Appendix R
Model Configuration, Calibration and Validation

Basin: Sacramento River

Contents

Watershed Background **1**
Water Body Characteristics 1
Soil Characteristics 3
Land Use Representation 3
Point Sources 8
Meteorological Data 8
Watershed Segmentation 9
Calibration Data and Locations 11
SWAT Modeling **12**
Assumptions 12
Hydrology Calibration 12
Hydrology Validation 16
Hydrology Results for Larger Watershed 18
Water Quality Calibration and Validation 20
References **24**

Tables

Table 1. Aggregation of NLCD land cover classes 5
Table 2. Land use distribution for the Sacramento River watershed (2001 NLCD) (mi^2) 6
Table 3. Major point source discharges in the Sacramento River watershed 8
Table 4. Precipitation stations for the Sacramento River watershed model 8
Table 5. Calibration and validation locations in the Sacramento River watershed 11
Table 6. Summary statistics at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period 15
Table 7. Summary statistics at USGS 11377100 Sacramento River Bend Bridge near Red Bluff, CA – validation period 18
Table 8. Summary statistics (percent error): all stations - calibration period 19
Table 9. Summary statistics: all stations - validation period 20
Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA 21
Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA 22
Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA 23

Figures

Figure 1. Location of the Sacramento River watershed. 2
Figure 2. Land use in the Sacramento River watershed. 4
Figure 3. Model segmentation and USGS stations utilized for the Sacramento River watershed. 10
Figure 4. Mean monthly flow at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – calibration period. 13
Figure 5. Seasonal regression and temporal aggregate at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period. 14
Figure 6. Seasonal medians and ranges at USGS 05317000 USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – calibration period. 14
Figure 7. Flow exceedance at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period. 15
Figure 8. Mean monthly flow at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period. 16
Figure 9. Seasonal regression and temporal aggregate at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period. 16
Figure 10. Seasonal medians and ranges at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period. 17
Figure 11. Flow exceedance at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period. 17
Figure 12. Fit for monthly load of TSS at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA. 21
Figure 13. Fit for monthly load of total phosphorus at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA. 22
Figure 14. Fit for monthly load of total nitrogen at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA. 22

Watershed Background

The Sacramento River basin was selected as one of the 15 non-pilot application watersheds for the 20 Watershed study. Watershed modeling for the non-pilot areas is accomplished using the SWAT model only, and model calibration and validation results are presented in abbreviated form.

Water Body Characteristics

The Sacramento River is the largest river in California, originating from eastern slopes of the Klamath Mountains and emptying into Suisun Bay (an arm of the San Francisco Bay) and eventually into the Pacific Ocean.

The entire Sacramento River drainage area is around 70,000 km^2 (27,000 mi^2; HUC4 – 1802). The Sacramento basin that is considered in the current 20 Watershed study, referred to as Sacramento River watershed in this report, is an upper portion of the Lower Sacramento basin that reaches from the downstream of Lake Shasta to just before the confluence of the Feather River (Figure 1). The Sacramento River watershed is comprised of 11 HUC8 cataloging units. The outflow of Lake Shasta is provided as a boundary condition by adding the outflow as a point source at the corresponding subwatershed. The Sacramento River is joined by small to moderate tributaries including Clear, Cottonwood, Cow, Thomes, Ash, Battle, Mill, Stony and Big Chico Creeks along its southward journey. In the middle of the watershed, near Red Bluff, a large portion of the river's flow is diverted into a pair of irrigation canals.

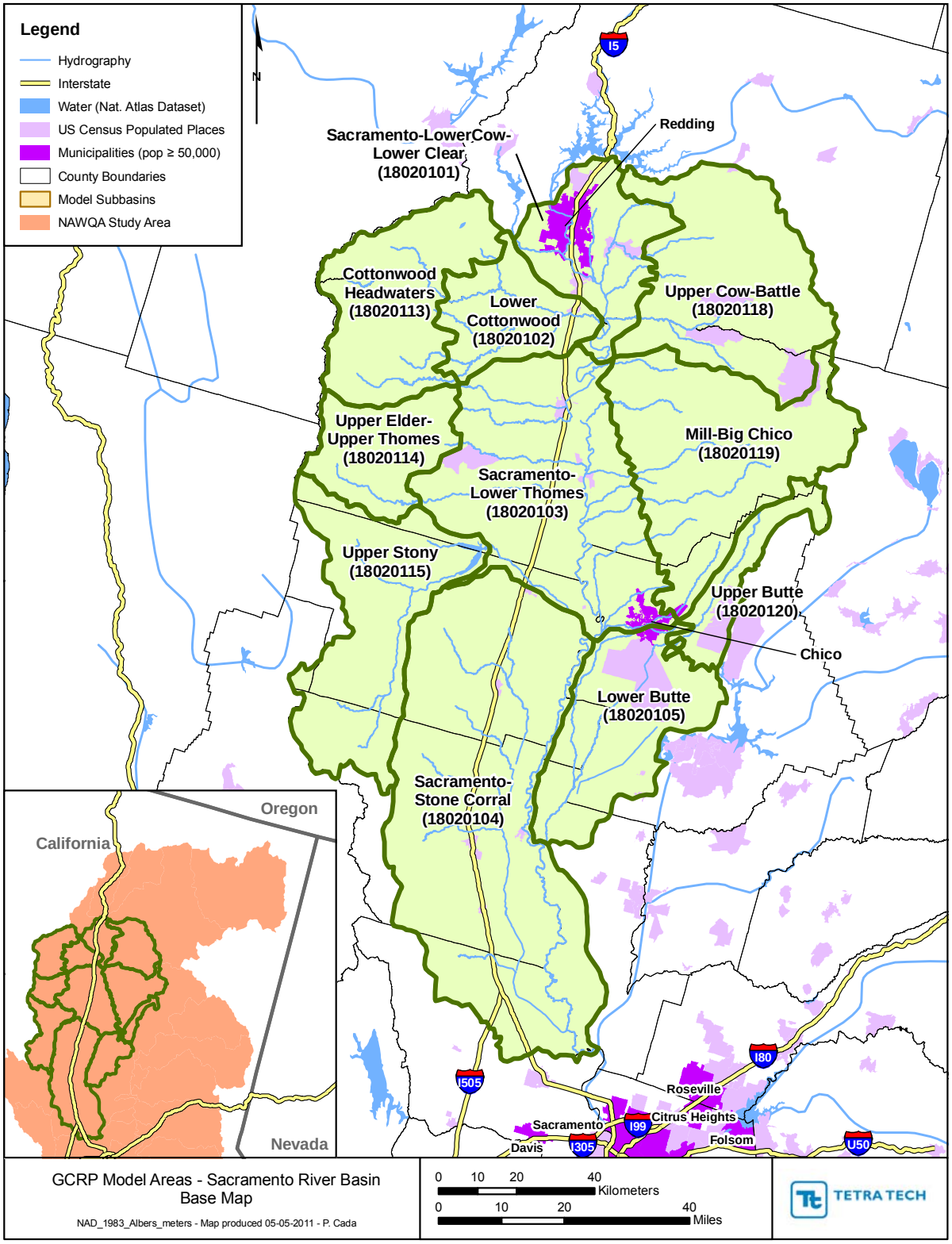

Figure 1. Location of the Sacramento River watershed.

Soil Characteristics

Soils in the watershed, as described in STATSGO soil surveys, fall primarily into hydrologic soil groups (HSGs) D (low infiltration capacity and high runoff potential) and B (moderately high infiltration capacity; correspondingly, moderately low runoff potential). SWAT uses information drawn directly from the soils data layer to populate the model.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage and is predominantly range grass and shrubland. Agriculture covers about 21 percent of the watershed area (Figure 2). NLCD land cover classes were aggregated according to the scheme shown in Table 1 for representation in the 20 Watershed model. SWAT uses the built-in hydrologic response unit (HRU) overlay mechanism in the ArcSWAT interface. SWAT HRUs are formed from an intersection of land use and SSURGO major soils. The distribution of land use in the watershed is summarized in Table 2.

