Appendix G
Model Configuration, Calibration and Validation

Basin: Minnesota River (Upper Mississippi River Basin Study Area)

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Watershed Background

Water Body Characteristics

The Minnesota River begins at Big Stone Lake on the South Dakota border, and from there flows 335 miles southeast to Mankato, Minnesota and then northeast to join the Mississippi River at Fort Snelling (Figure 1). Most of the watershed was originally native prairie and pothole wetlands. Intensive agricultural development began in the mid to late 19th century, and the watershed is now part of the corn belt, with the majority of the land area converted to corn-soybean rotation and other types of agriculture. Conversion of many parts of the watershed to agriculture required enhancement of drainage through ditches and subsurface tile drains. These drainage ditches and tile drains have resulted in a strong alteration of the hydrology by human modifications.

The watershed does not contain major reservoirs. However, there are a number of smaller lakes and reservoirs that influence flow in this low gradient terrain. As stated above, the Minnesota River's headwaters are located at Big Stone Lake, a natural lake with multiple outlets. The river proceeds through a series of impoundments in the upper reaches to Lac qui Parle, a US Army Corps of Engineers impoundment upstream of Montevideo, Minnesota. Irrigation and groundwater pumping in the watershed are generally small (although irrigation is somewhat more important in the western portions of the watershed). These factors are ignored for the purposes of the 20 Watershed model.

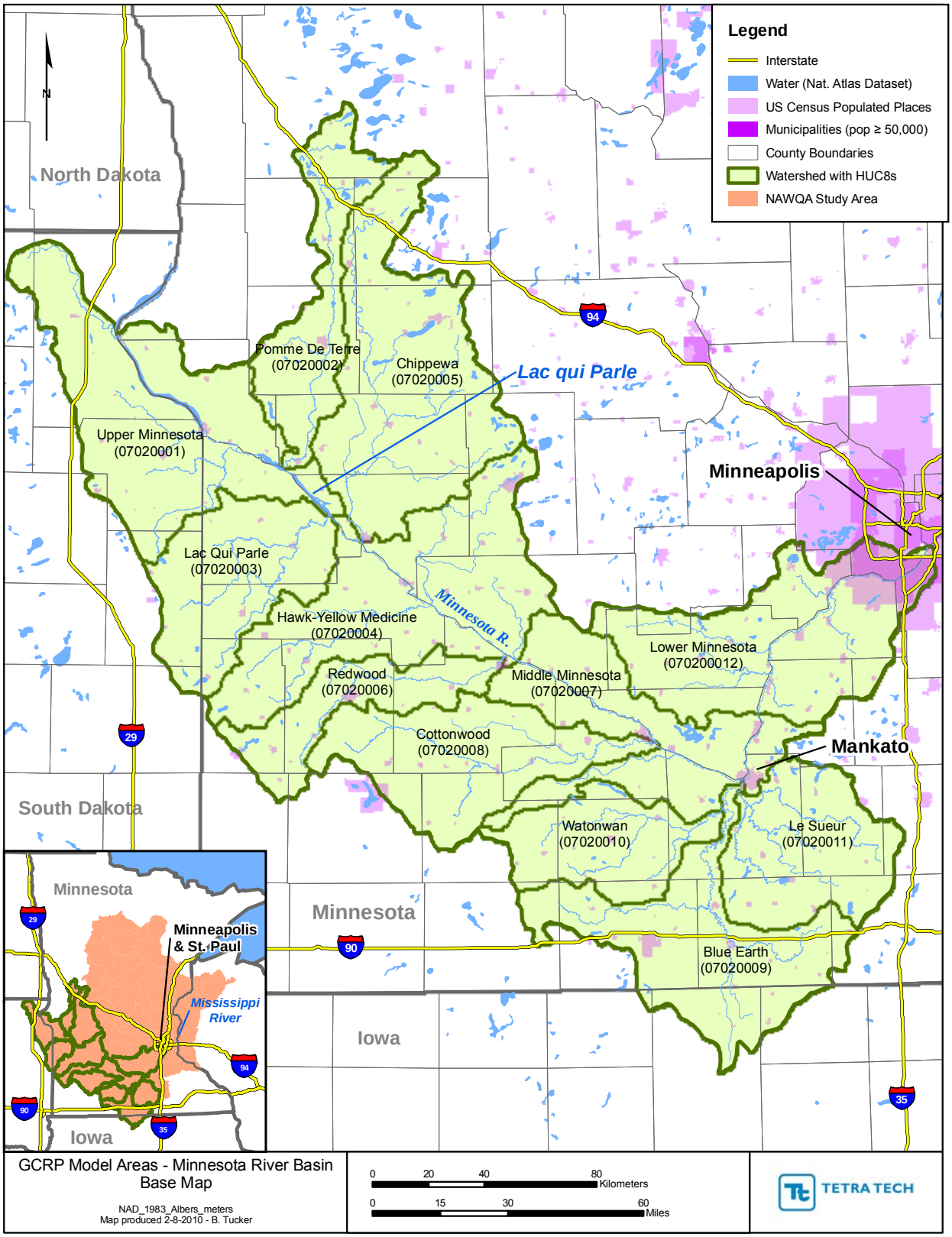

Figure 1. Location of the Minnesota River watershed.

