# Appendix T
# Model Configuration, Calibration and Validation

## Basin: South Platte (SoPlat)

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# Watershed Background

The South Platte River basin study area 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 South Platte River originates in the mountains of central Colorado at the Continental Divide and flows about 450 miles northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska. The model study area is almost 15,000 $mi^2$ in size and extends from the headwaters to the plains of central Colorado, consisting of 11 HUC8s within HUC 1019 (Figure 1). Elevation in the model study area ranges from 14,286 ft at Mt. Lincoln on the Continental Divide to about 4,400 ft at the downstream end of the model area. The basin includes two physiographic provinces, the Front Range Section of the Southern Rocky Mountain Province and the Colorado Piedmont Section of the Great Plains Province (Dennehy et al., 1993, 1998; USGS, 2008).

The basin has a continental-type climate modified by topography, in which there are large temperature ranges and irregular seasonal and annual precipitation. Mean temperatures increase from west to east and on the plains from north to south. Areas along the Continental Divide average 30 inches or more of precipitation annually, which includes snowfall in excess of 300 inches. In contrast, the annual precipitation on the plains east of Denver, Colorado, and in the South Park area in the southwest part of the basin, ranges from 7 to 15 inches. Most of the precipitation on the plains occurs as rain, which typically falls between April and September, while most of the precipitation in the mountains occurs as snow, which typically falls between October and March.

Land use and land cover in the South Platte River basin is divided into rangeland (46 percent), agricultural land (18 percent), forest land (24 percent), urban land (7 percent), and other land (5 percent). Rangeland is present across all areas of the basin except over the high mountain forests. Agricultural land is somewhat more restricted to the plains and the South Park area near Fairplay, Colorado. Forest land occurs in a north-south band in the mountains. Urban land is present primarily in the Front Range urban corridor. Irrigated agriculture comprises only 8 percent of the basin but accounts for 71 percent of the water use. Urban lands comprise only 7 percent of the basin but account for 12 percent of the water use (or 27 percent if power generation is considered an urban water use).

To augment water supplies in the basin there are significant diversions of water into the South Platte tributaries from tunnels that connect to the wetter, western side of the Continental Divide, most notably the Colorado-Big Thompson Project (Adams Tunnel) which transports about 285,000 acre-feet per year of Colorado River water through a 13-mile tunnel under the Continental Divide into the Big Thompson River. Overall there are 15 inter-basin transfers into the basin and almost 1,000 reservoirs. Only the three largest mainstem reservoirs are explicitly represented in the model. The limited data available on reservoirs and inter-basin transfers creates significant challenges for hydrologic simulation in this watershed.

The population of the South Platte River basin is about 2.8 million people, over 95 percent of them in Colorado. The basin contains the most concentrated population density in the Rocky Mountain region, located in the Denver metropolitan area and along the Front Range urban corridor in Colorado where the mountains meet the plains. Population densities outside the urban corridor are small and centered in small towns located along the principal streams. The principal economy in the mountainous headwaters is based on tourism and recreation; the economy in the urbanized south-central region mostly is related to manufacturing, service and trade industries, and government services; and the economy of the basin downstream from Denver is based on agriculture and livestock production.

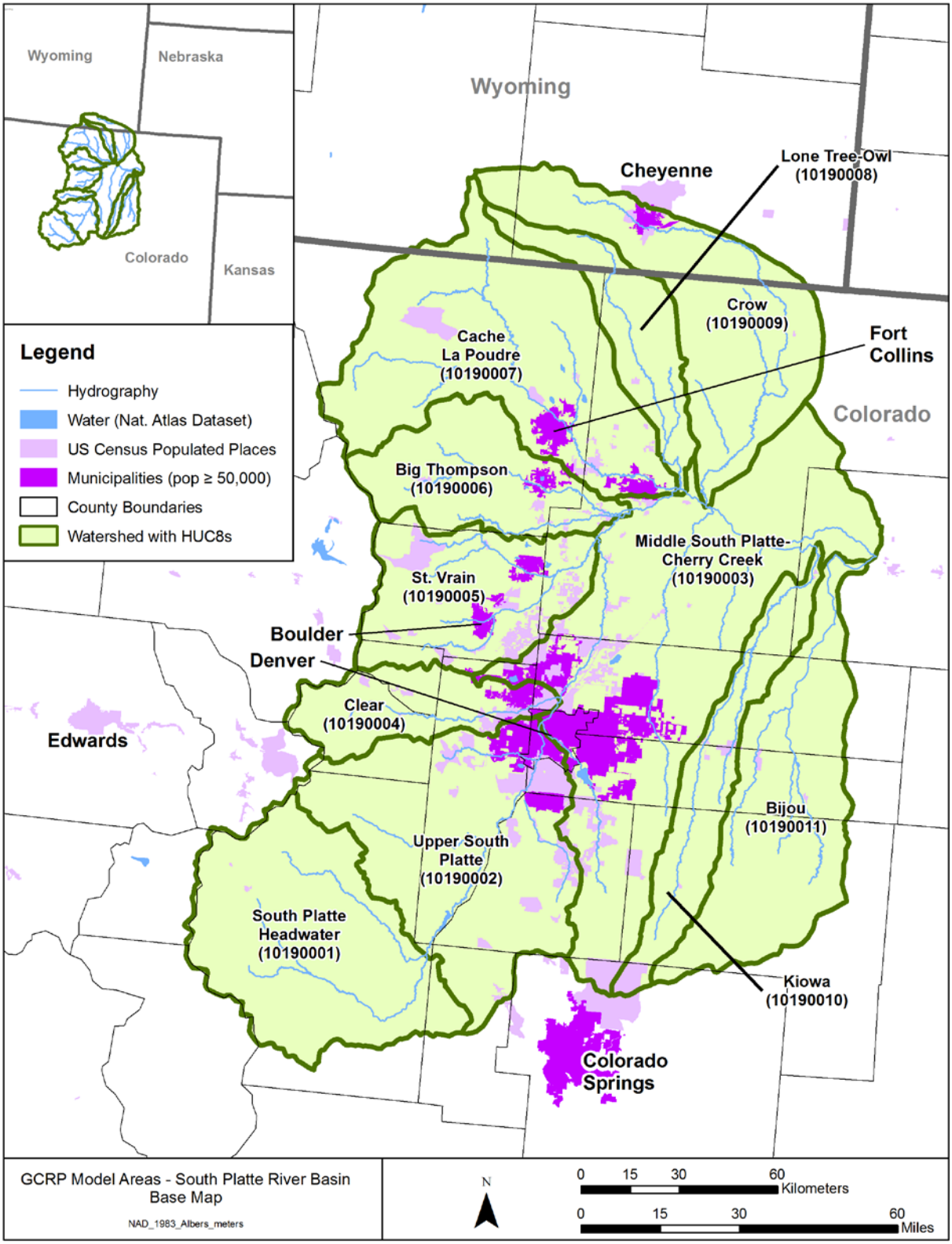


**Figure 1. Location of the South Platte watershed.**

## Soil Characteristics

Soils in the watershed, as described in STATSGO soil surveys, fall primarily (56 percent) into hydrologic soil group (HSG) B (moderately high 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 and is predominantly grassland in the high plains and forest in the mountains, with substantial urban development in the Denver area (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 SSURGO major soils. The distribution of land use in the watershed is summarized in Table 2.