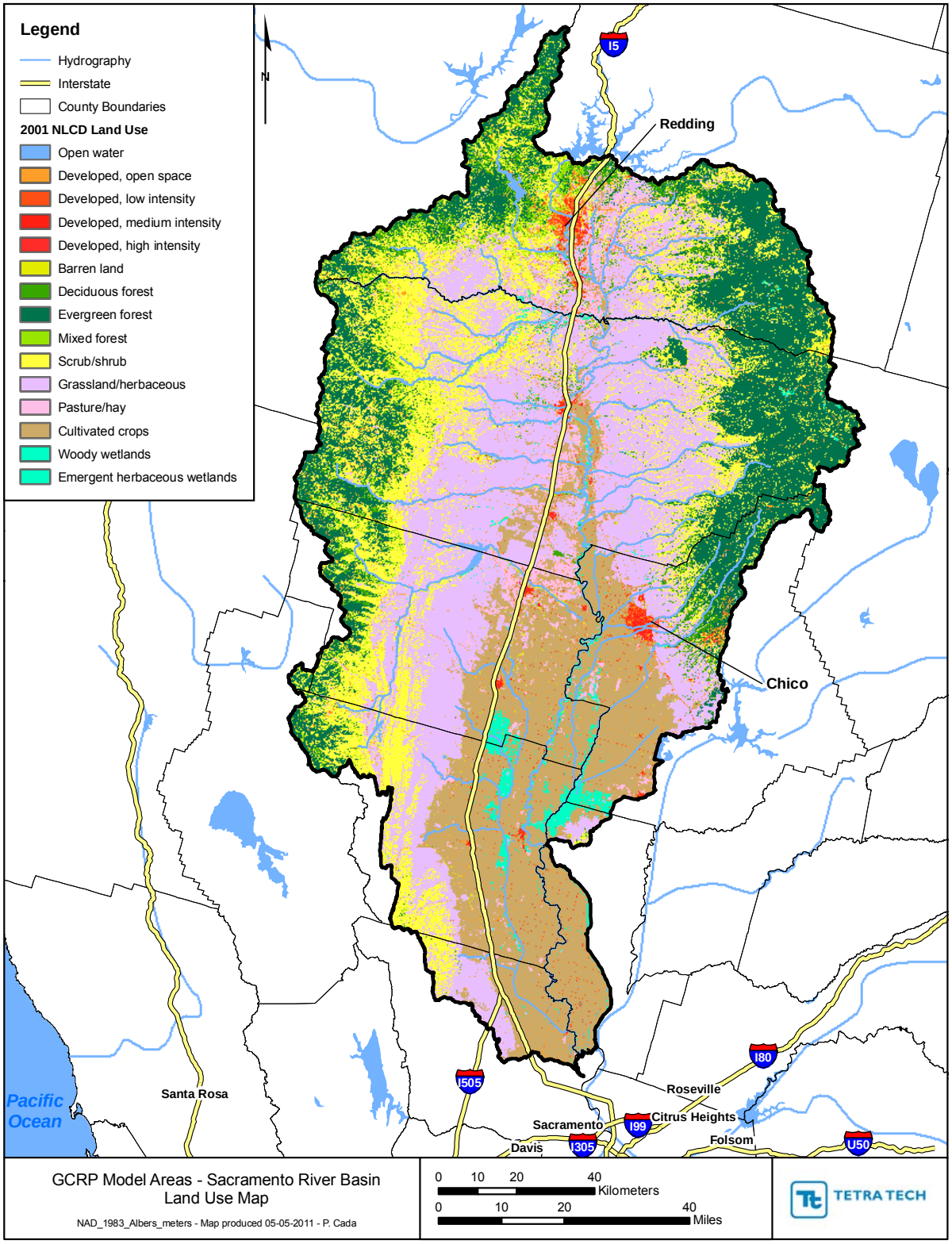

Figure 2. Land use in the Sacramento River watershed.

Table 1. Aggregation of NLCD land cover classes

NLCD Class	Comments	SWAT class
11 Water	Water surface area usually accounted for as reach area	WATR
12 Perennial ice/snow		WATR
21 Developed open space		URLD
22 Dev. Low Intensity		URMD
23 Dev. Med. Intensity		URHD
24 Dev. High Intensity		UIDU
31 Barren Land		SWRN
41 Forest	Deciduous	FRSD
42 Forest	Evergreen	FRSE
43 Forest	Mixed	FRST
51-52 Shrubland		RNGB
71-74 Herbaceous Upland		RNGE
81 Pasture/Hay		HAY
82 Cultivated		AGRR
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR

Table 2. Land use distribution for the Sacramento River watershed (2001 NLCD) (mi^2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland	Pasture/ Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
Sacramento-Stone Corral 18020104	11.7	53.8	19.0	7.7	1.4	11.6	3.0	162.1	535.2	1,012.3	65.9	1,883.7
Upper Stony 18020115	10.1	22.4	0.8	0.3	0.1	7.5	203.0	308.1	216.0	4.8	3.3	776.4
Clear Creek-Sacramento River 18020151	8.1	36.3	16.1	9.0	2.0	1.1	236.8	108.9	64.4	5.3	3.1	491.1
Cow Creek 18020152	0.5	9.9	1.1	0.1	0.0	0.6	188.6	107.6	113.6	4.3	0.9	427.1
Cottonwood Creek 18020153	0.8	24.5	1.4	0.5	0.1	2.2	251.3	407.8	241.6	0.4	12.4	943.1
Battle Creek-Sacramento River 18020154	1.2	10.6	1.0	0.6	0.2	2.0	288.0	111.1	138.7	5.3	4.4	563.2
Paynes Creek-Sacramento River 18020155	2.8	13.7	2.6	2.2	0.6	1.2	35.1	103.6	256.1	2.2	3.6	423.6
Thomes Creek-Sacramento River 18020156	2.8	26.0	3.3	1.0	0.3	7.4	257.2	222.1	434.2	48.5	5.9	1,008.7
Big Chico Creek-Sacramento River 18020157	3.6	24.0	11.0	8.5	1.5	4.3	236.3	108.1	399.2	142.3	13.1	952.1
Butte Creek 18020158	1.6	27.2	10.4	5.2	1.4	2.4	162.2	34.3	137.1	385.2	52.3	819.3
Cache Slough-Sacramento River 18020163	0.3	1.1	0.2	0.2	0.0	0.0	0.0	0.0	0.6	24.4	0.3	27.0
Total	43.67	249.6	66.8	35.2	7.7	40.3	1,861.5	1,673.8	2,536.7	1,635.0	165.2	8,315.4

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (5.95%), low density (30.02%), medium density (55.41%), and high density (81.20%).

Point Sources

There are numerous point source discharges in the watershed (Table 3). These are represented at long-term average flows, without accounting for changes over time or seasonal variations.

Table 3. Major point source discharges in the Sacramento River watershed

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
CA0079081	CHICO, CITY OF	9.00	4.17
CA0004821	PACTIV CORP	2.70	1.97
CA0077704	ANDERSON, CITY OF	2.00	1.42
CA0079731	REDDING, CITY OF	8.80	8.01
CA0078034	WILLOWS, CITY OF	1.12	0.91

Most of these point sources have reasonably good monitoring for total suspended solids (TSS), but not for total phosphorus and total nitrogen. The point sources were initially represented in the model with the median of reported values for the constituents (total phosphorus, total nitrogen, and TSS) and an assumed total nitrogen concentration of 11.2 mg/L and assumed total phosphorus concentration of 7.0 mg/L for secondary treatment facilities (Tetra Tech 1999). However, in cases where point source contribution was deemed unusually high, assumed values were substituted with the average concentration of the reported data.

Meteorological Data

The required meteorological time series for the 20 Watershed SWAT simulations are precipitation and air temperature. The 20 Watershed simulations do not include water temperature simulation and use a degree-day method for snowmelt. SWAT estimates Penman-Monteith potential evapotranspiration using a statistical weather generator for inputs other than temperature and precipitation. These meteorological time series are drawn from the BASINS4 Meteorological Database (USEPA 2008), which provides a consistent, quality-assured set of nationwide data with gaps filled and records disaggregated. Scenario application requires simulation over 30 years, so the available stations are those with a common 30-year period of record (or one that can be filled from an approximately co-located station) that covers the year 2001. A total of 28 precipitation stations were identified for use in the Sacramento River watershed model with a common period of record of 10/1/1971-9/30/2001 (Table 4). Temperature records are sparser; where these are absent temperature is taken from nearby stations with an elevation correction.

