000 | Cow C near Millville | 1101 | 62 | C/V | 1977–1978 |
| **5** | **11370500** | **Sacramento R at Keswick** | **16,752** | **73** | **B** | |
| 7 | 11376015 | Nf Battle C Battle C Dam | 173 | 9 | B | |
| 8 | 11372000 | Clear C near Igo | 591 | 71 | B | |
| 9 | 11375700 | Nf Cottonwood C near Igo | 230 | 24 | B | |
| 14 | 11375810 | Cottonwood C near Olinda | 1023 | 15 | C | 1977–1980 |
| 15 | 11374400 | Mf Cottonwood C near Ono | 632 | 19 | C | 1964–1966 |
| 16 | 11376550 | Battle C below Coleman Fish Hatchery | 925 | 50 | C/V | |
| 18 | 11376000 | Cottonwood C near Cottonwood | 2401 | 71 | C/V | 1962–1967<br>1978–1980 |
| **22** | **11377100** | **Sacramento R at Red Bluff** | **23,051** | **120** | **C/V** | **1977–1980** |
| 26 | 11379000 | Antelope C near Red Bluff Ca | 319 | 42 | | |
| 31 | 11381500 | Mill C near Los Molinos | 339 | 71 | C/V | |
| 40 | 11382000 | Thomes C at Paskenta Ca | 526 | 76 | C/V | 1962–1983 |
| 42 | 11383500 | Deer C near Vina | 539 | 100 | C/V | |
| 46 | 11390000 | Butte C near Chico | 381 | 81 | C/V | |
| 47 | 11388000 | Stony C below Black Butte Dam near Orland | 1911 | 35 | B | |
| **48** | **11383800** | **Sacramento R near Hamilton City** | **28,057** | **36** | **C** | **1977–1979** |
| **49** | **11389000** | **Sacramento R near Butte City** | **31,274** | **57** | **C/V** | **1977–1980** |
| 53 | 11407000 | Feather R at Oroville | 9386 | 113 | B | |
| 53 | 11407150 | Feather R near Gridley | 9521 | 34 | V | 1964–1993 |
| 57 | 11420500 | Dry C at Virginia Ranch | 185 | 13 | B | |
| 59 | 11407700 | Feather R at Yuba City | 10,293 | 12 | V | 1964–1976 |
| 60 | 11418500 | Deer C near Smartville Ca | 219 | 81 | B | |
| 60 | 11418000 | Yuba R below Englebright Dam | 2870 | 74 | B | |
| 60 | 11421000 | Yuba R near Marysville | 3467 | 72 | C/V | |
| **61** | **11389500** | **Sacramento R at Colusa** | **31,312** | **94** | **C/V** | **1972–1980** |
| 62 | 11391050 | Sutter Bypass near Nicolaus | 37,645 | 21 | V | 1979–1980 |
| 69 | 11425000 | Feather R near Nicolaus | 15,335 | 41 | V | 1978–1980 |
| 70 | 11451300 | Nf Cache C near Clearlake Oaks | 313 | 16 | B | |
| 73 | 11424000 | Bear R near Wheatland | 756 | 87 | B | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 74 | 11451760 | Cache C above Rumsey | 2473 | 26 | V | 1960–1986 |
| 76 | 11451000 | Cache C near Lower Lake | 1368 | 72 | B | |
| 77 | 11425310 | Hasley Powerhouse near Auburn | 15,335 | 34 | B | |
| 78 | 11391021 | Fremont Weir Spill To Yolo Bypass near Verona | 37,645 | 28 | C/V | |
| 84 | 11451950 | Cache C near Brooks | 2696 | 4 | V | 1983–1986 |
| 88 | 11452500 | Cache C at Yolo | 2950 | 112 | C/V | 1960–1967 |
| **90** | **11447500** | **Sacramento R at Sacramento** | **60,885** | **31** | **V** | **1956–1979** |
| 94 | 11453000 | Yolo Bypass near Woodland | 2950 | 76 | C/V | 1979–1980 |
| 95 | 11446500 | American R at Fair Oaks | 4890 | 111 | B | |
| **98** | **11390500** | **Sacramento R below Wilkins Slough near Grimes** | **33,463** | **77** | **C/V** | |
| **99** | **11425500** | **Sacramento R at Verona** | **37,645** | **87** | **V** | **1979–1980** |
| **97** | **11447650** | **Sacramento R at Freeport** | **60,885** | **67** | **C/V** | **1956–2014** |

Trap efficiency, or the amount of incoming sediment trapped by a dam, is a metric that depends on reservoir size, watershed area, and sediment yield. For this study, a simplified equation for the trap efficiency curve was used [5]:

$$C = 1 - 1/[1 + (0.00021 \times K/W)] \quad (1)$$

where $C$ is the trap efficiency, $K$ is the dam capacity ($m^3$) and $W$ is the watershed area ($km^2$). Sediment trap efficiency was then normalized by the watershed area to form a value, CW, representing the watershed area scaled by the trap efficiency, using:

$$\mathrm{CW} = C \times W \quad (2)$$

Dams were ranked by importance using the CW value, and an arbitrary lower cutoff value of 0.01 was used to determine which dams to incorporate (at least 1% of the upstream watershed sediment was estimated to be trapped by the dam). Thirteen dams from the NID database fit these criteria and were located on a tributary within the model domain (Table S2).