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 D (low infiltration capacity). However, these designations are believed to be somewhat misleading in the Minnesota River watershed, as most agricultural activity benefits from subsurface tile drainage, which has been extensively installed since the 19th century. It is our impression that soils in the basin have received a rating as HSG B primarily because of pre-existing drainage and would more likely be classified as B/D (moderately high surface infiltration with a restricting layer) in its absence. This was substantiated by a previously-developed HSPF model of the basin for TMDL development (Tetra Tech 2008). The TMDL model obtained an excellent fit to basin hydrology without accounting for different HSGs, using parameters typical of HSG D. Therefore, the 20 Watershed HSPF model was constructed with only a small increase in infiltration capacity between group B and group D soils.

The SWAT model relies on a curve number approach rather than direct simulation of infiltration. SWAT uses information drawn directly from the soils data layer to populate the model.

The soil survey data was also used to establish geographic distributions of infiltration rate and available soil water capacity. These were used to index the spatial distribution of infiltration and lower zone soil nominal storage capacities in the 20 Watershed model, as was done in the TMDL model.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage and is predominantly row crop agriculture (Figure 2). Pasture and wetlands are more predominant in the upstream, western portions of the watershed. A variety of small municipalities are present throughout the watershed; however, major urban development is found only in the downstream Minneapolis-St. Paul metropolitan area.

