Appendix V
Model Configuration, Calibration and Validation

Basin: Upper Colorado River (UppCol)

Contents

Watershed Background **V-4**
Water Body Characteristics V-4
Soil Characteristics V-5
Land Use Representation V-5
Point Sources V-9
Meteorological Data V-9
Watershed Segmentation V-11
Calibration Data and Locations V-12
SWAT Modeling **V-14**
Assumptions V-14
Hydrology Calibration V-14
Hydrology Validation V-18
Hydrology Results for Larger Watershed V-21
Water Quality Calibration and Validation V-24
Water Quality Results for Larger Watershed V-27
References **V-28**

Tables

Table 1. Aggregation of NLCD land cover classes V-7
Table 2. Land use distribution for the Upper Colorado River basin (2001 NLCD) (mi^2) V-8
Table 3. Major point source discharges in the Upper Colorado River basin V-9
Table 4. Precipitation stations for the Upper Colorado River watershed model V-10
Table 5. Calibration and validation locations in the Upper Colorado River basin V-13
Table 6. Summary statistics at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period V-18
Table 7. Summary statistics at USGS 09070500 Colorado River near Dotsero, Colorado – validation period V-21
Table 8. Summary statistics (percent error): all stations - calibration period V-22
Table 9. Summary statistics (percent error): all stations - validation period V-23
Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 09070500 Colorado River near Dotsero, Colorado V-25
Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 09070500 Colorado River near Dotsero, Colorado V-26
Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 09070500 Colorado River near Dotsero, Colorado V-27
Table 13. Summary statistics for water quality at all stations – calibration period 1992-2002 ..... V-27
Table 14. Summary statistics for water quality at all stations – validation period 1982-1992 ..... V-27

Figures

Figure 1. Location of the Upper Colorado River basin. V-5
Figure 2. Land use in the Upper Colorado River basin. V-6
Figure 3. Model segmentation and USGS stations utilized for the Upper Colorado River basin V-12
Figure 4. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period V-15
Figure 5. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period. V-16
Figure 6. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period V-16
Figure 7. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period V-17
Figure 8. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – validation period V-19
Figure 9. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – validation period. V-19
Figure 10. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – validation period V-20
Figure 11. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – validation period V-20
Figure 12. Fit for monthly load of TSS at USGS 09070500 Colorado River near Dotsero, Colorado V-24
Figure 13. Fit for monthly load of total phosphorus at USGS 09070500 Colorado River near Dotsero, Colorado. V-26
Figure 14. Fit for monthly load of total nitrogen at USGS 09070500 Colorado River near Dotsero, Colorado. V-26

Watershed Background

The Upper Colorado 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 Upper Colorado River basin model area has a drainage area of about 17,800 mi² and contains 12 HUC8s within HUC 1401 and 1402. All except 100 mi² of this area is in Colorado (Figure 1).

The Colorado River and its tributaries originate in the mountains of central Colorado and flow about southwest into Utah. The Continental Divide marks the eastern and southern boundary of the basin, with altitudes over 14,000 ft. Topography in the western part of the basin generally consists of high plateaus bordered by steep cliffs along the valleys, and the lowest altitude (4,300 ft) is near the Colorado-Utah border. The basin is divided almost equally into two physiographic provinces: the Southern Rocky Mountains in the east and the Colorado Plateau in the west (USGS, 2006; Apodaca et al., 1996).

Because of large changes in altitude, the climate in the basin varies from alpine conditions in the east to semiarid in the west. Mean annual temperatures range from as low as 32.8° F in Gunnison County near the Continental Divide to as high as 54.1° F near Grand Junction, Colorado. Precipitation in the basin ranges from more than 40 inches per year in the eastern mountainous regions to less than 10 inches per year in the lower altitude western regions. Mountain areas receive most of their precipitation during the winter months when accumulation of snow can exceed an annual average of 100 inches.

The Upper Colorado River basin is largely rural. Rangeland and forest occupy about 88 percent of the basin. Livestock (sheep and cattle) use large areas of rangeland for foraging. Forest land that includes most of the mountain and plateau areas is used for some commercial lumber production. Large parts of the watershed are set aside for recreational use, including all or parts of 4 National Park Service areas, 5 National Forests and numerous wilderness areas, 11 state parks, numerous State Wildlife Management areas, and 17 ski areas. Mining activities are also an important land use and have included the extraction of metals and energy fuels.

Less than 2 percent of the land area is developed. The largest population center is Grand Junction (population less than 60,000 in 2010), which is located at the confluence of the Colorado and Gunnison Rivers. The larger cities in the basin are located predominantly near agricultural lands or in mountain recreational communities. Agricultural activities (about 4 percent of the area) include production of crops such as alfalfa, fruits, grains, hay, and vegetables. Little crop production is possible without irrigation because of the semiarid climate. Irrigated lands are predominantly in river valleys or low-altitude regions where the water is supplied by an extensive system of canals and ditches.

The natural hydrology of the Upper Colorado River basin has been considerably altered by water development, which includes numerous reservoirs and diversions. In the watershed, there are 9 major interbasin water transfers, 7 major water diversions, 9 major reservoirs, and 10 major municipal discharges. The interbasin water transfers provide supplementary irrigation and municipal water supplies to the South Platte, Arkansas, and Rio Grande drainages. About 25 percent of the interbasin water transfers are to the South Platte watershed for the municipal water supply for the Denver metropolitan area. Most of the water used in the watershed comes from surface water sources. Groundwater sources account for less than 1 percent of the water used. Irrigation accounts for about 97 percent of off-stream water use. Besides off-stream water uses, there are in-stream water uses such as hydroelectric power generation.

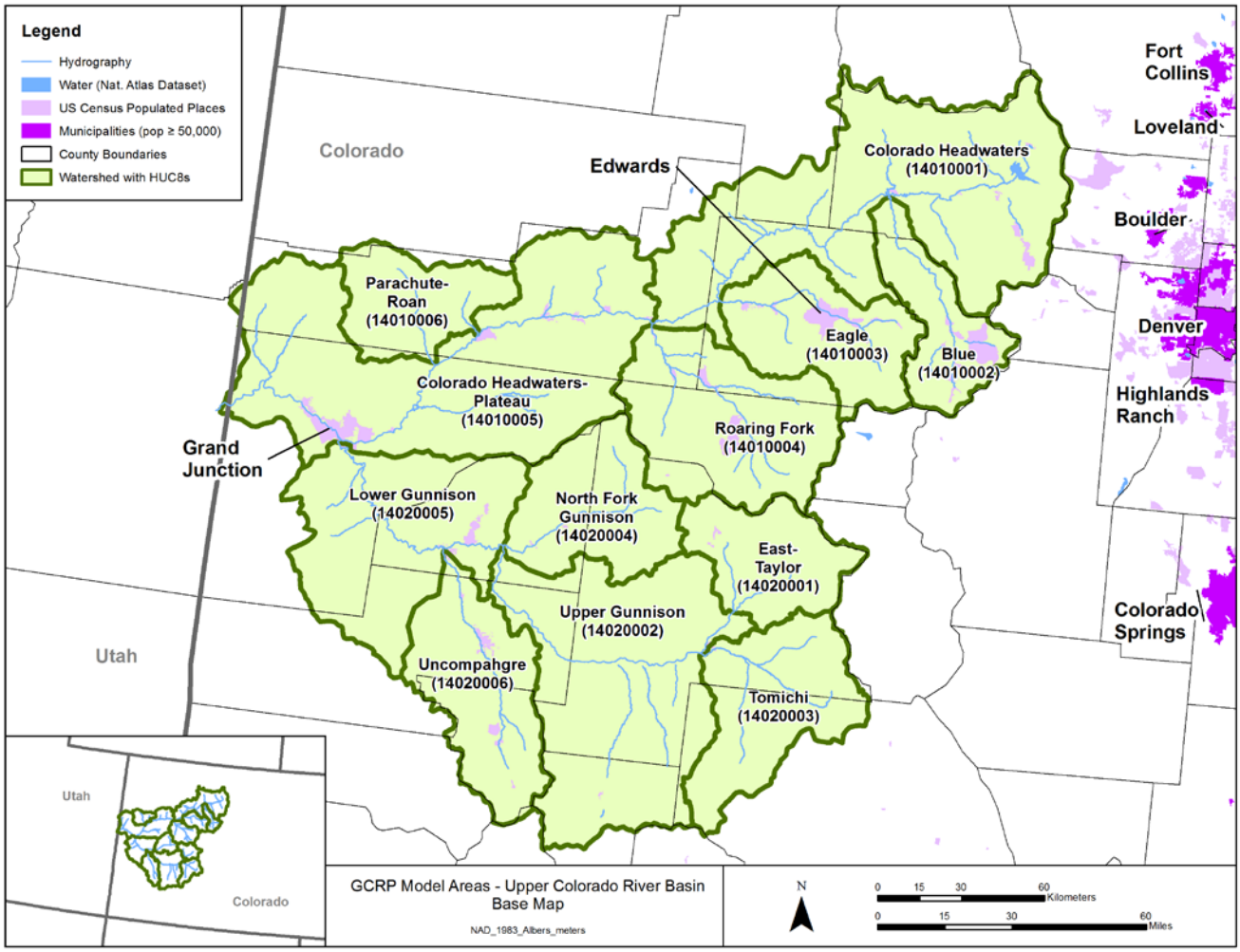

Figure 1. Location of the Upper Colorado River basin.