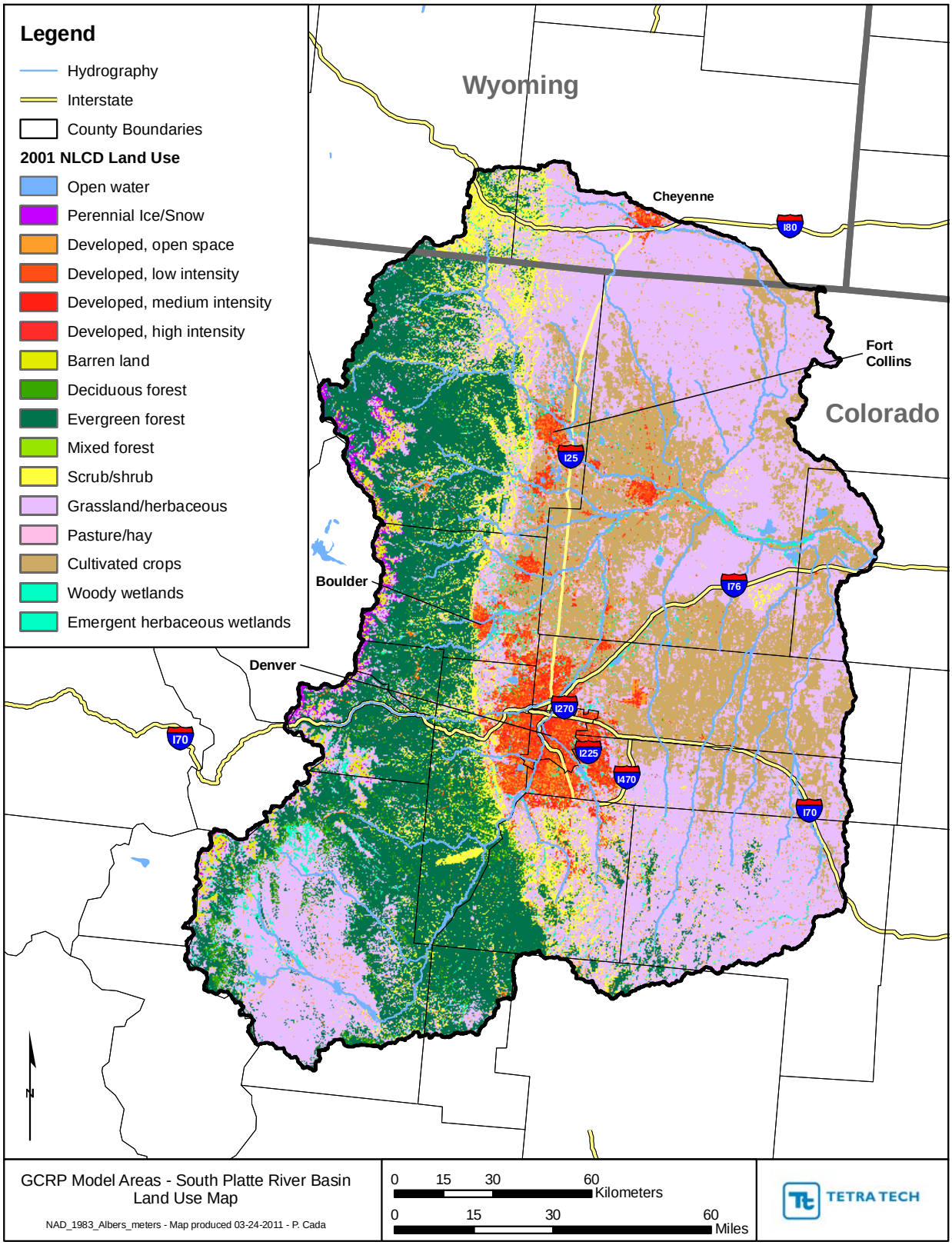


**Figure 2. Land use in the South Platte watershed.**

**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 South Platte watershed (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 | | | | | | | |
| South Platte Headwater. **10190001** | 13.7 | 7.5 | 19.8 | 1.2 | 0.0 | 0.0 | 37.9 | 526.3 | 921.1 | 6.6 | 0.1 | 70.0 | 1,604.3 |
| Upper Southe Platte **10190002** | 9.5 | 3.2 | 68.3 | 94.6 | 34.3 | 11.5 | 16.7 | 1,125.5 | 440.9 | 3.2 | 2.5 | 39.7 | 1,849.7 |
| Middle South Platte-Cherry Creek **10190003** | 40.0 | 0.0 | 131.9 | 129.8 | 71.2 | 27.6 | 4.2 | 45.4 | 1,301.2 | 71.6 | 977.5 | 78.3 | 2,878.6 |
| Clear **10190004** | 3.3 | 19.8 | 18.7 | 40.7 | 13.0 | 3.9 | 21.2 | 280.9 | 153.1 | 1.5 | 0.6 | 9.2 | 565.8 |
| St. Vrain, 1**0190005** | 16.6 | 27.5 | 29.0 | 43.5 | 15.7 | 3.9 | 25.6 | 397.4 | 174.1 | 42.1 | 166.8 | 37.1 | 979.2 |
| Big Thompson. **10190006** | 13.1 | 13.4 | 17.1 | 17.7 | 5.9 | 1.0 | 21.6 | 379.8 | 196.6 | 17.1 | 131.2 | 17.4 | 832.0 |
| Cache La Poudre. **10190007** | 27.0 | 24.7 | 36.1 | 41.8 | 14.1 | 3.3 | 18.3 | 630.0 | 721.8 | 44.6 | 288.4 | 40.3 | 1,890.5 |
| Lone Tree-Owl.. **10190008** | 0.7 | 0.0 | 14.9 | 2.2 | 0.5 | 0.0 | 1.3 | 1.9 | 414.9 | 6.9 | 130.9 | 3.6 | 578.0 |
| Crow. **10190009** | 1.9 | 0.0 | 33.2 | 12.8 | 7.0 | 1.8 | 5.6 | 30.9 | 1,126.2 | 12.7 | 148.5 | 9.1 | 1,389.8 |
| Kiowa. **10190010** | 0.2 | 0.0 | 23.1 | 1.5 | 0.5 | 0.1 | 0.6 | 31.0 | 414.6 | 4.2 | 231.0 | 10.1 | 716.8 |
| Bijou **10190011** | 1.1 | 0.0 | 42.9 | 2.3 | 0.5 | 0.0 | 0.6 | 27.9 | 938.9 | 8.7 | 342.0 | 18.8 | 1,383.7 |
| Total | 127.2 | 96.1 | 434.8 | 388.1 | 162.7 | 53.2 | 153.5 | 3,477.0 | 6,803.3 | 219.2 | 2,419.4 | 333.8 | 14,668.3 |

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (6.41%), low density (33.46%), medium density (60.79%), and high density (86.76%).

## Point Sources

There are numerous point source discharges in the watershed. Only the major dischargers, 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 South Platte watershed**

| NPDES ID | Name | Design flow (MGD) | Observed flow (MGD) (1991-2006 average) |
|---|---|---|---|
| CO0001091 | PUBLIC SERVICE CO. OF COLORADO | | 0.2798 |
| CO0001104 | PUBLIC SERVICE CO. OF COLO. | | 1.8487 |
| CO0001139 | PUBLIC SERVICE COMPANY OF COLO | | 0.0985 |
| CO0001147 | SUNCOR ENERGY (USA) INC. | | 1.7383 |
| CO0001163 | COORS BREWING COMPANY | | 11.436 |
| CO0001511 | LOCKHEED MARTIN SPACE SYSTEMS | | 0.3062 |
| CO0020290 | ESTES PARK SANITATION DISTRICT | 1.5 | 0.5006 |
| CO0020320 | WINDSOR, TOWN OF | 1.5 | 1.001 |
| CO0020478 | BOXELDER SANITATION DISTRICT | 2.34 | 1.6335 |
| CO0020508 | EVANS, CITY OF | 0.9 | 0.8319 |
| CO0020737 | SOUTH FORT COLLINS SAN DIST | 3 | 1.0112 |
| CO0021440 | FORT LUPTON, CITY OF | 2.75 | 1.0882 |
| CO0021547 | BRIGHTON, CITY OF | 3 | 1.8255 |
| CO0021580 | ST. VRAIN SANITATION DISTRICT | 1.5 | 0.5402 |
| CO0023078 | LOUISVILLE, CITY OF | 3.4 | 1.8457 |
| CO0023124 | LAFAYETTE, CITY OF | 4.4 | 1.6297 |
| CO0024147 | BOULDER, CITY OF | 20.5 | 16.177 |
| CO0024171 | WESTMINSTER, CITY OF | 9.2 | 6.3946 |
| CO0026409 | BROOMFIELD, CITY OF | 3.2 | 3.7007 |
| CO0026425 | FORT COLLINS, CITY OF | 7 | 16.261 |
| CO0026611 | AURORA, CITY OF | 2.6 | 2.7601 |
| CO0026638 | METRO WASTEWATER RECLAM DIST | 220 | 159.81 |
| CO0026662 | SOUTH ADAMS COUNTY W&S DIST | 2.28 | 2.8959 |
| CO0026671 | LONGMONT, CITY OF | 17 | 7.9692 |
| CO0026701 | LOVELAND, CITY OF | 10 | 5.6427 |
| CO0027707 | SWIFT BEEF COMPANY | 2.8 | 2.5889 |
| CO0032999 | LITTLETON/ENGLEWOOD, CITIES OF | 28 | 24.182 |
| CO0037966 | CENTENNIAL WATER & SAN. DIST. | 8.48 | 3.5751 |
| CO0040258 | GREELEY, CITY OF | 14.7 | 8.0844 |
| CO0040681 | ARAPAHOE COUNTY W&WW AUTHORITY | 2.4 | 0.842 |
| CO0041700 | ST. VRAIN SANITATION DISTRICT | 3 | 1.0304 |
| CO0043010 | SUPERIOR METROPOLITAN DIST NO1 | | 0.2913 |
| WY0000442 | Frontier Refining Inc | 0 | 0.8737 |
| WY0022381 | Cheyenne BOPU | 3.5 | 3.675 |

Most of these point sources have relatively sparse water quality monitoring for nutrients. The point sources were initially represented in the model with an assumed total phosphorus concentration of 7.2 mg/L and total nitrogen concentration of 11.2 mg/L for secondary treatment facilities (Tetra Tech 1999).

