Appendix T
Model Configuration, Calibration and Validation

Basin: South Platte

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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 basin is located in parts of three states: Colorado (79%), Nebraska (15%), and Wyoming (6%) (Figure 1). The South Platte River originates in the mountains of central Colorado and flows about 450 miles northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska. Altitude in the basin ranges from 14,286 ft at Mt. Lincoln on the Continental Divide to 2,750 ft at the confluence of the South Platte and North Platte Rivers.

The watershed 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. Most of the precipitation on the plains occurs as rain, which typically falls between April and September, whereas most of the precipitation in the mountains occurs as snow, which typically falls between October and March (Dennehy et al. 1993).

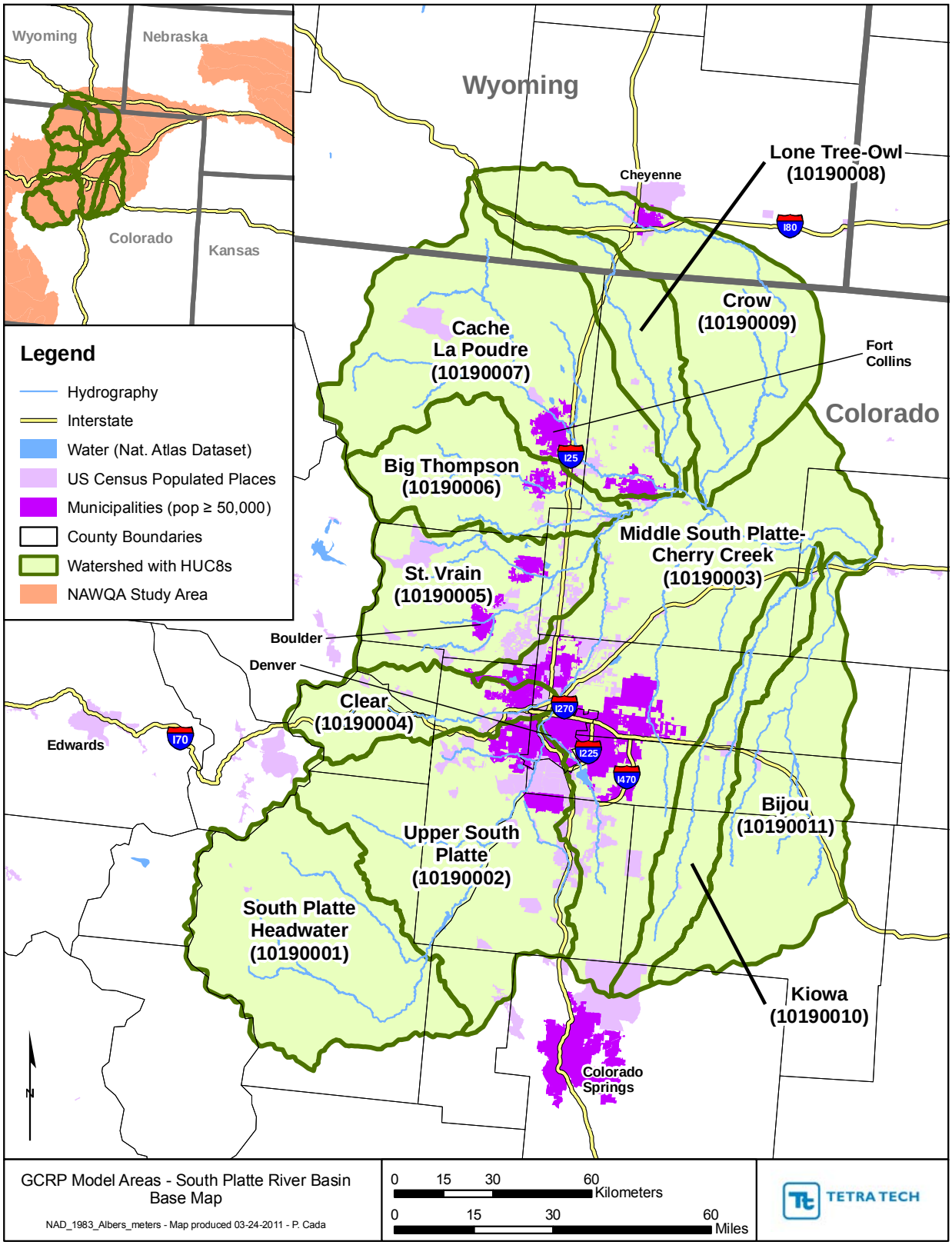

Figure 1. Location of the South Platte watershed.

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.

