Appendix W
Model Configuration, Calibration and Validation

Basin: Yellowstone River

Contents

Watershed Background **1**
Water Body Characteristics 1
Soil Characteristics 3
Land Use Representation 3
Point Sources 7
Meteorological Data 7
Watershed Segmentation 8
Calibration Data and Locations 10
SWAT Modeling **11**
Assumptions 11
Hydrology Calibration 11
Hydrology Validation 15
Hydrology Results for Larger Watershed 18
Water Quality Calibration and Validation 20
Water Quality Results for Larger Watershed 23
References **25**

Tables

Table 1. Aggregation of NLCD land cover classes 5
Table 2. Land use distribution for the Yellowstone River basin (2001 NLCD) (mi^2)....6
Table 3. Major point source discharges in the Yellowstone River basin 7
Table 4. Precipitation stations for the Yellowstone River watershed model....7
Table 5. Calibration and validation locations in the Yellowstone River basin 10
Table 6. Summary statistics at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period....15
Table 7. Summary statistics at USGS 06306300 Tongue River at State Line near Decker, MT – validation period....18
Table 8. Summary statistics (percent error): all stations - calibration period....19
Table 9. Summary statistics (percent error): all stations - validation period....19
Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 06306300 Tongue River at State Line near Decker, MT 21
Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 06306300 Tongue River at State Line near Decker, MT 22
Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 06306300 Tongue River at State Line near Decker, MT....23
Table 13. Summary statistics for water Quality at all stations – calibration period 1993-2003....23
Table 14. Summary statistics for water quality at all stations – validation period 1983-1993....24

Figures

Figure 1. Location of the Yellowstone River basin. 2
Figure 2. Land use in the Yellowstone River basin. 4
Figure 3. Model segmentation and USGS stations utilized for the Yellowstone River basin. 9
Figure 4. Mean monthly flow at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period....13
Figure 5. Seasonal regression and temporal aggregate at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period. 13
Figure 6. Seasonal medians and ranges at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period....14
Figure 7. Flow exceedance at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period....14
Figure 8. Mean monthly flow at USGS 06306300 Tongue River at State Line near Decker, MT – validation period....16
Figure 9. Seasonal regression and temporal aggregate at USGS 06306300 Tongue River at State Line near Decker, MT – validation period. 16
Figure 10. Seasonal medians and ranges at USGS 06306300 Tongue River at State Line near Decker, MT – validation period....17
Figure 11. Flow exceedance at USGS 06306300 Tongue River at State Line near Decker, MT – validation period....17
Figure 12. Fit for monthly load of TSS at USGS 06306300 Tongue River at State Line near Decker, MT...20
Figure 13. Fit for monthly load of total phosphorus at USGS 06306300 Tongue River at State Line near Decker, MT. 22
Figure 14. Fit for monthly load of total nitrogen at USGS 06306300 Tongue River at State Line near Decker, MT. 23

Watershed Background

The Yellowstone River basin was selected as one of the 15 non-pilot application watersheds for the 20 Watershed study. This basin was selected as representative of conditions in the northern plains. 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 Yellowstone River basin is part of the Missouri River system on the east side of the Rocky Mountains. The basin as a whole occupies an area of 70,000 square miles in Wyoming and Montana, with a small portion in North Dakota, and consists of four major drainages: the Yellowstone, Bighorn, Tongue, and Powder Rivers. The 20 Watershed study focuses on the eastern portion of the overall basin, consisting of the Tongue and Powder River drainages (Figure 1).

Annual rainfall in the Yellowstone basin is highly variable due to rain shadow effects, ranging from about 6 to 60 inches per year (Peterson et al. 2004). The Tongue and Powder watersheds arise in the Bighorn Mountains, part of the Middle Rockies ecoregion, but quickly transition to the Northwestern Great Plains ecoregion on Tertiary sedimentary rocks. Streams in the mountain headwaters are dominated by the accumulation and melting of the annual snowpack under current climatic conditions, while the plains streams flows are affected more by local and regional rain events (Peterson et al. 2004).

Population density in the basin is sparse with limited amounts of agriculture in the plains supported by surface water withdrawals. The majority of the land cover is rangeland. Dissolved solids concentrations are generally high in the plains region in both surface and groundwater. An important feature of the Tongue and Powder basins is extensive coalbed methane development, beginning in the late 1990s, which has involved extensive pumping of ground water, most of which is stored in surface impoundments.

The plains streams tend to have relatively high concentrations of nitrogen, mostly as organic nitrogen and from natural sources. Phosphorus concentrations are also relatively high and due to natural sources in marine sedimentary rocks. The sparse vegetative cover and erodible soils in the plains areas contribute to large suspended sediment concentrations, and the Powder River is estimated to produce an annual suspended sediment yield of about 275 tons per square mile (Peterson et al. 2004).

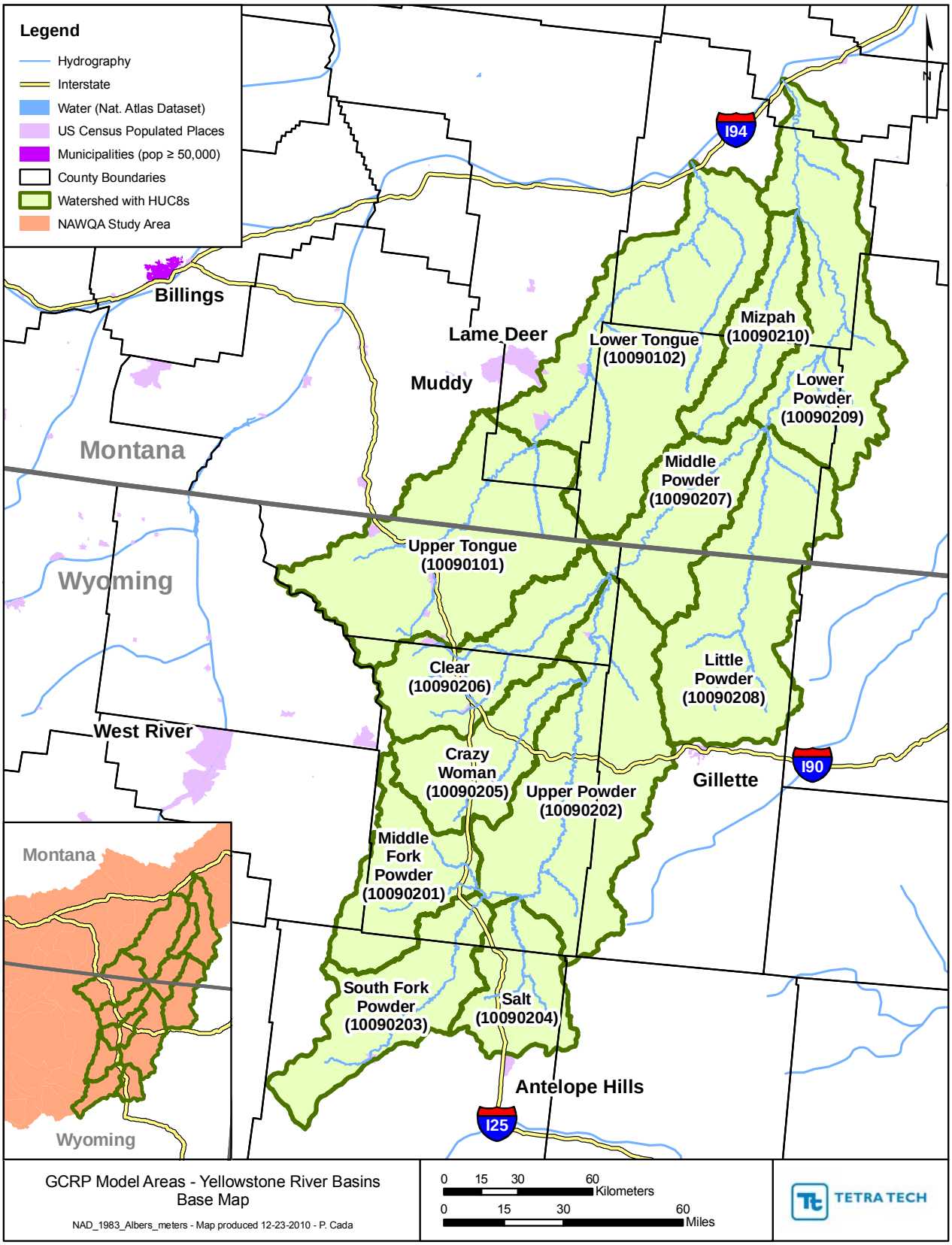

Figure 1. Location of the Yellowstone River basin.