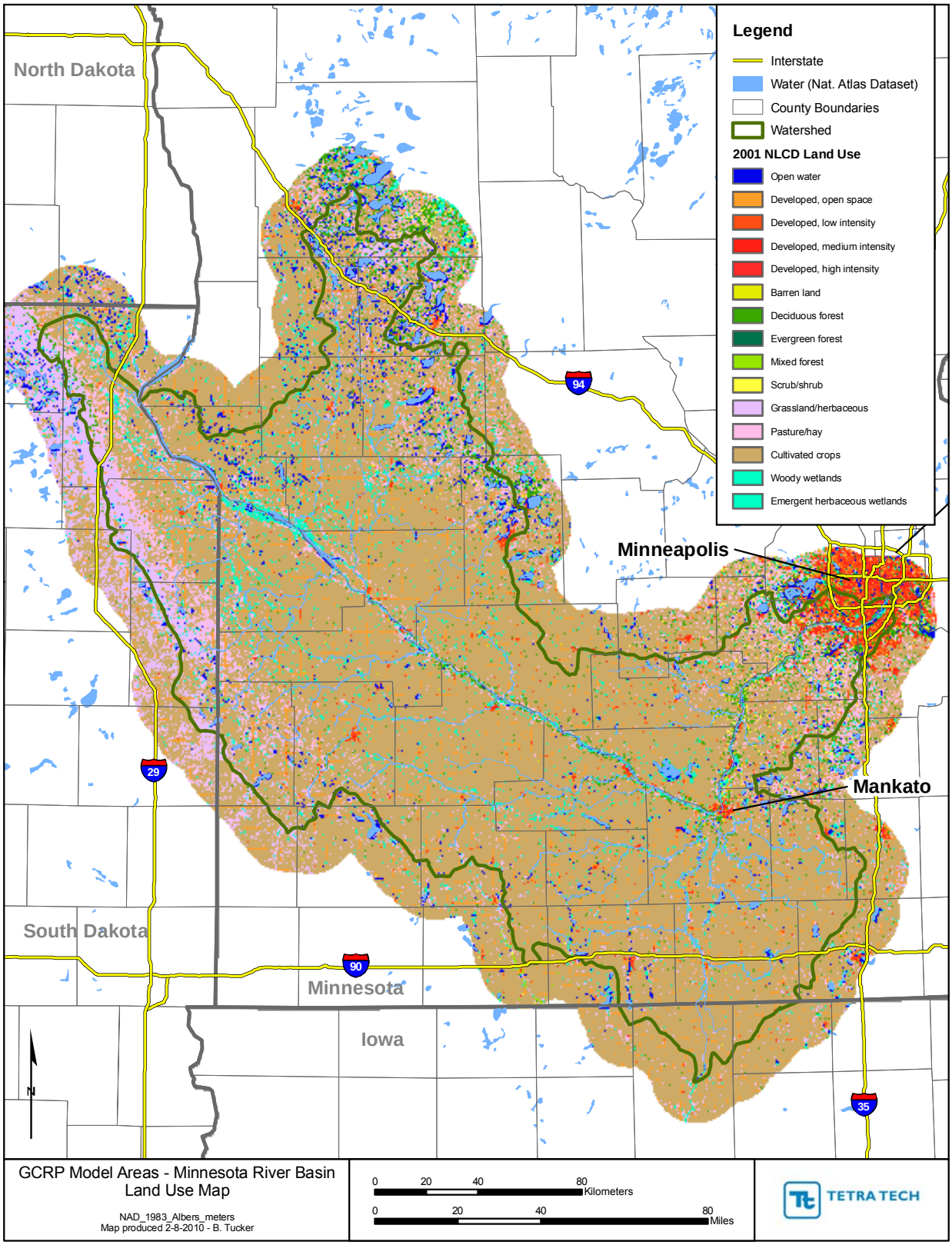

Figure 2. Land use in the Minnesota River watershed.

National Land Cover Database (NLCD) land cover classes were aggregated according to the scheme shown in Table 1 for representation in the 20 Watershed model, then overlain with the soils HSG grid. For HSPF, pervious and impervious lands are specified separately, so only one developed pervious class is used, along with an impervious class. HSPF simulates impervious land areas separately from pervious land. Impervious area distributions were determined from the NLCD Urban Impervious data coverage. Specifically, percent impervious area was calculated over the entire watershed for each of the four developed land use classes. These percentages were then used to separate out impervious land. NLCD impervious area data products are known to underestimate total imperviousness in rural areas; however, the model properly requires connected impervious area, not total impervious area, and the NLCD tabulation is assumed to provide a reasonable approximation of connected impervious area. In SWAT, different developed land classes are specified separately. In HSPF the WATER, BARREN, DEVPERV, and WETLAND classes are not subdivided by HSG; SWAT uses the built-in HRU overlay mechanism in the ArcSWAT interface.

Table 1. Aggregation of NLCD land cover classes

NLCD Class	Comments	SWAT class	HSPF (after processing)
11 Water	Water surface area usually accounted for as reach area	WATR	WATER
12 Perennial ice/snow		WATR	BARREN, Assume HSG D
21 Developed open space		URLD	DEVPERV; IMPERV
22 Dev. Low Intensity		URMD	
23 Dev. Med. Intensity		URHD	
24 Dev. High Intensity		UIDU	
31 Barren Land		SWRN	BARREN (D)
41 Forest	Deciduous	FRSD	FOREST (A,B,C,D)
42 Forest	Evergreen	FRSE	
43 Forest	Mixed	FRST	
51-52 Shrubland		RNGB	SHRUB (A,B,C,D)
71-74 Herbaceous Upland		RNGE	GRASS (A,B,C,D), BARREN (D)
81 Pasture/Hay		HAY	GRASS (A,B,C,D)
82 Cultivated		AGRR	AGRI (A,B,C,D)
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN	WETLAND, Assume HSG D
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR	WATER

The distribution of land use in the watershed is summarized in Table 2.

Table 2. Land use distribution for the Minnesota River watershed (2001 NLCD) (mi^2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
Middle Minnesota **07020007**	34.36	65.09	17.88	7.57	2.78	4.61	52.65	14.02	36.28	1,027.07	83.85	1,346.16
Cottonwood **07020008**	10.52	63.88	8.30	2.12	0.40	0.67	16.48	26.94	22.51	1,112.67	45.50	1,310.00
Blue Earth **07020009**	22.42	92.22	11.52	2.81	0.87	1.09	13.09	32.12	10.35	1,325.27	39.69	1,551.45
Watonwan **07020010**	12.17	46.47	6.11	1.61	0.27	0.38	9.46	8.16	4.65	756.69	27.46	873.43
Le Sueur **07020011**	22.73	61.31	7.42	1.57	0.51	0.55	16.00	26.86	15.86	914.84	38.48	1,106.13
Lower Minnesota **07020012**	52.49	85.53	88.31	45.80	21.74	0.82	150.06	48.05	205.56	1,048.44	63.52	1,810.30
Hawk-Yellow Medicine **07020004**	30.91	95.29	20.80	4.38	1.14	2.62	35.31	56.52	75.08	1,660.28	91.81	2,074.13
Redwood **07020006**	12.12	35.49	6.70	1.96	0.55	0.86	6.88	43.05	21.87	547.63	21.46	698.56
Lac Qui Parle **07020003**	17.00	47.25	3.05	0.78	0.26	0.62	9.80	119.28	101.55	720.07	76.57	1,096.23
Pomme De Terre **07020002**	75.09	39.68	5.49	1.18	0.30	0.66	46.25	40.13	59.04	540.28	52.33	860.42
Upper Minnesota **07020001**	90.81	85.99	10.59	2.91	0.67	2.64	36.03	307.84	263.03	1,122.98	177.34	2,100.83
Chippewa **07020005**	121.39	85.24	15.04	1.78	0.59	1.41	89.40	59.05	173.27	1,413.66	109.51	2,070.35
Total	502.01	803.45	201.20	74.48	30.07	16.93	481.43	782.02	989.04	12,189.86	827.51	16,897.99

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (6.59%), low density (29.20%), medium density (55.01%), and high density (83.31%).