**Table S2.** List of dams from National Inventory of Dams (NID) used in HSPF model of Sacramento Valley; chosen for a high trap efficiency-to-watershed ratio (CW) which indicates a relatively large dam with a small sediment load contribution to the watershed.

| Dam Name | Year Completed | River | Longitude | Latitude | CW Value |
|---|---|---|---|---|---|
| Keswick | 1949 | Sacramento River | −122.445 | 40.612 | 5.1 |
| Whiskeytown | 1963 | Clear Creek | −122.540 | 40.599 | 0.7 |
| Misselbeck | 1920 | North Fork Cottonwood Creek | −122.697 | 40.500 | 0.04 |
| Macumber | 1907 | North Fork Battle Creek | −121.733 | 40.538 | 0.1 |
| Eagle Canyon Canal Diversion | 1910 | North Fork Battle Creek | −121.921 | 40.423 | 0.02 |
| Red Bluff Diversion | 1967 | Sacramento River | −122.202 | 40.154 | 0.9 |
| Black Butte | 1963 | Stoney Creek | −122.337 | 39.818 | 2.4 |
| Oroville | 1968 | Feather River | −121.486 | 39.539 | 12.3 |
| Virginia Ranch | 1962 | French Dry Creek | −121.310 | 39.324 | 10.3 |
| Englebright | 1941 | Yuba River | −121.267 | 39.238 | 3.3 |
| Camp Far West Diversion | 1964 | Bear River | −121.332 | 39.042 | 0.1 |
| Indian Valley | 1975 | North Fork Cache Creek | −122.536 | 39.080 | 0.4 |
| New Camp Far West | 1963 | Bear River | −121.317 | 39.050 | 1.0 |
| Clear Lake | 1910 | Cache Creek | −122.566 | 38.923 | 1.8 |
| Lakewood | 1982 | Dry Creek | −121.072 | 38.962 | 0.02 |
| Nimbus | 1955 | American River | −121.220 | 38.636 | 1.9 |

Shasta Dam was omitted from the model because continuous time series data were available at Keswick Dam and an analysis of available sediment data from the Keswick gage indicated a very small contribution of sediment to the Sacramento River. When continuous daily time series data were not available at a dam or impoundment, the surrounding watershed above the dam was modeled to account for all sediment sources within the watershed. The Red Bluff Diversion Dam (RBDD) was constructed in 1967 and was used to divert streamflow to agricultural land southwest of the diversion. The RBDD was decommissioned to facilitate annual fish migrations but was operational through the end of the model period (2008). Time series data from the RBDD were not available, so average monthly values from the United States Bureau of Reclamation [6] were used and scaled during the calibration process to match agricultural demands from the Sacramento River.

## S3. Hydrologic Response Unit (HRU) Delineation

Using GIS data for soils, land use, elevation, and hydrography, the model domain was divided into HRUs. An initial HRU delineation was done using the USGS National Hydrography Dataset (NHD) eight-digit Hydrologic Units (HUC-8) defining the subdrainages of the Sacramento River Basin. Using similar soil and hydrologic characteristics the HUC-8 areas were either combined or subdivided to create 99 HRUs. BASINS [7] was used with the National Land Cover Database (NLCD) 2006 (mrlc.gov/nlcd2006.php) land cover data to calculate the proportion of each HRU that corresponded to each land use type. In HSPF, there is a limit to the number of model segments; therefore, the NLCD data was simplified from 15 to eight categories to decrease the total number of modeled PERLNDs and IMPLNDs. For each HRU, it is possible to have a maximum of eight pervious land units (PERLNDs, based on the land use within each HRU), and one impervious land unit (IMPLND) corresponding to the percent area of impervious land within the HRU. This enabled each HRU to be parameterized based on land use as well as physical properties including soil information and elevation. The delineation process resulted in 99 HRUs with a total of 361 PERLNDs and 99 IMPLNDs subdivided using the land use categories.

## S4. Snow Calibration

Prior to hydrology and sediment calibrations, snow parameters must be calibrated by comparing observed snow water equivalent (SWE) data to modeled outputs to ensure a reasonable simulation. The Snow Mountain and Humbug CDEC stations provided daily-adjusted SWE data and New Manzanita Lake, Lower Lassen Peak, and Feather River Meadow provided monthly values of SWE (Table S3). HSPF generally under-predicted observed SWE in the HRUs with snow stations but was close to the observed SWE in the smallest basin that had measured data available (Figure S1).

HSPF over-estimated snowpack for several of the years in HRU 7 but the average difference for the period of 1958–2000 was −7.5 mm and the overall trend of snowpack was similar to the observed data. The under-prediction of snow in the other model segments with snow gages (1, 24, 27 and 37) was expected because the snow-covered area was not represented by the large HRU that included lower elevations that did not receive snow.