Soil Characteristics

Soils in the watershed, as described in STATSGO soil surveys, fall primarily into hydrologic soil groups (HSGs) B (moderately high infiltration capacity) and C (moderate infiltration capacity). 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 (Figure 2). NLCD land cover classes were aggregated according to the scheme shown in Table 1 for representation in the GCRP 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 STATSGO major soils. The distribution of land use in the watershed is summarized in Table 2.

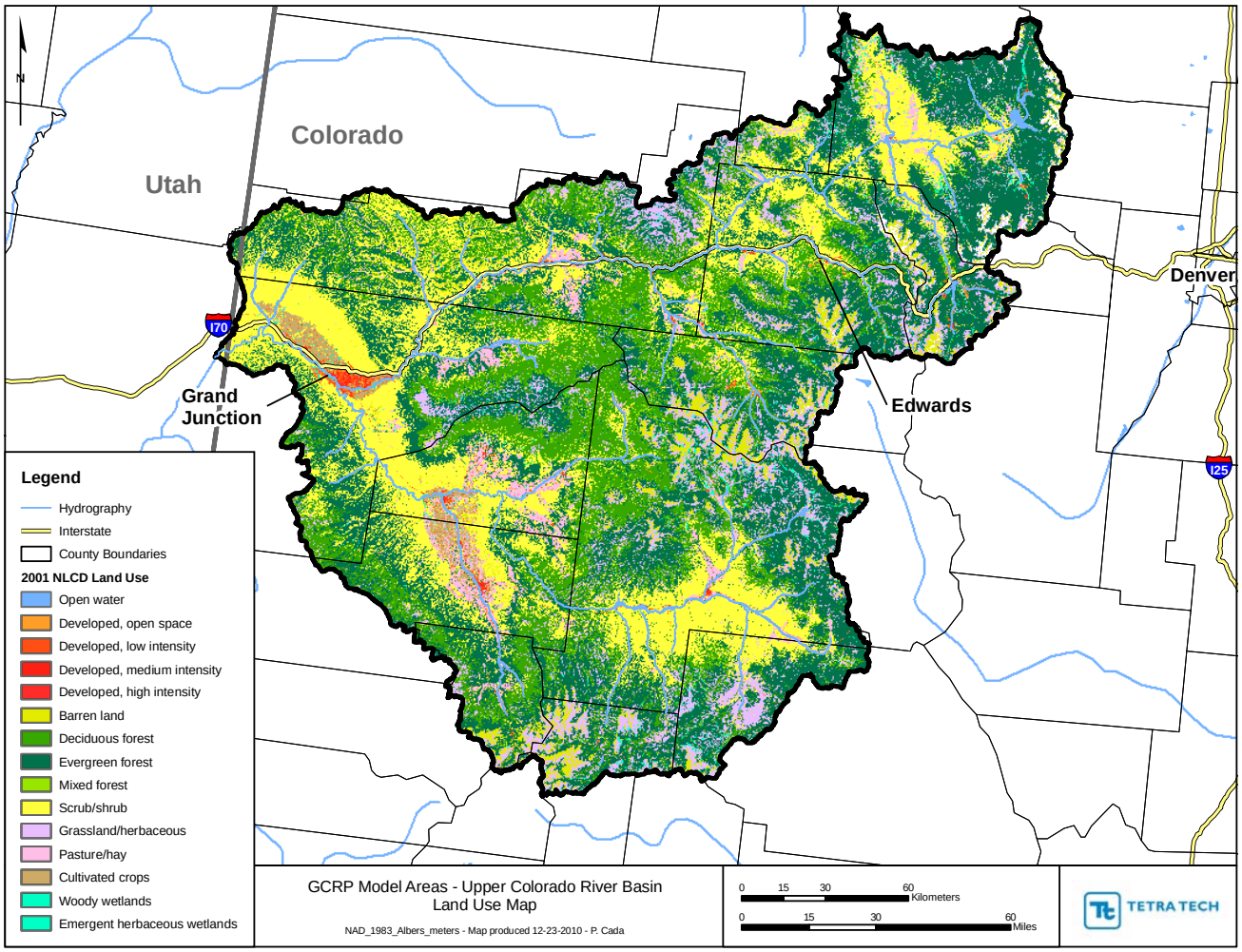

Figure 2. Land use in the Upper Colorado River basin.

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 Upper Colorado River basin (2001 NLCD) (mi^2)

HUC 8 watershed	Open water	Snow/Ice	Developed[a]				Barren land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
			Open space	Low density	Medium density	High density							
Colorado Headwaters **14010001**	**26.4**	**82.2**	**12.7**	**5.8**	**0.8**	**0.1**	**64.7**	**1,597.3**	**986.8**	**54.5**	**0.3**	**70.2**	**2,901.9**
Blue **14010002**	**10.0**	**26.5**	**8.1**	**6.2**	**2.2**	**0.2**	**66.7**	**334.9**	**205.7**	**5.1**	**0.2**	**17.2**	**683.1**
Eagle **14010003**	**1.7**	**6.2**	**8.3**	**8.5**	**2.6**	**0.2**	**48.8**	**563.4**	**306.6**	**10.2**	**0.3**	**15.6**	**972.5**
Roaring Fork **14010004**	**3.6**	**3.8**	**9.5**	**6.8**	**2.3**	**0.2**	**126.0**	**876.2**	**361.2**	**30.8**	**0.4**	**33.9**	**1,454.6**
Colorado Headwaters-Plateau **14010005**	**12.7**	**0.0**	**27.4**	**42.9**	**13.5**	**3.1**	**46.4**	**1,544.8**	**1,167.6**	**119.8**	**94.4**	**46.0**	**3,118.7**
Parachute-Roan **14010006**	**0.0**	**0.0**	**0.8**	**0.9**	**0.1**	**0.0**	**44.7**	**353.4**	**282.1**	**22.6**	**0.2**	**2.5**	**707.3**
East-Taylor **14020001**	**3.6**	**0.9**	**3.3**	**0.9**	**0.2**	**0.0**	**61.8**	**441.5**	**215.4**	**5.6**	**0.0**	**33.7**	**766.9**
Upper Gunnison **14020002**	**17.1**	**0.0**	**10.0**	**4.2**	**0.8**	**0.0**	**96.4**	**1,312.2**	**888.0**	**57.0**	**0.5**	**25.1**	**2,411.3**
Tomichi **14020003**	**0.5**	**0.1**	**5.4**	**1.2**	**0.4**	**0.1**	**17.4**	**544.5**	**488.5**	**30.8**	**0.0**	**13.9**	**1,102.7**
North Fork Gunnison **14020004**	**1.2**	**0.0**	**5.6**	**2.6**	**0.3**	**0.1**	**26.2**	**655.2**	**207.9**	**57.2**	**1.6**	**11.1**	**969.0**
Lower Gunnison **14020005**	**5.9**	**0.0**	**8.0**	**11.2**	**2.7**	**0.4**	**23.8**	**821.2**	**664.2**	**61.9**	**44.7**	**18.7**	**1,662.7**
Uncompahgre **14020006**	**2.3**	**0.0**	**12.0**	**13.2**	**4.1**	**1.0**	**52.9**	**576.8**	**282.4**	**109.1**	**54.5**	**6.3**	**1,114.6**
Total	**85.0**	**119.7**	**111.1**	**104.4**	**30.0**	**5.3**	**675.8**	**9,621.5**	**6,056.4**	**564.6**	**197.1**	**294.3**	**17,865.2**

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (9.78%), low density (31.89%), medium density (60.48%), and high density (87.41%).

Point Sources

There are numerous point source discharges in the watershed. Only the major dischargers, generally defined as those with a design flow greater than 1 MGD are included in the simulation (Table 3). The major dischargers are represented at long-term average flows, without accounting for changes over time or seasonal variations.