## Meteorological Data

The required meteorological time series for the GCRP SWAT simulations are precipitation and air temperature. The GCRP 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 2000. A total of 33precipitation stations were identified for use in the Minnesota River model with a common period of record of 10/1/1969-9/30/2000 (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 South Platte watershed model**

| COOP ID | Name | Latitude | Longitude | Temperature | Elevation (m) |
|---|---|---|---|---|---|
| CO050183 | ALLENSPARK 2SE | 40.1881 | -105.502 | X | 2504 |
| CO050263 | ANTERO RESERVOIR | 38.9933 | -105.892 | X | 2719 |
| CO050454 | BAILEY | 39.4047 | -105.477 | X | 2356 |
| CO050843 | BOULDER 2 | 40.0339 | -105.281 | X | 1650 |
| CO050848 | BOULDER | 39.9919 | -105.267 | X | 1672 |
| CO050945 | BRIGGSDALE | 40.635 | -104.327 | X | 1473 |
| CO051179 | BYERS 5 ENE | 39.7403 | -104.128 | X | 1554 |
| CO051186 | CABIN CREEK | 39.6553 | -105.709 | X | 3054 |
| CO051528 | CHEESMAN | 39.2203 | -105.278 | X | 2097 |
| CO051547 | CHERRY CREEK DAM | 39.6261 | -104.832 | X | 1721 |
| CO052162 | DEER TRAIL 3 NW | 39.6419 | -104.078 | | 1554 |
| CO052220 | DENVER STAPELTON | 39.7633 | -104.869 | X | 1611 |
| CO052494 | EASTONVILLE 2 NNW | 39.1092 | -104.6 | | 2198 |
| CO052790 | EVERGREEN | 39.6381 | -105.315 | X | 2129 |
| CO053005 | FORT COLLINS | 40.6147 | -105.131 | X | 1525 |
| CO053038 | FORT MORGAN | 40.2617 | -103.804 | X | 1320 |
| CO053530 | GRANT | 39.4608 | -105.679 | X | 2644 |
| CO053553 | GREELEY UNC | 40.4022 | -104.699 | X | 1437 |
| CO053584 | GREENLAND 6 NE | 39.2167 | -104.738 | | 2103 |
| CO054155 | HOYT | 39.9875 | -104.085 | | 1460 |
| CO054452 | KASSLER | 39.49 | -105.095 | X | 1703 |
| CO054762 | LAKEWOOD | 39.7489 | -105.121 | X | 1719 |
| CO055116 | LONGMONT 2 ESE | 40.1589 | -105.074 | X | 1509 |
| CO055121 | LONGMONT 6 NW | 40.2467 | -105.146 | | 1570 |
| CO056023 | NUNN | 40.7064 | -104.783 | X | 1584 |
| CO057510 | SEDALIA 4 SSE | 39.4036 | -104.952 | | 1821 |
| CO057664 | SIMLA | 39.1397 | -104.088 | | 1828 |
| CO058839 | WATERDALE | 40.4256 | -105.21 | X | 1594 |

| COOP ID | Name | Latitude | Longitude | Temperature | Elevation (m) |
|---|---|---|---|---|---|
| CO059210 | WOODLAND PARK 8 NNW | 39.1006 | -105.094 | | 2365 |
| WY481547 | CARPENTER 3N | 41.0844 | -104.379 | X | 1657 |
| WY481675 | CHEYENNE WSFO AP | 41.1578 | -104.807 | X | 1864 |
| WY484930 | JELM 2S | 41.06 | -106.026 | | 2310 |
| WY485420 | LARAMIE 2 WSW | 41.3042 | -105.641 | | 2187 |

## Watershed Segmentation

The South Platte River watershed was divided into 75 subwatersheds for the purposes of modeling (Figure 3). The initial calibration was done at gage 06714000, South Platte River at Denver. The model encompasses the complete watershed; however, there are significant inter-basin transfers across the Continental Divide into the headwaters of the system. These external sources are represented based on best available data and not changed for climate scenarios. The scenarios thus represent the changes due only to potential weather changes within the watershed.

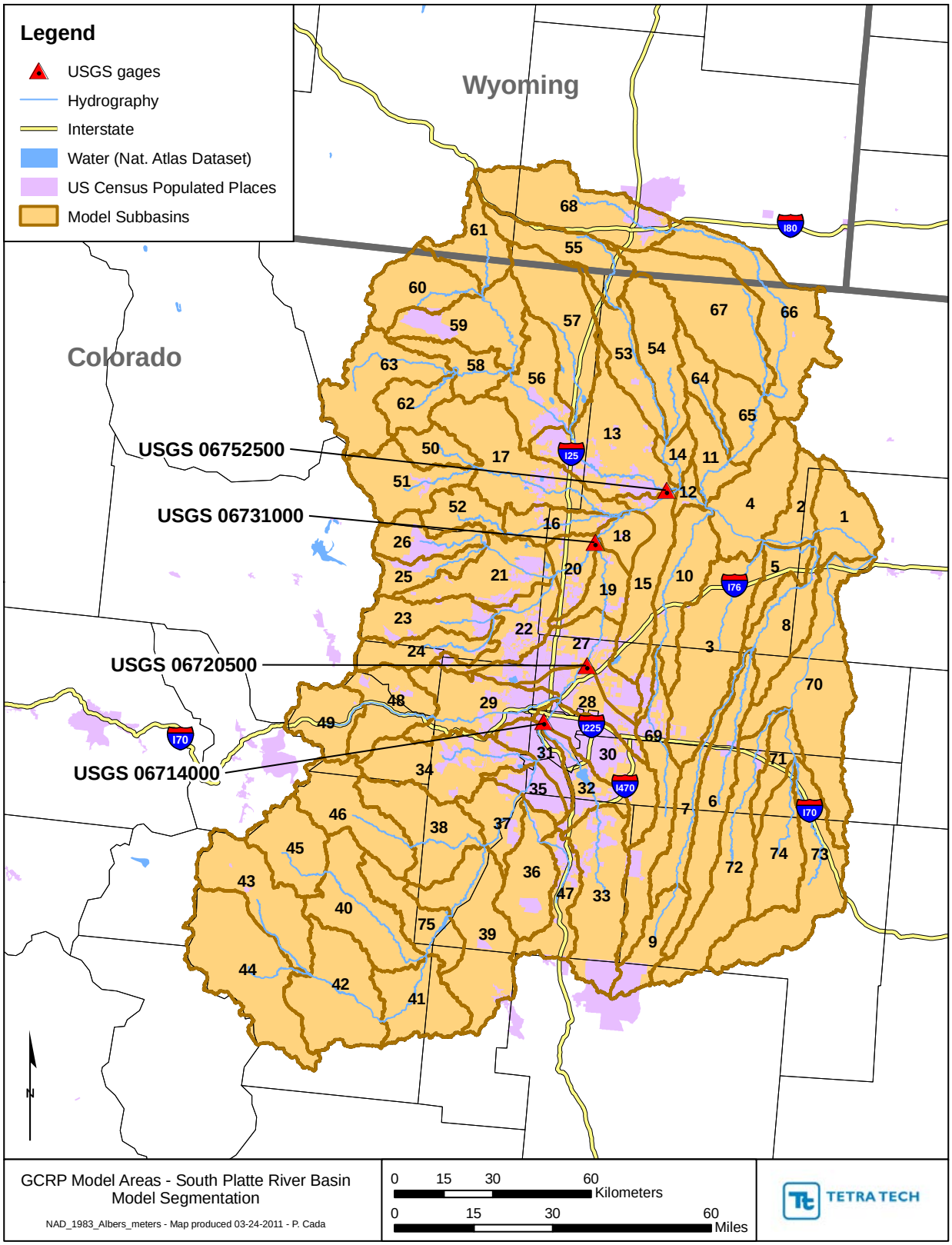


**Figure 3. Model segmentation and USGS stations utilized for the South Platte River watershed.**

## Calibration Data and Locations

The specific site chosen for initial calibration was the South Platte River at Denver (USGS 06714000), a flow and water quality monitoring location that approximately coincides with the mouth of an 8-digit HUC covering the upstream portion of the watershed. This station was selected because there is a good set of flow and water quality data available and the watershed lacks major point sources and impoundments. Calibration and validation were pursued at multiple locations (Table 5). Parameters derived at the initial station were not fully transferable to other portions of the watershed, and additional calibration was conducted at multiple gage locations.

**Table 5. Calibration and validation locations in the South Platte watershed**

| Station name | USGS ID | Drainage area ($mi^2$) | Hydrology calibration | Water quality calibration |
|---|---|---|---|---|
| South Platte River at Denver, CO | 06714000 | 3,861 | X | X |
| South Platte River at Henderson, CO | 06720500 | 4,768 | X | X |
| South Platte River near Kersey, CO | 06754000 | 9,659 | X | X |
| South Platte River near Weldona, CO | 06758500 | 13,190 | X | X |

The model hydrology calibration period was set to Water Years 1991-2000 (within the 30-year period of record for modeling). Hydrologic validation was then performed on Water Years 1981-1990. Water quality calibration used calendar years 1993-2000, while validation used 1988-1990, as only limited data were available for earlier years.

# SWAT Modeling

## Assumptions

The South Platte River basin has primarily a semiarid climate and, as a result, a long history of water development beginning about 1870 with live stream diversions from the Cache la Poudre River. Water shortages in the 1930s prompted the creation of large scale inter-basin transports, most notably the Colorado-Big Thompson Project (Adams Tunnel) which transports about 285,000 acre-feet per year of Colorado River water through a 13-mile tunnel under the Continental Divide into the Big Thompson River. Overall there are 15 inter-basin transfers into the basin and almost 1,000 reservoirs (Dennehy et al. 1993). There are also multiple water diversions within the system.