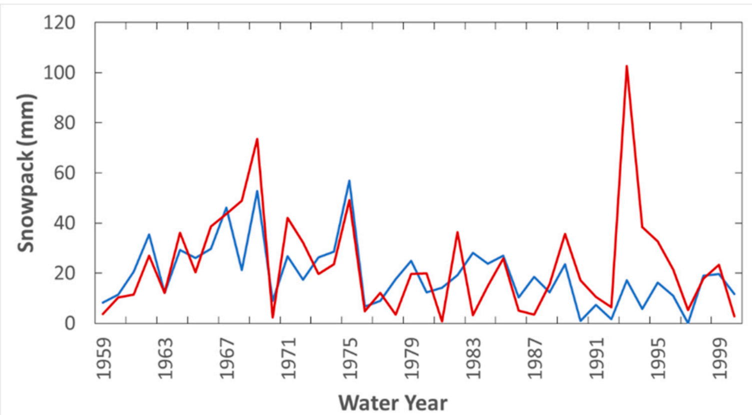


**Figure S1.** Modeled annual snowpack (mm) from hydrologic response unit (HRU) 7 (red) compared to the adjusted snow water equivalent (SWE) (blue) for California Data Exchange Center (CDEC) station New Manzanita Lake (NMN).

**Table S3.** California Data Exchange Center (CDEC) snow stations used for snow calibration. HRU = hydrologic response unit.

| Model HRU Number | Snow Station | CDEC ID | Time Interval | Data Available |
|---|---|---|---|---|
| 1 | Snow Mountain | SNM | Daily | 1983–2008 |
| 7 | New Manzanita Lake | NMN | Monthly | 1958–2000 |
| 24 | Lower Lassen Peak | LLP | Monthly | 1958–2008 |
| 27 | Feather River Meadow | FEM | Monthly | 1958–2008 |
| 37 | Humbug | HMB | Daily | 1981–2008 |

**S5. Hydrologic and Sediment Calibration**

Hydrologic parameters for each HRU were initially determined in BASINS by overlaying spatial layers of physical properties such as land use, erosion potential (k-factor), soil texture, slope, and hydrologic soil group. The calibration approach for this study maintained spatial relationships of physical properties used to estimate hydrologic parameters across the domain in order to compensate for sparse calibration data. This requires spatially distributed values corresponding to physical properties that can be scaled up or down during the calibration process yet still preserve the spatial characteristics of each HRU. Each hydrologic parameter was initially assessed using the BASINS Technical Note 6 [8], with subsequent adjustments during the calibration process. In this calibration method, parameters are a function of spatial inputs such as land use and soils data. Some of the parameters are considered "calibration parameters", which initially start at an arbitrary value ranging by land use and are further modified through the calibration process.

Once the hydrologic parameters were developed, calibration was completed with the aid of the BASINS Technical Note 6 [8]. The modeled output of daily mean streamflow was compared to observed stream gage data with the full time period record (Table S1). Visual inspection of hydrographs and daily comparison scatter plots allowed scaling of the parameters until the best fit possible was achieved with additional consideration given to the gages on the Sacramento River, the main calibration target. The complete list of hydrologic parameters and ranges used in the model can be found in Table S4. Visual inspection of flow hydrographs for the validation (Figure S2) and calibration periods showed a good relationship of modeled to observed streamflow data. Modeled annual streamflow at the Sacramento River at Freeport location generally matched very well against observed data (Figure S3). Calibration statistics for each gage are located in Table S5.

BASINS Technical Note 8 [9] was used to determine initial ranges for each sediment parameter. The most common method for calculating sediment transport of sand in HSPF is the power function method [9]. The power function method is based on velocity and relies on accurate FTABLEs. The user adjusts the coefficient and the exponent in the sandload power function for each reach segment until the modeled results coincide with observed data. The Toffaleti and Colby methods were developed for wide rivers where the hydraulic radius is approximately equal to the depth, and are not often used due to lack of calibration parameters [9]. The Toffaleti and Colby methods are based on empirical relationships instead of calibration-based coefficients and exponents. The Toffaleti method was chosen because it showed a better agreement with observed sediment data than the Colby method. The Toffaleti method requires values for particle diameters and fall velocities of sand particles and HSPF divides the stream into four zones, applying the power function below to represent the velocity profile:

$$U = (1 + \mathrm{CNV}) \times V \times (Y/\mathrm{FHRAD})\ \hat{}\,\mathrm{CNV} \quad (3)$$

where $U$ is the flow velocity at distance Y above the bed (m/s), $V$ is the mean stream velocity (m/s), CNV is the exponent derived empirically as a function of water temperature (0.1198 + 0.00048 × TMPR), TMPR is the water temperature in degrees C, and FHRAD is the hydraulic radius of the stream in meters.

A comprehensive explanation of the Toffaleti method can be found in the HSPF user manual [10]. To use the Toffaleti method, the modeled water temperature module HTRCH must be active within HSPF. The additional meteorological requirements for the HTRCH module are: daily solar radiation, wind speed, cloud cover and dew point. The transport of sediment is not very sensitive to water temperature for these conditions [11], the meteorological variables from the Fair Oaks California Irrigation Management Information System (CIMIS) [12] station for the year 2004 were used for the entire model period. The mean particle size ($D_{50}$) values were determined using a cumulative distribution function analysis of particle size distribution data from the USGS database [13]. Data were extracted for all gages in the model domain for which full particle size distributions were available.