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 20 Watershed model. SWAT uses the built-in hydrologic response unit (HRU) overlay mechanism in the ArcSWAT interface. SWAT HRUs are formed from an intersection of land use and STATSGO major soils. The distribution of land use in the watershed is summarized in Table 2.

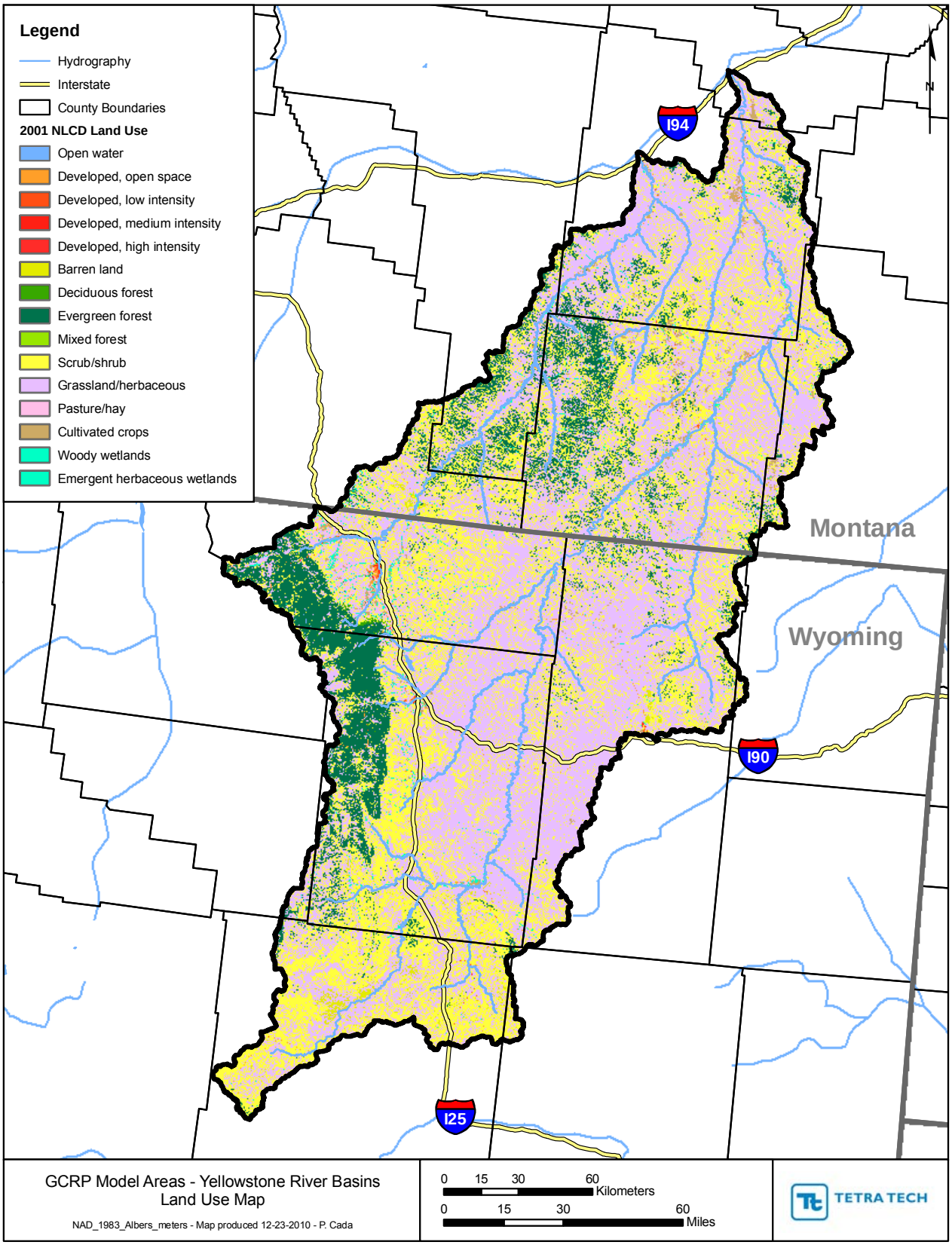

Figure 2. Land use in the Yellowstone River basin.

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 Yellowstone 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							
Lower Powder **10090209**	0.48	0.00	4.71	1.36	0.08	0.00	0.73	61.75	1,732.77	2.01	38.36	35.26	**1,877.51**
Lower Tongue **10090102**	0.96	0.00	9.19	1.91	0.54	0.06	2.85	525.93	2,209.00	12.89	31.45	62.91	**2,857.68**
Mizpah **10090210**	0.18	0.00	3.59	0.62	0.00	0.00	0.35	20.03	728.90	0.49	35.57	7.58	**797.31**
Upper Tongue **10090101**	3.35	0.00	16.81	5.92	2.03	0.51	13.14	493.15	1,838.36	52.52	23.30	79.80	**2,528.87**
Middle Powder **10090207**	1.04	0.00	2.22	0.68	0.11	0.01	3.85	111.08	913.59	3.36	10.16	16.88	**1,062.99**
Little Powder **10090208**	0.27	0.00	6.06	0.73	0.40	0.09	11.99	77.75	1,867.11	2.52	23.95	23.82	**2,014.69**
Clear **10090206**	6.95	0.36	7.31	2.34	0.73	0.10	1.32	229.32	848.49	17.76	10.55	24.20	**1,149.40**
Upper Powder **10090202**	0.15	0.00	5.10	1.02	0.01	0.00	9.19	18.02	2,449.96	2.77	7.98	29.52	**2,523.71**
Crazy Woman **10090205**	0.43	0.00	3.27	1.33	0.05	0.00	2.09	143.47	767.88	6.80	1.52	11.95	**938.79**
Middle Fork Powder **10090201**	0.10	0.00	1.52	0.59	0.04	0.00	8.34	170.87	781.65	4.96	0.18	19.42	**987.66**
South Fork Powder **10090203**	0.19	0.00	2.54	0.63	0.01	0.00	48.47	20.03	1,115.46	1.96	0.01	3.48	**1,192.80**
Salt **10090204**	0.08	0.00	2.26	2.44	0.21	0.00	22.02	8.40	759.54	0.02	0.00	2.49	**797.47**
Total	**14.19**	**0.36**	**64.58**	**19.57**	**4.21**	**0.77**	**124.32**	**1,879.79**	**16,012.71**	**108.05**	**183.04**	**317.31**	**18,728.90**

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (7.42%), low density (31.64%), medium density (59.16%), and high density (85.99%).