Table 3. Major point source discharges in the Upper Colorado River basin

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
CO0040053	MESA CO./GRAND JUNCTION - CITY	12.500	7.484
CO0039641	DELTA, CITY OF	3.800	1.060
CO0039624	MONTROSE, CITY OF	3.200	1.709
CO0035394	U.S. MOLY CORP.	0.000	0.347
CO0020516	GLENWOOD SPRINGS, CITY OF	2.300	0.875
CO0023086	SNOWMASS WATER & SAN DISTRICT	1.600	0.792
CO0026387	ASPEN CONSOLIDATED SAN DISTRCT	1.870	1.683
CO0020451	FRISCO SANITATION DISTRICT	1.700	0.577
CO0029955	SUMMIT CO BOARD OF COMMISS	2.600	0.631
CO0045420	IOWA HILL WATER RECLAMATION	1.500	0.683
CO0000230	CLIMAX MOLYBDENUM COMPANY	0.000	1.385
CO0037681	THREE LAKES WATER & SAN DIST	2.000	0.419
CO0040142	FRASER SANITATION DISTRICT	2.000	0.729
CO0024431	EAGLE RIVER WATER & SAN. DIST.	4.300	2.195
CO0037311	EAGLE RIVER WATER & SAN. DIST.	12.500	7.484
CO0021369	EAGLE RIVER WATER & SAN. DIST.	3.800	1.060
CO0042480	CBS OPERATIONS, INC.	3.200	1.709

Most of these point sources have reasonably complete monitoring for total suspended solids (TSS). Assumptions were made for total nitrogen and total phosphorus depending upon the type of facility. The point sources were initially represented in the model with the median of reported values for total phosphorus, total suspended solids and total nitrogen.

Meteorological Data

The required meteorological time series data for the GCRP SWAT simulations are precipitation and air temperature. The GCRP simulations do not include water temperature and uses a degree-day method for snowmelt. SWAT estimates Penmann-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 2002. A total of 47 precipitation stations were identified for use in the Upper Colorado River watershed model with a common period of record of 10/1/1972-9/30/2003

(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 Upper Colorado River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (m)
050183	ALLENSPARK 2 NNW	40.1881	-105.5010		2504
050214	ALTENBERN	39.5008	-108.3790	x	1731
050797	BLUE MESA LAKE	38.4668	-107.1670		2316
050843	BOULDER 2	40.0340	-105.2810	x	1650
050909	BRECKENRIDGE	39.4862	-106.0430		2920
051071	BUENA VISTA 2 S	38.8247	-106.1270	x	2422
051186	CABIN CREEK	39.6553	-105.7080	x	3054
051609	CIMARRON	38.4443	-107.5590	x	2102
051660	CLIMAX	39.3672	-106.1890	x	3442
051713	COCHETOPA CREEK	38.4462	-106.7610	x	2438
051772	COLORADO NATL MONUMENT	39.1014	-108.7330	x	1762
051959	CRESTED BUTTE	38.8743	-106.9760	x	2698
052281	DILLON 1 E	39.6262	-106.0350	x	2763
053146	FRUITA 1 W	39.1645	-108.7340	x	1373
053246	GATEWAY	38.6825	-108.9720	x	1387
053359	GLENWOOD SPGS #2	39.5181	-107.3170	x	1792
053488	GRAND JUNCTION WALKER	39.1342	-108.5400	x	1481
053489	GRAND JUNCTION 6 ESE	39.0423	-108.4660	x	1451
053496	GRAND LAKE 1 NW	40.2669	-105.8320	x	2658
053500	GRAND LAKE 6 SSW	40.1851	-105.8660	x	2526
053530	GRANT	39.4608	-105.6780	x	2644
053592	GREEN MT DAM	39.8790	-106.3330	x	2359
053662	GUNNISON 3 SW	38.5250	-106.9680	x	2329
053951	HERMIT 7 ESE	37.7718	-107.1090	x	2758
054664	KREMMLING	40.0575	-106.3680		2274
054734	LAKE CITY	38.0248	-107.3140	x	2643
055507	MEREDITH	39.3619	-106.7420	x	2385
055722	MONTROSE NO 2	38.4858	-107.8790	x	1763
056012	NORWOOD	38.1318	-108.2860	x	2140
056203	OURAY	38.0207	-107.6680	x	2390
056266	PALISADE	39.1136	-108.3500	x	1466

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (m)
056306	PAONIA 1 SW	38.8523	-107.6230	x	1701
056524	PLACERVILLE	37.9944	-108.0210		2301
057031	RIFLE	39.5329	-107.7920	x	1661
057337	SAGUACHE	38.0858	-106.1440	x	2347
057460	SARGENTS	38.4040	-106.4230		2579
057618	SHOSHONE	39.5717	-107.2260		1807
057656	SILVERTON	37.8193	-107.6650	x	2828
057848	SPICER	40.4725	-106.4470	x	2556
057936	STEAMBOAT SPRINGS	40.4884	-106.8230	x	2094
058064	SUGARLOAF RESERVOIR	39.2495	-106.3710	x	2968
058184	TAYLOR PARK	38.8184	-106.6080	x	2806
058204	TELLURIDE 4 WNW	37.9492	-107.8730	x	2643
058501	TWIN LAKES RES	39.0937	-106.3510	x	2806
058560	URAVAN	38.3762	-108.7420	x	1527
059175	WINTER PARK	39.8904	-105.7610		2775
059265	YAMPA	40.1562	-106.9090	x	2405

Watershed Segmentation

The Upper Colorado River basin was divided into 89 subwatersheds for the purposes of modeling (Figure 3). Colorado River near Dotsero at USGS 09070500 was chosen for initial calibration. The model encompasses the complete watershed and does not require specification of any upstream boundary conditions for application.

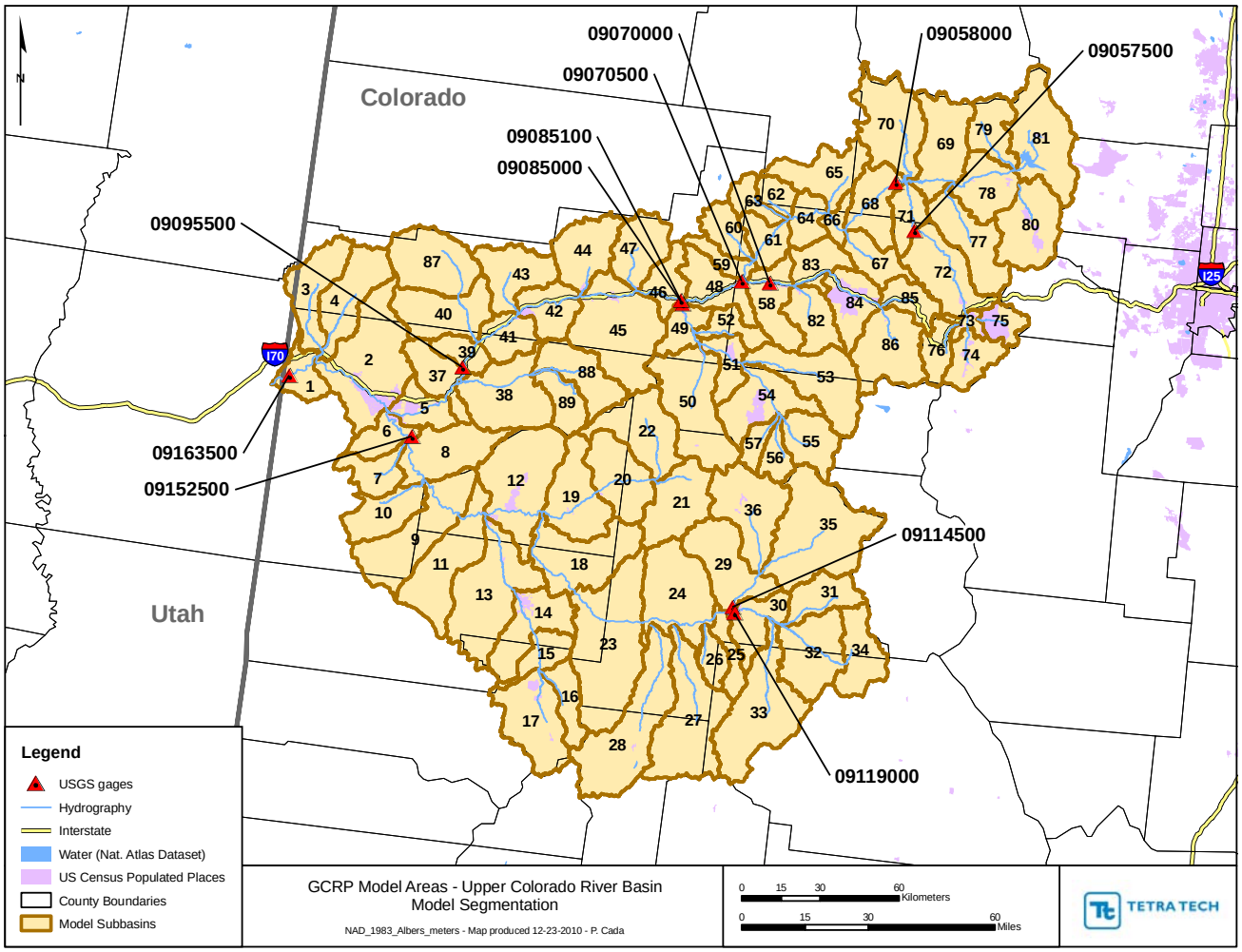

Figure 3. Model segmentation and USGS stations utilized for the Upper Colorado River basin.