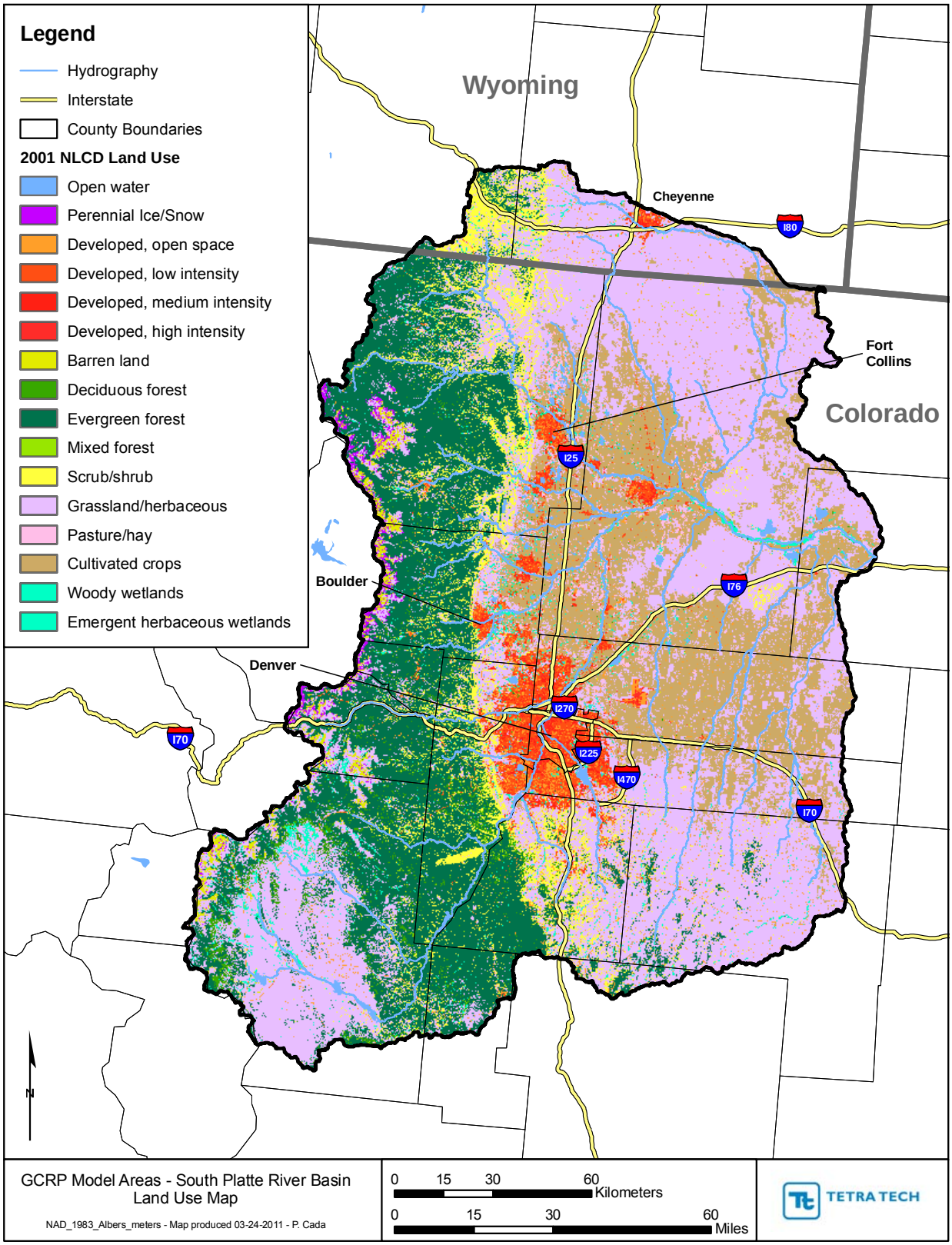

Figure 2. Land use in the South Platte watershed.

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**	13.70	7.41	19.84	1.20	0.03	0.00	37.52	523.35	920.60	6.59	0.06	70.07	1,600.38
Upper Southe Platte **10190002**	9.44	3.13	68.50	96.53	35.26	11.60	17.76	1,123.53	436.99	3.19	2.45	39.92	1,848.28
Middle South Platte-Cherry Creek **10190003**	39.56	0.00	130.37	123.96	67.79	25.40	4.00	46.51	1,298.09	70.50	963.22	76.72	2,846.11
Clear **10190004**	3.43	18.88	18.92	44.34	15.36	5.97	19.25	279.11	148.67	1.49	0.64	8.91	564.98
St. Vrain, 1**0190005**	16.80	27.28	29.35	43.24	15.62	3.87	25.77	395.03	177.49	42.72	172.96	37.53	987.66
Big Thompson. **10190006**	13.08	13.43	16.89	17.75	5.85	1.01	22.26	385.33	194.70	17.42	128.16	17.58	833.47
Cache La Poudre. **10190007**	27.09	22.23	36.74	42.24	14.21	3.35	15.87	623.36	737.28	44.63	296.35	40.44	1,903.80
Lone Tree-Owl.. **10190008**	0.78	0.00	14.76	2.28	0.51	0.04	1.33	1.96	408.81	6.90	126.39	4.25	568.00
Crow. **10190009**	1.91	0.00	32.36	12.53	7.02	1.84	5.21	30.02	1,093.97	12.80	147.79	9.41	1,354.88
Kiowa. **10190010**	0.20	0.00	23.07	1.55	0.61	0.09	0.57	29.62	415.65	4.25	234.56	10.09	720.25
Bijou **10190011**	1.10	0.00	42.40	2.23	0.39	0.03	0.60	27.45	928.58	8.62	340.57	18.47	1,370.43
Total	127.09	92.37	433.20	387.83	162.63	53.19	150.14	3,465.29	6,760.85	219.12	2,413.15	333.37	14,598.24

[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.