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 Yellowstone River basin

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
MT0000892	DECKER COAL CO (WEST MINE)		0.861
MT0020001	MILES CITY- CITY OF	1.980	1.0638
MT0024210	DECKER COAL CO (EAST MINE)		0.884
WY0020010	SHERIDAN, CITY OF		2.489

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 for the 20 Watershed SWAT simulations are precipitation and air temperature. The 20 Watershed 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 2003. A total of 37 precipitation stations were identified for use in the Yellowstone 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 Yellowstone River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (m)
241084	BRANDENBERG	45.8161	-106.2310	X	844
241127	BROADUS	45.4443	-105.4070	X	924
241297	BUSBY	45.5398	-106.9590	X	1045
241905	COLSTRIP	45.8944	-106.6330	X	981
242266	DECKER 4 NNE	45.0117	-106.8630		1073
242689	EKALAKA	45.8904	-104.5460	X	1044
244442	ISMAY	46.4997	-104.7990	X	762
245303	MAC KENZIE	46.1423	-104.7350		856
245690	MILES CITY AP	46.4267	-105.8820	X	800

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (m)
245754	MIZPAH 4 NNW	46.2859	-105.2910	X	756
245870	MOORHEAD 9 NE	45.1759	-105.7510	X	981
246691	POWDERVILLE 8 NNE	45.8525	-105.0340	X	853
247034	RIDGEWAY 1 S	45.5023	-104.4470	X	1011
247740	SONNETTE 2 WNW	45.4184	-105.8680	X	1189
248165	TERRY	46.7940	-105.3020	X	685
248607	VOLBORG	45.8437	-105.6800		908
249175	WYOLA 1 SW	45.1217	-107.4060	X	1137
480740	BILLY CREEK	44.1243	-106.7310	X	1516
481165	BUFFALO	44.3450	-106.7200	X	1423
481220	BURGESS JUNCTION	44.7743	-107.5210	X	2457
481570	CASPER WSCMO	42.8976	-106.4630	X	1627
482881	ECHETA 2 NW	44.4828	-105.8990	X	1219
483801	GAS HILLS 4 E	42.8394	-107.5130		1972
483855	GILLETTE 6 SE	44.2645	-105.4910	X	1414
485055	KAYCEE	43.7144	-106.6370	X	1420
485506	LEITER 9 N	44.8501	-106.2880	X	1268
486195	MIDWEST	43.4132	-106.2770	X	1481
486395	MOORCROFT 3 S	44.2170	-104.9290	X	1318
487375	POWDER RIVER SCHOOL	43.0359	-106.9880		1736
487376	POWDER RIVER NO 2	43.0350	-106.9880	X	1737
487545	RECLUSE	44.7409	-105.7260		1265
488155	SHERIDAN AP	44.7694	-106.9680	X	1202
488160	SHERIDAN FIELD STN	44.8407	-106.8380	X	1143
488626	STORY	44.5772	-106.8960		1549
488852	TEN SLEEP 4 NE	44.0657	-107.3800	X	1469
488858	TEN SLEEP 16 SSE	43.8112	-107.3640	X	1426
489580	WESTON 1 E	44.6406	-105.3050	X	1074

Watershed Segmentation

The Yellowstone River basin was divided into 77 subwatersheds for the purposes of modeling (Figure 3). Tongue River at State Line near Decker at USGS 06306300 was chosen for initial calibration. The model encompasses the complete watershed and does not require specification of any upstream boundary conditions for application.

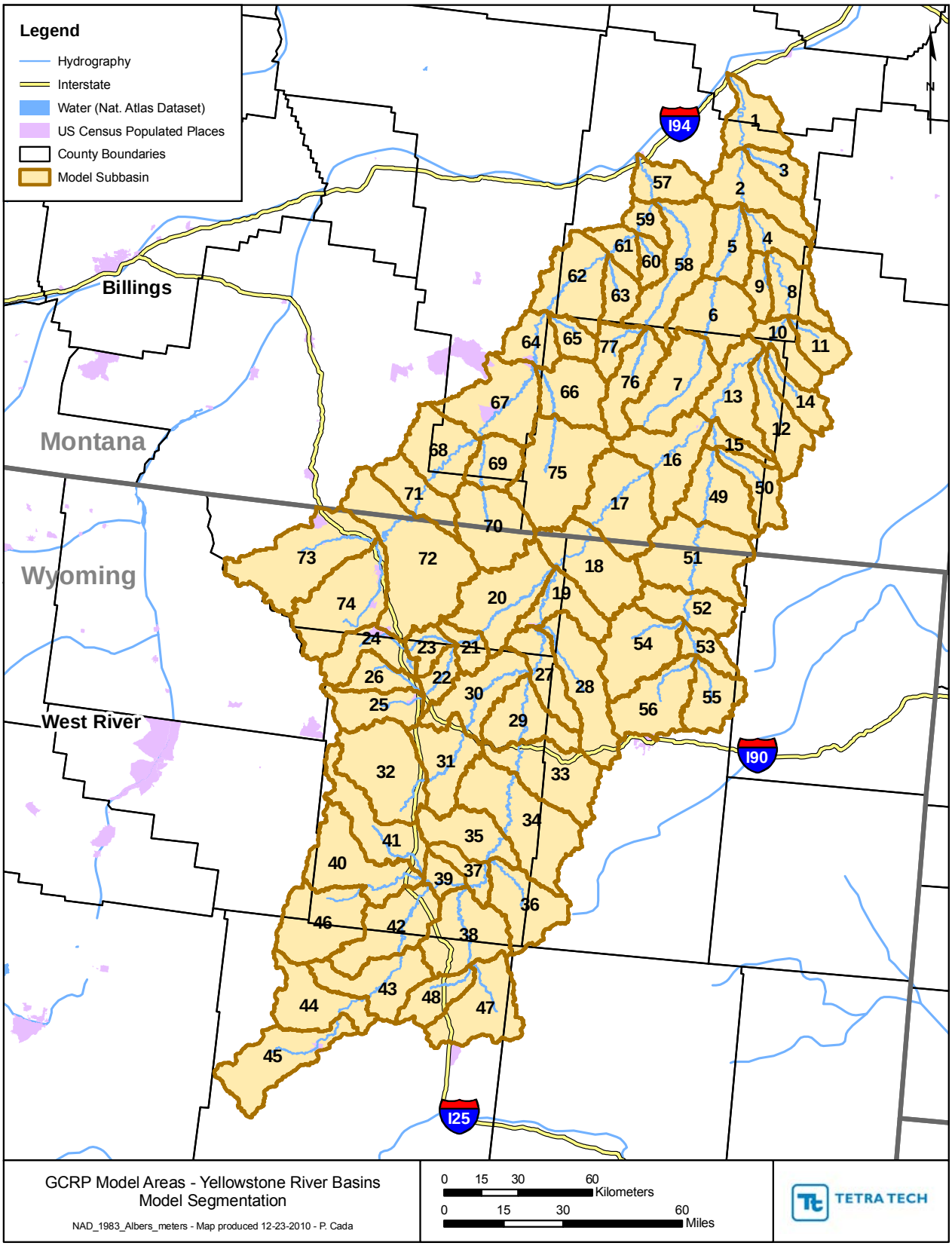

Figure 3. Model segmentation and USGS stations utilized for the Yellowstone River basin.

Calibration Data and Locations

The specific site chosen for initial calibration was the Tongue River at State Line near Decker, MT a flow and water quality monitoring location. The USGS gage located at Tongue River at State Line near Decker 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 Yellowstone River basin, and additional calibration was conducted at multiple gage locations.

Table 5. Calibration and validation locations in the Yellowstone River basin

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Tongue River at Tongue R Dam nr Decker MT	06307500	1,770	x	
Tongue River at State Line nr Decker MT	06306300	1,453	x	x
Tongue River at Birney Day School Br nr Birney MT	06307616	2,621	x	
Tongue River at Miles City MT	06308500	5,397	x	x
Powder River at Moorhead MT	06324500	8,086	x	
Powder River near Locate MT	06326500	13,068	x	

The model hydrology calibration period was set to Water Years 1993-2003 (within the 32-year period of record for modeling). Hydrologic validation was then performed on Water Years 1983-1993. Water quality calibration used calendar years 1993-2003, while validation used 1983-1993.