The HSPF model is set up on a hydrologic response unit (HRU) basis. For HSPF, HRUs were formed from an intersection of land use and hydrologic soil group, then further subdivided by precipitation gage. Because slopes in the basin are relatively mild, HSPF HRUs were not further subdivided by slope. However, average slopes (which tend to correlate with soils) were calculated for each HRU. The water land use area was adjusted to prevent double counting with area described in HSPF reaches. SWAT HRUs are formed from an intersection of land use and SSURGO major soils.

Point Sources

There are numerous point source discharges in the watershed, including approximately 70 mechanical wastewater treatment plants and various industrial discharges. In addition, Minnesota PCA has identified approximately 70 stabilization ponds in the watershed that receive wastewater, primarily serving small communities, and that discharge seasonally to the stream network.

For the purposes of 20 Watershed modeling, only the 13 major dischargers, with a design flow greater than 1 MGD are included in the simulation (Table 3 and Figure 3). The total of all discharges in the basin is believed to be in the range of 100 MGD. The major dischargers account for about 80 percent of that total, so the effect of the omitted sources distributed throughout the watershed will be relatively small, except during extreme low flow conditions. 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 Minnesota River watershed

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
MN0022535	SAINT PETER	4.00	1.04
MN0030171	MANKATO	11.25	6.56
SD0020371	MILBANK - CITY OF	1.50	8.45
MN0020133	MONTEVIDEO	3.00	0.96
MN0022179	MARSHALL	4.50	2.57
MN0057037	MINNESOTA CORN PROCESSORS	2.60	1.31
MN0030066	NEW ULM	6.77	2.55
MN0030112	FAIRMONT	3.90	1.38
MN0025267	WINNEBAGO	1.70	0.40
MN0024759	SAINT JAMES	2.96	1.08
MN0024040	MADELIA	1.31	0.71
MN0029882	METROPOLITAN COUNCIL-BLUE LAKE	42.00	26.44
MN0030007	METROPOLITAN COUNCIL-SENECA	38.00	23.89
MN0020796	WASECA	3.50	1.36
MN0020150	NEW PRAGUE	1.38	0.65
MN0025259	WILLMAR	5.04	3.48

Most of these point sources have reasonably good monitoring for total phosphorus and total suspended solids (TSS), but not for total nitrogen. In many cases, only ammonia nitrogen is monitored. The point sources were

initially represented in the model with the median of reported values for total phosphorus and TSS and an assumed total nitrogen concentration of 11.2 mg/L for secondary treatment facilities (Tetra Tech 1999).