Representing these managed features is a challenge for modeling. The three largest inter-basin transfers, each with a quantity of greater than 50,000 acre feet per year (Adams, Moffat, and Roberts, to the Big Thompson River, Boulder Creek, and Bear Creek respectively) were represented in the model based on a constant monthly pattern. These account for about 95 percent of the inter-basin transfers (383,000 acre feet per year). Only a few of the many reservoirs in the basin are modeled explicitly, with a focus on those that control flow in the mainstem rather than providing sidestream storage. Three reservoirs were represented in the South Platte watershed model, namely, Eleven Mile Canyon, Cheesman and Chatfield. The target storage method was adopted for these reservoirs, yielding an approximation of actual behavior. Pertinent reservoir information was collected from the Colorado Decision Support Systems.

Numerous other reservoirs and water transfers are not included in the model. This limits the ability of the simulation to mimic observed flows. Conclusions should thus be drawn on the relative change in flows predicted under future scenarios, rather than on quantitative estimates of flow.

## Hydrology Calibration

A spatial calibration approach was adopted for GCRP-SWAT modeling for the South Platte basin. The initial calibration at the edge of the Rockies was extended downstream with adjustment of parameters for the high plains portion of the watershed. The calibration is strongly influenced by assumptions about water transfers, withdrawals, and discharges in the basin.