SWAT Modeling

Assumptions

The Yellowstone River basin is comprised of the areas drained by the Tongue River and Powder River. Tongue River reservoir is the only major impoundment that is represented in the model. Pertinent reservoir information including surface area and storage at principal (normal) and emergency spillway levels for the reservoir were obtained from the State Water Resources Bureau. The SWAT model provides four options to simulate reservoir outflow: measured daily outflow, measured monthly outflow, average annual release rate for uncontrolled reservoir, and controlled outflow with target release. Keeping in view the 20 Watershed climate change impact evaluation application 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. Hence, the target release approach was used for the Tongue River reservoir.

Hydrology Calibration

A spatial calibration approach was adopted for GCRP-SWAT modeling for the Yellowstone 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 three 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 Tongue River and Powder River basins were modeled separately. The water balance of the Tongue River basin predicted by the SWAT model over the 32-year simulation period is as follows:

```
PRECIP =    374.4 MM
SNOW FALL = 116.02 MM
SNOW MELT =    98.58 MM
SUBLIMATION =    16.87 MM
SURFACE RUNOFF Q =    26.86 MM
LATERAL SOIL Q =   22.46 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    17.25 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    0.09 MM
DEEP AQ RECHARGE =    10.78 MM
TOTAL AQ RECHARGE =   28.11 MM
TOTAL WATER YLD =    66.57 MM
PERCOLATION OUT OF SOIL =   28.46 MM
ET =    388.6 MM
PET =   1268.1MM
TRANSMISSION LOSSES =     0.00 MM
```