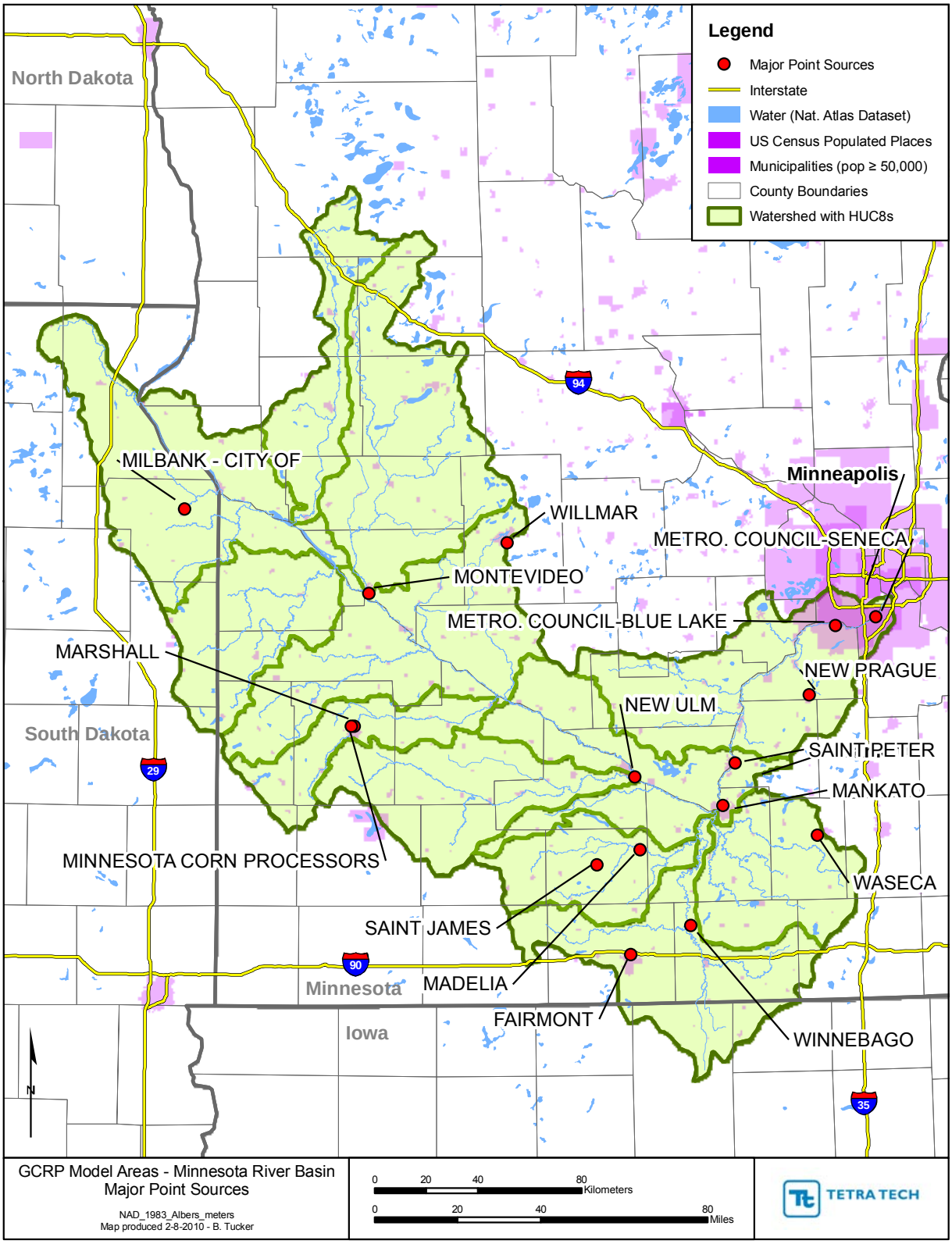

Figure 3. Major point sources in the Minnesota River watershed.

Meteorological Data

The required meteorological data series for the 20 Watershed study are precipitation, air temperature, and potential evapotranspiration. The 20 Watershed model does not include water temperature or algal simulation and uses a degree-day method for snowmelt. These meteorological data 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 will require 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 2001. A total of 39 precipitation stations were identified for use in the Minnesota River model with a common period of record of 10/1/1972-9/30/2002 (Table 4 and Figure 4). Temperature records are sparser; where these are absent temperature is taken from nearby stations with an elevation correction. For each weather station, Penman-Monteith reference evapotranspiration was calculated for use in HSPF using observed precipitation and temperature coupled with SWAT weather generator estimates of solar radiation, wind movement, cloud cover, and relative humidity.

For the 20 Watershed model applications, SWAT uses daily meteorological data, while HSPF requires hourly data. It is important to note that a majority of the meteorological stations available for the Minnesota River watershed are Cooperative Summary of the Day stations that do not report sub-daily data. The BASINS4 dataset already has versions of the daily data that have been disaggregated to an hourly time step using template stations. For each daily station, this disaggregation was undertaken in reference to a single disaggregation template. Occasionally, this automated procedure provides undesirable results, particularly when the total rainfall for the day is very different between the subject station and the disaggregation template. This yields a small number of hourly precipitation intensity estimates that are unrealistically high (e.g., much greater than the 100-yr 1-hour event for the region). This has only a small impact on the basin-scale hydrologic calibration as gages are influenced by rainfall from multiple weather stations, but can introduce significant problems for the prediction of erosion and sediment loads. Perhaps more importantly, past experience makes clear that the available precipitation network is not sufficiently dense to accurately resolve watershed-scale precipitation depths, particularly during summer convective storms (Tetra Tech 2008). This introduces an unavoidable level of uncertainty into the hydrologic calibration.