Table 4. Precipitation stations for the Sacramento River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
40546	CA040546	40.4000	-122.1500	No	128
41159	CA041159	39.9372	-121.3140	No	1890
41700	CA041700	40.3034	-121.2420	Yes	4531
41715	CA041715	39.6911	-121.8210	Yes	184
41806	CA041806	38.9240	-122.5670	Yes	1348
41907	CA041907	40.4000	-122.1430	No	420
41948	CA041948	39.1806	-122.0290	Yes	49
42084	CA042084	39.8261	-123.0840	No	1512
42402	CA042402	39.8739	-121.6170	Yes	2710
42640	CA042640	39.3593	-122.5170	Yes	1204
43791	CA043791	40.3636	-122.9650	No	2749
45311	CA045311	40.5419	-121.5760	Yes	5751
45385	CA045385	39.1459	-121.5850	Yes	56
45679	CA045679	40.3458	-121.6090	Yes	4875
46194	CA046194	38.9261	-121.5440	No	43

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
46506	CA046506	39.7459	-122.1990	Yes	253
46521	CA046521	39.5179	-121.5530	Yes	171
46685	CA046685	39.7540	-121.6240	Yes	1749
46726	CA046726	39.8876	-122.5530	No	755
47292	CA047292	40.1519	-122.2530	Yes	354
47581	CA047581	40.7957	-121.9350	No	2100
48135	CA048135	40.7142	-122.4160	Yes	1076
48580	CA048580	39.3754	-122.5460	No	1171
48587	CA048587	39.5862	-122.5340	Yes	801
49390	CA049390	40.4569	-121.8650	No	2221
49621	CA049621	40.6117	-122.5280	Yes	1296
49699	CA049699	39.5231	-122.3050	Yes	233
49781	CA049781	38.6829	-121.7940	Yes	69

Watershed Segmentation

The Sacramento River basin was divided into 71 subwatersheds for the purposes of modeling (Figure 3). The model doesn't encompass the complete watershed. The Upper Sacramento and Pit Rivers join in Lake Shasta, a huge reservoir formed by Shasta Dam. The watershed area considered for this 20 Watershed study is the drainage between downstream of Shasta to the confluence of Feather River and Sacramento River. The outflow from Lake Shasta was considered as a boundary condition. No specific site was considered as a calibration focus area.

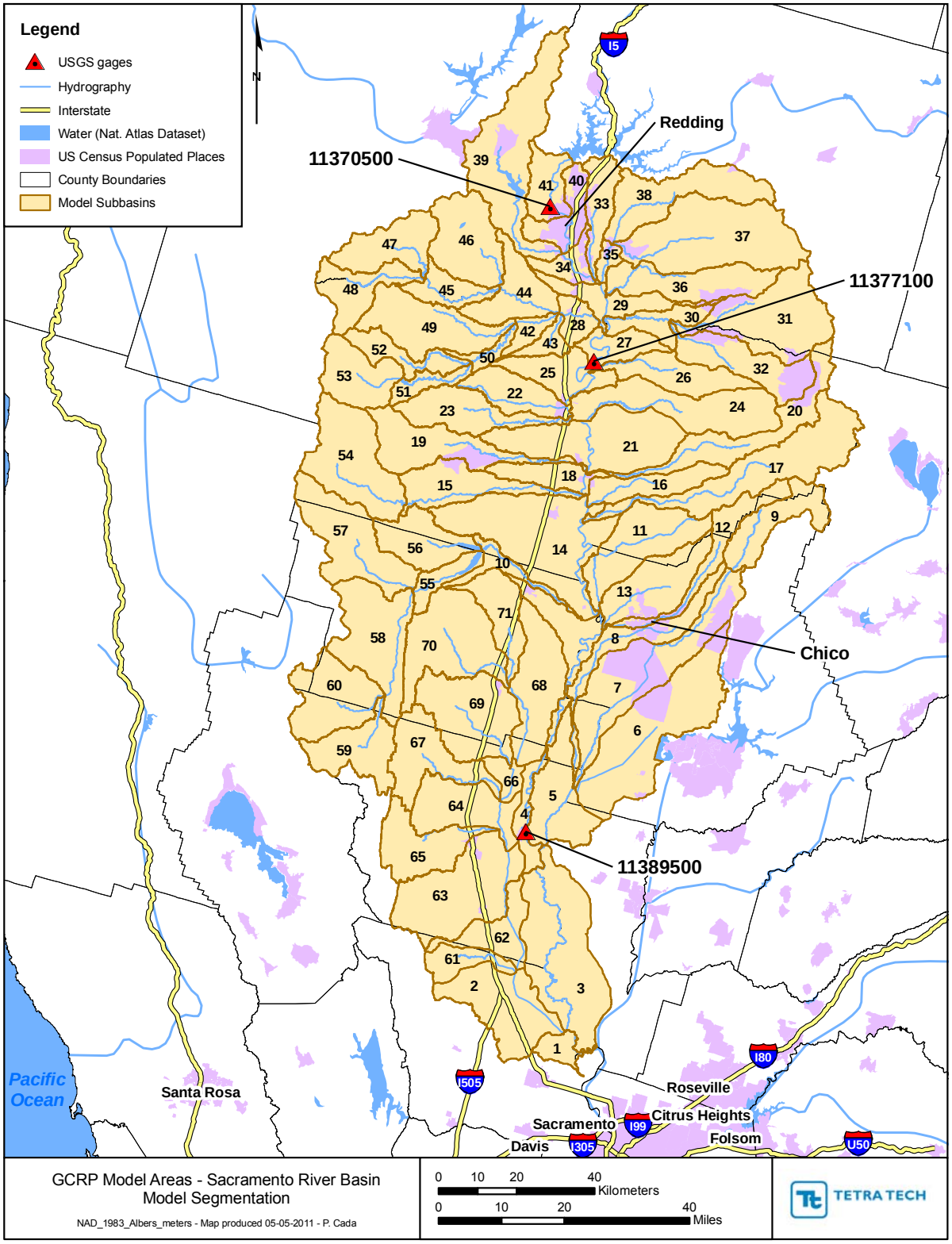

Figure 3. Model segmentation and USGS stations utilized for the Sacramento River watershed.

Calibration Data and Locations

There are three gages at which long term streamflow data were available (Table 5). All the three gages are on the main stem of Sacramento River. As mentioned earlier, the watershed area considered for this study is the drainage between downstream of Shasta to the confluence of Feather River and Sacramento River. Therefore, no specific site was chosen for initial calibration. The results at the gaging site on Sacramento River above Bend Bridge near Red Bluff are presented in detail.

Table 5. Calibration and validation locations in the Sacramento River watershed

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Sacramento River above Bend Bridge near Red Bluff, CA	11377100	8,900	X	X
Sacramento River at Colusa, CA	11389500	12,090	X	
Sacramento River at Keswick, CA	11370500	6,468	X	

The model hydrology calibration period was set to Water Years 1992-2001 (within the 30-year period of record for modeling). Hydrologic validation was then performed on Water Years 1983-1992. Unfortunately, the Sacramento River watershed had no good water quality data. Water quality data available at the Keswick station were used as a point source in the simulation because of the lack of these data from Shasta Dam, unlike the outflow data availability. Due to very limited data at Colusa station, only Bend Bridge station was used for water quality calibration. Although sediment data were available for a longer period, the nutrient data were again limited. A period from 1997-2001 was used for calibration and 1973-1996 was used for validation.