The water balance of the Powder River basin predicted by the SWAT model over the 32-year simulation period is as follows:

```
PRECIP =    363.5 MM
SNOW FALL = 106.55 MM
SNOW MELT =    91.10 MM
SUBLIMATION =    15.05 MM
SURFACE RUNOFF Q =    25.65 MM
LATERAL SOIL Q =   17.88 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    14.03 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    0.04 MM
DEEP AQ RECHARGE =     0.00 MM
TOTAL AQ RECHARGE =   14.06 MM
TOTAL WATER YLD =    55.33 MM
PERCOLATION OUT OF SOIL =   12.00 MM
ET =    441.3 MM
PET =   1427.9MM
TRANSMISSION LOSSES =     2.23 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)

The calibration achieves a moderately high coefficient of model fit efficiency, but is above on summer flow volumes. Calibration results for the Tongue River at State Line near Decker are summarized **in** Figure 4, Figure 5, Figure 6, Figure 7 and Table 6.

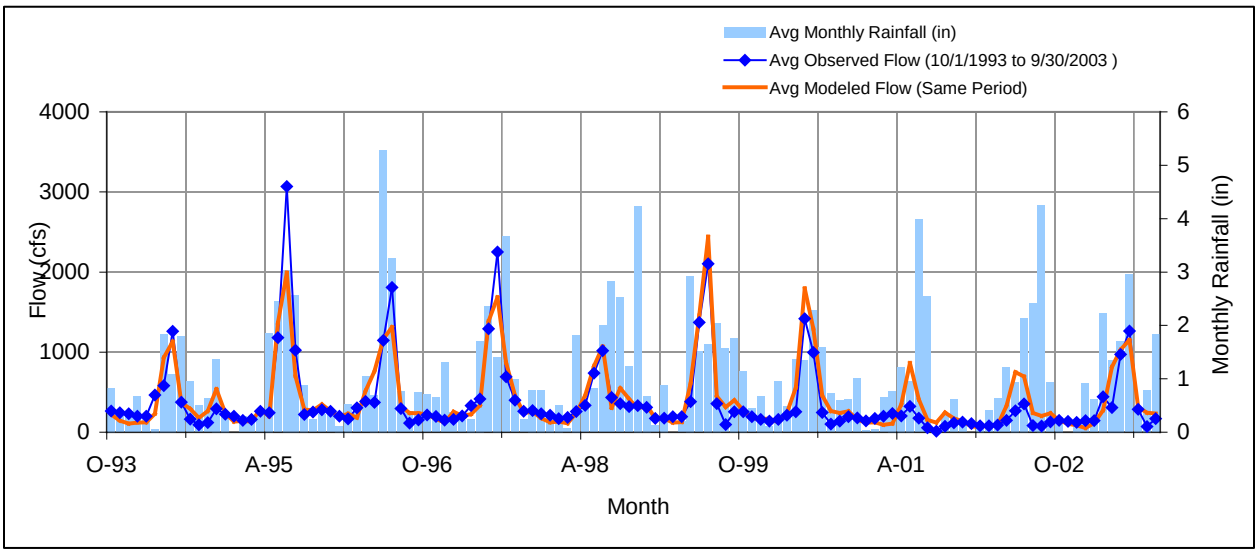

Figure 4. Mean monthly flow at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period.

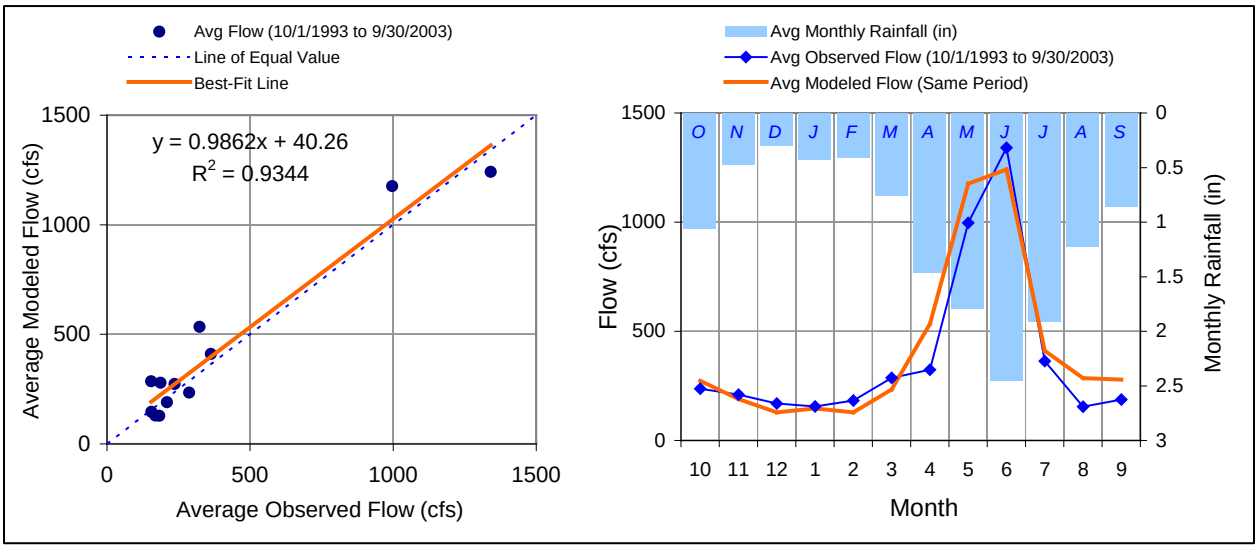

Figure 5. Seasonal regression and temporal aggregate at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period.

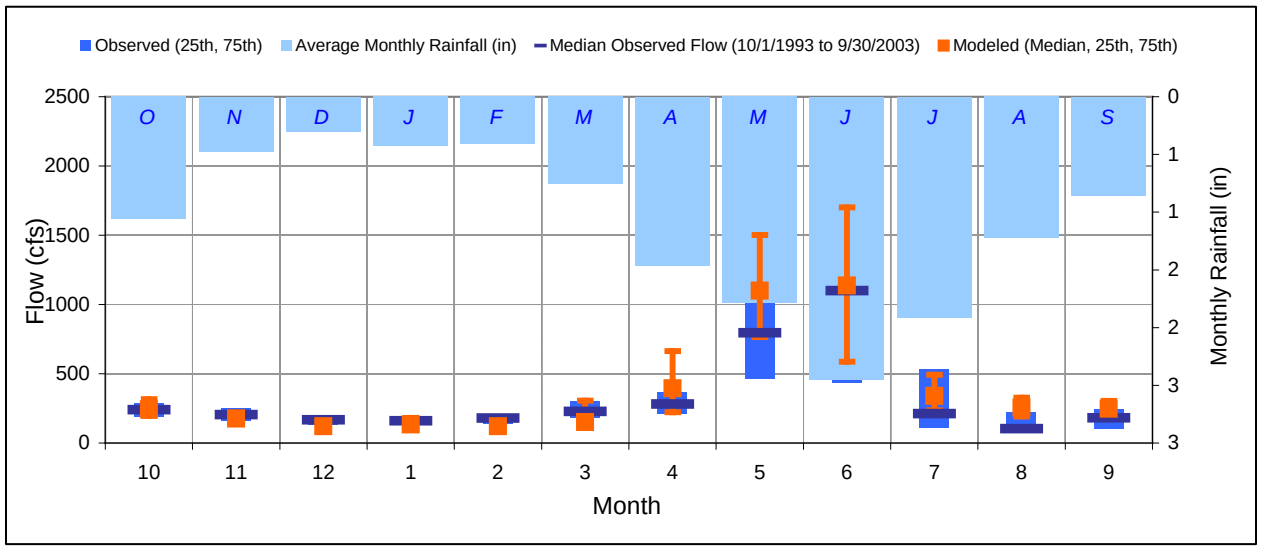

Figure 6. Seasonal medians and ranges at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period.

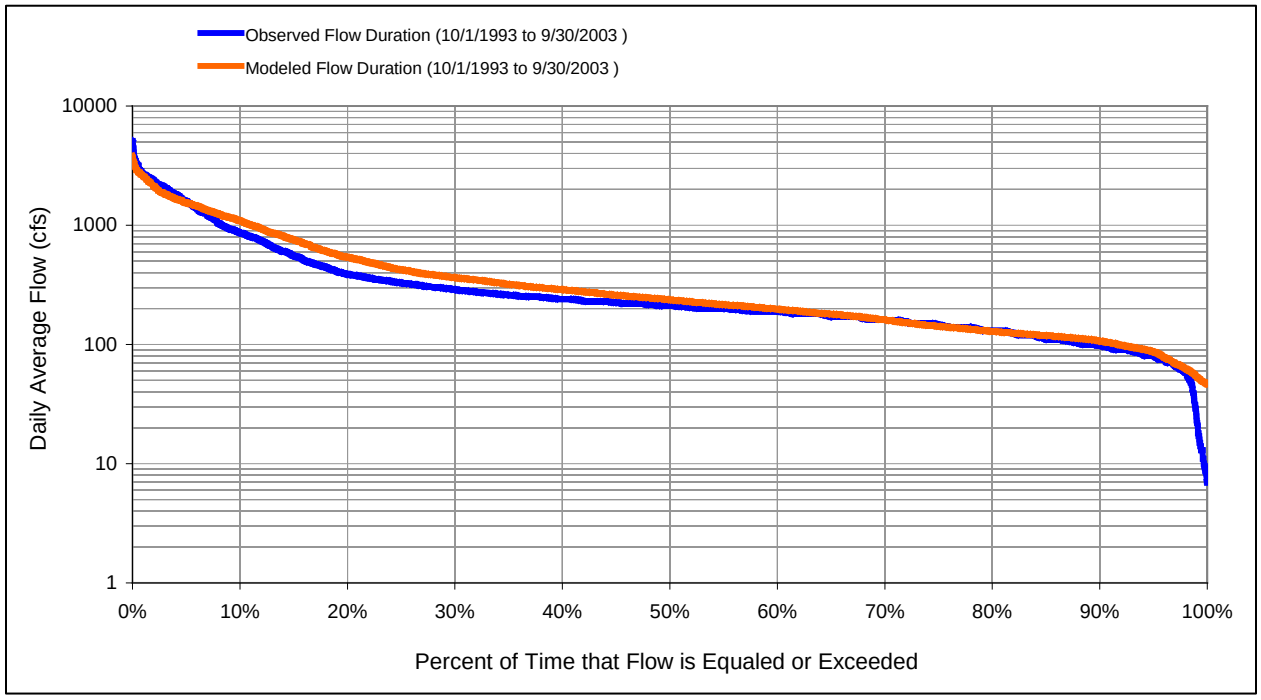

Figure 7. Flow exceedance at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period.

Table 6. Summary statistics at USGS 06306300 Tongue River at State Line near Decker, MT – calibration period

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 16 10-Year Analysis Period: 10/1/1993 - 9/30/2003 Flow volumes are (inches/year) for upstream drainage area		USGS 06306300 Tongue River at State Line nr Decker MT Hydrologic Unit Code: 10090101 Latitude: 45.0088632 Longitude: -106.836178 Drainage Area (sq-mi): 1453		
Total Simulated In-stream Flow:	**3.92**	Total Observed In-stream Flow:		**3.59**
Total of simulated highest 10% flows:	**1.58**	Total of Observed highest 10% flows:		**1.63**
Total of Simulated lowest 50% flows:	**0.69**	Total of Observed Lowest 50% flows:		**0.66**
Simulated Summer Flow Volume (months 7-9):	**0.77**	Observed Summer Flow Volume (7-9):		**0.55**
Simulated Fall Flow Volume (months 10-12):	**0.47**	Observed Fall Flow Volume (10-12):		**0.48**
Simulated Winter Flow Volume (months 1-3):	**0.39**	Observed Winter Flow Volume (1-3):		**0.48**
Simulated Spring Flow Volume (months 4-6):	**2.30**	Observed Spring Flow Volume (4-6):		**2.07**
Total Simulated Storm Volume:	**0.83**	Total Observed Storm Volume:		**0.73**