Table 4. Precipitation stations for the Minnesota River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
IA138270	TITONKA	43.2353	-94.0417	No	1,170
MN210112	ALEXANDRIA CHANDLER FL	45.8686	-95.3942	Yes	1,416
MN210287	ARTICHOKE LAKE	45.3783	-96.1542	Yes	1,075
MN210667	BENSON	45.3167	-95.6167	Yes	1,040
MN210981	BRICELYN	43.5514	-93.8481	No	1,170
MN211263	CANBY	44.7183	-96.2697	Yes	1,243
MN212698	FAIRMONT	43.6447	-94.4656	Yes	1,187
MN212768	FERGUS FALLS	46.2919	-96.1172	Yes	1,250
MN213076	GAYLORD	44.5564	-94.2206	Yes	1,018
MN213174	GLENWOOD 2 WNW	45.6633	-95.4442	Yes	1,198
MN213311	GRANITE FALLS	44.8108	-95.5178	No	910

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
MN214176	JORDAN 2E	44.6622	-93.5933	Yes	930
MN214546	LAMBERTON SW EXP STN	44.2394	-95.3153	Yes	1,144
MN214994	MADISON SEWAGE PLANT	45.0025	-96.1661	Yes	1,080
MN215073	MANKATO	44.1556	-94.0242	Yes	850
MN215204	MARSHALL	44.4706	-95.7908	Yes	1,152
MN215400	MILAN 1 NW	45.1219	-95.9269	Yes	1,020
MN215435	MINNEAPOLIS/ST PAUL AP	44.8831	-93.2289	Yes	872
MN215563	MONTEVIDEO 1 SW	44.9364	-95.7536	Yes	985
MN215638	MORRIS WC EXP STN	45.5903	-95.8747	Yes	1,140
MN215887	NEW ULM 2 SE	44.3006	-94.4897	Yes	860
MN216152	OLIVIA 3E	44.7628	-94.9297	Yes	1,100
MN216835	REDWOOD FALLS FAA ARPT	44.5472	-95.0822	Yes	1,025
MN217326	ST JAMES FILT PLANT	43.9908	-94.6122	Yes	1,100
MN217405	ST PETER	44.3222	-93.9556	Yes	850
MN217602	SHERBURN 3 WSW	43.6303	-94.7744	Yes	1,320
MN217907	SPRINGFIELD 1 NW	44.2469	-94.9864	Yes	1,066
MN218025	STEWART	44.7344	-94.3425	Yes	1,040
MN218323	TRACY	44.2394	-95.6308	Yes	1,403
MN218429	TYLER	44.2781	-96.1281	No	1,735
MN218520	VESTA	44.5069	-95.4111	No	1,080
MN218692	WASECA EXP STATION	44.0725	-93.5328	Yes	1,153
MN218808	WELLS	43.7333	-93.7333	No	1,197
MN219004	WILLMAR RTC	45.1403	-95.0183	Yes	1,128
MN219046	WINNEBAGO	43.7689	-94.1883	Yes	1,110
SD391777	CLEAR LAKE	44.7506	-96.6906	Yes	1,800
SD395536	MILBANK 2 SSW	45.2061	-96.6361	Yes	1,160
SD397742	SISSETON	45.6667	-97.0419	Yes	1,220
SD399337	WILMOT	45.4081	-96.8600	No	1,160