SWAT Modeling

Assumptions

The reservoirs simulated in this study include Black Butte, East Park, Stony Gorge, and Whiskeytown dams. Pertinent reservoir information including surface area and storage at principal (normal) and emergency spillway levels for the reservoirs modeled were obtained from the National Inventory of Dams (NID) database. The SWAT model provides four options to simulate reservoir outflow: measured daily outflow, measured monthly outflow, average annual release rate for uncontrolled reservoir, and controlled outflow with target release. Keeping in view the 20 Watershed climate change impact evaluation application, it was assumed that the best representation of the reservoirs was to simulate them without supplying time series of outflow records. Therefore, the target release approach was used in the GCRP-SWAT model.

The monthly reservoir target storage was calculated based on daily reservoir storage data obtained from Department of Water Resources-California Data Exchange Center (http://cdec.water.ca.gov/selectQuery.html) and input in the reservoir input files in the model. A diversion was simulated for subwatershed 25 to represent removal of water for irrigation from the Sacramento River near Red Bluff. Elevation bands were input for selected subwatersheds to account for high altitudes.

Hydrology Calibration

A spatial calibration approach was not adopted for GCRP-SWAT modeling for the Sacramento River watershed. As no specific calibration focus area was considered, simulated results were compared with the observed flow at all three gaging stations, simultaneously.

Land Use / Soil / Slope Definition

A 5/10/5 percent threshold was used for land use/soil/slope in the SWAT model while defining the HRUs. Urban land use classes were exempted from the HRU overlay thresholds.

The parameters were adjusted within the practical range to obtain reasonable fit between the simulated and measured flows in terms of Nash-Sutcliffe modeling efficiency and the high flow and low flow components as well as the seasonal flows.

The water balance of the whole Sacramento GRCP model predicted by the SWAT model over the 30-year simulation period is as follows:

```
PRECIP =    864.7 MM
SNOW FALL =  152.06 MM
SNOW MELT =   132.35 MM
SUBLIMATION =    20.93 MM
SURFACE RUNOFF Q =   138.52 MM
LATERAL SOIL Q =  200.95 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    24.57 MM
REVAP (SHAL AQ => SOIL/PLANTS) =   74.30 MM
DEEP AQ RECHARGE =   100.46 MM
TOTAL AQ RECHARGE =  200.92 MM
TOTAL WATER YLD =   360.76 MM
PERCOLATION OUT OF SOIL =  198.01 MM
ET =    353.1 MM
```

```
PET =   1590.3MM
TRANSMISSION LOSSES =     2.50 MM
```

Hydrologic calibration adjustments focused on the following parameters:

- Curve Number
- FFCB (initial soil water storage)
- SURLAG (surface runoff lag coefficient)
- CNCOEFF (plant ET curve number coefficient)
- Baseflow factor
- GW_DELAY (groundwater delay time)
- GWQMN (threshold depth of water in the shallow aquifer for return flow to occur [mmH2O])
- RevapMN (threshold depth of water in the shallow aquifer required for "revap" or percolation to the deep aquifer to occur
- RCHRG_DP (deep aquifer percolation fraction)
- Sol_AWC (available water capacity of the soil layer, mm water/mm of soil)
- Snow parameters SFTMP, SMTMP, SMFMX and SMFMN, TIMP
- ESCO (soil evaporation compensation factor)
- CH_K2 (channel hydraulic conductivity)
- Elevation bands
- TLAPS (temperature lapse rate)

Calibration results for the Sacramento River above Bend Bridge near Red Bluff, CA (USGS 11377100) are summarized in Figures 4 through 7 and Table 6. In general, model simulated streamflows, both in magnitude and timing, compared very well with observed except some overestimation of total storm volumes, especially the summer storm volumes (Figure 4, Figure 5, Figure 6, Figure 7, and Table 6).

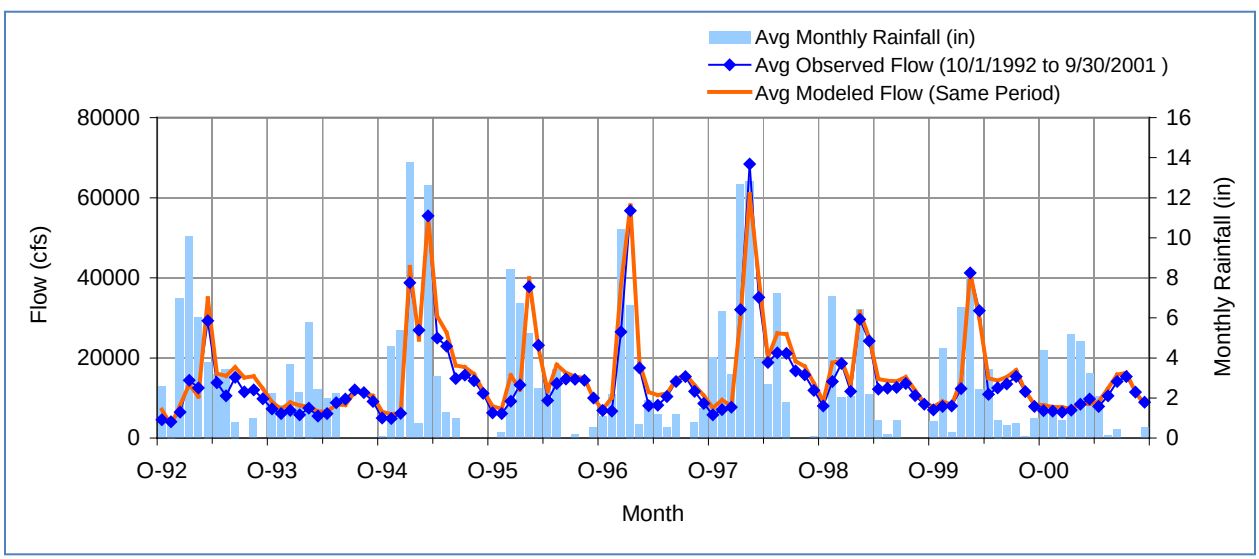

Figure 4. Mean monthly flow at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – calibration period.

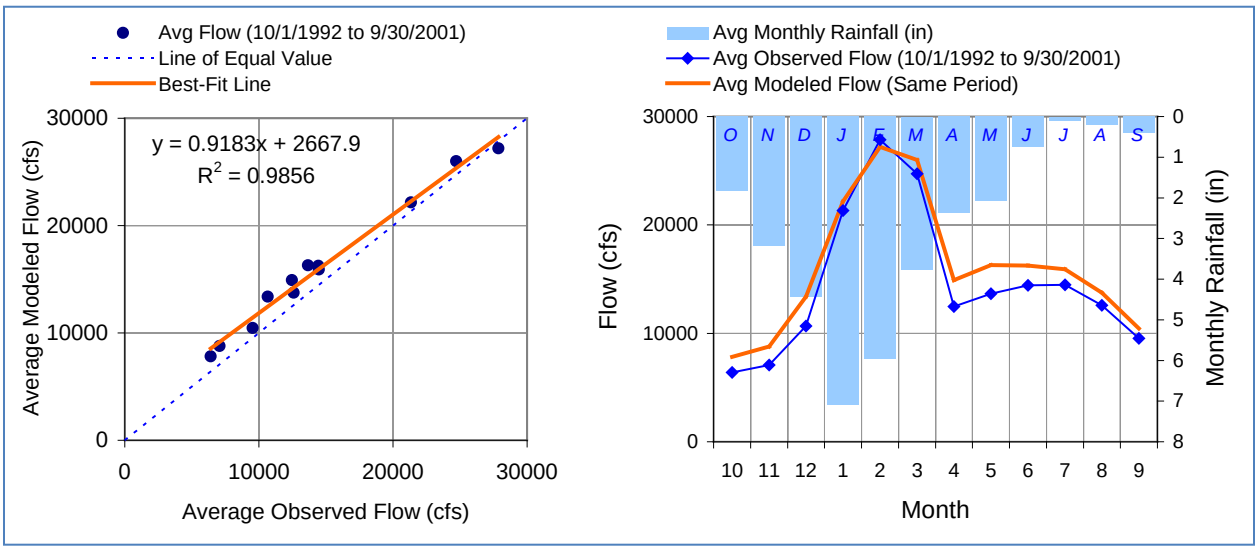

Figure 5. Seasonal regression and temporal aggregate at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period.