Simulated Summer Storm Volume (7-9):	**0.13**	Observed Summer Storm Volume (7-9):		**0.10**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	9.26	10	9.26	10.58
Error in 50% lowest flows:	4.58	10	4.58	5.16
Error in 10% highest flows:	-2.92	15	-2.92	-4.12
Seasonal volume error - Summer:	**38.16**	**30**	**38.16**	**56.52**
Seasonal volume error - Fall:	-3.70	30	-3.70	-1.92
Seasonal volume error - Winter:	-18.41	30	-18.41	-24.68
Seasonal volume error - Spring:	10.99	30	10.99	9.42
Error in storm volumes:	13.40	20	13.40	10.79
Error in summer storm volumes:	27.25	50	27.25	52.12
Nash-Sutcliffe Coefficient of Efficiency, E:	0.719	Model accuracy increases	0.719	0.693
Baseline adjusted coefficient (Garrick), E':	0.494	as E or E' approaches 1.0	0.494	0.468
Monthly NSE	0.878			

Hydrology Validation

Hydrology validation for Tongue River was performed for the period 10/1/1983 through 9/30/1993. The validation achieves a moderately high coefficient of model fit efficiency, but is below on 50% low flow and winter flow volumes (Figure 8, Figure 9, Figure 10, Figure 11 and Table 7).

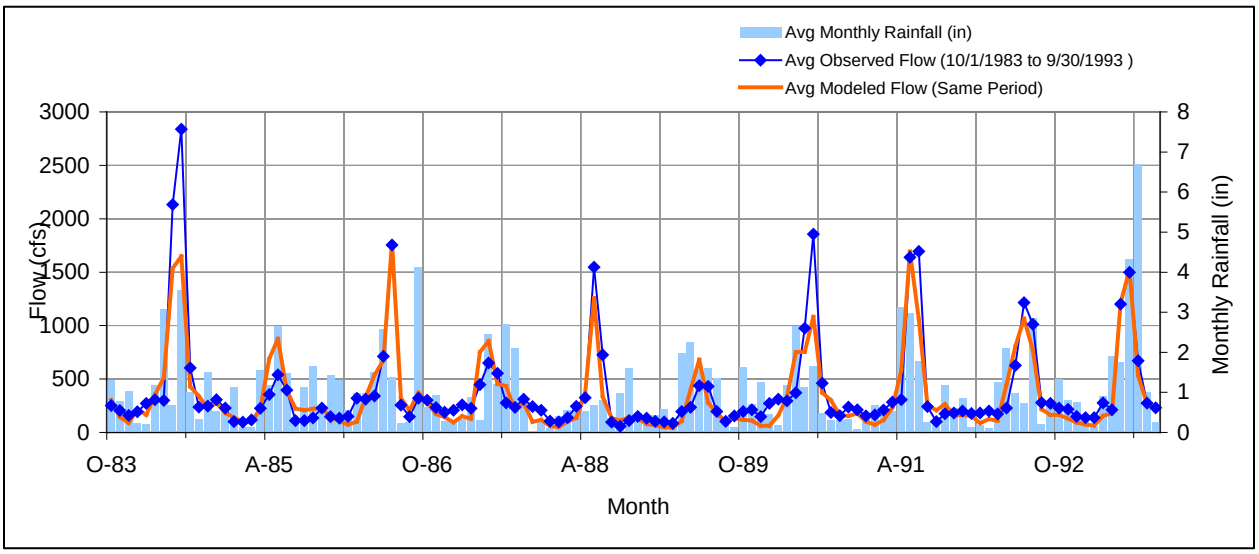

Figure 8. Mean monthly flow at USGS 06306300 Tongue River at State Line near Decker, MT – validation period.

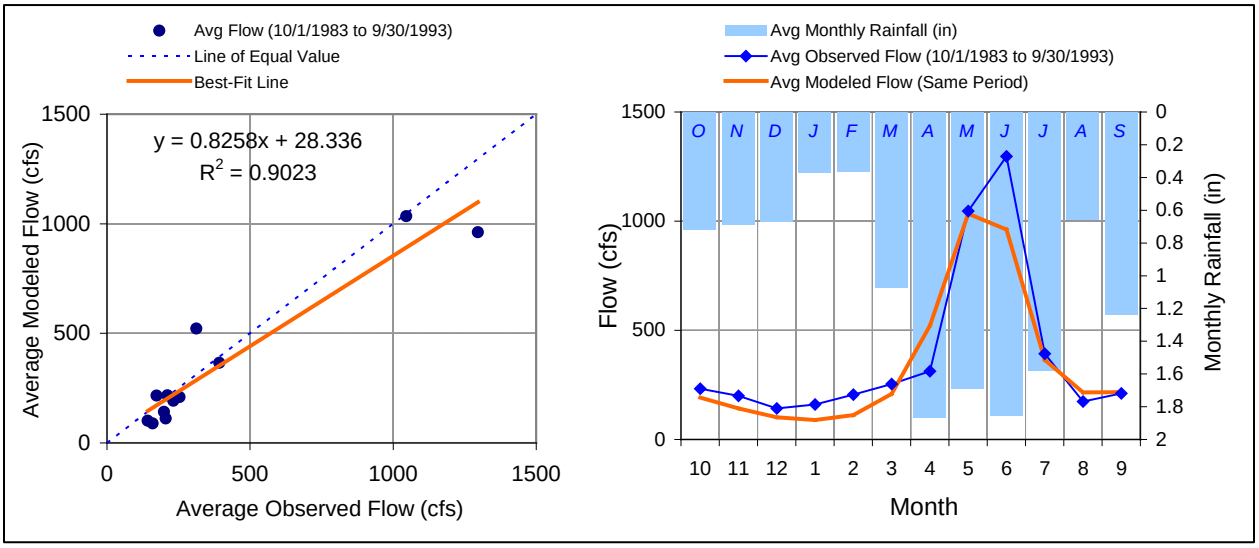

Figure 9. Seasonal regression and temporal aggregate at USGS 06306300 Tongue River at State Line near Decker, MT – validation period.

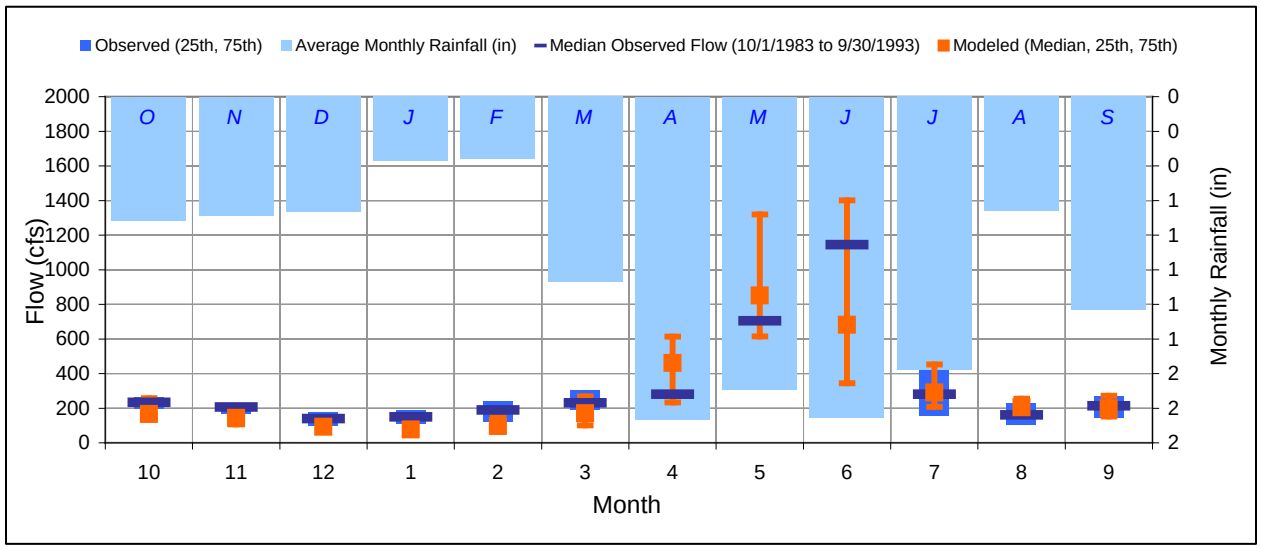

Figure 10. Seasonal medians and ranges at USGS 06306300 Tongue River at State Line near Decker, MT – validation period.

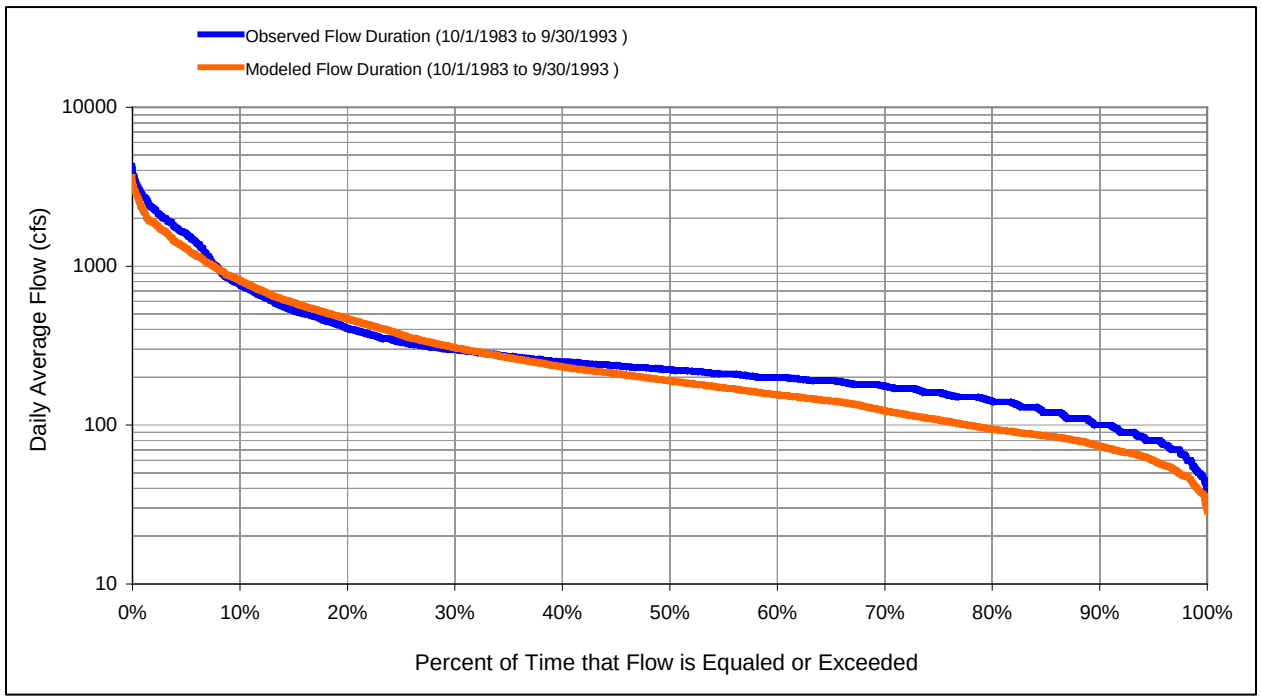

Figure 11. Flow exceedance at USGS 06306300 Tongue River at State Line near Decker, MT – validation period.

Table 7. Summary statistics at USGS 06306300 Tongue River at State Line near Decker, MT – validation period

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 16 10-Year Analysis Period: 10/1/1983 - 9/30/1993 Flow volumes are (inches/year) for upstream drainage area		USGS 06306300 Tongue River at State Line nr Decker MT Hydrologic Unit Code: 10090101 Latitude: 45.0088632 Longitude: -106.836178 Drainage Area (sq-mi): 1453		
Total Simulated In-stream Flow:	**3.25**	Total Observed In-stream Flow:		**3.60**
Total of simulated highest 10% flows:	**1.36**	Total of Observed highest 10% flows:		**1.59**
Total of Simulated lowest 50% flows:	**0.53**	Total of Observed Lowest 50% flows:		**0.71**
Simulated Summer Flow Volume (months 7-9):	**0.63**	Observed Summer Flow Volume (7-9):		**0.61**
Simulated Fall Flow Volume (months 10-12):	**0.34**	Observed Fall Flow Volume (10-12):		**0.45**
Simulated Winter Flow Volume (months 1-3):	**0.32**	Observed Winter Flow Volume (1-3):		**0.48**