Calibration Data and Locations

The specific site chosen for initial calibration was the Colorado River near Dotsero, CO (USGS 09070500) a flow and water quality monitoring location. The USGS gage located at Colorado River near Dotsero was selected because there is a good set of flow and water quality data available and the watershed lacks major point sources and impoundments. Additional calibration and validation was pursued at multiple locations (Table 5). Parameters derived from the initial calibration were not fully transferable to other portions of the Upper Colorado River basin, and additional calibration was conducted at multiple gage locations.

Table 5. Calibration and validation locations in the Upper Colorado River basin

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Colorado River near Kremmling, CO	09058000	2,379	x	x
Eagle River below Gypsum, CO	09070000	945	x	
Colorado River near Dotsero, CO	09070500	4,390	x	x
Colorado river below Glenwood Springs, CO	09085100	6,014	x	
Roaring fork River at Glenwood Springs, CO	09085000	1,451	x	x
Colorado River near Cameo, CO	09095500	7,986	x	x
Gunnison River near Gunnison, CO	09114500	1,011	x	x
Tomichi Creek at Gunnison, CO	09119000	1,061	x	x
Gunnison River near Grand Junction, CO	09152500	7,928	x	x
Colorado River near Utah State Line, CO	09163500	17, 843	x	x

The model hydrology calibration period was set to Water Years 1992-2002 (within the 32-year period of record for modeling). Hydrologic validation was then performed on Water Years 1982-1992. Water quality calibration used calendar years 1992-2002, while validation used 1982-1992.

SWAT Modeling

Assumptions

The Upper Colorado River basin is comprised of the areas drained by the Colorado River and Gunnison River. There are a number of reservoirs and diversion structures on Colorado and Gunnison rivers. Only major reservoirs in the basin, namely, Green Mountain, Blue Mesa and Morrow Point, were represented in the model. The Green Mountain reservoir is located on the Colorado River, while the Blue Mesa and Morrow Point reservoirs are located on the Gunnison River. Pertinent reservoir information including surface area and storage at principal (normal) and emergency spillway levels for the reservoir were obtained from the Colorado Bureau of Reclamation. 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 GCRP climate change impact evaluation application to future climate scenarios, it was assumed that the best representation of the reservoir was to simulate it without supplying time series of outflow records. The target release approach was used for the Green Mountain reservoir. Due to lack of detailed data annual average release approach was used fort the Blue Mesa and Morrow Point reservoirs.

Hydrology Calibration

A spatial calibration approach was adopted for GCRP-SWAT modeling for the Upper Colorado River basin. A systematic adjustment of parameters has been adopted and some adjustments are applied throughout the basin. Most of the calibration efforts were geared towards getting a closer match between simulated and observed flows at the outlet of calibration focus area.

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 calibration focus area includes twenty-eight subwatersheds and is generally representative of the general land use characteristics of the overall watershed. 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 whole Upper Colorado River basin predicted by the SWAT model over the 32-year simulation period is as follows:

```
PRECIP =    418.2 MM
SNOW FALL = 177.21 MM
SNOW MELT =   136.22 MM
SUBLIMATION =    38.94 MM
SURFACE RUNOFF Q =    15.54 MM
LATERAL SOIL Q =   80.11 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    44.64 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    0.00 MM
DEEP AQ RECHARGE =     5.87 MM
TOTAL AQ RECHARGE =   50.51 MM
TOTAL WATER YLD =   127.56 MM
```

```
PERCOLATION OUT OF SOIL =   38.88 MM
ET =    332.7 MM
PET =   1075.9MM
TRANSMISSION LOSSES =    12.72 MM
```

Hydrologic calibration adjustments focused on the following parameters:

- CN2 (initial SCS runoff curve number for moisture condition II)
- ESCO (soil evaporation compensation factor)
- SURLAG (surface runoff lag coefficient)
- SOL_AWC (available water capacity of the soil layer, mm water/mm of soil)
- ALPHA_BF (baseflow alpha factor, days)
- GW_DELAY (groundwater delay time, days)
- GWQMIN (threshold depth of water in the shallow aquifer required for return flow to occur, mm)
- GW_REVAP (groundwater "revap" coefficient)
- CH_N1 (Manning's "n" value for tributary channels)
- CH_N2 (Manning's "n" value for main channels)
- CH_K1 (Effective hydraulic conductivity in tributary channel alluvium)
- CH_K2 (Effective hydraulic conductivity in main channel alluvium)
- SFTMP (Snowfall temperature)
- SMTMP (Snowmelt base temperature)
- SMFMX (Maximum melt rate for snow during the year)
- SMFMN (Minimum melt rate for snow during the year)

Calibration results for the Colorado River near Dotsero are summarized in Figure 4, Figure 5, Figure 6, Figure 7 and Table 6.

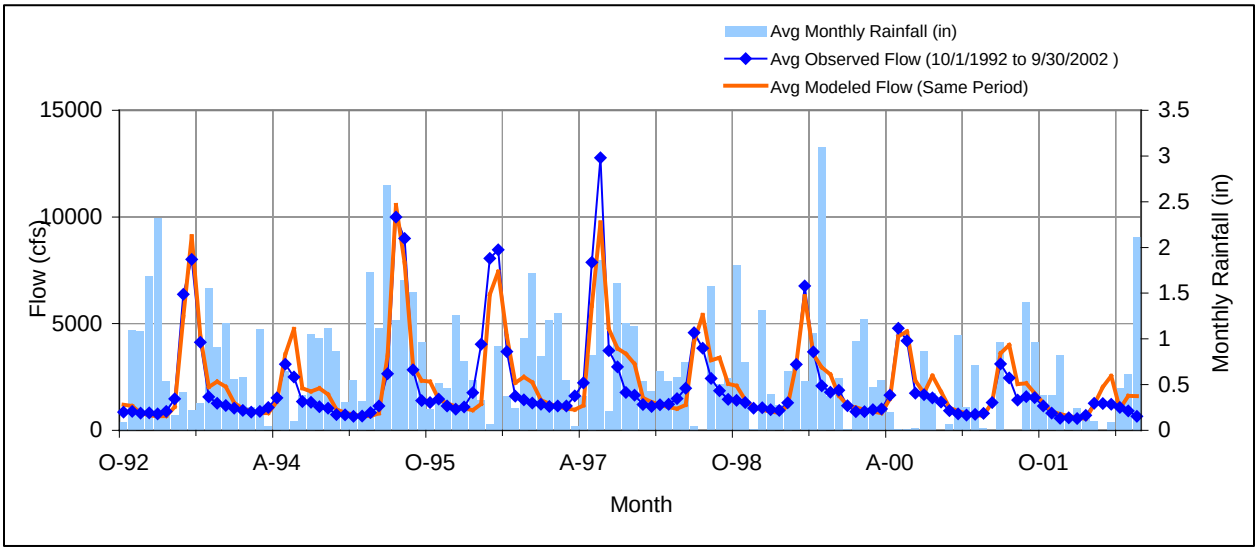

Figure 4. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.

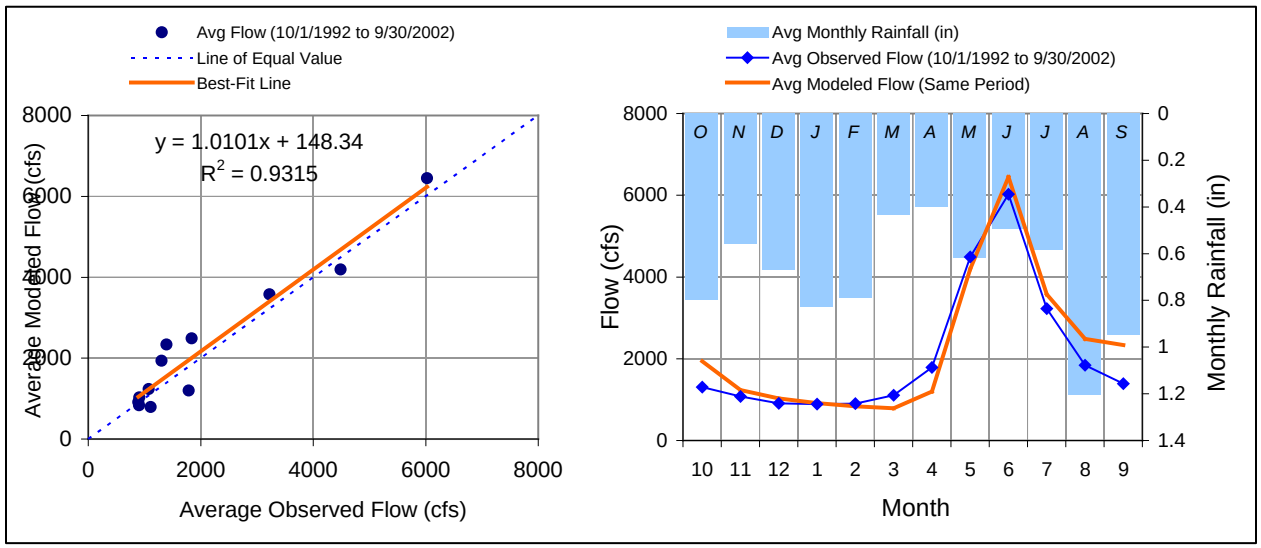

Figure 5. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.