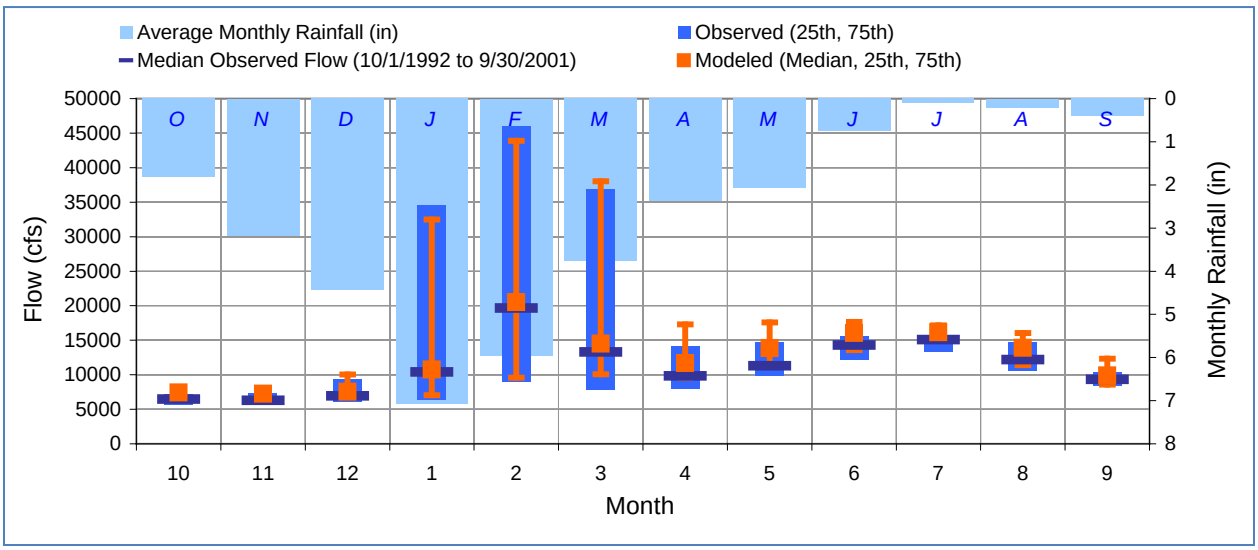

Figure 6. Seasonal medians and ranges at USGS 05317000 USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – calibration period.

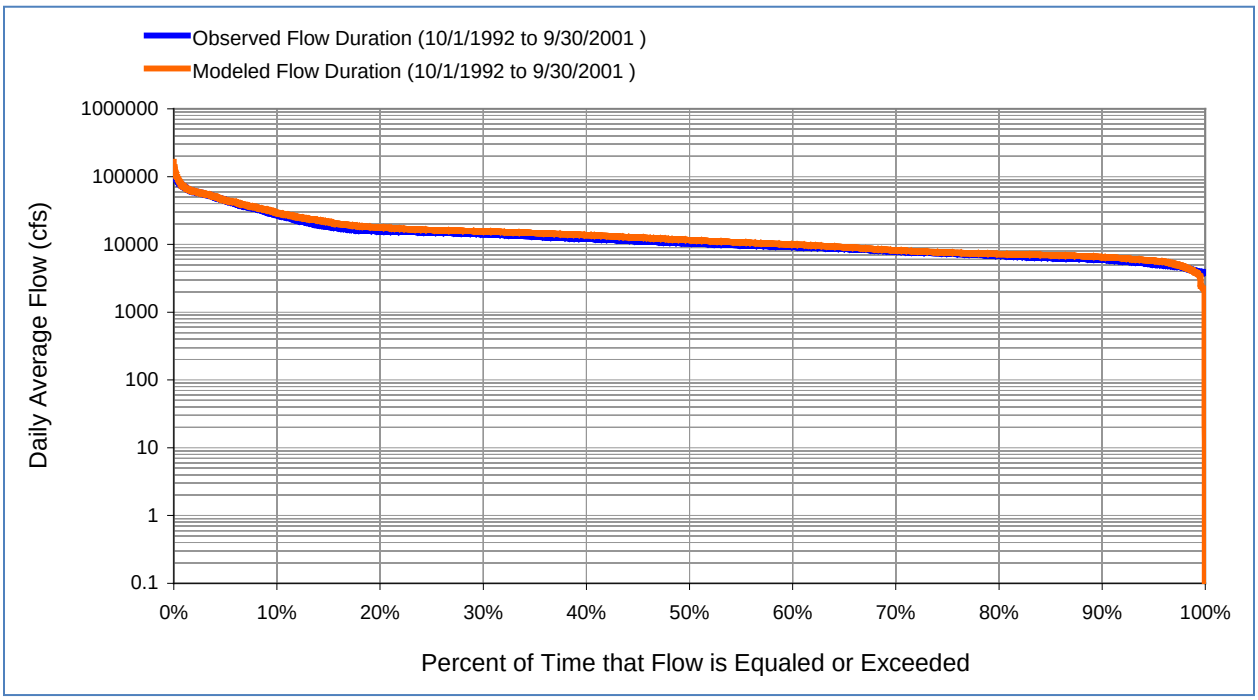

Figure 7. Flow exceedance at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period.

Table 6. Summary statistics at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA - calibration period

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 27 9-Year Analysis Period: 10/1/1992 - 9/30/2001 Flow volumes are (inches/year) for upstream drainage area		USGS 11377100 SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA Hydrologic Unit Code: 18020103 Latitude: 40.28848836 Longitude: -122.1866645 Drainage Area (sq-mi): 8900		
Total Simulated In-stream Flow:	**24.47**	Total Observed In-stream Flow:		**22.20**
Total of simulated highest 10% flows:	**7.94**	Total of Observed highest 10% flows:		**7.47**
Total of Simulated lowest 50% flows:	**6.21**	Total of Observed Lowest 50% flows:		**5.68**
Simulated Summer Flow Volume (months 7-9):	**5.15**	Observed Summer Flow Volume (7-9):		**4.70**
Simulated Fall Flow Volume (months 10-12):	**3.85**	Observed Fall Flow Volume (10-12):		**3.10**
Simulated Winter Flow Volume (months 1-3):	**9.45**	Observed Winter Flow Volume (1-3):		**9.25**
Simulated Spring Flow Volume (months 4-6):	**6.02**	Observed Spring Flow Volume (4-6):		**5.14**
Total Simulated Storm Volume:	**6.33**	Total Observed Storm Volume:		**4.39**
Simulated Summer Storm Volume (7-9):	**0.47**	Observed Summer Storm Volume (7-9):		**0.26**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	**10.23**	**10**	**10.27**	
Error in 50% lowest flows:	9.28	10	9.31	
Error in 10% highest flows:	6.22	15	6.27	
Seasonal volume error - Summer:	9.59	30	9.59	
Seasonal volume error - Fall:	24.24	30	24.33	
Seasonal volume error - Winter:	2.11	30	2.15	
Seasonal volume error - Spring:	16.99	30	17.02	
Error in storm volumes:	**43.97**	**20**	**44.10**	
Error in summer storm volumes:	**78.74**	**50**	**78.77**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.746	Model accuracy increases	0.745	
Baseline adjusted coefficient (Garrick), E':	0.625	as E or E' approaches 1.0	0.624	
Monthly NSE	0.972			

Hydrology Validation

Hydrology validation results for the station on the Sacramento River above Bend Bridge near Red Bluff, CA (USGS 11377100), performed for the period 10/1/1982 through 9/30/1992 are presented in Figures 8 throiugh 11 and Table 7. Based on the model performance statistics, it can be noted that the timing and magnitude of simulated flows, overall as well as seasonal flows were consistent with the pattern observed during the calibration period (Figure 8, Figure 9, Figure 10, Figure 11, and Table 7).