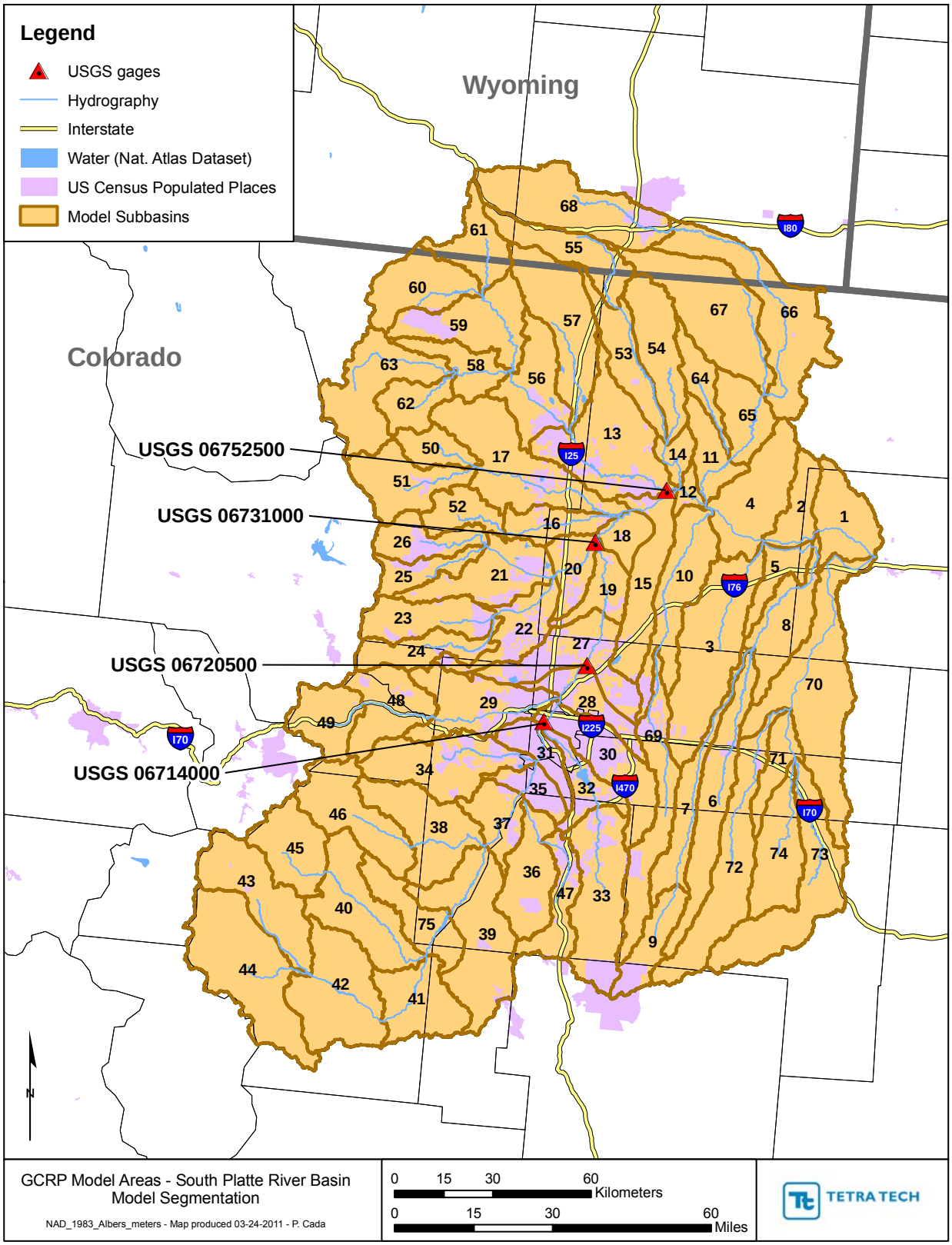

Figure 3. Model segmentation and USGS stations utilized for the South Platte River watershed.

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.

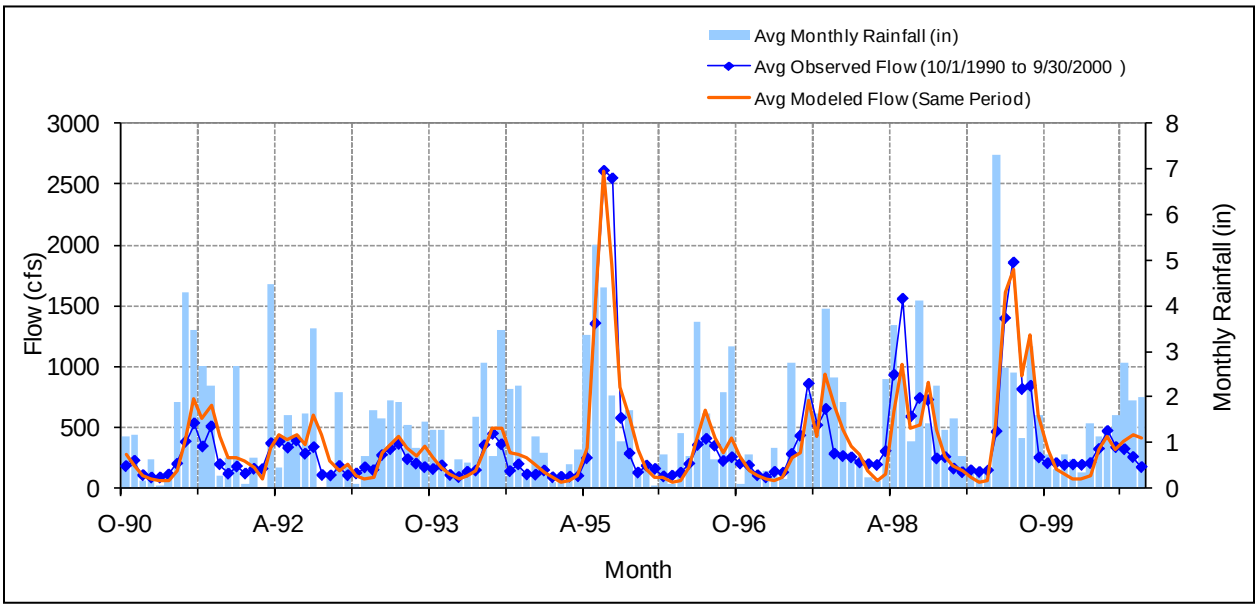

Figure 4. Mean monthly flow at USGS 06714000, South Platte River at Denver, CO – calibration period.