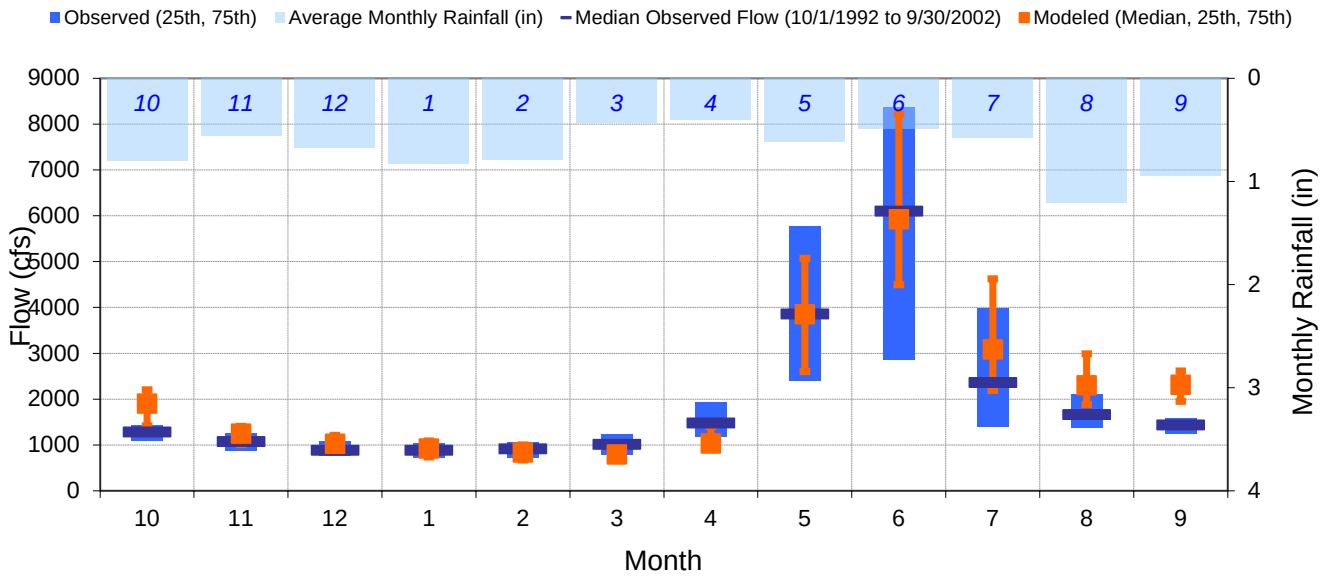

Figure 6. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.

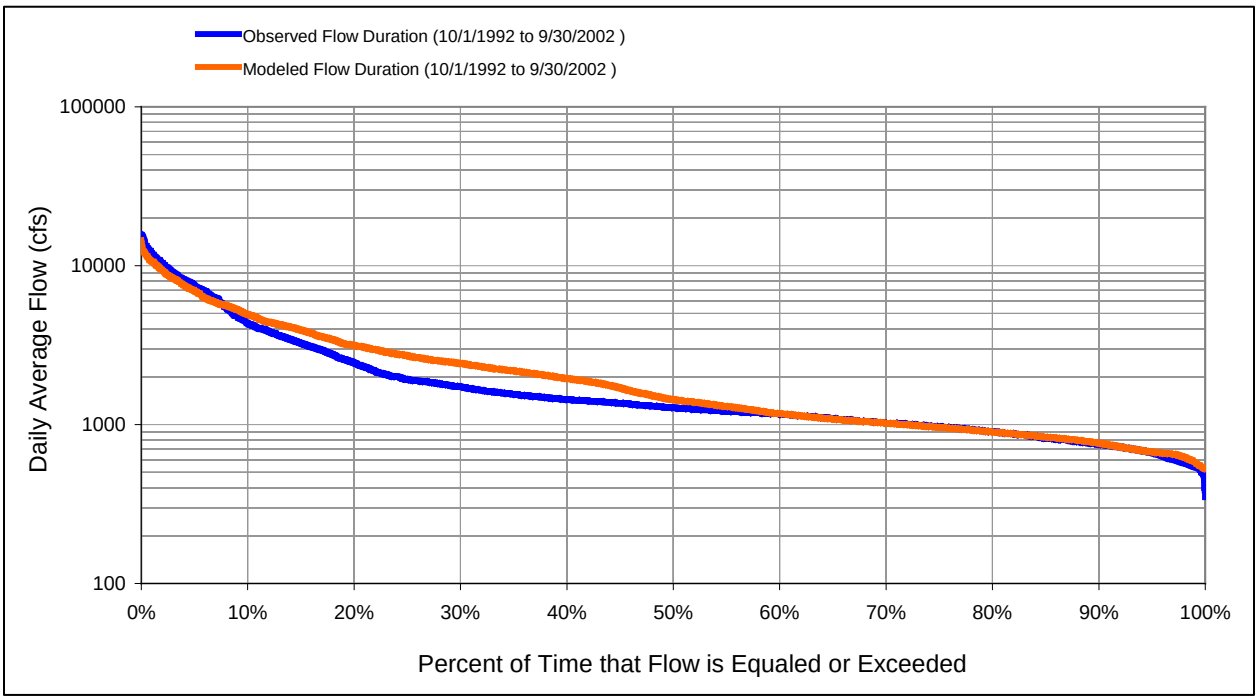

Figure 7. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.

Table 6. Summary statistics at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET(S) 58, 59 10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		USGS 09070500 COLORADO RIVER NEAR DOTSERO, CO Hydrologic Unit Code: 14010001 Latitude: 39.6446111 Longitude: -107.0780139 Drainage Area (sq-mi): 4394	
Total Simulated In-stream Flow:	**6.97**	Total Observed In-stream Flow:	**6.44**
Total of simulated highest 10% flows:	**2.27**	Total of Observed highest 10% flows:	**2.46**
Total of Simulated lowest 50% flows:	**1.49**	Total of Observed Lowest 50% flows:	**1.47**
Simulated Summer Flow Volume (months 7-9):	**2.18**	Observed Summer Flow Volume (7-9):	**1.68**
Simulated Fall Flow Volume (months 10-12):	**1.09**	Observed Fall Flow Volume (10-12):	**0.85**
Simulated Winter Flow Volume (months 1-3):	**0.65**	Observed Winter Flow Volume (1-3):	**0.74**
Simulated Spring Flow Volume (months 4-6):	**3.04**	Observed Spring Flow Volume (4-6):	**3.16**
Total Simulated Storm Volume:	**0.69**	Total Observed Storm Volume:	**0.98**
Simulated Summer Storm Volume (7-9):	**0.23**	Observed Summer Storm Volume (7-9):	**0.23**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	8.18	10	
Error in 50% lowest flows:	1.31	10	
Error in 10% highest flows:	-7.51	15	
Seasonal volume error - Summer:	29.83	30	
Seasonal volume error - Fall:	27.91	30	
Seasonal volume error - Winter:	-12.66	30	
Seasonal volume error - Spring:	-3.78	30	
Error in storm volumes:	**-29.75**	**20**	
Error in summer storm volumes:	0.27	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.829	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.580		
Monthly NSE	0.864		

Hydrology Validation

Hydrology validation for Saco River was performed for the period 10/1/1982 through 9/30/1992. The validation achieves a moderately high coefficient of model fit efficiency, but is over on summer flow volumes (Table 8, Table 9, Table 10, Table 11and Table 7).