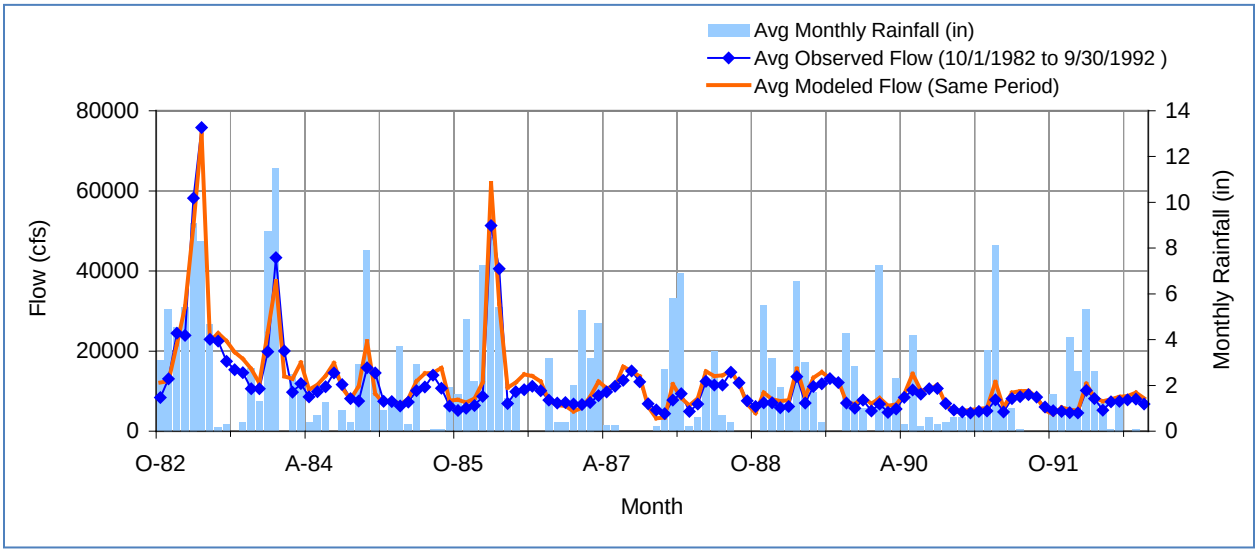

Figure 8. Mean monthly flow at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period.

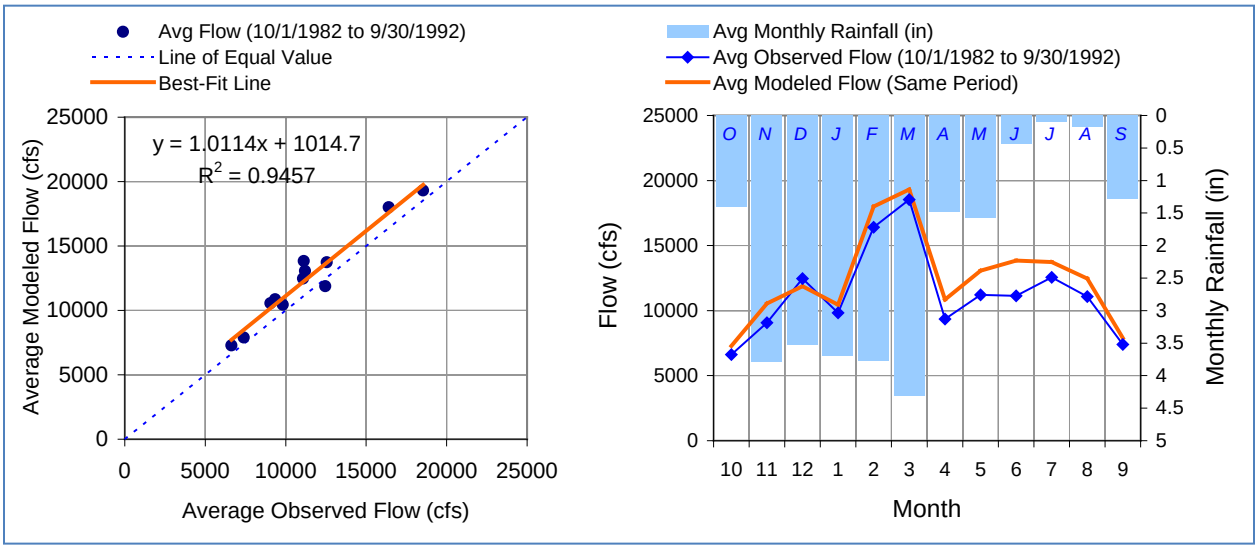

Figure 9. Seasonal regression and temporal aggregate at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period.

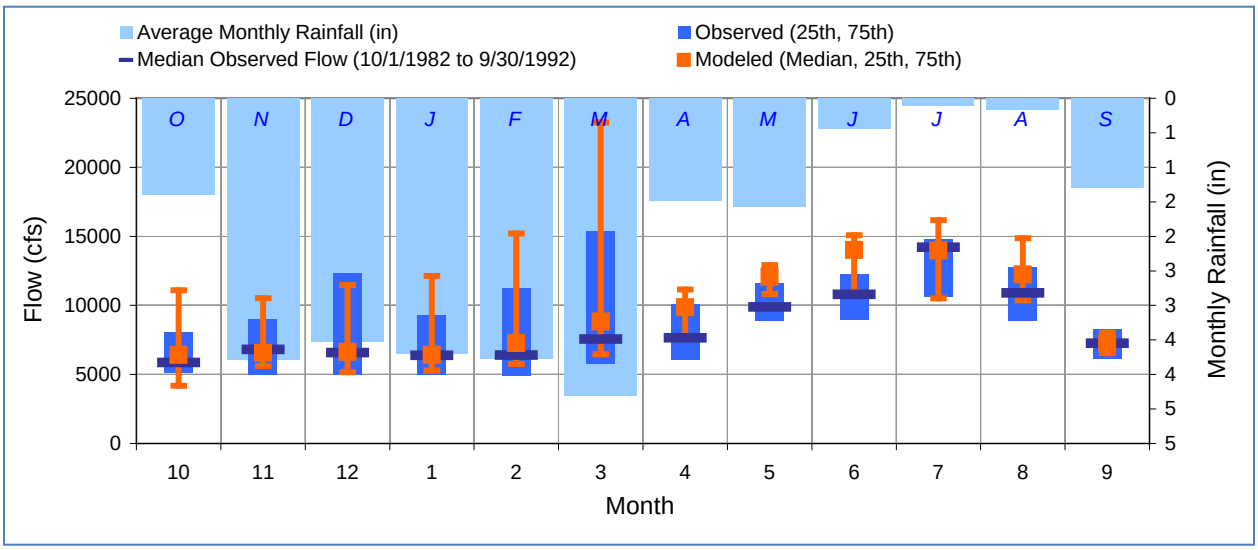

Figure 10. Seasonal medians and ranges at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period.

