# Appendix V
# Model Configuration, Calibration and Validation

## Basin: Upper Colorado River

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# 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 primary river in the basin, the Colorado River, originates in the mountains of central Colorado and flows about 230 miles southwest into Utah. The basin is composed of two physiographic provinces: the Southern Rocky Mountains and the Colorado Plateau. The topography varies from rugged mountainous regions in the east to high plateaus bordered by steep cliffs along valleys in the west. Because of differences in altitude of about 10,000 feet from east to west, the climate ranges from alpine conditions to semiarid/arid conditions. Precipitation ranges from 40 inches or more per year at high elevations in the eastern part of the basin to less than 10 inches per year at low elevations in the western part of the basin.

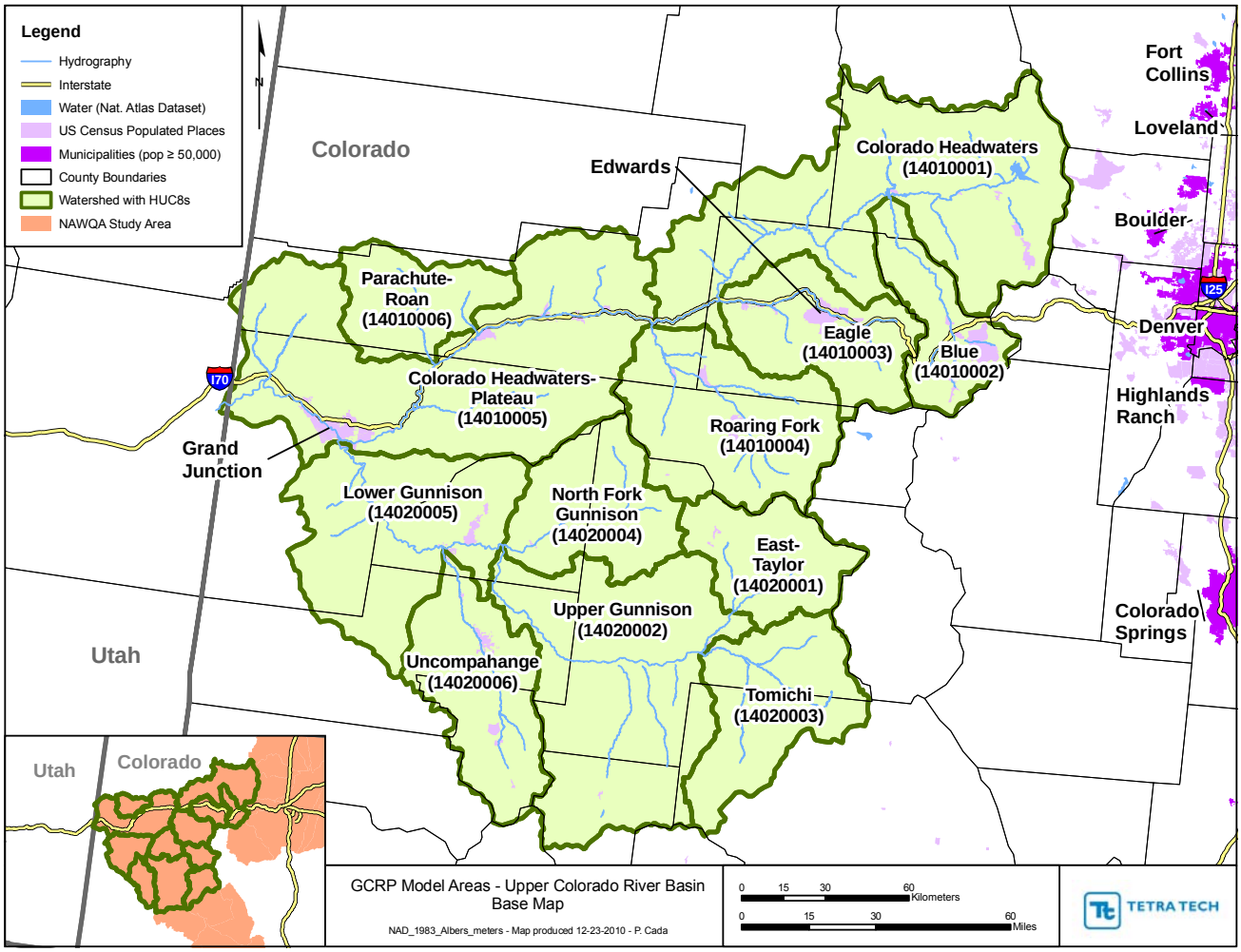


**Figure 1. Location of the Upper Colorado River basin.**

## 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.

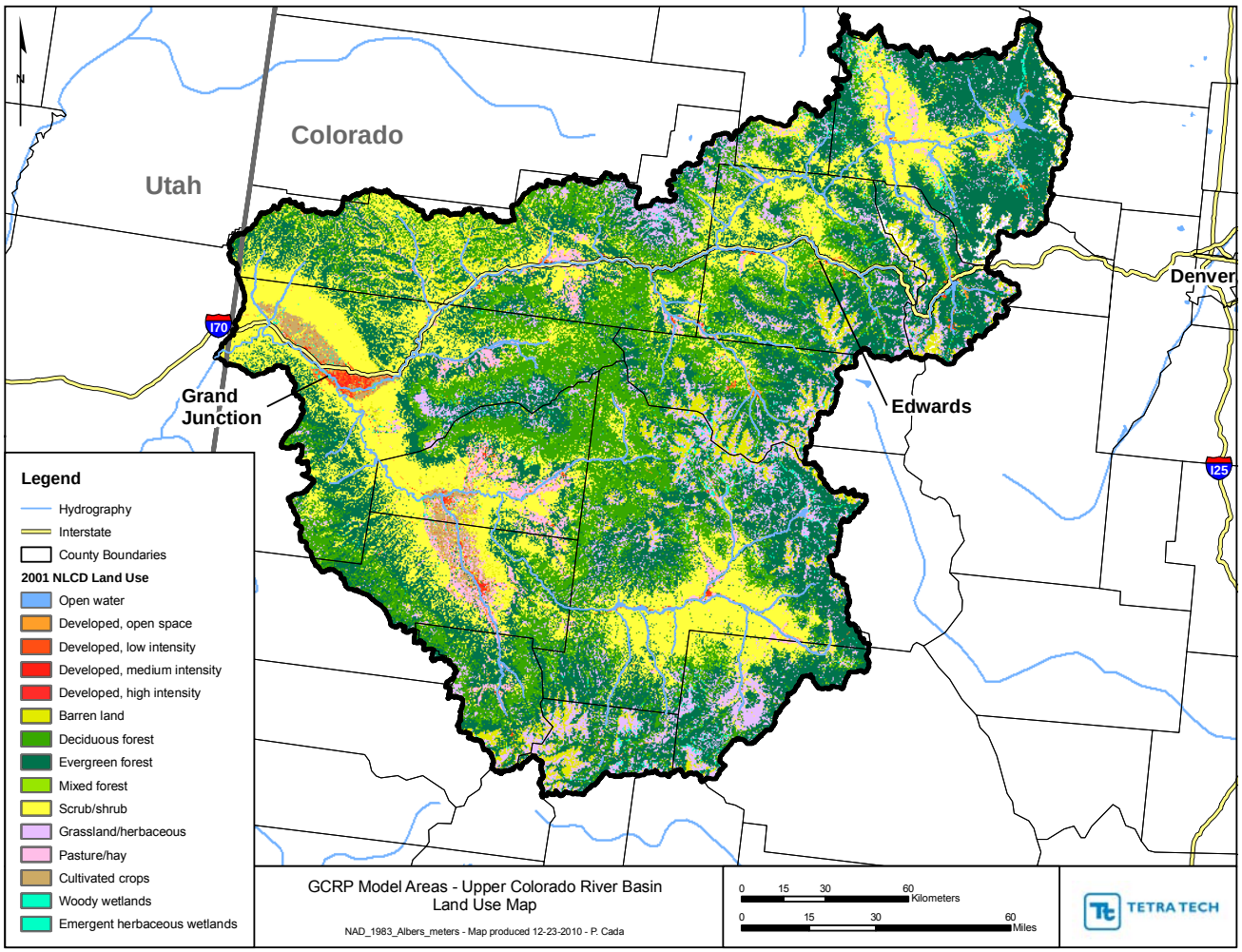


**Figure 2. Land use in the Upper Colorado River basin.**

**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** | 26.37 | 78.71 | 12.69 | 6.05 | 0.87 | 0.09 | 57.62 | 1,590.07 | 978.53 | 54.64 | 0.33 | 70.02 | **2,875.98** |
| Blue **14010002** | 10.00 | 26.08 | 8.02 | 6.23 | 2.24 | 0.18 | 60.28 | 333.82 | 200.63 | 4.95 | 0.21 | 17.05 | **669.69** |
| Eagle **14010003** | 1.65 | 6.12 | 8.26 | 8.47 | 2.62 | 0.18 | 45.50 | 566.33 | 308.47 | 10.22 | 0.33 | 15.53 | **973.69** |