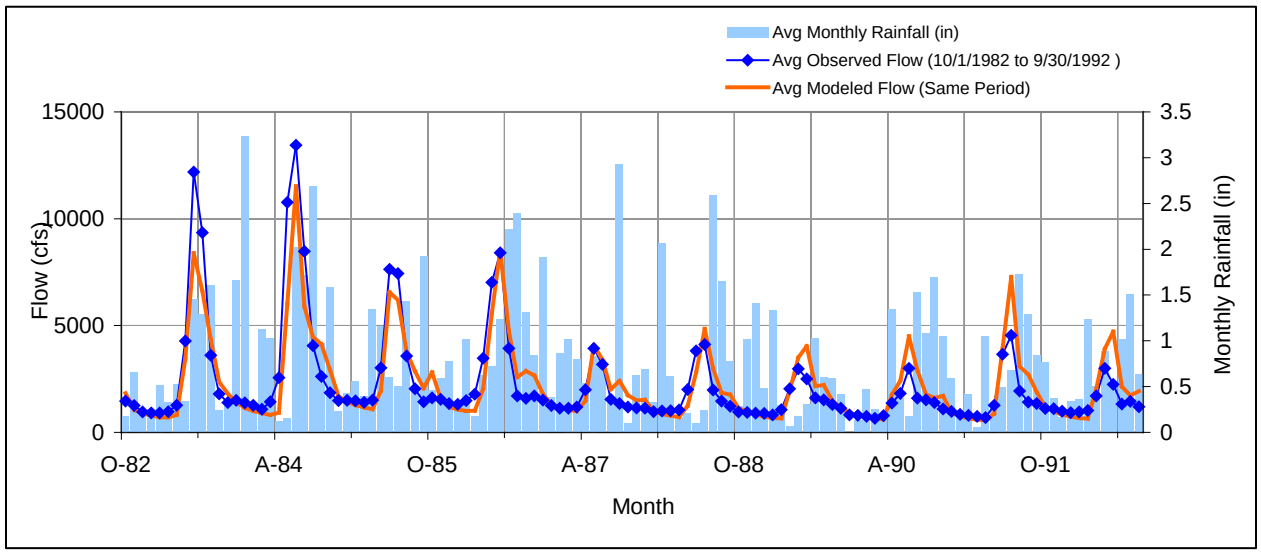

Figure 8. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.

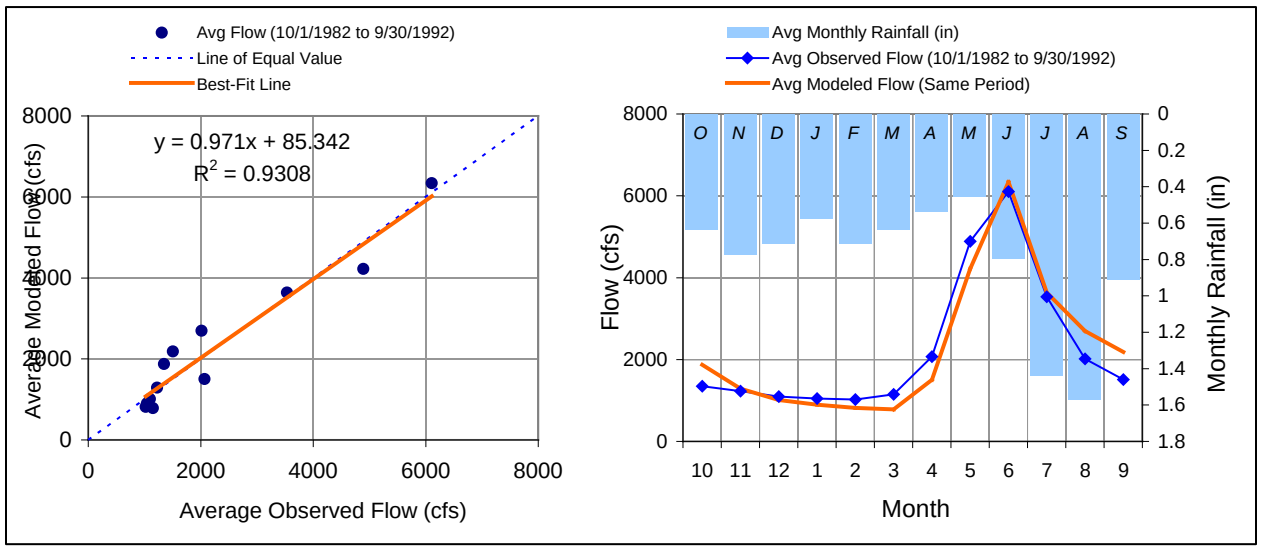

Figure 9. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.

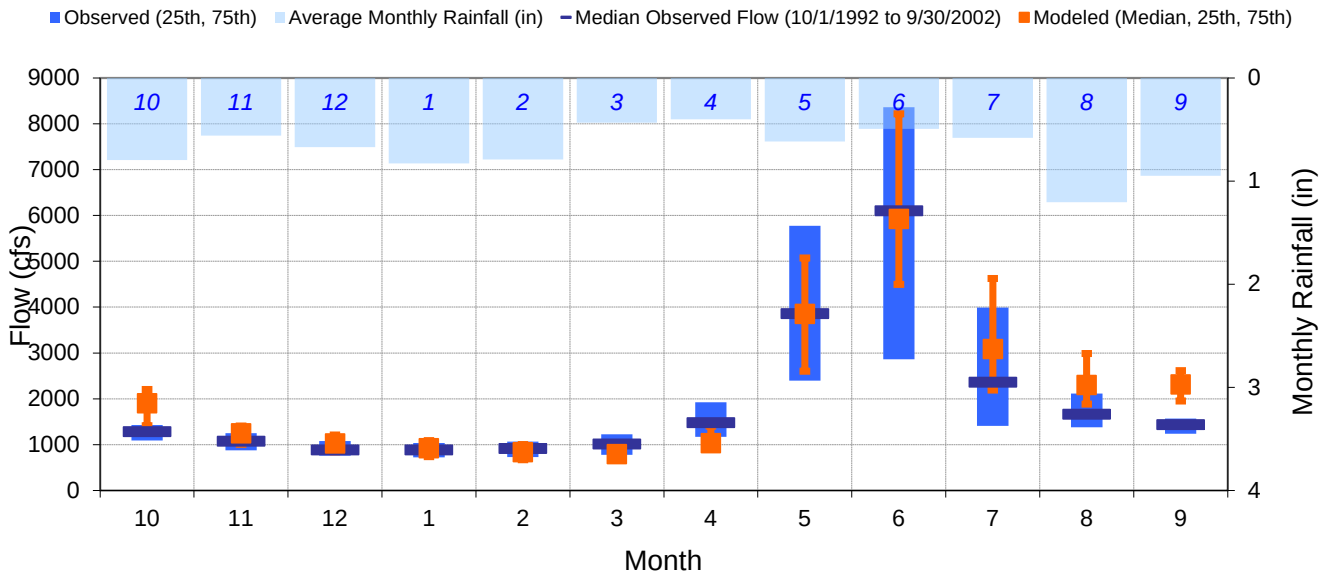

Figure 10. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.

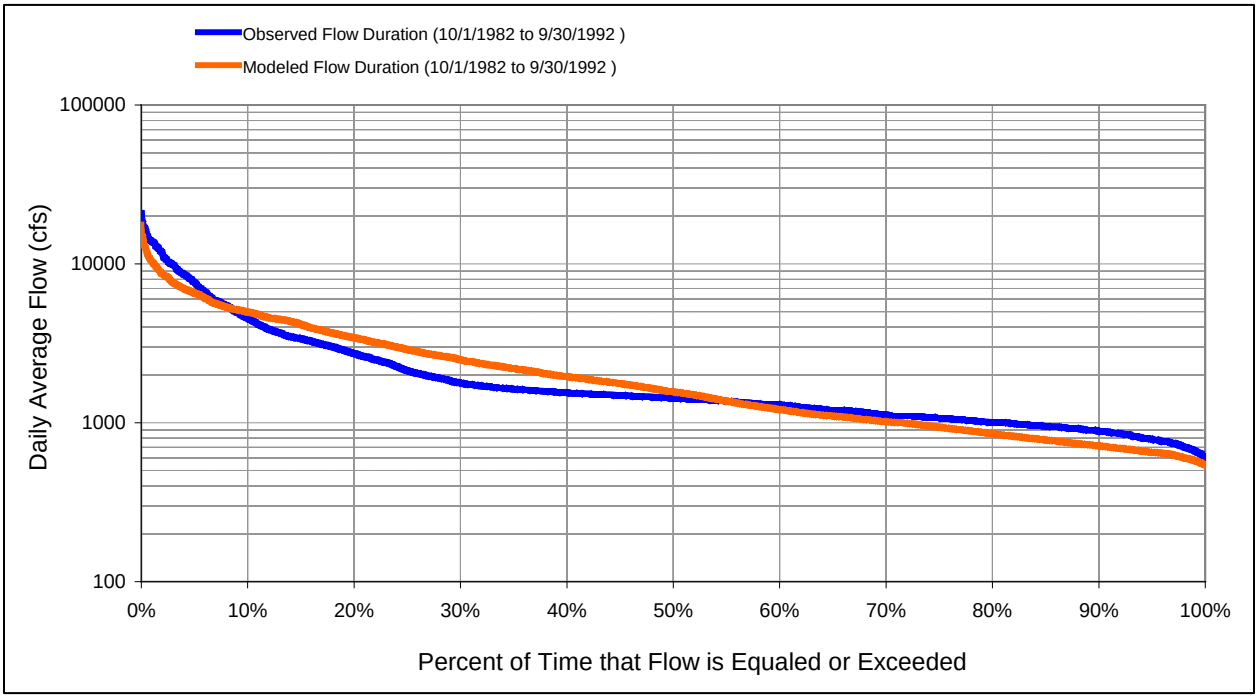

Figure 11. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.