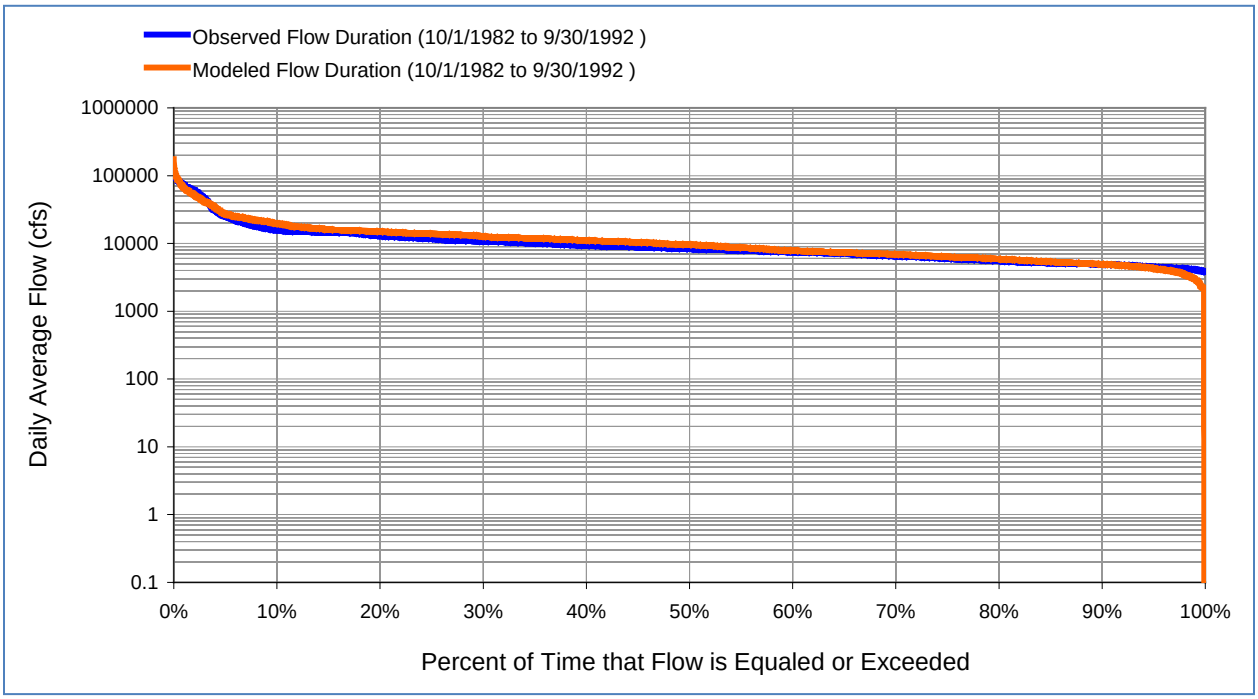

Figure 11. Flow exceedance at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA – validation period.

Table 7. Summary statistics at USGS 11377100 Sacramento River Bend Bridge near Red Bluff, CA – validation period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 27 10-Year Analysis Period: 10/1/1982 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		USGS 11377100 SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA Hydrologic Unit Code: 18020103 Latitude: 40.28848836 Longitude: -122.1866645 Drainage Area (sq-mi): 8900	
Total Simulated In-stream Flow:	**18.96**	Total Observed In-stream Flow:	**17.23**
Total of simulated highest 10% flows:	**5.87**	Total of Observed highest 10% flows:	**5.65**
Total of Simulated lowest 50% flows:	**4.93**	Total of Observed Lowest 50% flows:	**4.67**
Simulated Summer Flow Volume (months 7-9):	**4.38**	Observed Summer Flow Volume (7-9):	**3.99**
Simulated Fall Flow Volume (months 10-12):	**3.80**	Observed Fall Flow Volume (10-12):	**3.61**
Simulated Winter Flow Volume (months 1-3):	**5.98**	Observed Winter Flow Volume (1-3):	**5.61**
Simulated Spring Flow Volume (months 4-6):	**4.79**	Observed Spring Flow Volume (4-6):	**4.02**
Total Simulated Storm Volume:	**3.91**	Total Observed Storm Volume:	**3.10**
Simulated Summer Storm Volume (7-9):	**0.42**	Observed Summer Storm Volume (7-9):	**0.23**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	**10.06**	**10**	**10.10**	
Error in 50% lowest flows:	5.52	10	5.56	
Error in 10% highest flows:	3.98	15	4.04	
Seasonal volume error - Summer:	9.90	30	9.91	
Seasonal volume error - Fall:	5.42	30	5.49	
Seasonal volume error - Winter:	6.62	30	6.67	
Seasonal volume error - Spring:	19.20	30	19.22	
Error in storm volumes:	**26.05**	**20**	**26.24**	
Error in summer storm volumes:	**81.28**	**50**	**81.40**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.571	Model accuracy increases	0.570	
Baseline adjusted coefficient (Garrick), E':	0.403	as E or E' approaches 1.0	0.402	
Monthly NSE	0.953			

Hydrology Results for Larger Watershed

As mentioned above, no specific site was chosen for initial calibration and no spatial calibration was carried out except some adjustments made to the diversion introduced in one subwatershed. Along with the Bend Bridge site, two other sites on the main stem of the Sacramento River were chosen to compare model simulated streamflows with observed flow. The calibration results for all three sites are summarized in Table 8. The Keswick site is right downstream of Shasta Dam and the measured outflow from Shasta was used as a boundary condition. Lack of accurate representation of the amounts and timings of withdrawal from diversions above the Colusa site, most likely, resulted in poor Nash-Sutcliffe modeling efficiency at this site. Results of the validation exercise summarized in Table 9 reflect the same successes and problems experienced during the calibration period.

Table 8. Summary statistics (percent error): all stations - calibration period

Station	11377100 Sacramento River above Bend Bridge near Red Bluff, CA	11389500 Sacramento River at Colusa, CA	11370500 Sacramento River at Keswick, CA
Error in total volume:	10.23	-0.13	-1.31
Error in 50% lowest flows:	9.28	-8.68	-3.21
Error in 10% highest flows:	6.22	26.63	5.35
Seasonal volume error - Summer:	9.59	15.44	-6.04
Seasonal volume error - Fall:	24.24	9.62	5.14
Seasonal volume error - Winter:	2.11	-13.18	2.18
Seasonal volume error - Spring:	16.99	5.10	-4.76
Error in storm volumes:	43.97	55.14	36.67
Error in summer storm volumes:	78.74	-45.91	69.25
Nash-Sutcliffe Coefficient of Efficiency, E:	0.746	-0.484	0.952
Baseline adjusted coefficient (Garrick), E':	0.625	0.255	0.791

Table 9. Summary statistics: all stations - validation period

Station	11377100 Sacramento River above Bend Bridge near Red Bluff, CA	11389500 Sacramento River at Colusa, CA	11370500 Sacramento River at Keswick, CA
Error in total volume:	10.06	-8.63	-5.38
Error in 50% lowest flows:	5.52	-27.84	-11.24
Error in 10% highest flows:	3.98	10.85	-8.59
Seasonal volume error - Summer:	9.90	15.74	-6.58
Seasonal volume error - Fall:	5.42	-13.05	-10.64
Seasonal volume error - Winter:	6.62	-17.70	-2.81
Seasonal volume error - Spring:	19.20	-9.92	-2.38
Error in storm volumes:	26.05	15.20	-24.11
Error in summer storm volumes:	81.28	-41.12	69.72
Nash-Sutcliffe Coefficient of Efficiency, E:	0.571	-0.469	0.617
Baseline adjusted coefficient (Garrick), E':	0.403	0.119	0.500

Water Quality Calibration and Validation

The model calibration and validation relied on the data from only one station (11377100; Sacramento River above Bend Bridge near Red Bluff, CA) in the entire modeled watershed. A period from 1997-2001 was used for calibration and 1973-1996 was used for validation.

Calibration adjustments for sediment focused on the following parameters:

- SPCON (Linear parameters for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- PRF (Peak rate adjustment factor for sediment routing in the main channel)
- USLE-P (USLE support practice factor)
- USLE-K (USLE erodibility factor)
- SLSUBBSN (average slope length)
- RSDCO (Residue decomposition coefficient)

Simulated and estimated sediment loads at the Bend Bridge station for both the calibration and validation periods are shown in Figure 12 and statistics for the two periods are provided separately in Table 10. The key statistic in Table 10 is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. Table 10 also shows the relative average absolute error, which is the average of the relative

magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows better agreement.