For bed sediment, the median particle sizes for gravel and sand fractions were computed for each sample and averaged for each gage to estimate a $D_{50}$ value for every reach. Settling velocities for sand, silt, and clay were computed using the method outlined by Deitrich [14]. The complete list of sediment parameters is in Tables S6 and S7. The lack of reach calibration parameters with Toffaleti's method made the pervious and impervious land parameters essential in the calibration process and required a greater spatial distribution to compensate for the minimal observed data and fewer calibration parameters. Highly detailed and accurate FTABLEs also contributed to the successful calibration using the Toffaleti method. Results from the calibration of sediment varied by gage and results are shown in Table S8. Modeled annual sediment loads at the Sacramento River at Freeport location showed a good relationship to observed data (Figure S4).

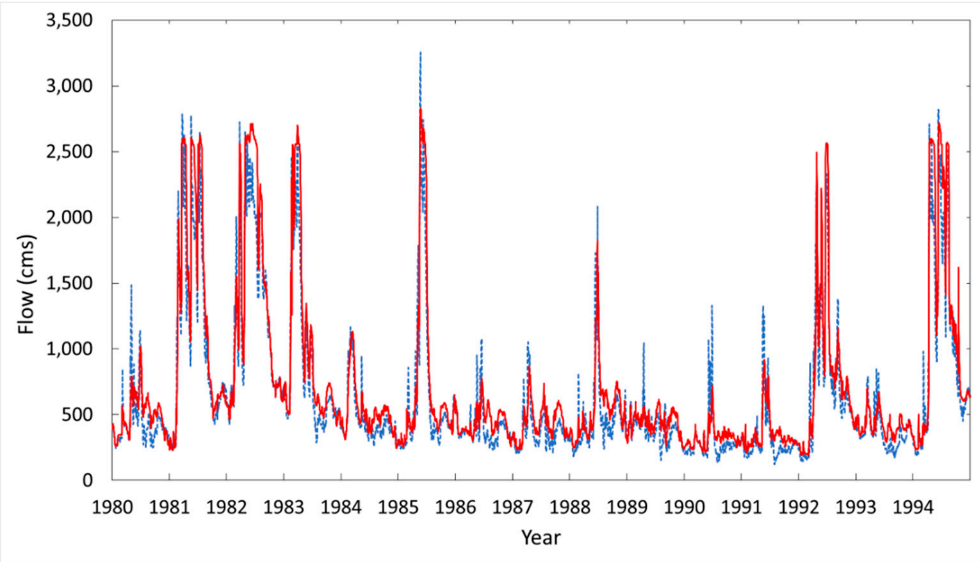


**Figure S2.** Modeled daily flow at Reach 97 ( red) compared to observed flow for Sacramento River at Freeport (11447650) (dashed blue) for the validation period (1980–1995).