| Roaring Fork **14010004** | 3.57 | 4.03 | 9.41 | 6.57 | 2.24 | 0.17 | 126.82 | 880.41 | 362.49 | 30.81 | 0.37 | 33.90 | **1,460.80** |
| Colorado Headwaters-Plateau **14010005** | 12.60 | 0.00 | 27.60 | 44.26 | 13.85 | 3.19 | 45.40 | 1,539.52 | 1,157.09 | 119.52 | 94.95 | 46.02 | **3,104.01** |
| Parachute-Roan **14010006** | 0.02 | 0.00 | 0.84 | 0.88 | 0.10 | 0.02 | 45.08 | 344.42 | 274.54 | 22.26 | 0.13 | 2.36 | **690.66** |
| East-Taylor **14020001** | 3.64 | 0.86 | 3.26 | 0.87 | 0.18 | 0.01 | 62.34 | 444.22 | 217.65 | 5.64 | 0.00 | 33.81 | **772.48** |
| Upper Gunnison **14020002** | 17.07 | 0.00 | 10.09 | 4.23 | 0.86 | 0.05 | 96.54 | 1,306.13 | 885.27 | 57.15 | 0.49 | 24.76 | **2,402.65** |
| Tomichi **14020003** | 0.47 | 0.03 | 5.25 | 1.10 | 0.28 | 0.05 | 14.25 | 539.59 | 483.09 | 30.30 | 0.00 | 13.76 | **1,088.17** |
| North Fork Gunnison **14020004** | 1.23 | 0.00 | 5.68 | 2.66 | 0.37 | 0.05 | 26.00 | 658.08 | 210.63 | 57.92 | 1.58 | 11.03 | **975.24** |
| Lower Gunnison **14020005** | 5.90 | 0.00 | 7.39 | 9.91 | 2.31 | 0.29 | 24.56 | 818.30 | 662.49 | 61.38 | 42.97 | 18.66 | **1,654.17** |
| Uncompahgre **14020006** | 2.21 | 0.00 | 12.05 | 13.14 | 4.11 | 1.04 | 50.79 | 569.78 | 280.41 | 109.21 | 55.76 | 6.15 | **1,104.65** |
| **Total** | **84.73** | **115.84** | **110.53** | **104.37** | **30.03** | **5.34** | **655.18** | **9,590.68** | **6,021.31** | **563.99** | **197.14** | **293.06** | **17,772.20** |

[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.