The initial calibration focus area (South Platte River at Denver) includes 15 subwatersheds and is representative the Rocky Mountain portion 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 the whole South Platte River basin predicted by the SWAT model over the 30-year simulation period is as follows:

```
PRECIP =    384.4 MM
SNOW FALL =  108.78 MM
SNOW MELT =    99.46 MM
SUBLIMATION =     9.04 MM
SURFACE RUNOFF Q =    41.26 MM
LATERAL SOIL Q =   26.55 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    32.28 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    2.96 MM
```

```
DEEP AQ RECHARGE =     0.00 MM
TOTAL AQ RECHARGE =   35.25 MM
TOTAL WATER YLD =    79.88 MM
PERCOLATION OUT OF SOIL =   15.10 MM
ET =    346.2 MM
PET =   1383.3MM
TRANSMISSION LOSSES =    20.20 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 South Platte River at Denver are summarized in Figure 4, Figure 5, Figure 6, Figure 7, and Table 6. The quality of the fit is fair, with a tendency to underpredict flows in the winter and overpredict flows in the summer and fall. Much of this discrepancy is believed to be due to the complex series of water imports, storage, and withdrawals in the watershed.

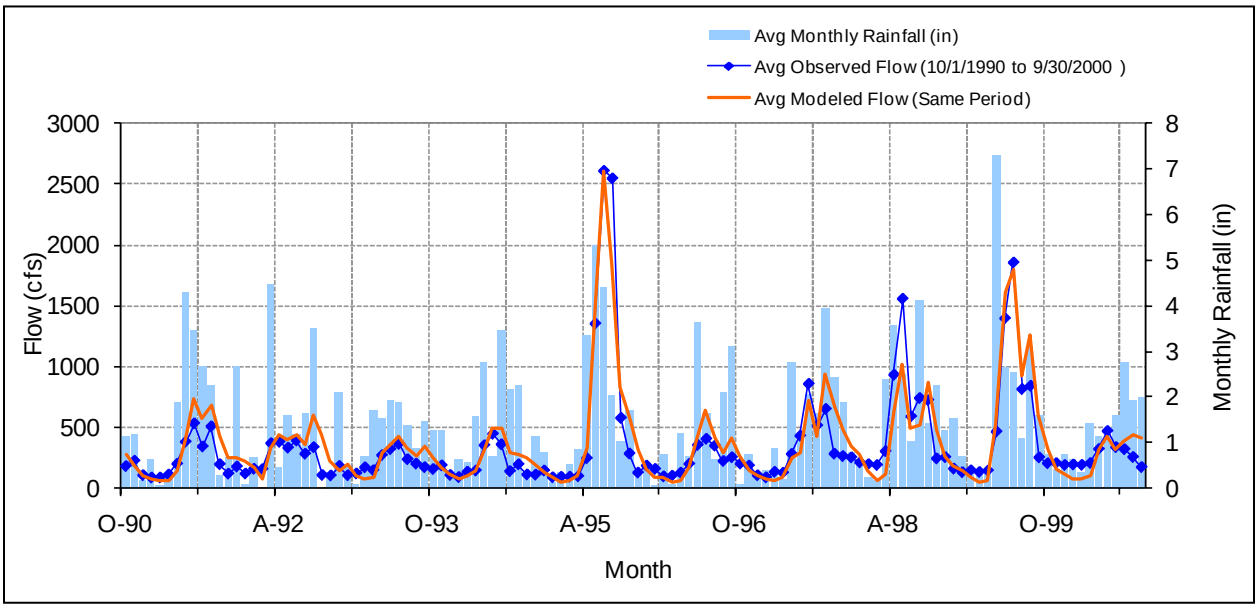


**Figure 4. Mean monthly flow at USGS 06714000, South Platte River at Denver, CO – calibration period.**

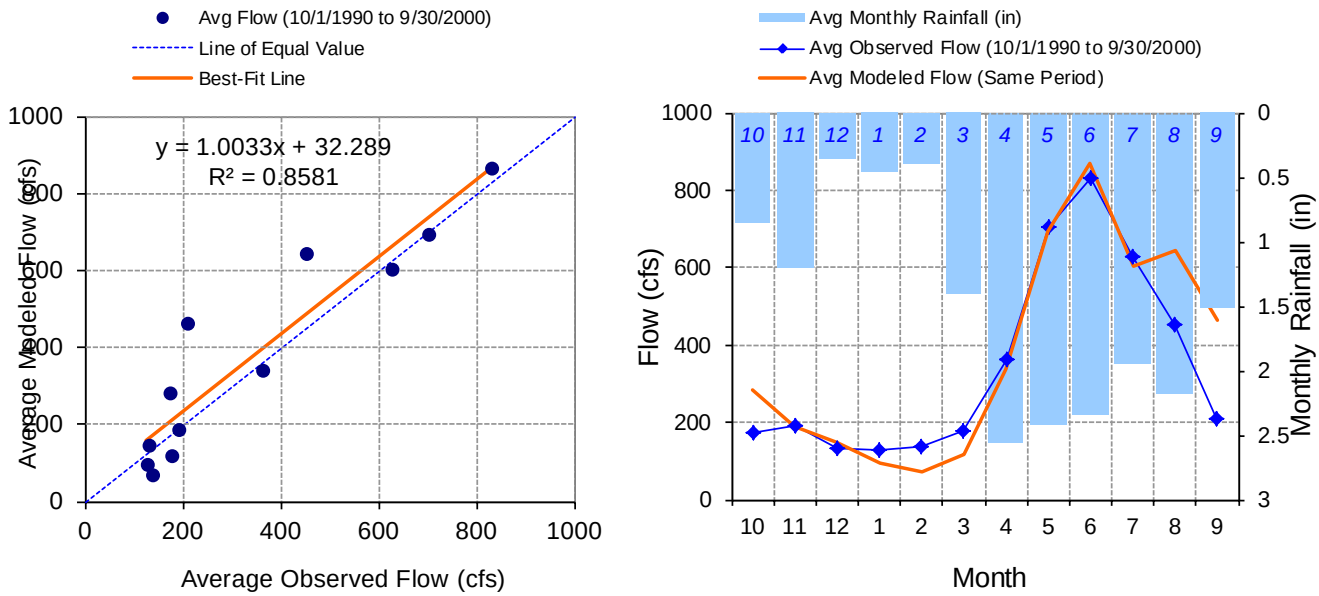


**Figure 5. Seasonal regression and temporal aggregate at USGS 06714000, South Platte River at Denver, CO - calibration period.**

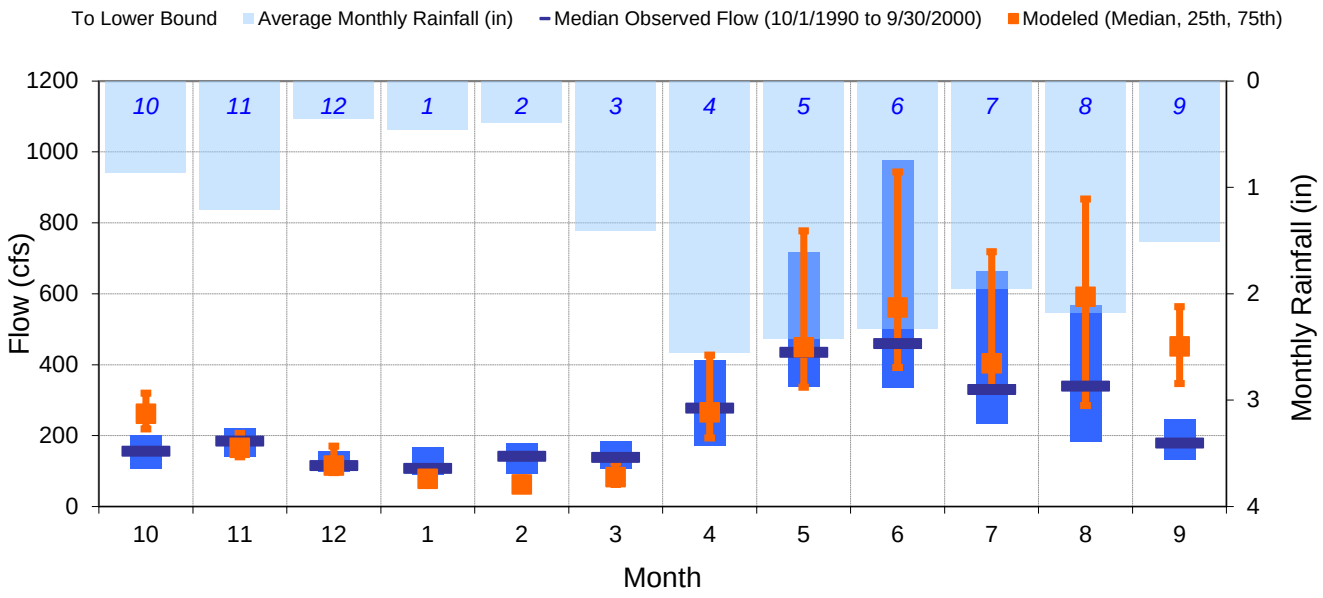


**Figure 6. Seasonal medians and ranges at USGS 06714000, South Platte River at Denver, CO – calibration period.**

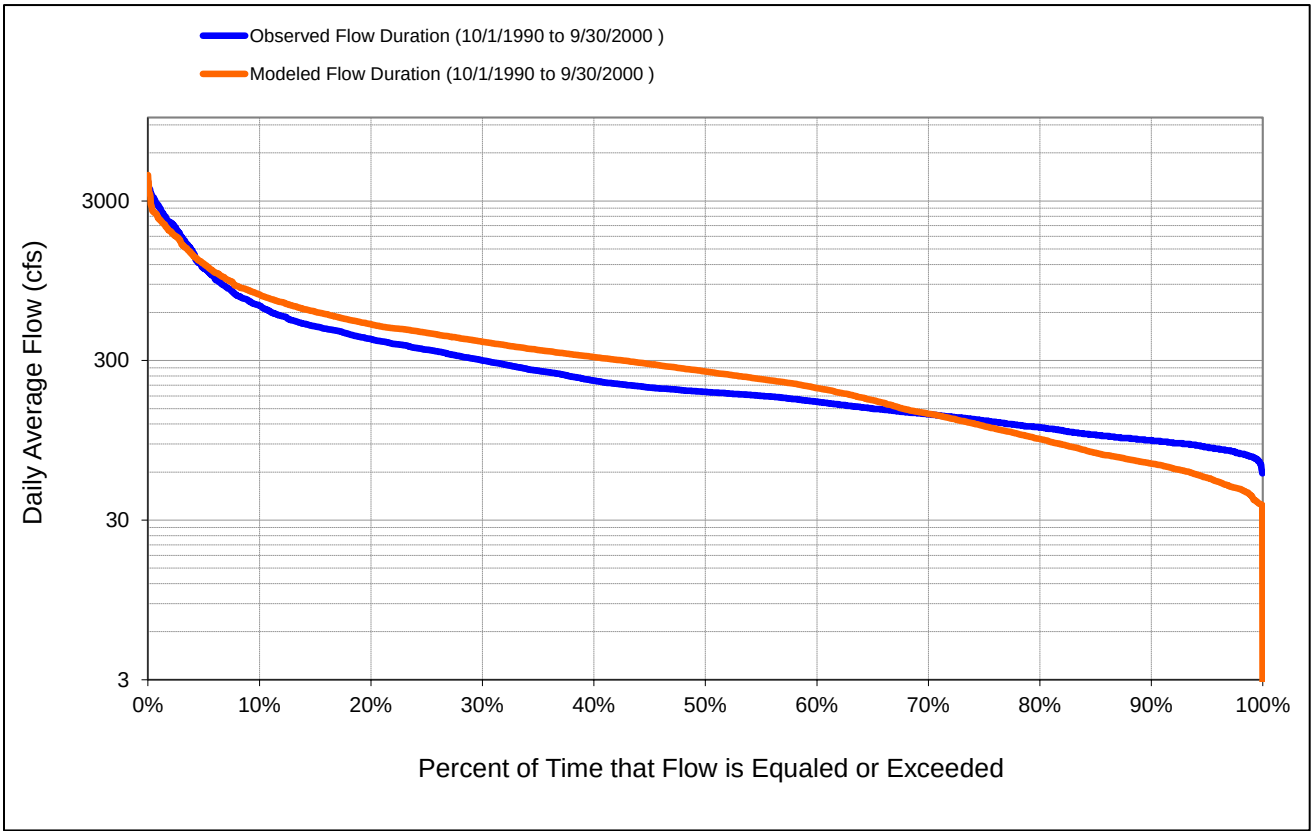


**Figure 7. Flow exceedance at USGS 06714000, South Platte River at Denver, CO - calibration period.**

**Table 6. Summary statistics at USGS 06714000, South Platte River at Denver, CO – calibration period**

| SWAT Simulated Flow | | Observed Flow Gage | |
|---|---|---|---|
| REACH OUTFLOW FROM OUTLET(S) 31, 32<br>10-Year Analysis Period: 10/1/1990 - 9/30/2000<br>Flow volumes are (inches/year) for upstream drainage area | | USGS 06714000 SOUTH PLATTE RIVER AT DENVER, CO<br>Hydrologic Unit Code: 10190003<br>Latitude: 39.759722222<br>Longitude: -105.166666666<br>Drainage Area (sq-mi): 3861 | |
| Total Simulated In-stream Flow: | **1.05** | Total Observed In-stream Flow: | **0.95** |
| Total of simulated highest 10% flows: | **0.40** | Total of Observed highest 10% flows: | **0.41** |
| Total of Simulated lowest 50% flows: | **0.18** | Total of Observed Lowest 50% flows: | **0.18** |
| Simulated Summer Flow Volume (months 7-9): | **0.40** | Observed Summer Flow Volume (7-9): | **0.30** |
| Simulated Fall Flow Volume (months 10-12): | **0.14** | Observed Fall Flow Volume (10-12): | **0.11** |
| Simulated Winter Flow Volume (months 1-3): | **0.07** | Observed Winter Flow Volume (1-3): | **0.10** |
| Simulated Spring Flow Volume (months 4-6): | **0.44** | Observed Spring Flow Volume (4-6): | **0.44** |
| Total Simulated Storm Volume: | **0.20** | Total Observed Storm Volume: | **0.29** |
| Simulated Summer Storm Volume (7-9): | **0.07** | Observed Summer Storm Volume (7-9): | **0.10** |
| *Errors (Simulated-Observed)* | *Error Statistics* | *Recommended Criteria* | |
| Error in total volume: | 9.82 | 10 | |
| Error in 50% lowest flows: | 1.05 | 10 | |
| Error in 10% highest flows: | -3.29 | 15 | |