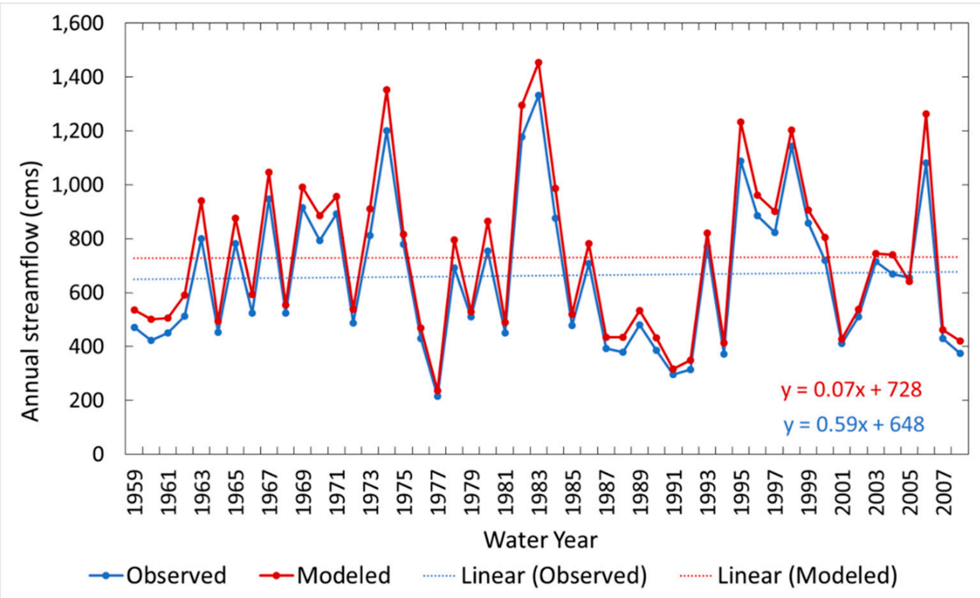


**Figure S3.** Modeled annual streamflow (cms) (Reach 97, red) and observed (Sacramento River at Freeport, blue).

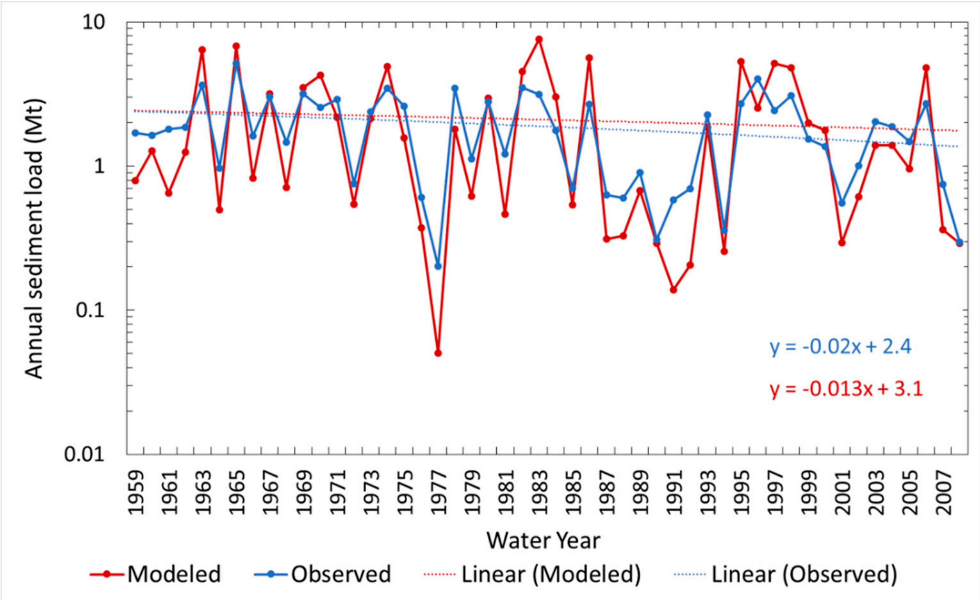


**Figure S4.** Modeled annual sediment loads (Mt) (Reach 97, red) and observed (Sacramento River at Freeport, blue).

**Table S4.** Hydrologic parameters used in the Hydrological Simulation Program—FORTRAN (HSPF) model. Table modified from [8]. ET = evapotranspiration, mm = millimeters, m = meters.

| Name | Definition | Units | Range of Values | | | | Function of | Range of Values Used in Calibrated Model |
|---|---|---|---|---|---|---|---|---|
| | | | Typical | | Possible | | | |
| | | | Min | Max | Min | Max | | |
| SNOW–PARM1 | | | | | | | | |
| LAT | Latitude of watershed segment | degrees | 30 | 50 | −90 | 90 | Location | 40 |
| MELEV | Mean elevation of watershed segment | meters | 15 | 900 | 0 | 10,000 | Topography | 800 |
| SHADE | Fraction shaded from solar radiation | none | 0.1 | 0.5 | 0 | 0.8 | Forest cover, topography | 0.3 |
| SNOWCF | Snow gage catch correction factor | none | 1.1 | 1.5 | 1 | 2 | Gage type, characteristics, location | 1.2 |
| COVIND | Snowfall required to fully cover surface | mm | 25 | 76 | 0.25 | none | Topography, climate | 10 |
| PWAT–PARM2 | | | | | | | | |
| FOREST | Fraction forest cover | none | 0 | 0.5 | 0 | 0.95 | Forest cover | 0–1 |
| LZSN | Lower zone nominal soil moisture storage | mm | 76 | 200 | 0.25 | 2500 | Soil, climate | 76.2–508 |
| INFILT | Index to infiltration capacity | mm/hr | 0.25 | 6.35 | 0.003 | 2500 | Soil, land use | 0.25–38.1 |
| LSUR | Length of overland flow | meters | 61 | 152 | 0.3 | none | Topography | 91.4–152.4 |
| SLSUR | Slope of overland flow plane | m/m | 0.01 | 0.15 | 0.001 | 0.3 | Topography | 0.001–0.22 |
| KVARY | Variable groundwater recession | 1/mm | 0 | 76 | 0 | 127 | Baseflow recession variation | 12.7–88.9 |
| AGWRC | Base groundwater recession | none | 0.92 | 0.99 | 0.85 | 0.999 | Baseflow recession | 0.85–0.999 |
| PWAT–PARM3 | | | | | | | | |
| PETMAX | Temperature below which ET is reduced | °C | 2 | 7 | none | none | Climate, vegetation | 4.4 |
| PETMIN | Temperature below which ET is set to zero | °C | −1 | 2 | none | none | Climate, vegetation | 1.67 |
| INFEXP | Exponent in infiltration equation | none | 2 | 2 | 1 | 3 | Soil variability | 2 |
| INFILD | Ratio of max/mean infiltration capacities | none | 2 | 2 | 1 | 3 | Soil variability | 2 |
| DEEPFR | Fraction of groundwater inflow to deep recharge | none | 0 | 0.2 | 0 | 0.5 | Geology, groundwater recharge | 0 |
| BASETP | Fraction of remaining ET from baseflow | none | 0 | 0.05 | 0 | 0.2 | Riparian vegetation | 0–0.2 |
| AGWETP | Fraction of remaining ET from active groundwater | none | 0 | 0.05 | 0 | 0.2 | Marsh/wetlands extent | 0–0.4 |
| PWAT–PARM4 | | | | | | | | |
| CEPSC | Interception storage capacity | mm | 0.8 | 5 | 0 | 250 | Vegetation type/density, land use | 2.5–6.35 (monthly values) |
| UZSN | Upper zone nominal soil moisture storage | mm | 2.5 | 25.4 | 0.2 | 250 | Surface soil conditions, land use | 6.9–50.8 |
| NSUR | Manning's n for overland flow | none | 0.15 | 0.35 | 0.05 | 0.5 | Surface conditions, residue, etc. | 0.08–0.5 |
| INTFW | Interflow inflow parameter | none | 1 | 3 | 1 | 10 | Soil, topography, land use | 1.0–10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IRC | Interflow recession parameter | none | 0.5 | 0.7 | 0.3 | 0.85 | Soil, topography, land use | 0.3–0.98 |
| LZETP | Lower zone ET parameter | none | 0.2 | 0.7 | 0.1 | 0.9 | Vegetation type/density, root depth | 0.15–0.8 (monthly values) |
| | | | | IWAT–PARM2 | | | | |
| LSUR | Length of overland flow plane | meters | 15 | 46 | 0.3 | none | Topography, drainage system | 91.4 |
| SLSUR | Slope of overland flow plane | none | 0.01 | 0.05 | 0.004 | 0.15 | Topography, drainage | 0.05 |
| NSUR | Manning's n for overland flow | none | 0.03 | 0.1 | 0.01 | 0.15 | Impervious surface conditions | 0.05 |
| RETSC | Retention storage capacity | mm | 0.8 | 2.5 | 0 | 250 | Impervious surface conditions | 2.5 |
| | | | | IWAT–PARM3 | | | | |
| PETMAX | Temperature below which ET is reduced by half | °C | 2 | 7 | none | none | Climate, vegetation | 4.4 |
| PETMIN | Temperature below which ET is set to zero | °C | −1 | 2 | none | none | Climate, vegetation | 1.7 |