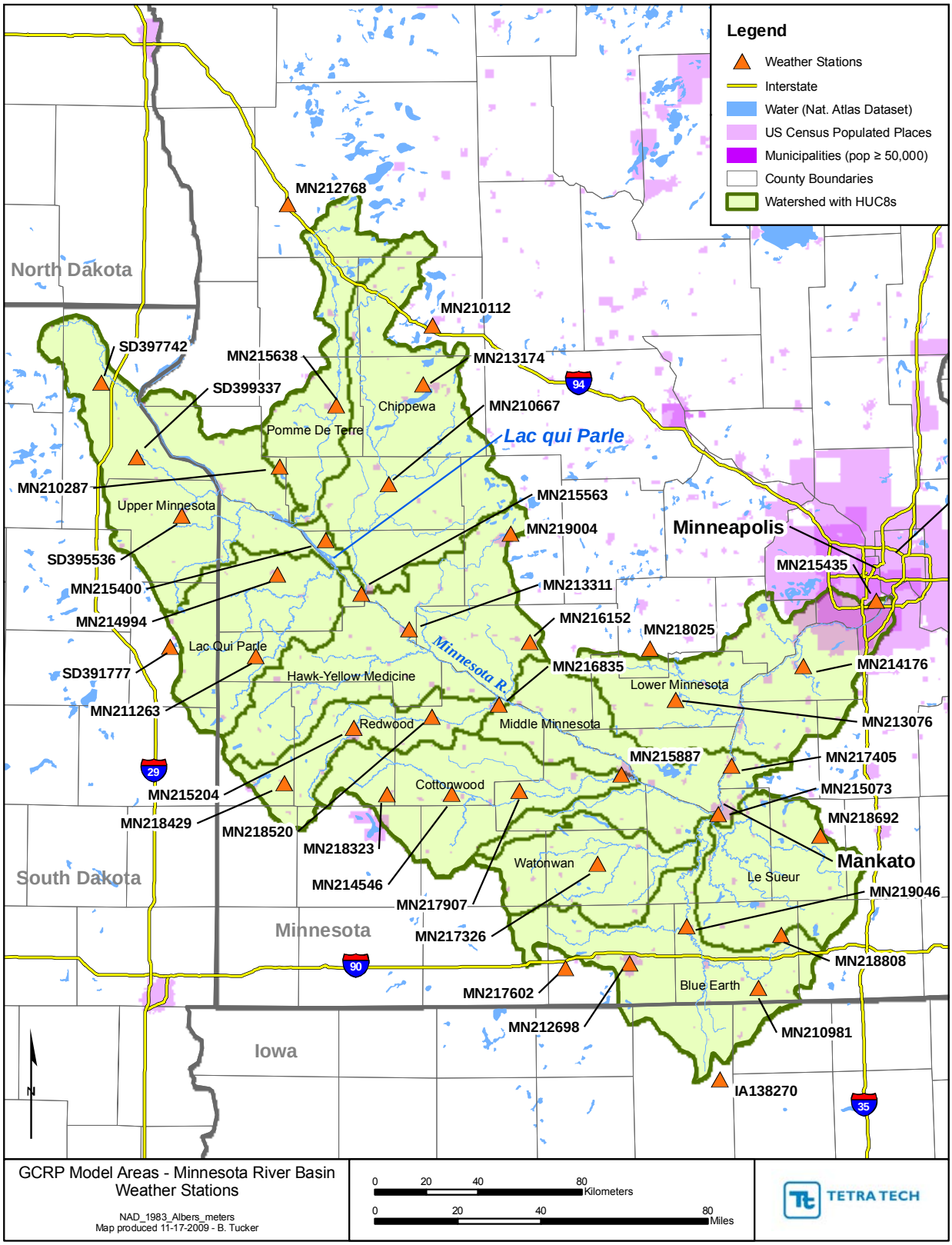

Figure 4. Weather stations for the Minnesota River watershed model.

Watershed Segmentation

The Minnesota River basin was divided into 95 subwatersheds for the purposes of modeling (Figure 5). The initial calibration watershed (Cottonwood River) is highlighted. The model encompasses the complete watershed and does not require specification of any upstream boundary conditions for application. It should be noted, however, that Big Stone Lake (subwatershed 63) is separated from nearby Lake Traverse (which is not part of the watershed) by only a small dike, and Lake Traverse sometimes overflows into Big Stone Lake when winter ice jams are present. This boundary phenomenon is not represented in the model.

The model subwatersheds approximate the HUC-10 scale, but are subdivided as needed to account for the connection of tributaries and location of flow gages. The subwatersheds range in size from 10 to 436 mi^2, with an average size of 178 mi^2.

In developing the HSPF simulation it was noted that the FTable simulation of Lac qui Parle did not perform well for the model validation period. Therefore, for the purposes of HSPF hydrologic validation only, a separate version of the model was created with outflow from Lac qui Parle set as a boundary condition.