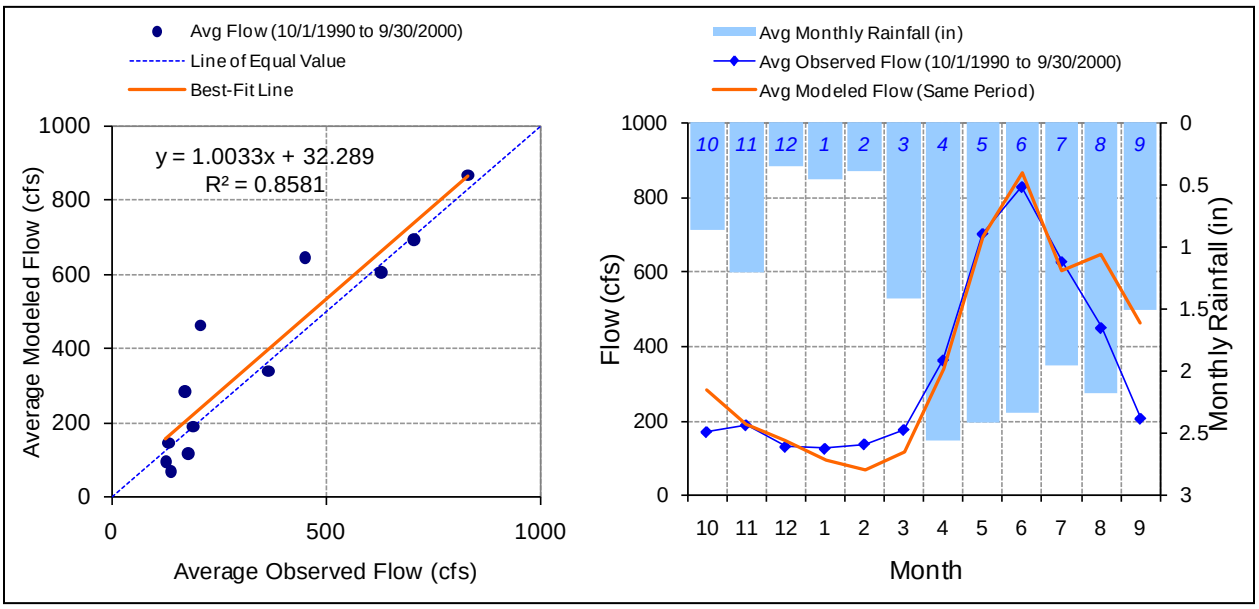

Figure 5. Seasonal regression and temporal aggregate at USGS 06714000, South Platte River at Denver, CO - calibration period.

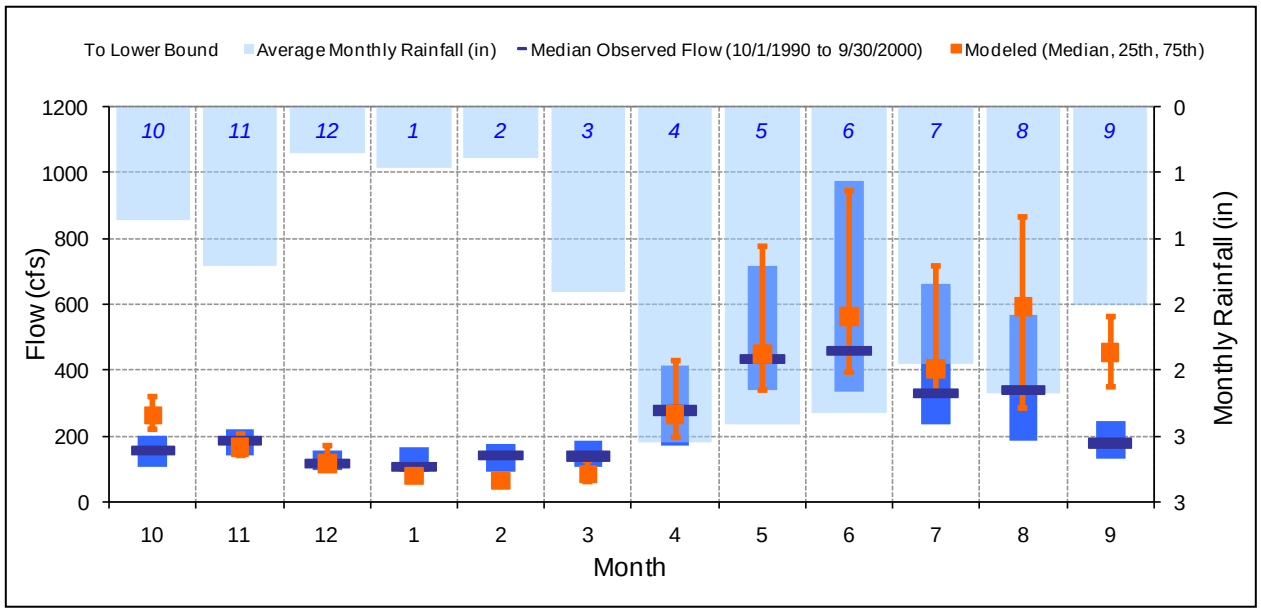

Figure 6. Seasonal medians and ranges at USGS 06714000, South Platte River at Denver, CO – calibration period.