**Table S5.** Daily flow statistics for the simulation period (All, 1958–2008), the calibration period (C, 1998–2008), and the validation period (V, 1980–1995). $R^2$ = coefficient of determination, ME% = mean error, in percent, NSE = Nash Sutcliffe efficiency. Bold rows indicate gages located on the Sacramento River.

| Model Reach Number | Gage Name | NSE | | | $R^2$ | | | ME% | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | All | C | V | All | C | V | All | C | V |
| 1 | Cow C near Millville | 0.56 | 0.55 | 0.61 | 0.60 | 0.58 | 0.66 | −33 | −39 | −43 |
| 16 | Battle C below Coleman Fish Hatchery | 0.52 | 0.61 | 0.53 | 0.55 | 0.62 | 0.56 | 10 | 8 | 5 |
| 18 | Cottonwood C near Cottonwood | 0.69 | 0.66 | 0.69 | 0.75 | 0.70 | 0.74 | −36 | −27 | −39 |
| **22** | **Sacramento R at Red Bluff** | **0.93** | **0.92** | **0.93** | **0.93** | **0.92** | **0.94** | **−8** | **−7** | **−10** |
| 31 | Mill C near Los Molinos | 0.32 | 0.51 | 0.50 | 0.57 | 0.61 | 0.62 | 45 | 29 | 19 |
| 40 | Thomes C at Paskenta Ca [1] | 0.55 | – | 0.45 | 0.61 | – | 0.58 | −19 | – | −20 |
| 42 | Deer C near Vina | 0.48 | 0.55 | 0.53 | 0.61 | 0.64 | 0.65 | −19 | −30 | −35 |
| 46 | Butte C near Chico | 0.57 | 0.69 | 0.70 | 0.76 | 0.76 | 0.81 | 11 | 3 | −5 |
| **49** | **Sacramento R near Butte City** | **0.91** | **0.89** | **0.93** | **0.92** | **0.91** | **0.94** | **−9** | **−11** | **−12** |
| 53 | Feather R near Gridley [2] | 0.93 | – | 0.94 | 0.93 | – | 0.94 | −4 | – | −3 |
| 60 | Yuba R near Marysville | 0.81 | 0.84 | 0.82 | 0.82 | 0.85 | 0.82 | 90 | 457 | −15 |
| **61** | **Sacramento R at Colusa** | **0.89** | **0.89** | **0.90** | **0.92** | **0.92** | **0.93** | **−11** | **−12** | **−13** |
| 62 | Sutter Bypass near Nicolaus [3] | 0.53 | – | – | 0.76 | – | – | 95 | – | – |
| 78 | Fremont Weir Spill To Yolo Bypass near Verona [4] | 0.58 | – | – | 0.68 | – | – | 10 | – | – |
| 88 | Cache C at Yolo | 0.77 | 0.75 | 0.80 | 0.80 | 0.79 | 0.82 | −44 | −43 | −49 |
| **90** | **Sacramento R at Sacramento [5]** | **0.91** | – | – | **0.91** | – | – | **7** | – | – |
| 94 | Yolo Bypass near Woodland | 0.67 | 0.62 | 0.60 | 0.90 | 0.85 | 0.91 | 69 | 38 | 975 |
| **98** | **Sacramento R below Wilkins Slough near Grimes** | **0.84** | **0.85** | **0.83** | **0.91** | **0.92** | **0.90** | **−14** | **−15** | **−17** |
| **99** | **Sacramento R at Verona** | **0.94** | **0.92** | **0.94** | **0.95** | **0.93** | **0.95** | **−7** | **−4** | **−8** |
| **97** | **Sacramento R at Freeport** | **0.91** | **0.90** | **0.91** | **0.93** | **0.91** | **0.93** | **−8** | **−6** | **−9** |

Notes: [1] 1958–1996, [2] 1964–1998, [3] 1959–1980, [4] 1958–1975, [5] 1958–1979.