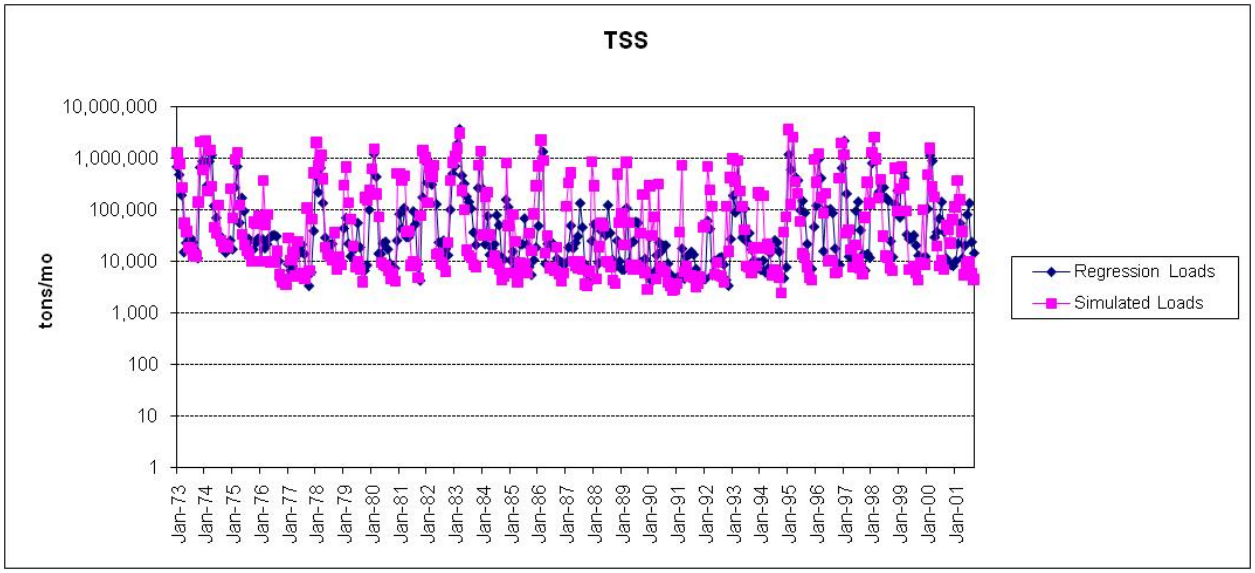

Figure 12. Fit for monthly load of TSS at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA.

Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA

Statistic	Calibration period (1997-2001)	Validation period (1973-1996)
Relative Percent Error	-2%	-55%
Relative Average Absolute Error	59%	92%
Relative Median Absolute Error	28.4%	18.2%

Calibration adjustments for total phosphorus and total nitrogen focused on the following parameters:

- CMN (rate factor of humus mineralization of active organic nutrients)
- NPERCO (nitrogen percolation coefficient)
- PHOSKD (phosphorus soil partitioning coefficient)
- SOL_CBN1 (organic carbon in the first soil layer)
- QUAL2E parameters such as organic nitrogen settling rate in the reach, fraction of algal biomass that is nitrogen, benthic source rate for ammonia in the reach, rate coefficient for organic N settling in the reach, rate constant for biological oxidation of nitrite to nitrate in the reach, rate constant for hydrolysis of organic N to ammonia, Michaelis-Menton half-saturation constant for nitrogen, Maximum specific algal growth rate

Results for the phosphorus simulation are shown in Figure 13 and Table 11. Results for the nitrogen simulation are shown in Figure 14 and Table 12. The model fit is generally good for phosphorus. However, the model overestimates nitrogen loads. The calibration efforts were limited because of the lack of long term monitored nutrient data. Moreover, only one station had monitored data that were used in model calibration.

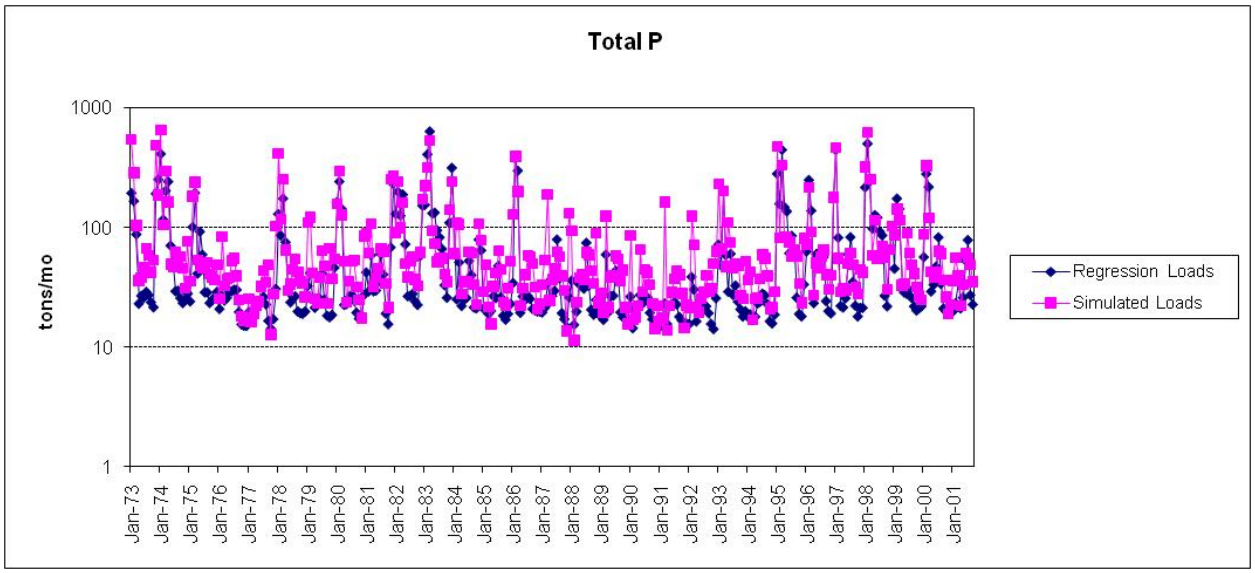

Figure 13. Fit for monthly load of total phosphorus at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA.

Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA

Statistic	Calibration period (1997-2001)	Validation period (1973-1996)
Relative Percent Error	-8%	-33
Average Absolute Error	29%	52%
Median Absolute Error	20.3%	27.8%

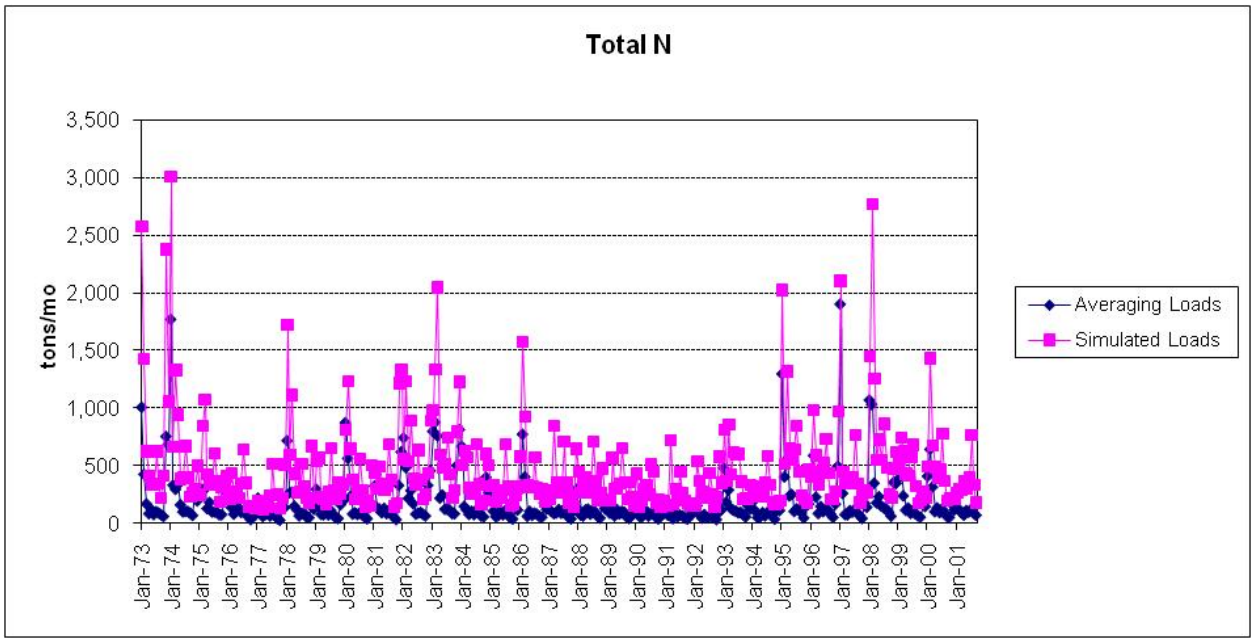

Figure 14. Fit for monthly load of total nitrogen at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA.

Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 11377100 Sacramento River at Bend Bridge near Red Bluff, CA

Statistic	Calibration period (1997-2001)	Validation period (1973-1996)
Relative Percent Error	-135%	-156%
Average Absolute Error	136%	159%
Median Absolute Error	111.5%	124.5%

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