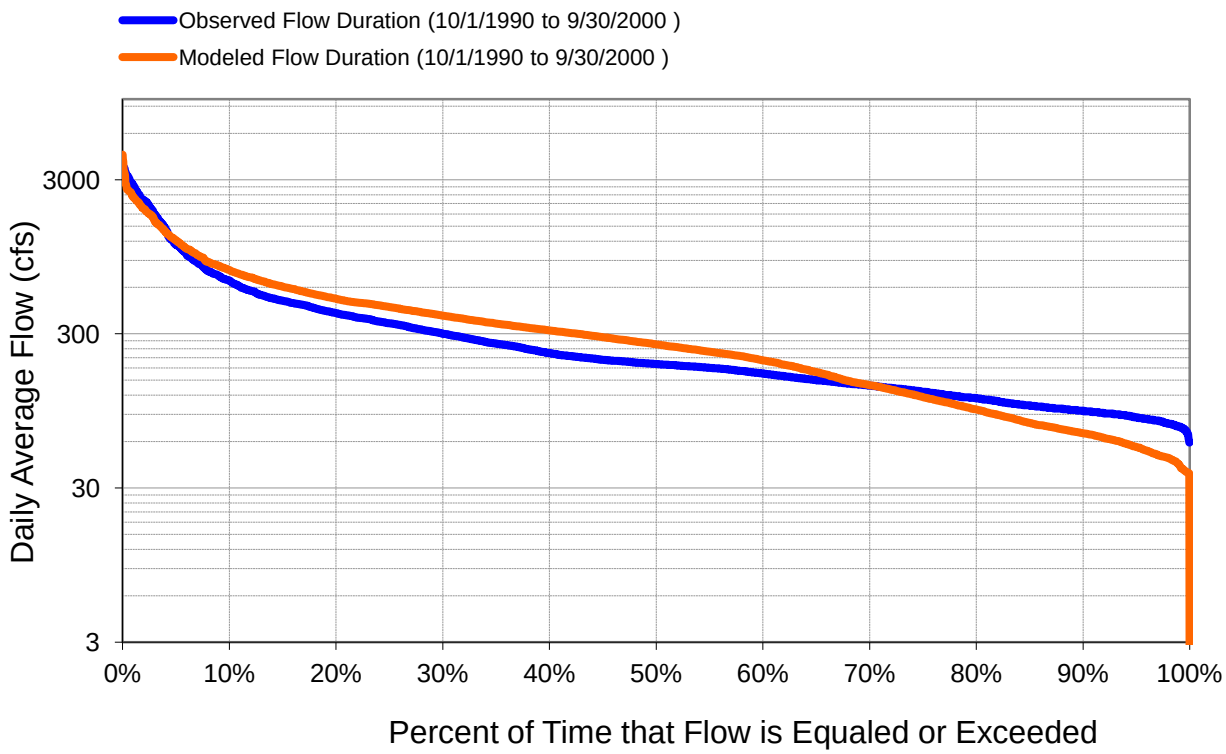

Figure 7. Flow exceedance at USGS 06714000, South Platte River at Denver, CO - calibration period.

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 10-Year Analysis Period: 10/1/1990 - 9/30/2000 Flow volumes are (inches/year) for upstream drainage area		USGS 06714000 SOUTH PLATTE RIVER AT DENVER, CO Hydrologic Unit Code: 10190003 Latitude: 39.759722222 Longitude: -105.166666666 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	0.895		

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.

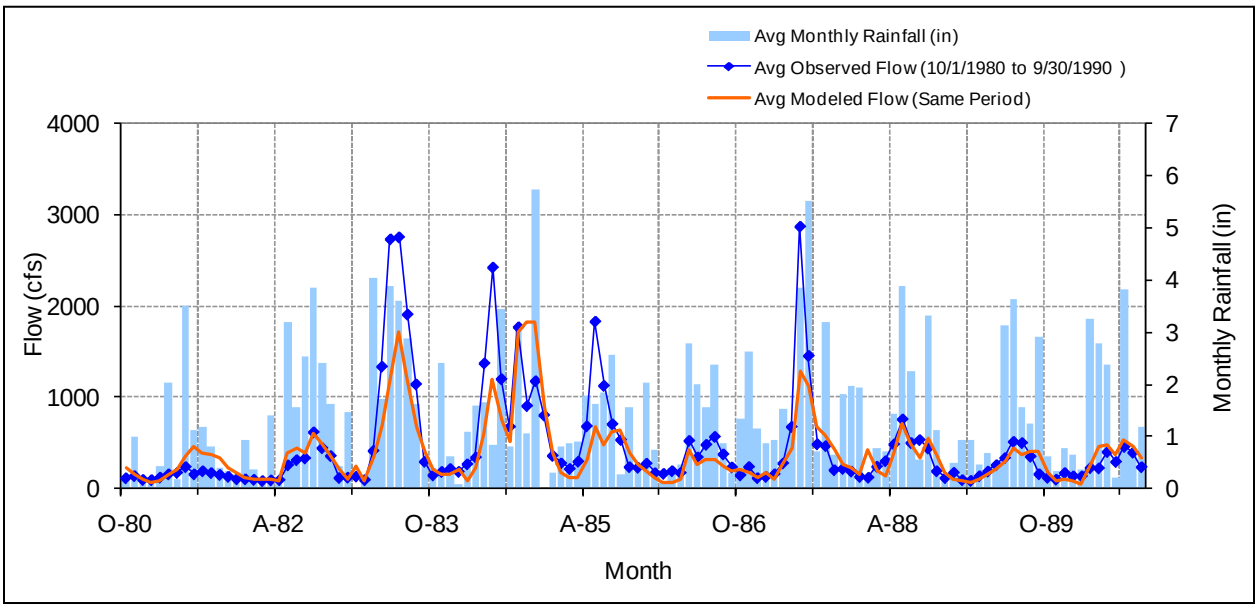

Figure 8. Mean monthly flow at USGS 06714000, South Platte River at Denver, CO – validation period.