**Table S6.** Sediment land parameters used in the Hydrological Simulation Program—FORTRAN (HSPF) model. Table modified from [9]. kg/ha/day = kilogram per hectare per day.

| Name | Definition | Units | Range of Values | | | | Function of | Range of Values |
|---|---|---|---|---|---|---|---|---|
| | | | Typical | | Possible | | | |
| | | | Min | Max | Min | Max | | |
| SED–PARM2 | | | | | | | | |
| SMPF | Management practice factor from universal soil loss equation | none | 0 | 1 | 0 | 1 | Agricultural use and practices | 0.5–1 |
| KRER | Coefficient in the soil detachment equation | complex | 0.15 | 0.45 | 0.05 | 0.75 | Soil | 0.17–0.46 |
| JRER | Exponent in the soil detachment equation | none | 1.5 | 2.5 | 1 | 3 | Soil, climate | 1.5–2.5 |
| AFFIX | Daily reduction in detached sediment | per day | 0.03 | 0.1 | 0.01 | 0.5 | Soil, compaction, agricultural operations | 0.03 |
| COVER | Fraction land surface protected from rainfall | none | 0 | 0.9 | 0 | 0.98 | Vegetation cover, land use | 0–0.9 |
| NVSI | Atmospheric additions to sediment storage | kg/ha/day | 0 | 3 | none | none | Deposition, activities, etc. | 0 |
| SED–PARM3 | | | | | | | | |
| KSER | Coefficient in the sediment washoff equation | complex | 0.5 | 5 | 0.1 | 10 | Soil, surface conditions | 0.015–4.3 |
| JSER | Exponent in the sediment washoff equation | none | 1.5 | 2.5 | 1 | 3 | Soil, surface conditions | 1.1–3.0 |
| KGER | Coefficient in the soil matrix scour equation | complex | 0 | 0.5 | 0 | 10 | Soil, evidence of gullies | 0–10 |
| JGER | Exponent in the soil matrix scour equation | none | 1 | 3 | 1 | 5 | Soil, evidence of gullies | 1–1.6 |
| SLD–PARM2 | | | | | | | | |
| KEIM | Coefficient in the solids washoff equation | complex | 0.5 | 5 | 0.1 | 10 | Surface conditions, solids characteristics | 0.5 |
| JEIM | Exponent in the solids washoff equation | none | 1 | 2 | 1 | 3 | Surface conditions, solids characteristics | 1.8 |
| ACCSDP | Solids accumulation rate on the land surface | kg/ha/day | 0 | 1 | none | none | Land use, traffic, human activities | 0.0044 |
| REMSDP | Fraction of solids removed per day | per day | 0.03 | 0.2 | 0.01 | 1 | Street sweeping, wind, traffic | 0.05 |

**Table S7.** Sediment reach parameters used in the Hydrological Simulation Program—FORTRAN (HSPF) model. Table modified from [9]. km = kilometers, mm = millimeters, g/cm$^3$ = grams per cubic centimeter, kg/m$^2$ = kilogram per square meter.

| Name | Definition | Units | Range of Values | | | | Function of | Range of Values |
|---|---|---|---|---|---|---|---|---|
| | | | Typical | | Possible | | | |
| | | | Min | Max | Min | Max | | |
| SANDFG | | | | | | | | |
| SANDFG | Indicates method used for sandload simulation | none | 1 | 3 | 1 | 3 | Type of stream; user experience | 1 |
| SED–GENPARM | | | | | | | | |
| BEDWID | Width of cross-section over which HSPF will assume bed sediment is deposited | meters | 3 | 152 | 0.3 | none | Reach/waterbody morphology | 3.1–6980 |
| BEDWRN | Bed depth which, if exceeded will cause a warning message | meters | 0.15 | 3 | 0.000 3 | none | Reach/waterbody morphology, user needs | 4.6–500 |
| POR | Porosity of the bed (volume voids/total volume) | none | 0.3 | 0.6 | 0.1 | 0.9 | Reach/sediment bed characteristics | 0.4 |
| SED–HYDPARM | | | | | | | | |
| LEN | Length of the reach | km | 0.16 | 1.6 | 0.016 | none | Topography, stream morhpology | 10.4–74.7 |
| DELTH | Drop in water elevation from upstream to downstream extremities of the reach | meters | 1.5 | 2.5 | 0 | none | Topography, stream morphology | 4.6–1755 |
| DB50 | Median diameter of bed sediment (assumed constant) | mm | 0.25 | 0.51 | 0.002 5 | 2500 | Channel bed properties | 0.25 |
| SAND–PM | | | | | | | | |
| D | Effective diameter of the transported sand particles | mm | 0.0508 | 2.03 | 0.025 | 2500 | Sediment properties | 0.15 |
| W | Fall velocity of transported sand particles in still water | mm/sec | 5.1 | 102 | 0.5 | 12,500 | Particle diameter and density | 5.8–228 |
| RHO | Density of sand particles | g/cm$^3$ | 2.2 | 2.7 | 1 | 4 | Sediment properties | 2.6 |
| KSAND | Coefficient in sandload power function formula | complex | 0.01 | 0.5 | 0.001 | none | Sand properties and hydraulics | 2 |
| EXPSAND | Exponent in sandload power function formula | complex | 1.5 | 3.5 | 1 | none | Sand properties and hydraulics | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | SILT–CLAY–PM [1] | | | | |
| D | Effective diameter of silt (clay) particles | mm | 0.005 (0.00025) | 0.064 (0.004) | 0 | 0.07 | Sediment properties | 0.001–0.15 |
| W | Fall velocity of transported silt (clay) particles in still water | mm/sec | 0.00254 | 0.254 | 0 | 5 | Particle diameter and density | 0.2–5 |
| RHO | Density of silt (clay) particles | g/cm³ | 1.8 | 2.7 | 1.5 | 3 | Sediment properties | 2.8 |
| TAUCD | Critical bed shear stress for deposition | kg/m² | 0.0045 | 0.14 | 0 | none | Silt/clay properties and hydraulics | 0.002–0.16 |
| TAUCS | Critical bed shear stress for scour | kg/m² | 0.023 | 0.23 | 0 | none | Silt/clay properties and hydraulics | 0.002–0.6 |
| M | Erodibility coefficient | kg/m².day | 0.0045 | 0.91 | 0 | none | Silt/clay properties and hydraulics | 0.002 |