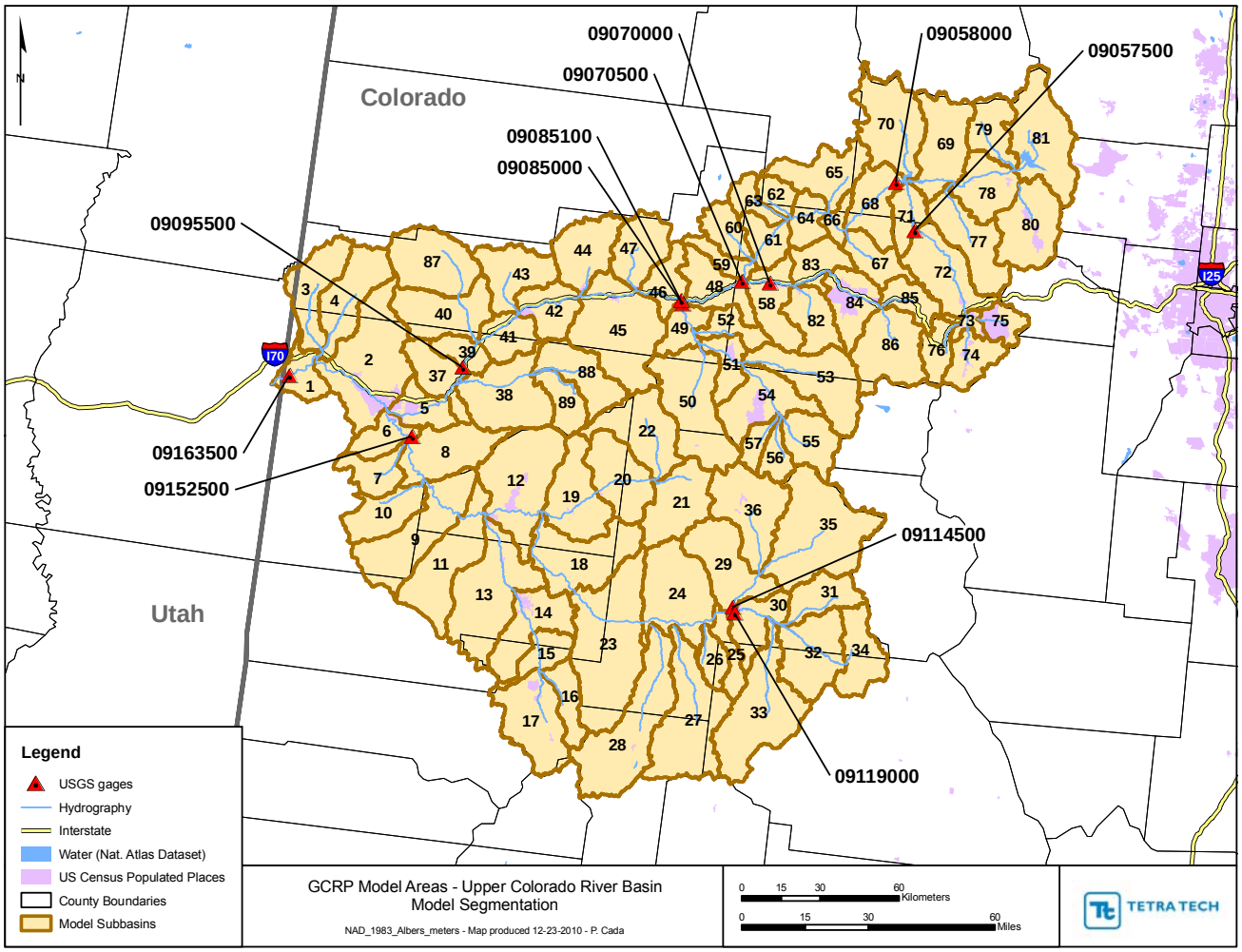


**Figure 3. Model segmentation and USGS stations utilized for the Upper Colorado River basin.**

## 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.

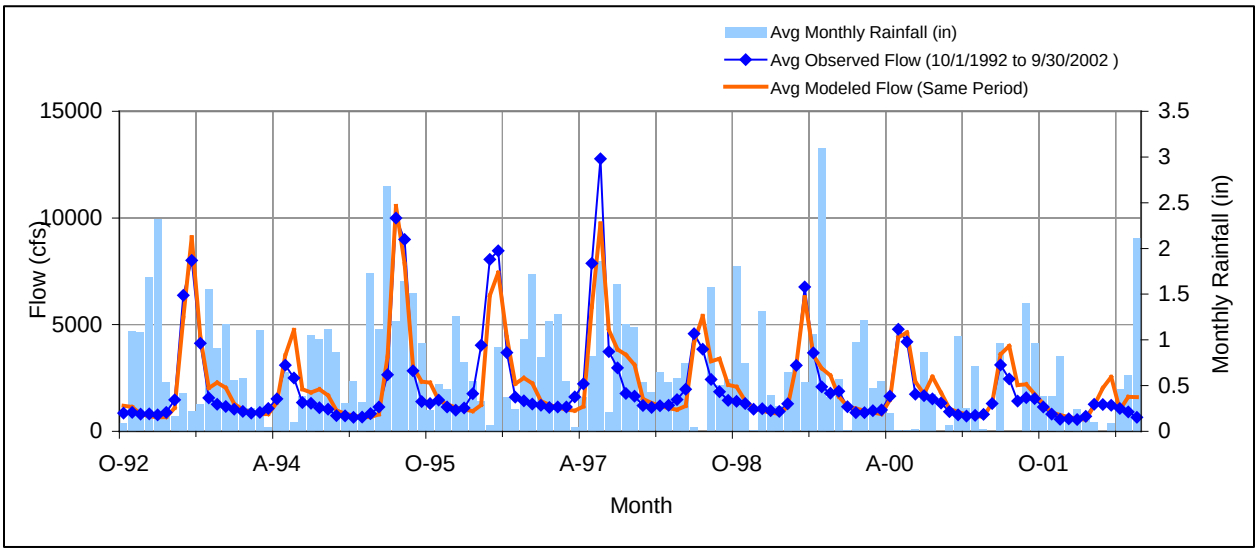


**Figure 4. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.**

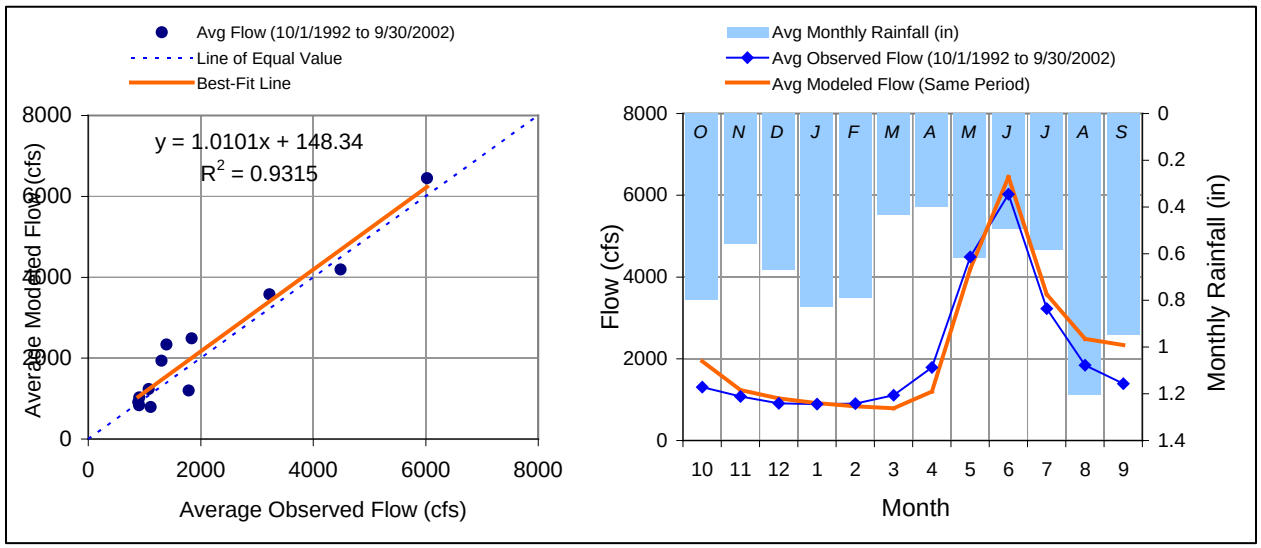


**Figure 5. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.**

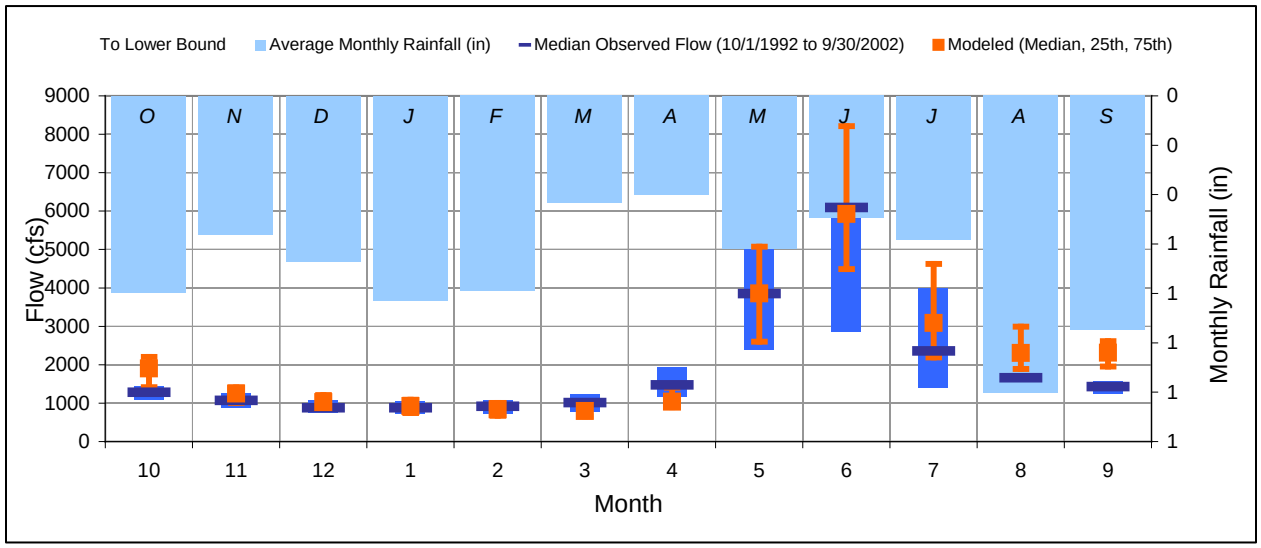


**Figure 6. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.**

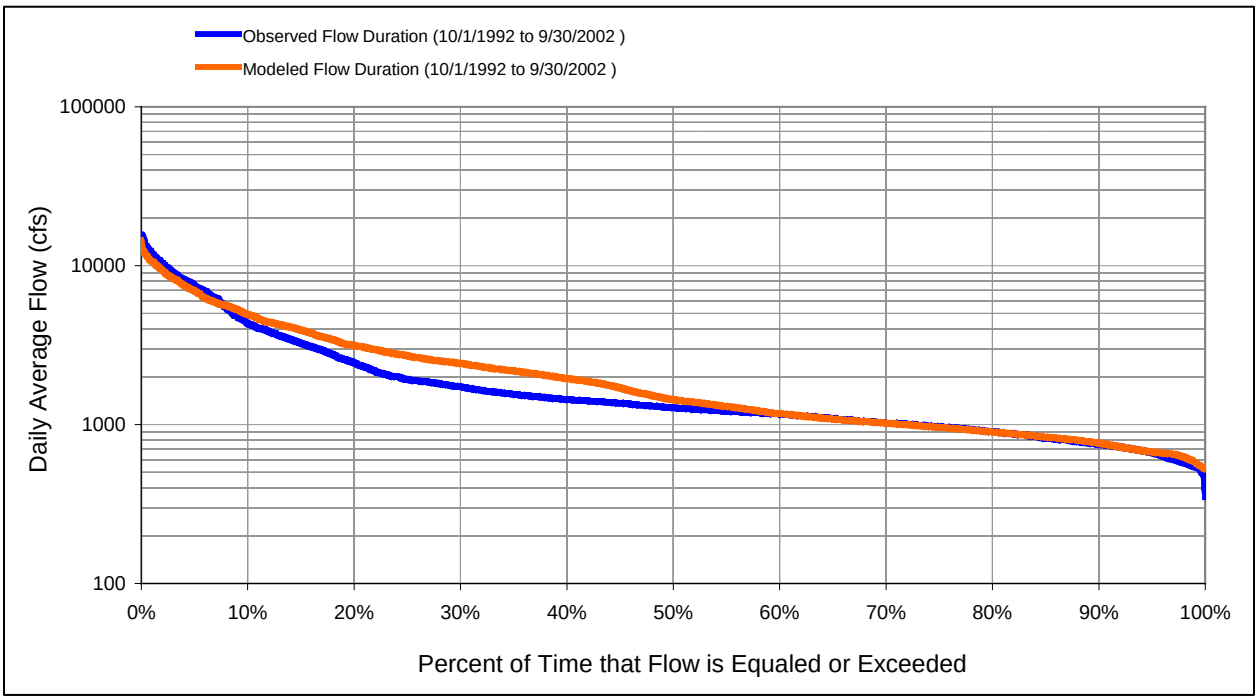


**Figure 7. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – calibration period.**

**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<br>10-Year Analysis Period: 10/1/1992 - 9/30/2002<br>Flow volumes are (inches/year) for upstream drainage area | | USGS 09070500 COLORADO RIVER NEAR DOTSERO, CO<br>Hydrologic Unit Code: 14010001<br>Latitude: 39.6446111<br>Longitude: -107.0780139<br>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 | |
| Baseline adjusted coefficient (Garrick), E': | 0.580 | as E or E' approaches 1.0 | |
| Monthly NSE | 0.902 | | |