Simulated Spring Flow Volume (months 4-6):	**1.96**	Observed Spring Flow Volume (4-6):		**2.07**
Total Simulated Storm Volume:	**0.73**	Total Observed Storm Volume:		**0.74**
Simulated Summer Storm Volume (7-9):	**0.10**	Observed Summer Storm Volume (7-9):		**0.11**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	-9.95	10	-9.15	-9.13
Error in 50% lowest flows:	**-25.59**	**10**	**-26.79**	**-26.79**
Error in 10% highest flows:	-14.65	15	-14.87	-14.85
Seasonal volume error - Summer:	2.57	30	12.55	12.58
Seasonal volume error - Fall:	-24.24	30	-24.09	-24.09
Seasonal volume error - Winter:	**-33.45**	**30**	**-40.20**	**-40.19**
Seasonal volume error - Spring:	-5.12	30	-5.15	-5.13
Error in storm volumes:	-0.73	20	-6.81	-6.75
Error in summer storm volumes:	-3.56	50	7.72	7.83
Nash-Sutcliffe Coefficient of Efficiency, E:	0.703	Model accuracy increases	0.693	0.693
Baseline adjusted coefficient (Garrick), E':	0.494	as E or E' approaches 1.0	0.497	0.497
Monthly NSE	0.872			

Hydrology Results for Larger Watershed

As described above, parameters determined for the gage at Tongue River at State Line near Decker 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 six 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	06307500	06306300	06307616	06308500	06324500
Error in total volume:	0.01	9.26	1.10	-5.78	7.55
Error in 50% lowest flows:	1.04	4.58	-6.88	-18.16	17.10
Error in 10% highest flows:	-6.35	-2.92	-3.80	0.83	-7.16
Seasonal volume error - Summer:	-18.08	38.16	-21.91	28.90	35.93
Seasonal volume error - Fall:	2.93	-3.70	0.48	-33.44	16.00
Seasonal volume error - Winter:	-3.32	-18.41	16.34	-31.74	3.45
Seasonal volume error - Spring:	10.83	10.99	10.69	3.58	-0.63
Error in storm volumes:	-18.89	13.40	-19.82	-40.42	13.11
Error in summer storm volumes:	22.94	27.25	5.64	1.54	16.28
Nash-Sutcliffe Coefficient of Efficiency, E:	0.68	0.72	0.67	0.36	0.49
Baseline adjusted coefficient (Garrick), E':	0.45	0.49	0.39	0.31	0.30

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

Station	06307500	06306300	06307616	06308500	06324500
Error in total volume:	-15.51	-9.95	-13.85	-0.30	-14.83
Error in 50% lowest flows:	-11.29	-25.59	-29.38	-41.64	-21.34
Error in 10% highest flows:	-13.96	-14.65	-8.00	35.98	-22.75
Seasonal volume error - Summer:	-30.86	2.57	-24.08	62.05	2.81
Seasonal volume error - Fall:	-14.00	-24.24	-18.99	-22.35	-29.02
Seasonal volume error - Winter:	-17.72	-33.45	-5.64	-42.94	-7.25
Seasonal volume error - Spring:	-5.72	-5.12	-8.23	-6.63	-19.24
Error in storm volumes:	-10.41	-0.73	-7.07	-14.47	-0.77
Error in summer storm volumes:	68.91	-3.56	76.33	38.90	-7.71