| **Seasonal volume error - Summer:** | **32.89** | **30** | |
| Seasonal volume error - Fall: | 26.06 >> | 30 | Clear |
| **Seasonal volume error - Winter:** | **-35.47** | **30** | |
| Seasonal volume error - Spring: | 0.17 | 30 | |
| **Error in storm volumes:** | **-29.43** | **20** | |
| Error in summer storm volumes: | -35.56 | 50 | |
| Nash-Sutcliffe Coefficient of Efficiency, E: | 0.738 | Model accuracy increases | |
| Baseline adjusted coefficient (Garrick), E': | 0.439 | as E or E' approaches 1.0 | |
| Monthly NSE | 0.857 | | |

## Hydrology Validation

Hydrology validation for the South Platte River at Denver was performed for the period 10/1/1980 through 9/30/1990. Like the calibration, the validation fails to achieve all desired seasonal criteria and attains only a mediocre value for model fit efficiency – likely due in large part to water imports and withdrawals. Results are summarized in Figure 8, Figure 9, Figure 10, Figure 11, and Table 7.

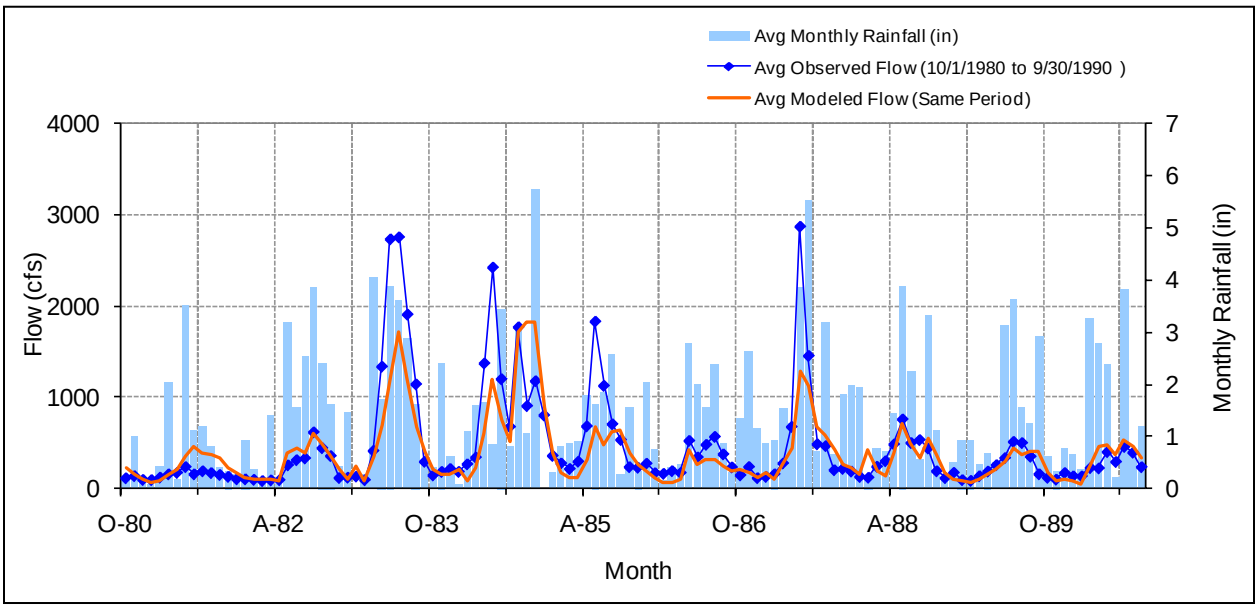


**Figure 8. Mean monthly flow at USGS 06714000, South Platte River at Denver, CO – validation period.**

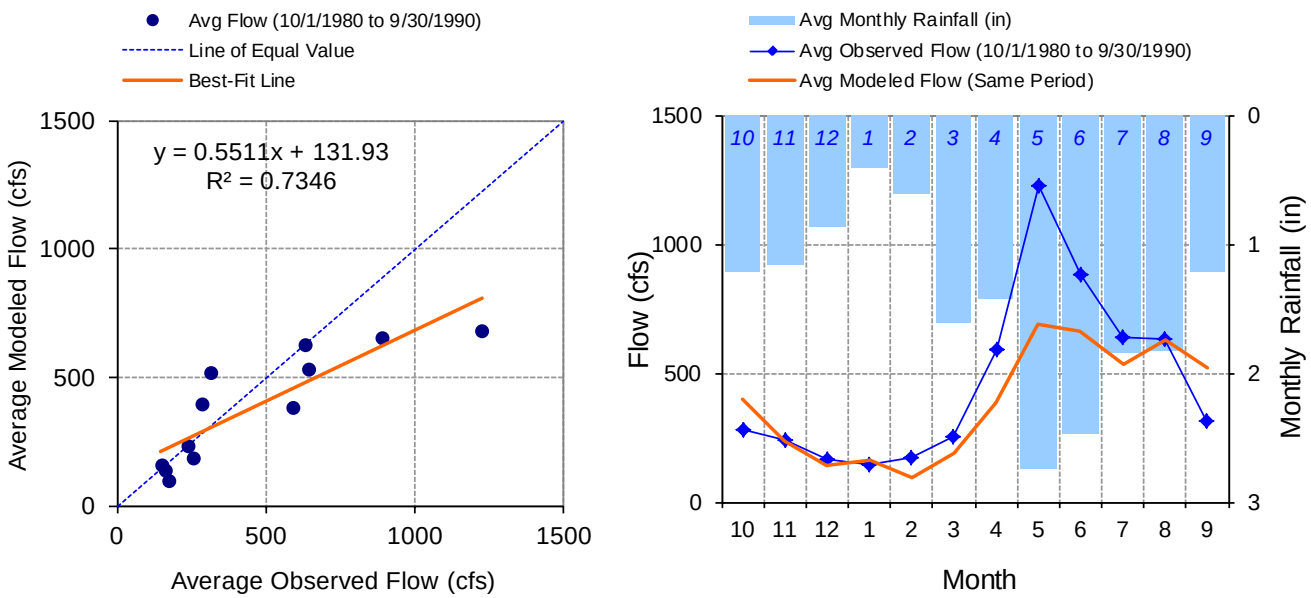


**Figure 9. Seasonal regression and temporal aggregate at USGS 06714000, South Platte River at Denver, CO - validation period.**

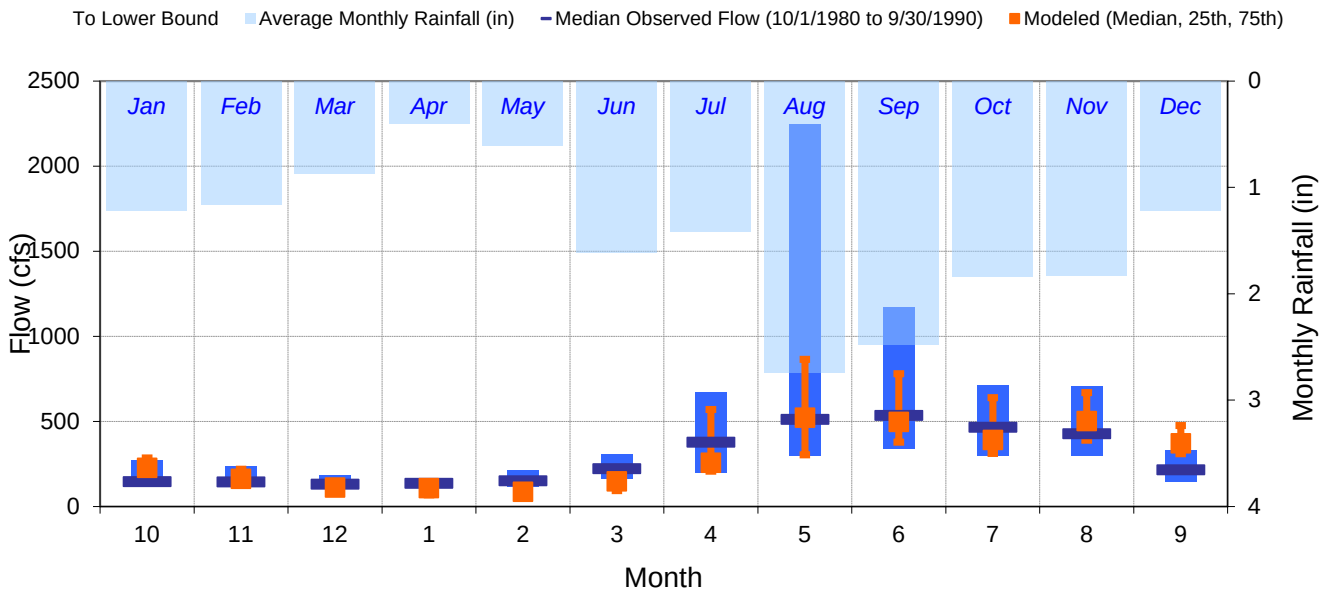


**Figure 10. Seasonal medians and ranges at USGS 06714000, South Platte River at Denver, CO – validation period.**

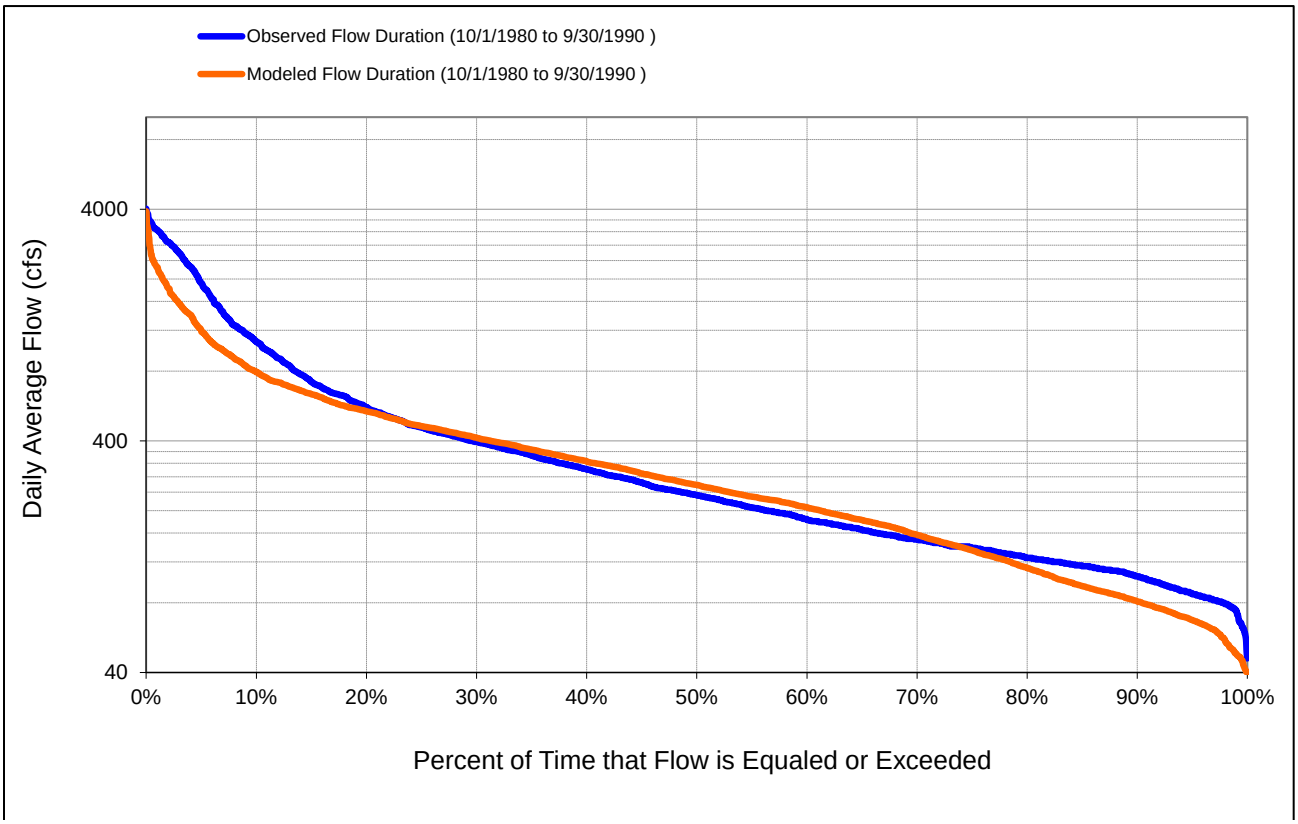


**Figure 11. Flow exceedance at USGS 06714000, South Platte River at Denver, CO - validation period.**

**Table 7. Summary statistics at USGS 06714000, South Platte River at Denver, CO - validation period**

| SWAT Simulated Flow | | Observed Flow Gage | |
|---|---|---|---|
| REACH OUTFLOW FROM OUTLET(S) 31, 32<br>10-Year Analysis Period: 10/1/1980 - 9/30/1990<br>Flow volumes are (inches/year) for upstream drainage area | | USGS 06714000 SOUTH PLATTE RIVER AT DENVER, CO<br>Hydrologic Unit Code: 10190003<br>Latitude: 39.759722222<br>Longitude: -105.166666666<br>Drainage Area (sq-mi): 3861 | |
| Total Simulated In-stream Flow: | **1.07** | Total Observed In-stream Flow: | **1.28** |
| Total of simulated highest 10% flows: | **0.39** | Total of Observed highest 10% flows: | **0.58** |
| Total of Simulated lowest 50% flows: | **0.20** | Total of Observed Lowest 50% flows: | **0.20** |
| Simulated Summer Flow Volume (months 7-9): | **0.39** | Observed Summer Flow Volume (7-9): | **0.37** |
| Simulated Fall Flow Volume (months 10-12): | **0.18** | Observed Fall Flow Volume (10-12): | **0.16** |
| Simulated Winter Flow Volume (months 1-3): | **0.10** | Observed Winter Flow Volume (1-3): | **0.13** |
| Simulated Spring Flow Volume (months 4-6): | **0.40** | Observed Spring Flow Volume (4-6): | **0.62** |
| Total Simulated Storm Volume: | **0.25** | Total Observed Storm Volume: | **0.42** |
| Simulated Summer Storm Volume (7-9): | **0.08** | Observed Summer Storm Volume (7-9): | **0.14** |
| *Errors (Simulated-Observed)* | *Error Statistics* | *Recommended Criteria* | |
| **Error in total volume:** | **-16.28** | **10** | |
| Error in 50% lowest flows: | -0.62 | 10 | |
| **Error in 10% highest flows:** | **-32.91** | **15** | |
| Seasonal volume error - Summer: | 5.88 | 30 | |
| Seasonal volume error - Fall: | 13.67 | 30 | |
| Seasonal volume error - Winter: | -21.65 | 30 | |
| **Seasonal volume error - Spring:** | **-35.95** | **30** | |
| **Error in storm volumes:** | **-39.52** | **20** | |