## 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 (Figure 8, Figure 9, Figure 10, Figure 11 and Table 7).

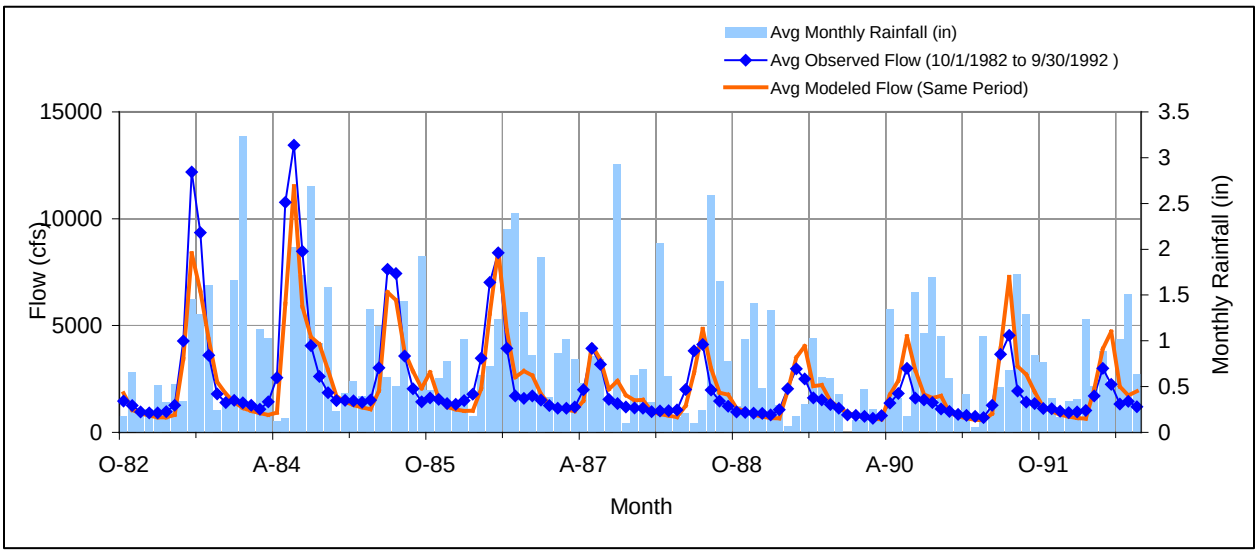


**Figure 8. Mean monthly flow at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.**

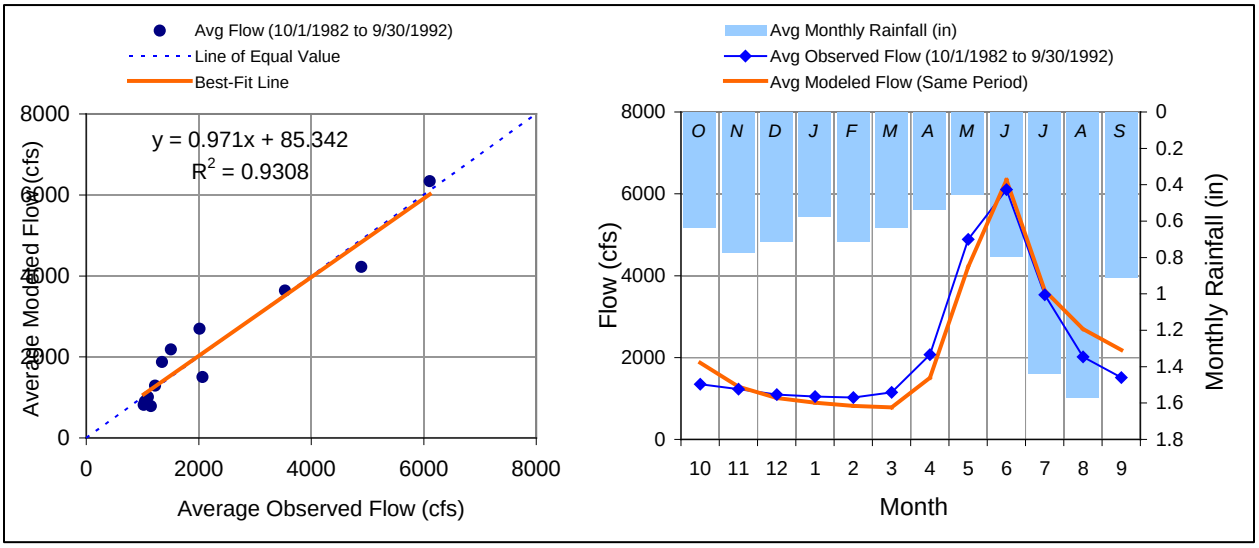


**Figure 9. Seasonal regression and temporal aggregate at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.**

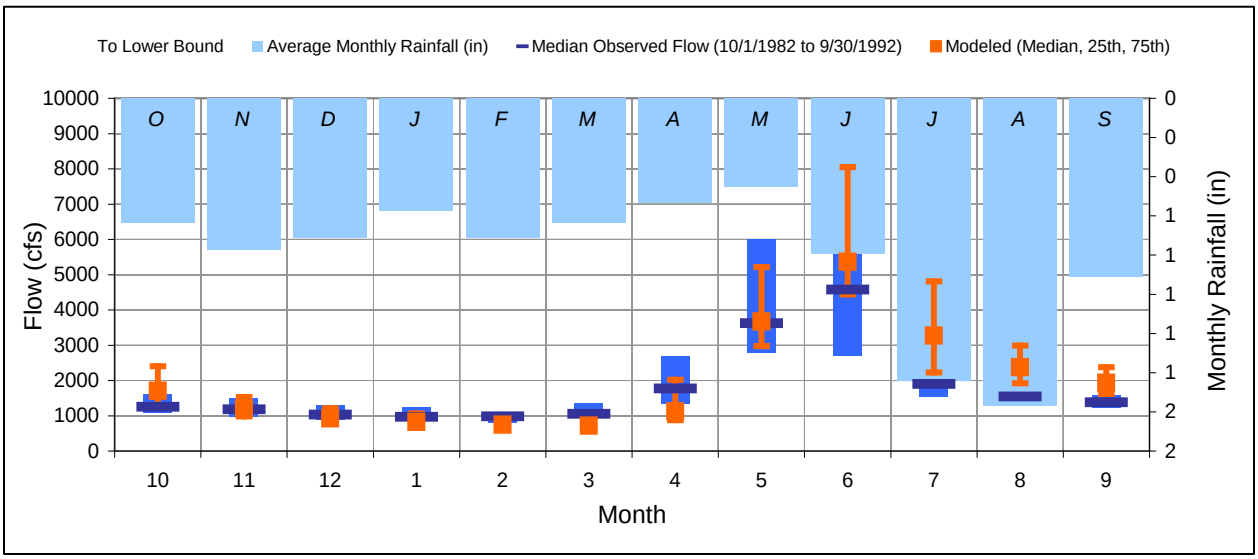


**Figure 10. Seasonal medians and ranges at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.**

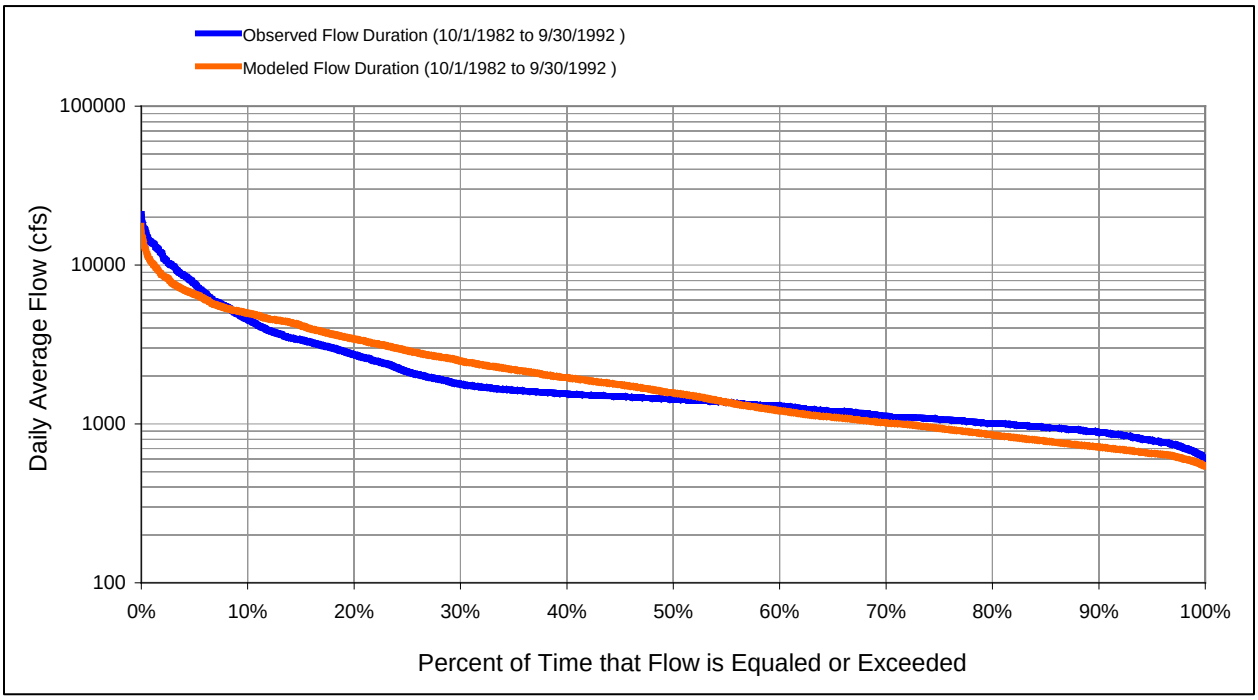


**Figure 11. Flow exceedance at USGS 09070500 Colorado River near Dotsero, Colorado – validation period.**

**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<br>10-Year Analysis Period: 10/1/1982 - 9/30/1992<br>Flow volumes are (inches/year) for upstream drainage area | | USGS 09070500 COLORADO RIVER NEAR