Note: [1] Table used twice, once for silt and once for clay parameters.

**Table S8.** Daily sediment calibration statistics. Values in bold are located on the Sacramento River. $R^2$ = coefficient of determination, ME% = mean error.

| Model Reach Number | SSC (mg/L) or Sediment Loads (Tons/Day) | Gage Name | Sample Size (n) | $R^2$ | Modeled/Observed | ME% |
|---|---|---|---|---|---|---|
| 1 | Sediment loads | Cow C near Millville | 212 | 0.12 | 1.5 | 194 |
| 14 | SSC | Cottonwood C near Olinda | 798 | 0.40 | 0.9 | 66 |
| 15 | Sediment loads | Mf Cottonwood C near Ono | 196 | 0.72 | 1.1 | 55 |
| 18 | Sediment loads | Cottonwood C near Cottonwood | 1864 | 0.70 | 1.3 | 476 |
| 18 | SSC | Cottonwood C near Cottonwood | 2335 | 0.31 | 0.9 | 173 |
| **22** | **Sediment loads** | **Sacramento R at Red Bluff** | **966** | 0.46 | 1.3 | −7 |
| 40 | Sediment loads | Thomes C at Paskenta Ca | 4163 | 0.25 | 0.8 | 833 |
| 40 | SSC | Thomes C at Paskenta Ca | 4163 | 0.20 | 1.3 | 177 |
| **48** | **Sediment loads** | **Sacramento R near Hamilton City** | **733** | 0.72 | 0.5 | −53 |
| **49** | **Sediment loads** | **Sacramento R near Butte City** | **697** | 0.83 | 0.8 | −25 |
| **49** | **SSC** | **Sacramento R near Butte City** | **699** | 0.64 | 0.7 | −41 |
| 53 | Sediment loads | Feather R near Gridley | 10,353 | 0.78 | 0.9 | 51 |
| 53 | SSC | Feather R near Gridley | 10,556 | 0.54 | 0.9 | 24 |
| 59 | Sediment loads | Feather R at Yuba City | 4383 | 0.66 | 0.9 | −0.1 |
| 59 | SSC | Feather R at Yuba City | 4383 | 0.24 | 0.7 | −22 |
| **61** | **Sediment loads** | **Sacramento R at Colusa** | **949** | 0.52 | 1.3 | 49 |
| **61** | **SSC** | **Sacramento R at Colusa** | **944** | 0.37 | 0.8 | 19 |
| 69 | Sediment loads | Feather R near Nicolaus | 425 | 0.82 | 1.0 | 48 |
| 69 | SSC | Feather R near Nicolaus | 425 | 0.49 | 1.2 | 46 |
| 74 | Sediment loads | Cache C above Rumsey | 9638 | 0.21 | 0.2 | 2605 |
| 74 | SSC | Cache C above Rumsey | 9638 | 0.31 | 0.6 | 723 |
| 78 | Sediment loads | Sutter Bypass near Nicolaus | 97 | 0.74 | 1.2 | −61 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 78 | SSC | Sutter Bypass near Nicolaus | 97 | 0.59 | 0.4 | −79 |
| 84 | Sediment loads | Cache C near Brooks | 637 | 0.42 | 0.7 | 816 |
| 84 | SSC | Cache C near Brooks | 637 | 0.54 | 1.1 | 220 |
| 88 | Sediment loads | Cache C at Yolo | 573 | 0.38 | 1.0 | 2213 |
| 88 | SSC | Cache C at Yolo | 685 | 0.54 | 1.2 | 5539 |
| 94 | Sediment loads | Yolo Bypass near Woodland | 78 | 0.07 | 1.1 | 187 |
| 94 | SSC | Yolo Bypass near Woodland | 78 | 0.009 | 1.9 | 195 |
| **99** | **Sediment loads** | **Sacramento R at Verona** | **212** | 0.21 | 0.4 | 151 |
| **99** | **SSC** | **Sacramento R at Verona** | **212** | 0.21 | 1.5 | 250 |
| **97** | **Sediment loads** | **Sacramento R at Freeport** | **10,593** | 0.38 | 1.1 | 10 |
| **97** | **SSC** | **Sacramento R at Freeport** | **10,593** | 0.25 | 0.7 | −7 |

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