| Error in summer storm volumes: | -39.71 | 50 | |
| Nash-Sutcliffe Coefficient of Efficiency, E: | 0.523 | Model accuracy increases | |
| Baseline adjusted coefficient (Garrick), E': | 0.423 | as E or E' approaches 1.0 | |
| Monthly NSE | 0.627 | | |

## Hydrology Results for Larger Watershed

Minor adjustments were made to the parameters determined for the initial calibration gage to improve the fit downstream. Calibration and validation was pursued at a total of four gages in the watershed. Calibration results were fair at most gages, as summarized in Table 8, with significant seasonal volume errors. This is primarily the result of the simplified representation of inter-basin transfers and reservoir storage in the watershed, and so is deemed acceptable.

Results of the validation exercise are summarized in Table 9. Problems similar to those experienced in the calibration period were seen at all the gages and total flows tended to be underpredicted, likely due to an increase in storage and withdrawals since the 1980s.

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

| Station | 06714000 South Platte River at Denver, CO | 06720500 South Platte River at Henderson, CO | 06754000 South Platte River near Kersey, CO | 06758500 South Platte River near Weldona, CO |
|---|---|---|---|---|
| Error in total volume: | 9.82 | 3.89 | 10.69 | -0.38 |
| Error in 50% lowest flows: | 1.05 | 1.79 | -1.85 | -9.55 |
| Error in 10% highest flows: | -3.29 | -3.37 | -1.04 | 8.26 |
| Seasonal volume error - Summer: | 32.89 | 14.68 | 54.26 | 33.55 |
| Seasonal volume error - Fall: | 26.06 | -5.77 | -25.53 | -28.93 |
| Seasonal volume error - Winter: | -35.47 | -27.37 | -23.18 | -45.57 |
| Seasonal volume error - Spring: | 0.17 | 10.68 | 20.03 | 11.49 |
| Error in storm volumes: | -29.43 | -0.10 | -32.95 | -41.56 |
| Error in summer storm volumes: | -35.56 | -0.31 | -24.85 | -25.86 |
| Daily Nash-Sutcliffe Coefficient of Efficiency, E: | 0.738 | 0.610 | 0.597 | 0.628 |
| Monthly Nash-Sutcliffe Coefficient: | 0.857 | 0.811 | 0.689 | 0.734 |

**Table 9. Summary statistics: all stations - validation period**

| Station | 06714000 South Platte River at Denver, CO | 06720500 South Platte River at Henderson, CO | 06754000 South Platte River near Kersey, CO | 06758500 South Platte River near Weldona, CO |
|---|---|---|---|---|
| Error in total volume: | -16.28 | -15.23 | -18.38 | -34.38 |
| Error in 50% lowest flows: | -0.62 | -3.83 | -3.73 | -15.24 |
| Error in 10% highest flows: | -32.91 | -26.23 | -36.86 | -37.64 |
| Seasonal volume error - Summer: | 5.88 | 3.72 | 16.98 | -3.46 |
| Seasonal volume error - Fall: | 13.67 | -6.26 | -32.91 | -49.87 |
| Seasonal volume error - Winter: | -21.65 | -28.43 | -39.92 | -57.46 |
| Seasonal volume error - Spring: | -35.95 | -25.81 | -18.82 | -32.82 |
| Error in storm volumes: | -39.52 | -7.64 | -42.20 | -52.40 |
| Error in summer storm volumes: | -39.71 | 6.38 | -42.38 | -37.33 |
| Daily Nash-Sutcliffe Coefficient of Efficiency, E: | 0.523 | 0.521 | 0.572 | 0.568 |
| Monthly Nash-Sutcliffe Coefficient: | 0.627 | 0.665 | 0.612 | 0.632 |

## Water Quality Calibration and Validation

Initial calibration of water quality was done for the South Platte River at Denver (USGS 06714000), using available data for 1993-2000. Insufficient earlier data were available to allow a separate validation period at this station; however, validation for brief earlier periods was performed at downstream sites. As with hydrology, water quality calibration was performed on the later period as this better reflects the land use included in the model. The start of the validation period is constrained by data availability.