Table 7. Summary statistics at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET(S) 58, 59 10-Year Analysis Period: 10/1/1982 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		USGS 09070500 COLORADO RIVER NEAR DOTSERO, CO Hydrologic Unit Code: 14010001 Latitude: 39.6446111 Longitude: -107.0780139 Drainage Area (sq-mi): 4394	
Total Simulated In-stream Flow:	**7.03**	Total Observed In-stream Flow:	**6.97**
Total of simulated highest 10% flows:	**2.19**	Total of Observed highest 10% flows:	**2.63**
Total of Simulated lowest 50% flows:	**1.48**	Total of Observed Lowest 50% flows:	**1.66**
Simulated Summer Flow Volume (months 7-9):	**2.22**	Observed Summer Flow Volume (7-9):	**1.84**
Simulated Fall Flow Volume (months 10-12):	**1.08**	Observed Fall Flow Volume (10-12):	**0.95**
Simulated Winter Flow Volume (months 1-3):	**0.64**	Observed Winter Flow Volume (1-3):	**0.82**
Simulated Spring Flow Volume (months 4-6):	**3.10**	Observed Spring Flow Volume (4-6):	**3.36**
Total Simulated Storm Volume:	**0.69**	Total Observed Storm Volume:	**0.98**
Simulated Summer Storm Volume (7-9):	**0.20**	Observed Summer Storm Volume (7-9):	**0.24**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	0.93	10	
Error in 50% lowest flows:	**-10.42**	**10**	
Error in 10% highest flows:	**-16.51**	**15**	
Seasonal volume error - Summer:	20.53	30	
Seasonal volume error - Fall:	13.79	30	
Seasonal volume error - Winter:	-22.44	30	
Seasonal volume error - Spring:	-7.74	30	
Error in storm volumes:	**-29.14**	**20**	
Error in summer storm volumes:	-16.53	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.780	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.545		
Monthly NSE	0.819		

Hydrology Results for Larger Watershed

As described above, parameters determined for the gage at Colorado River at Dotsero were initially transferred to other gages in the watershed. However, changes to subwatershed level parameters were required to fit the model to the observed flows. In all, calibration and validation was pursued at a total of ten gages throughout the watershed. Results of the calibration and validation exercise are summarized in Table 8 and Table 9, respectively. Calibration and validation results were acceptable at most gages.

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

Station	09058000	09070000	09085100	09085000	09095500	09114500	09119000	09152500	09163500
Error in total volume:	1.25	8.77	-1.09	8.13	1.99	-0.20	3.22	3.82	4.43
Error in 50% lowest flows:	-10.98	-19.88	-9.84	-2.04	-3.28	6.02	-23.16	3.70	7.11
Error in 10% highest flows:	4.73	3.06	-6.45	-2.62	-14.74	3.27	13.39	-9.13	-13.89
Seasonal volume error - Summer:	2.01	33.81	15.28	29.89	28.02	8.52	34.72	30.15	39.13
Seasonal volume error - Fall:	8.41	13.61	-1.55	18.07	21.42	29.01	4.60	-2.68	13.70
Seasonal volume error - Winter:	-21.75	-28.40	-11.66	-12.04	-18.43	5.64	-48.21	-18.15	-19.72
Seasonal volume error - Spring:	5.65	2.88	-8.73	-2.31	-12.04	-12.12	2.18	1.02	-8.47
Error in storm volumes:	-7.91	-3.45	8.00	-18.68	-32.12	17.03	-27.67	6.01	-29.66
Error in summer storm volumes:	2.53	42.75	28.46	16.84	0.28	6.25	-11.96	43.58	-7.11
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.484	0.812	0.847	0.877	0.858	0.638	0.678	0.629	0.817
Monthly Nash-Sutcliffe Coefficient of Efficiency, E:	0.636	0.904	0.912	0.922	0.892	0.790	0.762	0.694	0.843

Table 9. Summary statistics (percent error): all stations - validation period

Station	09058000	09070000	09085100	09085000	09095500	09114500	09119000	09152500	09163500
Error in total volume:	-6.24	1.02	-3.72	1.29	-3.41	-9.88	0.51	1.76	-3.29
Error in 50% lowest flows:	-20.25	-16.89	-10.53	-8.69	-3.35	-9.66	-15.95	9.77	4.74
Error in 10% highest flows:	-6.85	-4.81	-9.36	-12.98	-24.88	-5.91	-8.04	-19.66	-27.78
Seasonal volume error - Summer:	-4.31	9.24	8.19	20.69	20.15	2.80	35.99	39.80	30.79
Seasonal volume error - Fall:	0.85	1.21	-9.61	8.36	16.70	10.92	3.17	3.70	10.27
Seasonal volume error - Winter:	-27.64	-27.33	-13.61	-17.52	-19.76	-16.02	-29.15	-27.50	-25.03
Seasonal volume error - Spring:	-3.48	1.09	-6.83	-7.04	-16.89	-20.52	-8.20	-4.02	-16.84
Error in storm volumes:	-8.73	-7.96	2.88	-24.74	-35.18	-6.67	-37.92	1.83	-33.40
Error in summer storm volumes:	-11.69	5.33	17.51	-2.57	-20.98	-22.07	-25.04	41.16	-13.83
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.504	0.795	0.847	0.853	0.796	0.440	0.480	0.554	0.701
Monthly Nash-Sutcliffe Coefficient of Efficiency, E:	0.586	0.882	0.887	0.914	0.834	0.639	0.525	0.618	0.739

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done at USGS 09070500, Colorado River near Dotsero from water years 1995 to 2002, due to limited water quality data. Subject to the availability of water quality data for the other gages, 1992-2002 was adopted as the calibration period and 1982-1992 was adopted as the validation period. As with hydrology, calibration was performed on the later period as this better reflects the land use included in the model.

Calibration adjustments for sediment focused on the following parameters:

- SPCON (linear parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- SPEXP (exponential parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- CH_COV (channel cover factor)
- CH_EROD (channel erodibility factor)
- USLE_P (USLE support practice factor)

Simulated and estimated sediment loads at the Colorado River station near Dotsero for both the calibration and validation periods are shown in Figure 12 and statistics 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.

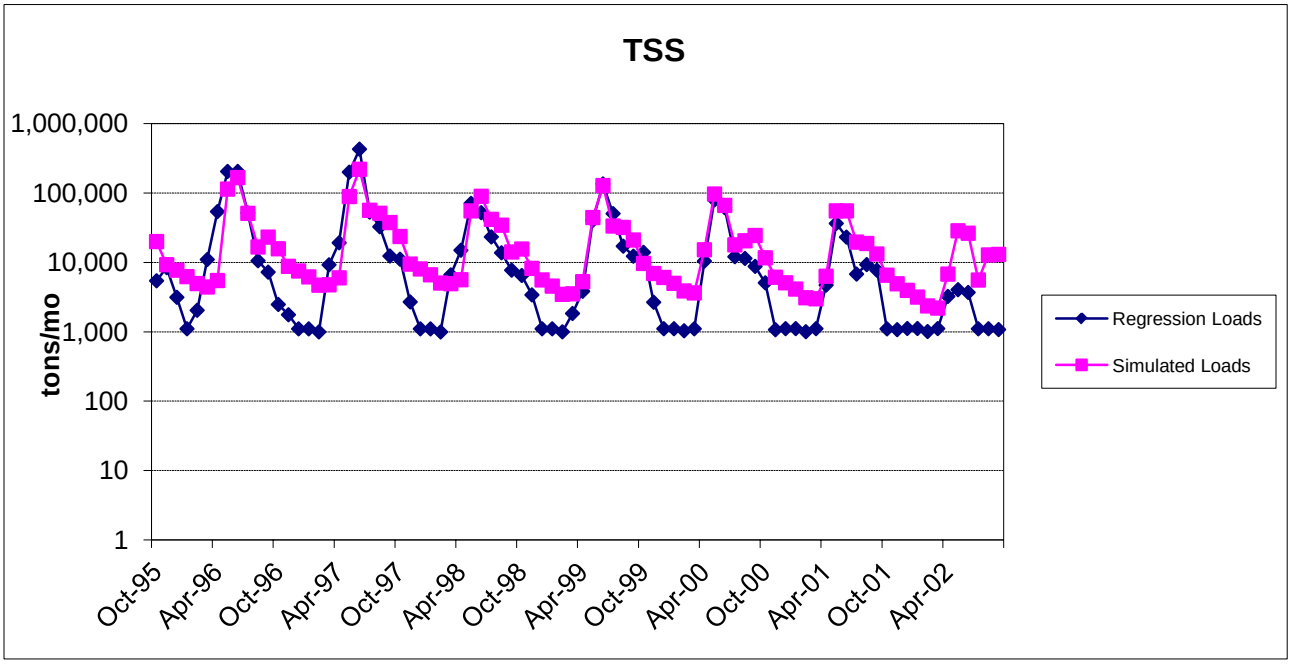

Figure 12. Fit for monthly load of TSS at USGS 09070500 Colorado River near Dotsero, Colorado.

Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 09070500 Colorado River near Dotsero, Colorado

Statistic	Calibration/validation period (1995-2002)
Relative Percent Error	0.4%
Relative Average Absolute Error	53.7%
Relative Median Absolute Error	21.6%

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

- RHOQ (algal respiration rate at 20° C)
- PHOSKD (phosphorus soil partitioning coefficient)
- PSP (phosphorus availability index)
- RS1 (Local algal settlement rate in the reach at 20° C)
- AL1 (Fraction of algal biomass that is nitrogen)
- AL2 (Fraction of algal biomass that is phosphorus)
- MUMAX (Rate of oxygen uptake per unit NO_2-N oxidation at 20° C)
- RHOQ (Algal respiration rate at 20° C)
- RS2 (benthic source rate for dissolved P in the reach at 20° C)
- RS3 (Benthic source rate for NH_4-N in the reach at 20° C)
- RS5 (organic P settling rate in the reach at 20° C)
- BC4 (rate constant for mineralization of organic P to dissolved P in the reach at 20° C)
- RS4 (rate coefficient for organic N settling in the reach at 20° C)
- CH_ONCO (Channel organic nitrogen concentration)
- CH_OPCO (Channel organic phosphorus concentration)
- SDNCO (Denitrification threshold water content)
- CDN (Denitrification exponential rate constant)

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 acceptable.

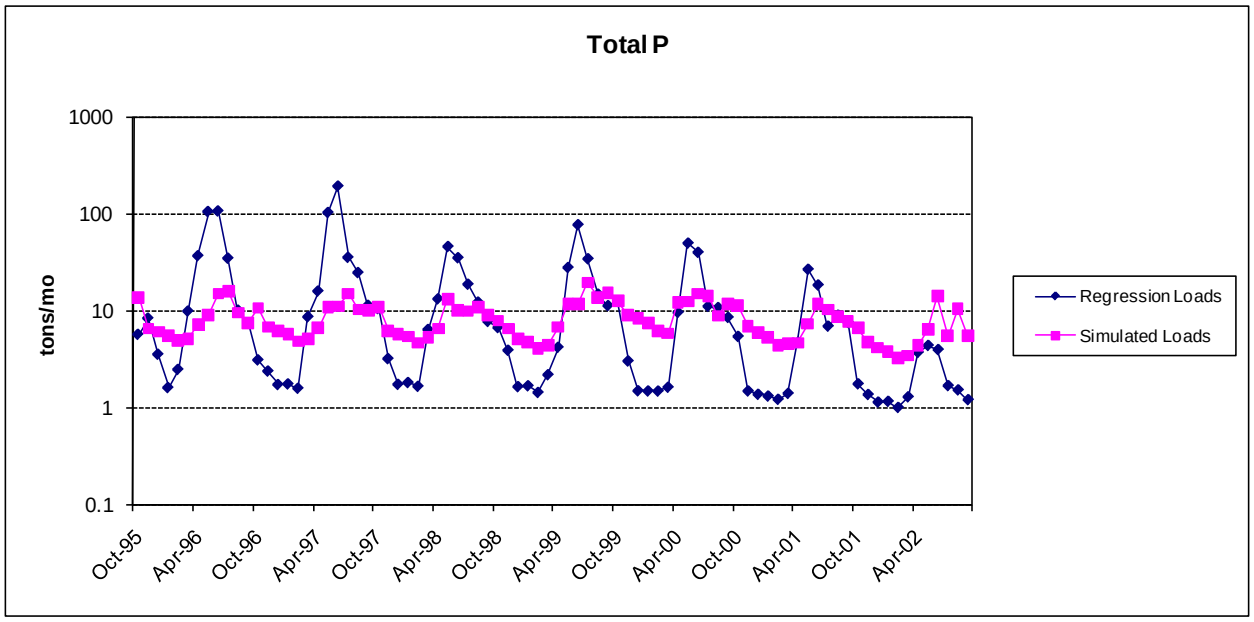

Figure 13. Fit for monthly load of total phosphorus at USGS 09070500 Colorado River near Dotsero, Colorado.

Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 09070500 Colorado River near Dotsero, Colorado

Statistic	Calibration/validation period (1995-2002)
Relative Percent Error	47.4%
Relative Average Absolute Error	75.9%
Relative Median Absolute Error	23.8%

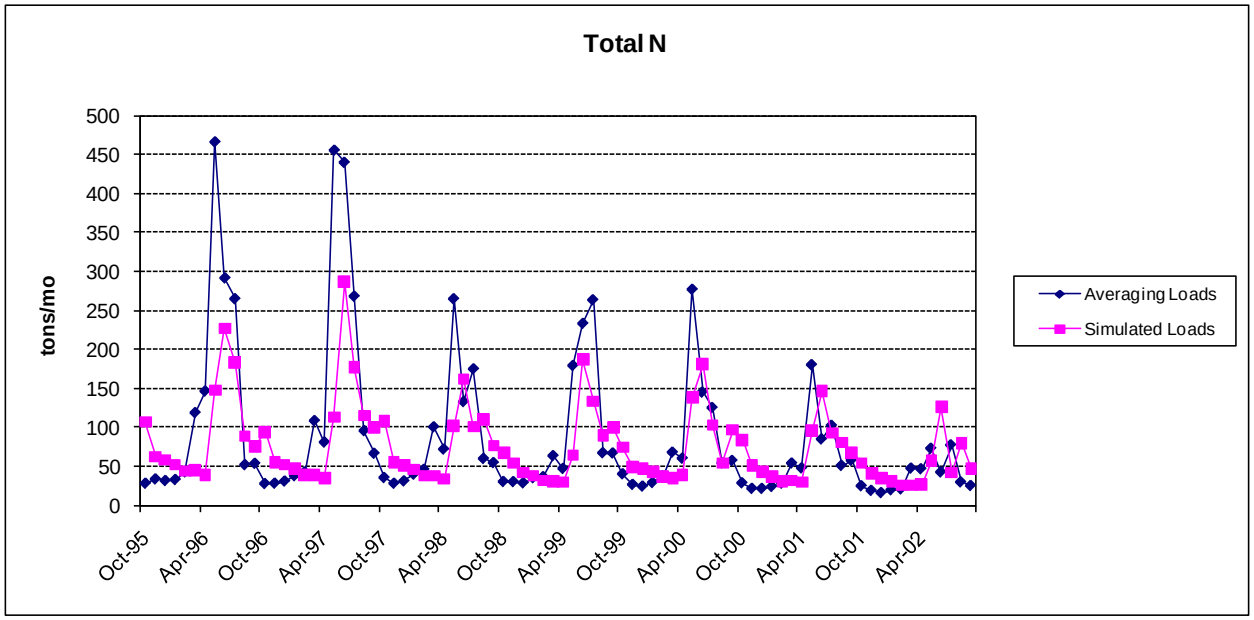

Figure 14. Fit for monthly load of total nitrogen at USGS 09070500 Colorado River near Dotsero, Colorado.

Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 09070500 Colorado River near Dotsero, Colorado

Statistic	Calibration/Validation period (1995-2002)
Relative Percent Error	15.1%
Relative Average Absolute Error	52.2%
Relative Median Absolute Error	32.4%

Water Quality Results for Larger Watershed

As with hydrology, a spatial calibration approach was adopted. SWAT model parameters for water quality derived from calibrations performed at the USGS gage at Colorado River near Dotsero were transferred to other portions of the watershed with necessary changes to subbasin level parameters. Summary statistics for the SWAT water quality calibration and validation at other stations in the watershed are provided in Table 13 and Table 14.

Table 13. Summary statistics for water quality at all stations – calibration period 1992-2002

Station	09058000	09085000 (1996-2002)	09095500	09114500 (1995-2002)	09119000 (1995-2002)	09152500	09163500
Relative Percent Error TSS Load			33.3	4.9	19.3	25.1	43.9
Relative Percent Error TP Load	14.1	13.1	80.1	-27.5	28.7	-9.7	60.6
Relative Percent Error TN Load	29.7	-25.9	-22.0	-37.4	17.9	-42.9	-60.9

Table 14. Summary statistics for water quality at all stations – validation period 1982-1992

Station	09058000 (1989-1992)	09085000	09095500	09114500	09119000	09152500	09163500
Relative Percent Error TSS Load			47.9			36.9	60.2
Relative Percent Error TP Load	-26.4		84.8			-1.2	66.8
Relative Percent Error TN Load	7.7		-11.5			-38.6	-48.9

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