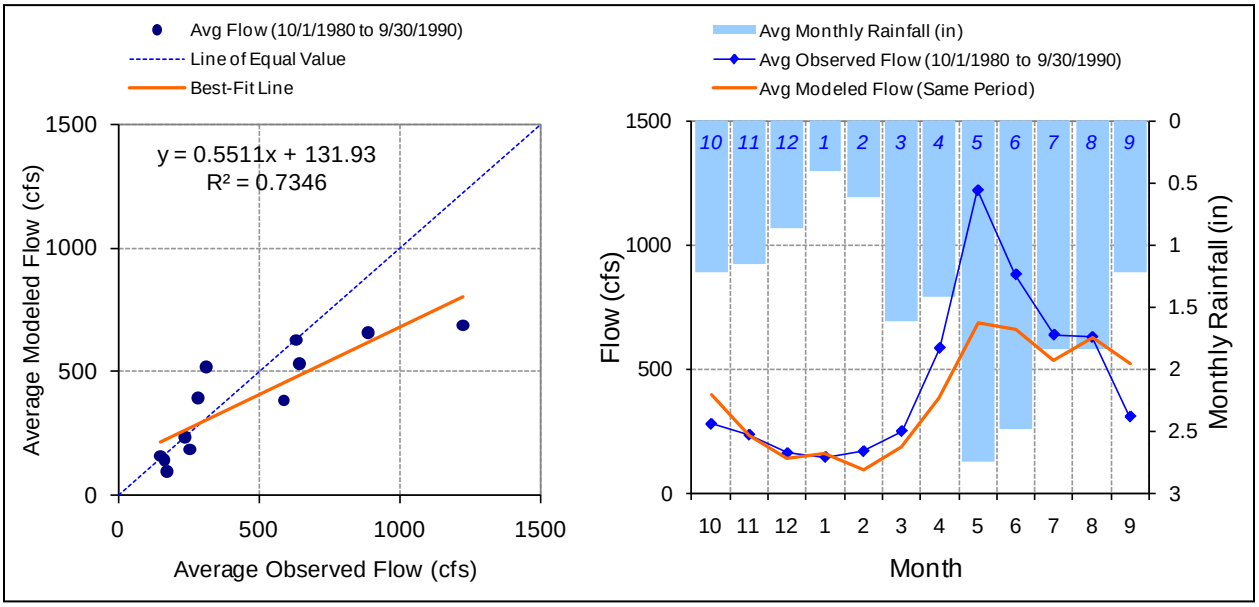

Figure 9. Seasonal regression and temporal aggregate at USGS 06714000, South Platte River at Denver, CO - validation period.

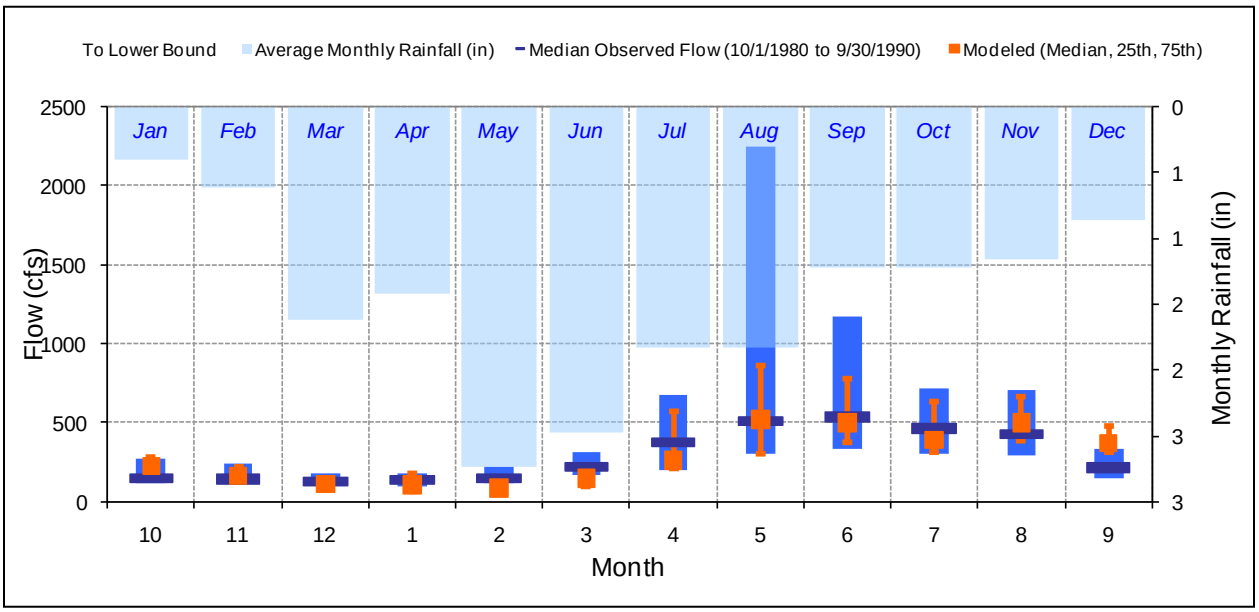

Figure 10. Seasonal medians and ranges at USGS 06714000, South Platte River at Denver, CO – validation period.