DOTSERO, CO<br>Hydrologic Unit Code: 14010001<br>Latitude: 39.6446111<br>Longitude: -107.0780139<br>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 | |
| Baseline adjusted coefficient (Garrick), E': | 0.545 | as E or E' approaches 1.0 | |
| Monthly NSE | 0.871 | | |

## 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 |
| Nash-Sutcliffe Coefficient of Efficiency, E: | 0.484 | 0.812 | 0.847 | 0.877 | 0.858 | 0.638 | 0.678 | 0.629 | 0.817 |
| Baseline adjusted coefficient (Garrick), E': | 0.298 | 0.591 | 0.643 | 0.645 | 0.614 | 0.539 | 0.349 | 0.354 | 0.512 |

**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 |
| Nash-Sutcliffe Coefficient of Efficiency, E: | 0.504 | 0.795 | 0.847 | 0.853 | 0.796 | 0.440 | 0.480 | 0.554 | 0.701 |
| Baseline adjusted coefficient (Garrick), E': | 0.293 | 0.591 | 0.650 | 0.622 | 0.589 | 0.464 | 0.289 | 0.249 | 0.458 |

## 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.

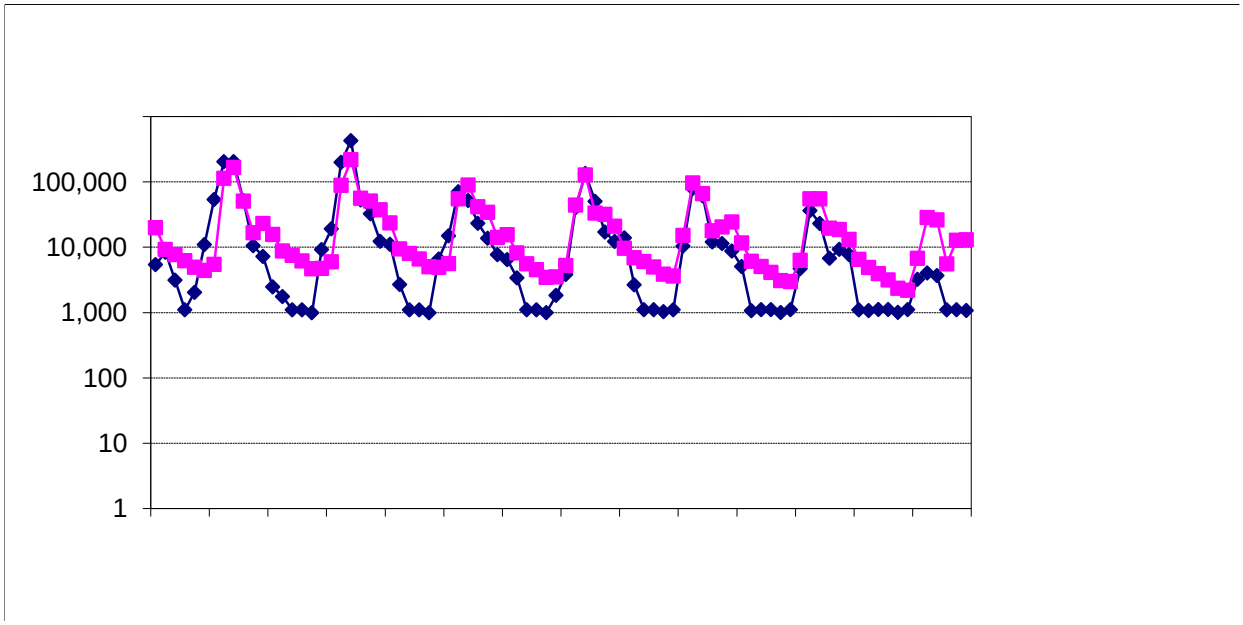


**Figure 12. Fit for monthly load of TSS at USGS 09070500 Colorado River near Dotsero, Colorado.**

**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 $20^{O}$ C)
- PHOSKD (phosphorus soil partitioning coefficient)
- PSP (phosphorus availability index)
- RS1 (Local algal settlement rate in the reach at $20^{O}$ 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 $20^{O}$ C)
- RHOQ (Algal respiration rate at $20^{O}$ C)
- RS2 (benthic source rate for dissolved P in the reach at $20^{O}$ C)
- RS3 (Benthic source rate for $NH_4$-N in the reach at $20^{O}$ C)
- RS5 (organic P settling rate in the reach at $20^{O}$ C)
- BC4 (rate constant for mineralization of organic P to dissolved P in the reach at $20^{O}$ C)
- RS4 (rate coefficient for organic N settling in the reach at $20^{O}$ 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.