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 for the South Platte River at Denver station are shown in Figure 12 and statistics are provided 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. Several large loading events were underpredicted by the model, likely due to uncertainty in the simulation of reservoir trapping. 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.

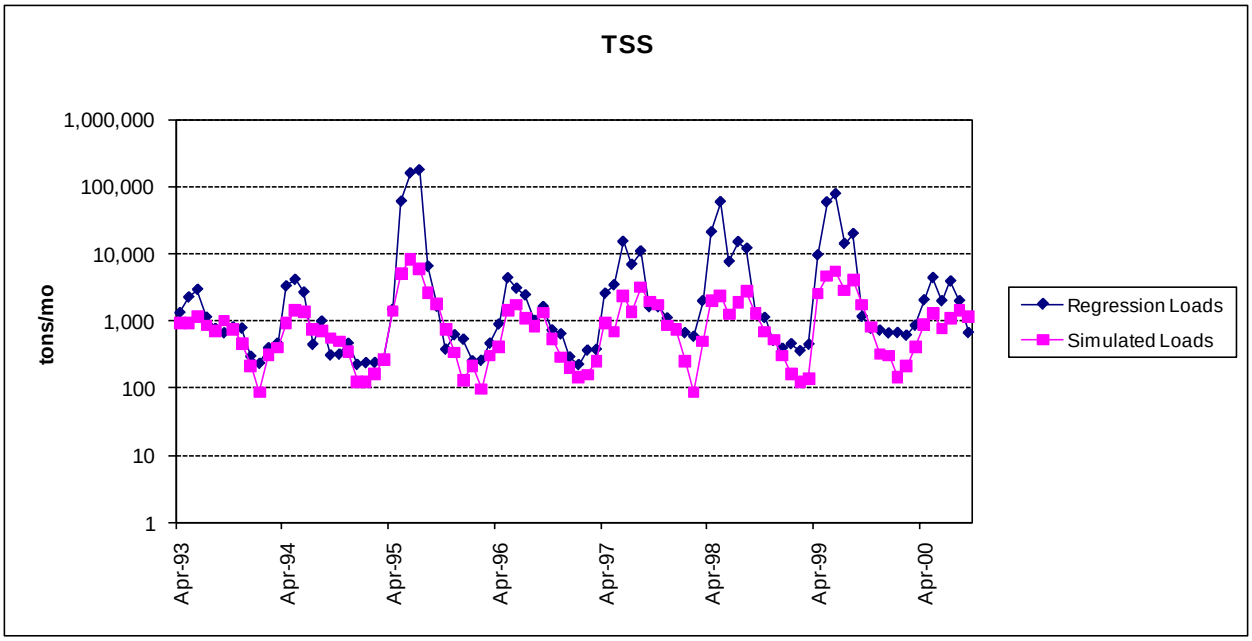


**Figure 12. Fit for monthly load of TSS at USGS 06714000, South Platte River at Denver, CO.**

**Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 06714000, South Platte River at Denver, CO**

| Statistic | Calibration period (1993-2000) |
|---|---|
| Relative Percent Error | 86.6% |
| Relative Average Absolute Error | 77% |
| Relative Median Absolute Error | 4.2% |

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 good for the nutrients.

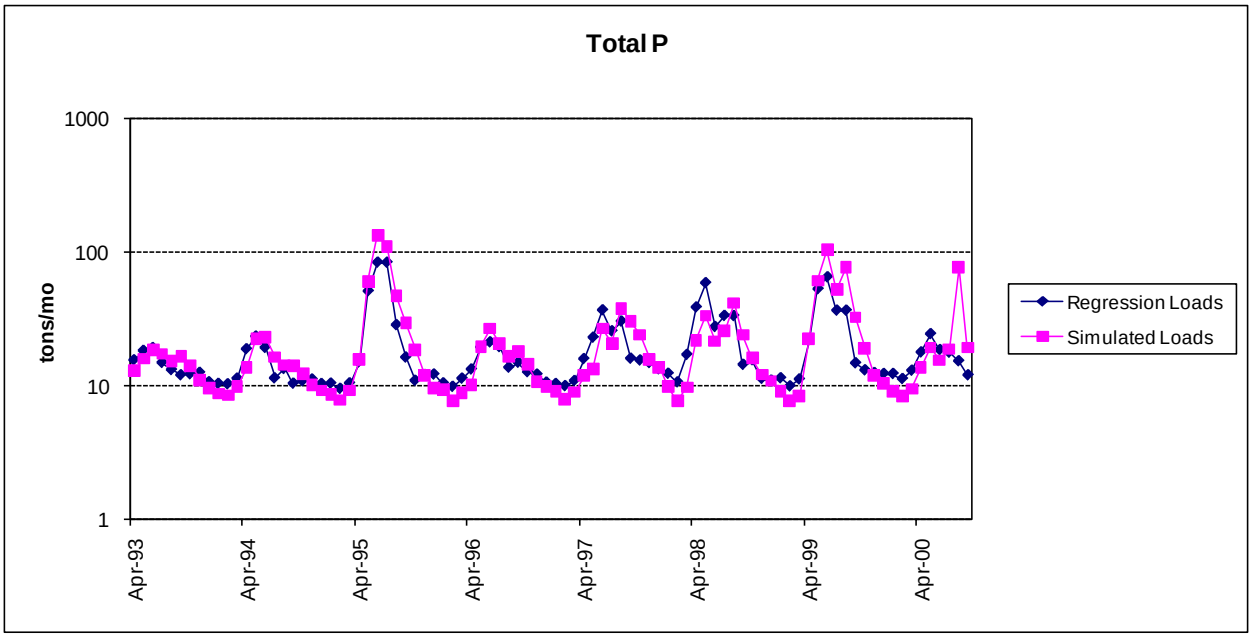


**Figure 13. Fit for monthly load of total phosphorus at USGS 06714000, South Platte River at Denver, CO.**

**Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 06714000, South Platte River at Denver, CO**

| Statistic | Calibration period (1993-2000) |
|---|---|
| Relative Percent Error | -14.0% |
| Average Absolute Error | 34% |
| Median Absolute Error | 13.4% |

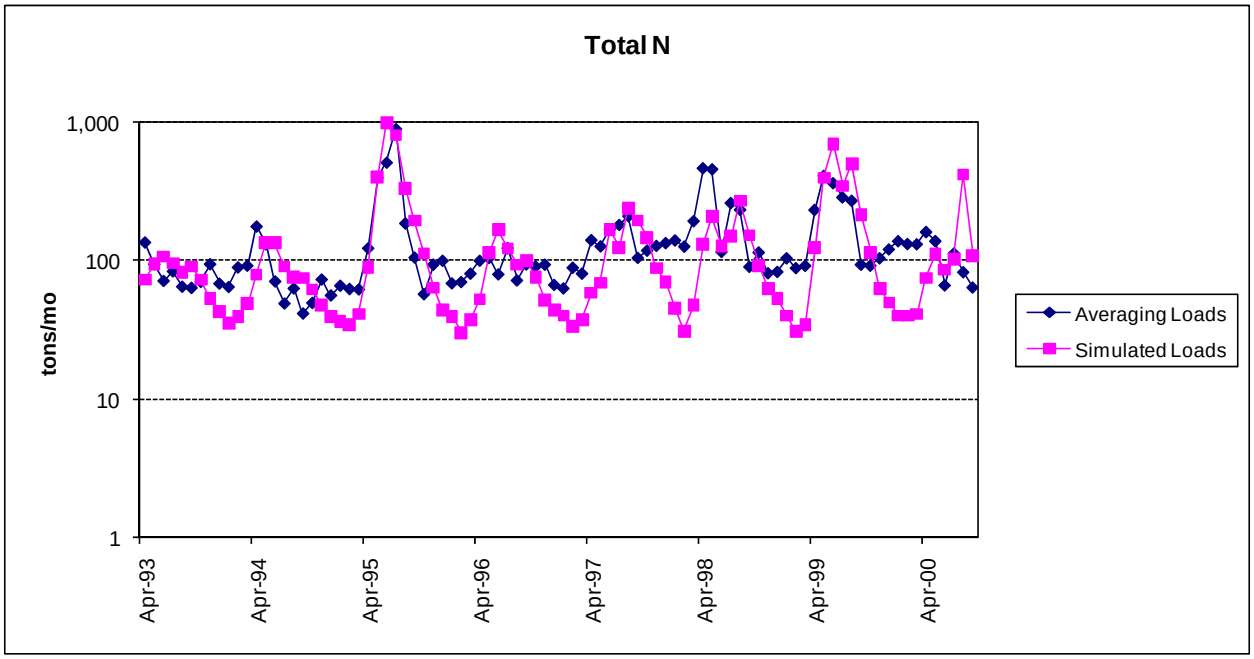


**Figure 14. Fit for monthly load of total nitrogen at USGS 06714000, South Platte River at Denver, CO.**

**Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 06714000, South Platte River at Denver, CO**

| Statistic | Calibration period (1993-2000) |
|---|---|
| Relative Percent Error | 6.1% |
| Average Absolute Error | 46% |
| Median Absolute Error | 29.4% |

## Water Quality Results for Larger Watershed

The SWAT model parameters for water quality determined for South Platte River at Denver were directly transferred to other portions of the watershed. Application of the SWAT model without spatial adjustments resulted in relatively large errors in predicting loads and concentrations at some stations. Sediment loads appear to be under-predicted throughout, reflecting the underprediction at the upstream station, but nutrients are fit fairly well. 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 1993-2002**

| Station | 06714000 South Platte River at Denver, CO | 06720500 South Platte River at Henderson, CO | 06754000 South Platte River near Kersey, CO | 06758500 South Platte River near Weldona, CO |
|---|---|---|---|---|
| Relative Percent Error TSS Load | 86.6% | 75.2% | 73.3% | ND |
| Relative Percent Error TP Load | -14.0% | -6.8% | 0.5% | 36.9% |
| Relative Percent Error TN Load | 6.1% | 11.9% | 9.1% | -36.0% |

**Table 14. Summary statistics for water quality at all stations – validation period 1986-1992**

| Station | 06714000 South Platte River at Denver, CO | 06720500 South Platte River at Henderson, CO | 06754000 South Platte River near Kersey, CO | 06758500 South Platte River near Weldona, CO |
|---|---|---|---|---|
| Relative Percent Error TSS Load | ND | 14.7% | ND | ND |
| Relative Percent Error TP Load | ND | -0.8% | ND | 5.0% |
| Relative Percent Error TN Load | ND | 2.7% | ND | 7.7% |

# References

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