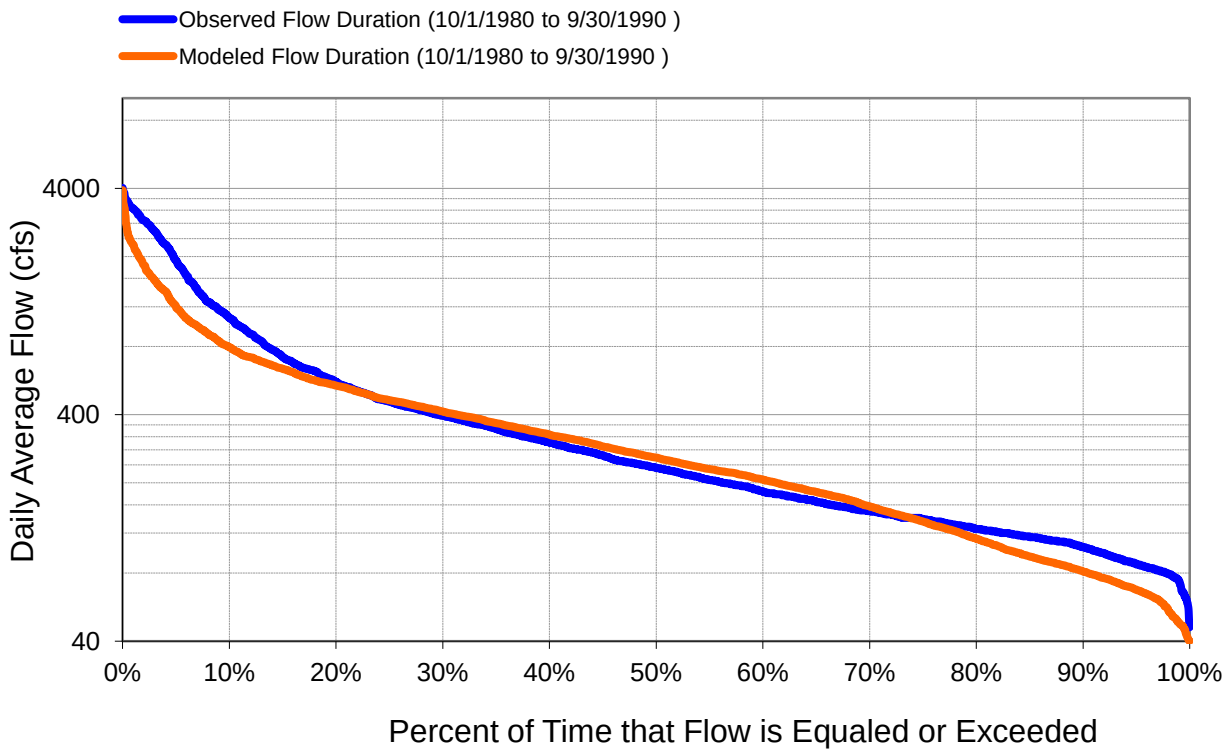

Figure 11. Flow exceedance at USGS 06714000, South Platte River at Denver, CO - validation period.

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 10-Year Analysis Period: 10/1/1980 - 9/30/1990 Flow volumes are (inches/year) for upstream drainage area		USGS 06714000 SOUTH PLATTE RIVER AT DENVER, CO Hydrologic Unit Code: 10190003 Latitude: 39.759722222 Longitude: -105.166666666 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	Clear
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	0.753		

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
Nash-Sutcliffe Coefficient of Efficiency, E:	0.738	0.610	0.597	0.628
Monthly Nash-Sutcliffe Coefficient:	0.895	0.875	0.748	0.783

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
Nash-Sutcliffe Coefficient of Efficiency, E:	0.523	0.521	0.572	0.568
Monthly Nash-Sutcliffe Coefficient:	0.753	0.789	0.691	0.710

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.

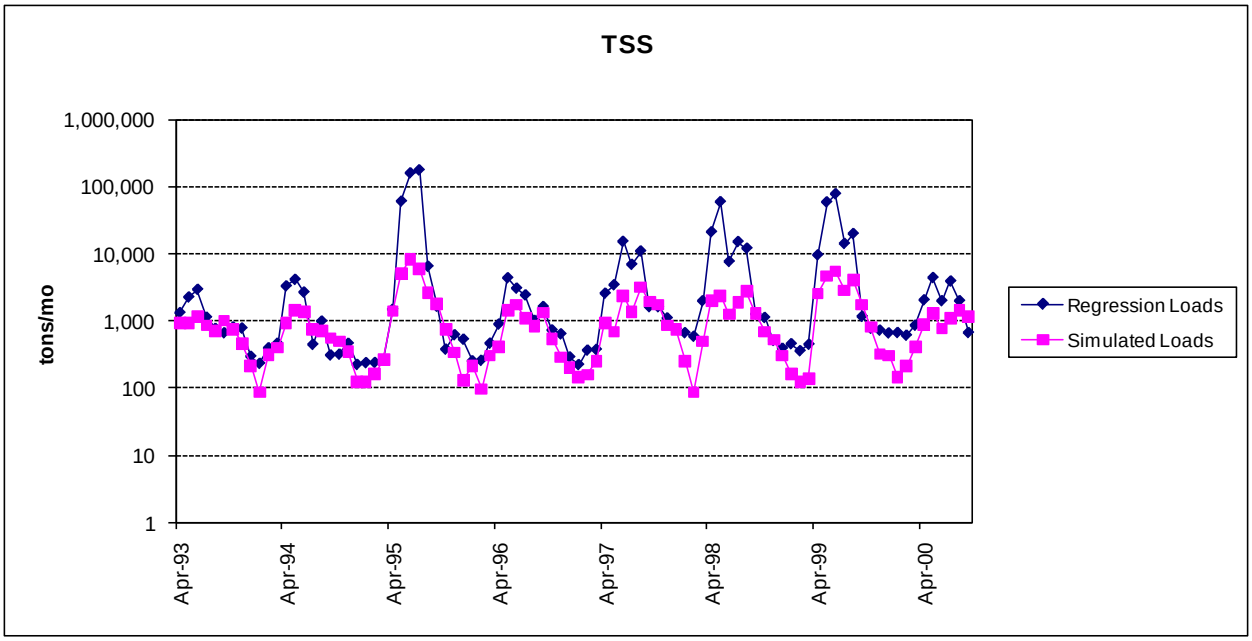

Figure 12. Fit for monthly load of TSS at USGS 06714000, South Platte River at Denver, CO.

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° 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 good for the nutrients.