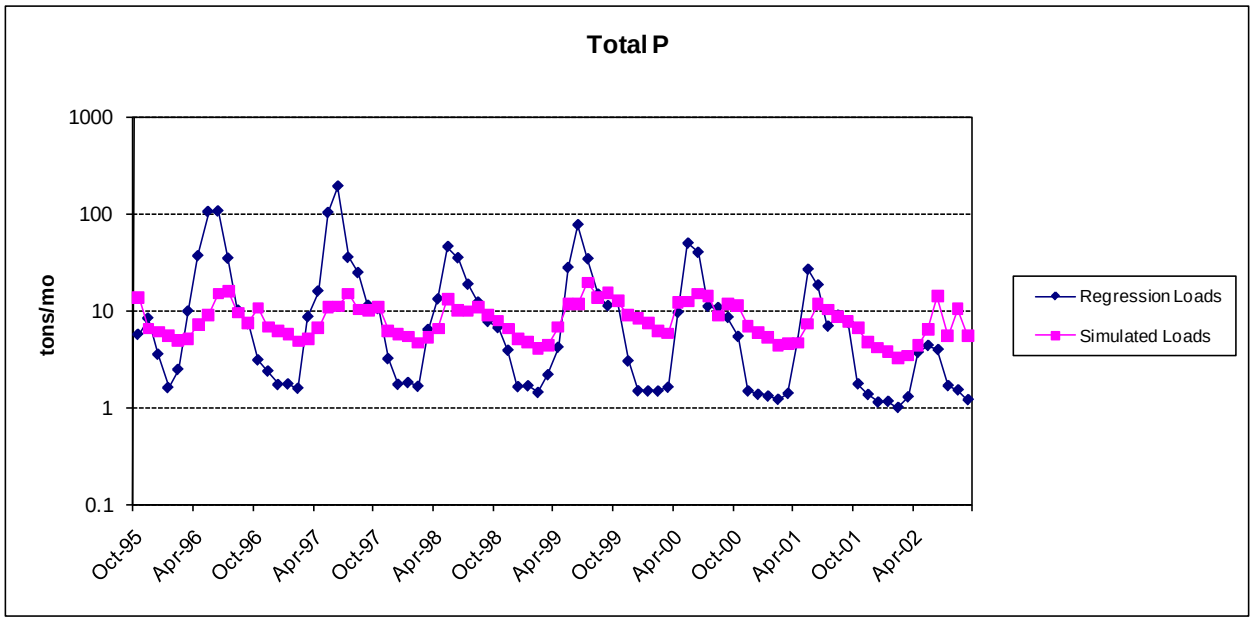


**Figure 13. Fit for monthly load of total phosphorus at USGS 09070500 Colorado River near Dotsero, Colorado.**

**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% |

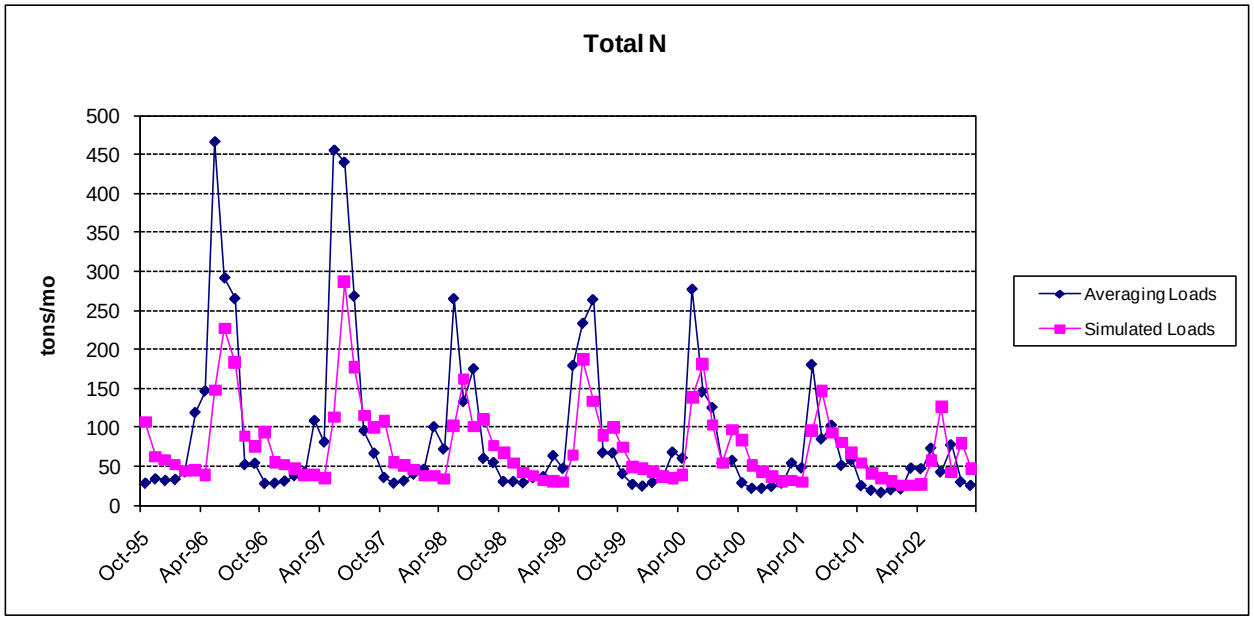


**Figure 14. Fit for monthly load of total nitrogen at USGS 09070500 Colorado River near Dotsero, Colorado.**

**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 |

# References

USEPA. 2008. Using the BASINS Meteorological Database (Version 2006). BASINS Technical Note 10. Office of Water, U.S. Environmental Protection Agency, Washington, DC.