Nash-Sutcliffe Coefficient of Efficiency, E:	0.65	0.70	0.53	-0.55	0.47
Baseline adjusted coefficient (Garrick), E':	0.37	0.49	0.25	0.00	0.35

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done at USGS 06306300, Tongue River at State Line near Decker from water years 1983 to 2003. Subject to the availability of water quality data for the other gages, 1993-2003 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 Tongue River station at State Line near Decker 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.

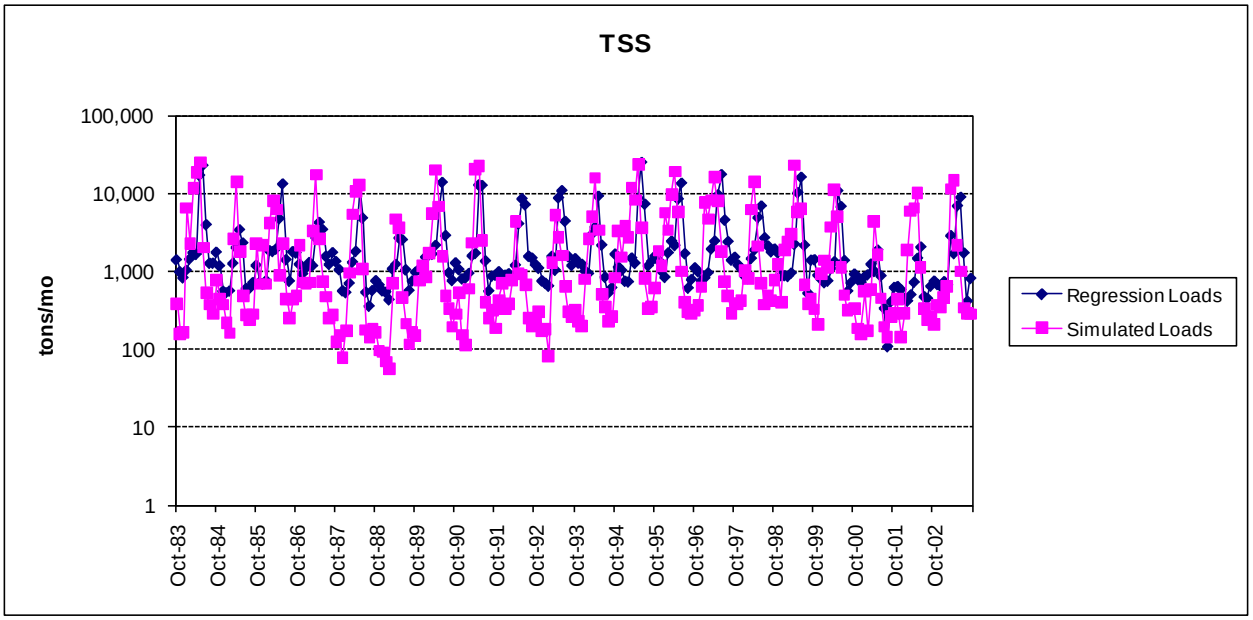

Figure 12. Fit for monthly load of TSS at USGS 06306300 Tongue River at State Line near Decker, MT.

Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 06306300 Tongue River at State Line near Decker, MT

Statistic	Calibration period	Validation period
Relative Percent Error	-21.8%	-3.4%
Relative Average Absolute Error	128.5%	109.7%
Relative Median Absolute Error	43.2%	38.2%

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 acceptable.

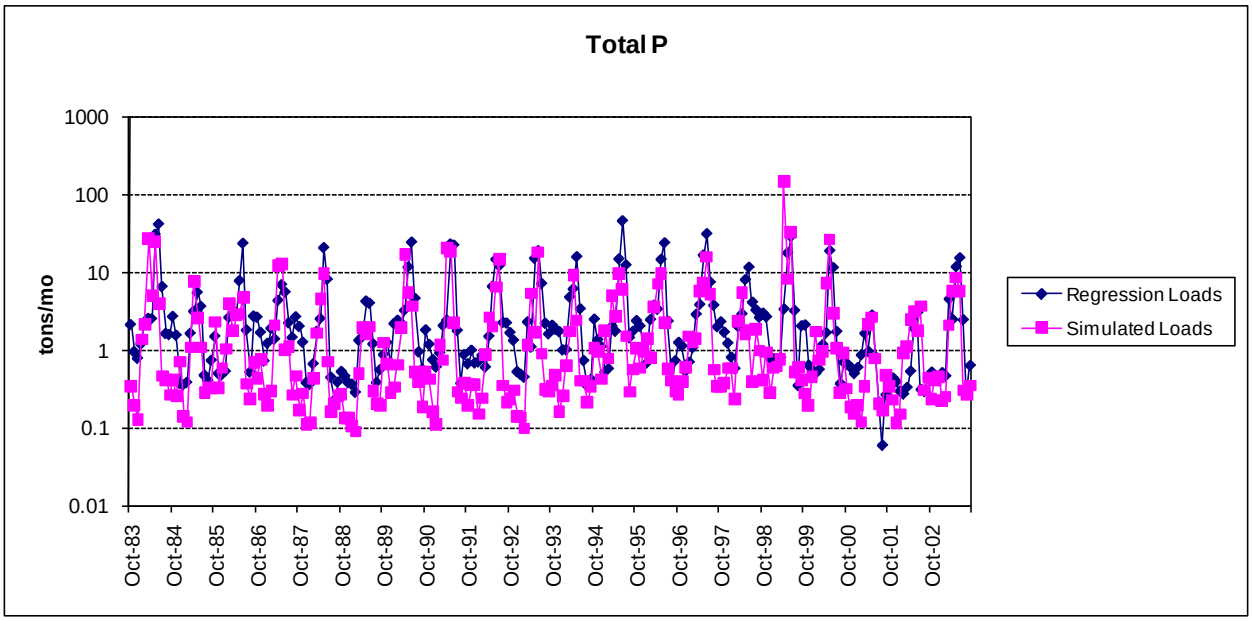

Figure 13. Fit for monthly load of total phosphorus at USGS 06306300 Tongue River at State Line near Decker, MT.

Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 06306300 Tongue River at State Line near Decker, MT

Statistic	Calibration period	Validation period
Relative Percent Error	8.8%	35.1%
Relative Average Absolute Error	94.1%	76.0%
Relative Median Absolute Error	27.6%	25.7%

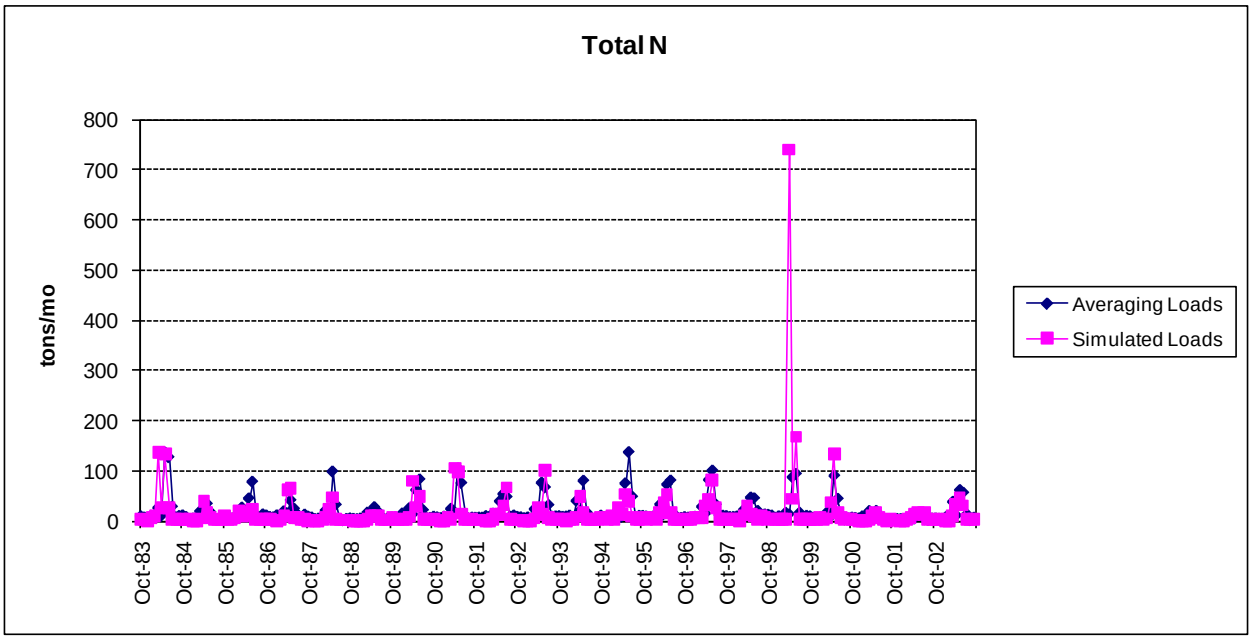

Figure 14. Fit for monthly load of total nitrogen at USGS 06306300 Tongue River at State Line near Decker, MT.

Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 06306300 Tongue River at State Line near Decker, MT

Statistic	Calibration period	Validation period
Relative Percent Error	3.9%	31.5%
Relative Average Absolute Error	93.3%	74.5%
Relative Median Absolute Error	33.6%	37.1%

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 Tongue River at State Line near Decker 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 1993-2003

Station	06308500
Relative Percent Error TSS Load	35.6
Relative Percent Error TP Load	12.5
Relative Percent Error TN Load	3.8

Table 14. Summary statistics for water quality at all stations – validation period 1983-1993

Station	06308500
Relative Percent Error TSS Load	-14.1
Relative Percent Error TP Load	-45.5
Relative Percent Error TN Load	-52.9

References

Peterson, D.A., K.A. Miller, T.T. Bartos, M.L. Clark, S.D. Porter, and T.L. Quinn. 2004. Water Quality in the Yellowstone River Basin, Wyoming, Montana, and North Dakota, 1999-2001. Circular 1234. U.S. Geological Survey, Reston, 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.