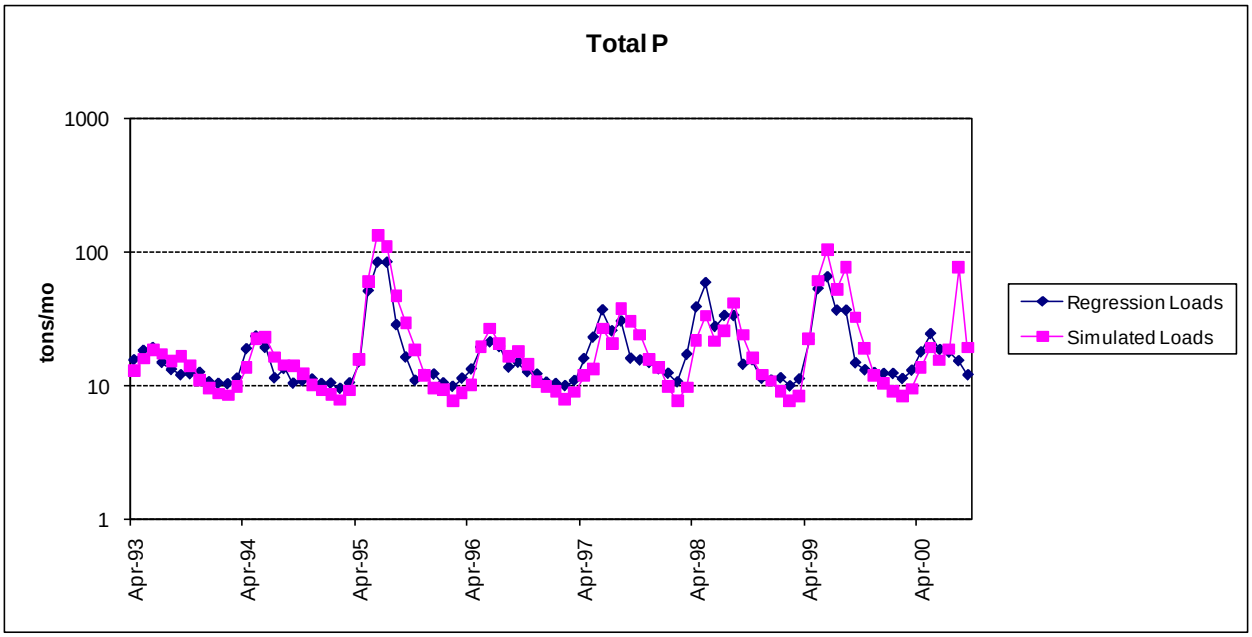

Figure 13. Fit for monthly load of total phosphorus at USGS 06714000, South Platte River at Denver, CO.

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%

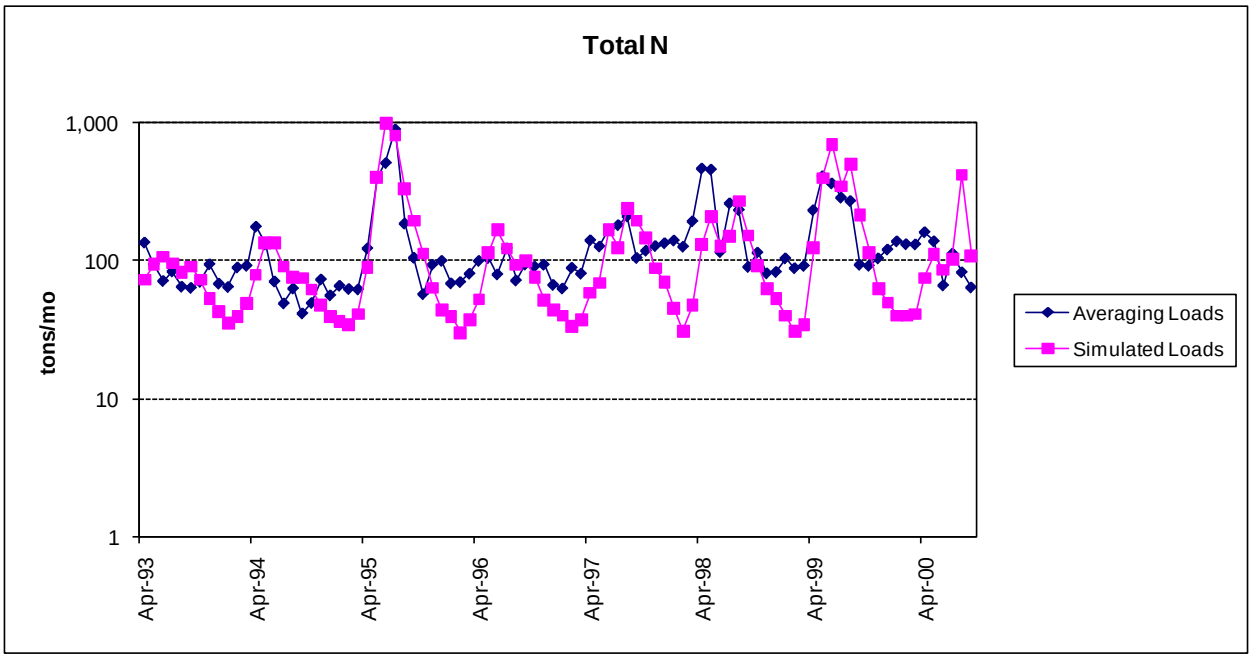

Figure 14. Fit for monthly load of total nitrogen at USGS 06714000, South Platte River at Denver, CO.

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

Dennehy, K.F., D.W. Litke, C.M. Tate, and J.S. Heiny. 1993. South Platte River Basin – Colorado, Nebraska, and Wyoming. *Water Resources Bulletin*, 29(4):647-683.

Tetra Tech. 1999. Improving Point Source Loadings Data for Reporting National Water Quality Indicators. Final Technical Report prepared for U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, by Tetra Tech, Inc., Fairfax, VA.

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