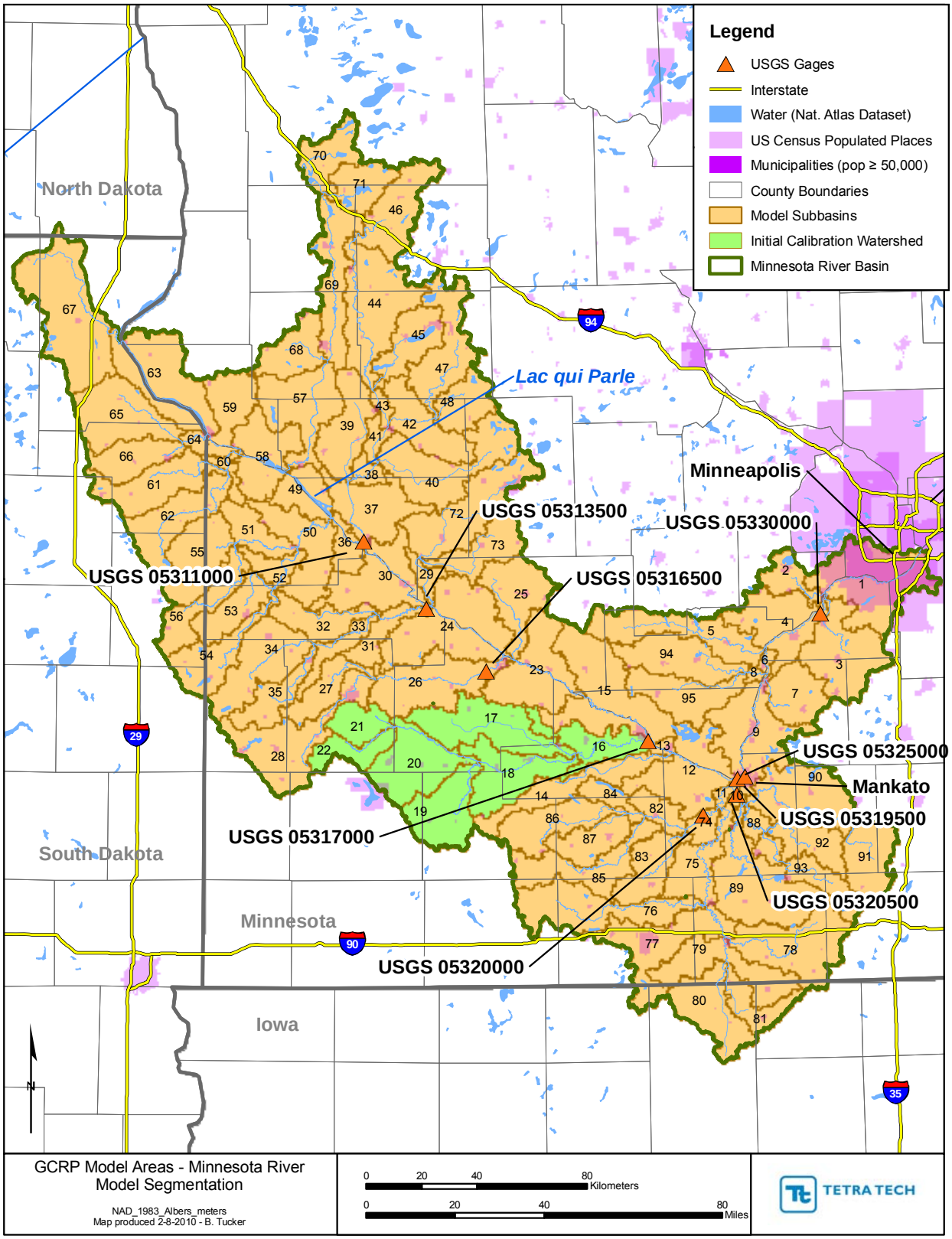

Figure 5. Model segmentation and USGS stations utilized for the Minnesota River watershed.
Note: SWAT subwatersheds numbering is shown; the HSPF model for this watershed uses the same subwatershed boundaries with an alternative internal numbering scheme.

Calibration Data and Locations

The Minnesota River basin was selected as an early pilot site because of extensive previous experience in modeling this watershed. The specific site chosen for initial calibration was the Cottonwood River at New Ulm, a flow and water quality monitoring location that approximately coincides with the mouth of an 8-digit HUC at its outflow to the Minnesota River. The Cottonwood watershed was selected for several reasons: 1) there is a good set of flow and water quality data available, 2) previous modeling efforts were successful, and 3) the watershed lacks major point sources and impoundments.

Previous experience in the watershed indicates that model fit is very sensitive to hydrologic parameter specification – in part because precipitation and ET are, in general, balanced such that minor perturbations in soil moisture persist for long periods of time. In addition, the Minnesota River watershed was an initial test case of procedures; therefore, calibration and validation was pursued at multiple locations (Table 5). Parameters derived on the Cottonwood were not fully transferable to other portions of the Minnesota River watershed, and additional calibration was conducted at multiple gage locations.

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

Station Name	USGS ID	Drainage Area (mi^2)	Hydrology Calibration	Water Quality Calibration
Minnesota River at Montevideo, MN	05311000	6,180	X	
Yellow Medicine River at Granite Falls, MN	05313500	664	X	X
Redwood River nr Redwood Falls, MN	05316500	629	X	X
Cottonwood River near New Ulm, MN	05317000	1,300	X	X
Watonwan River near Garden City, MN	05319500	851	X	X
Blue Earth River near Rapidan, MN	05320000	2,410	X	X
LeSueur River near Rapidan, MN	05320500	1,110	X	X
Minnesota River at Mankato, MN	05325000	14,900	X	X
Minnesota River near Jordan, MN	05330000	16,200	X	X

The model hydrology calibration period was set to Water Years 1993-2002 (within the 30-year period of record for modeling). The end date was constrained by the common period of the set of 20 Watershed meteorological stations available for the watershed, and a ten year calibration period was desired. Calibration was done on the later data, due to concerns that there have been significant changes in agricultural management practices and land retirement programs since the 1980s. Hydrologic validation was then performed on Water Years 1983-1992. Water quality calibration used calendar years 1993-2002, while validation used 1986-1992, as limited data were available prior to 1986.

HSPF Modeling

A detailed HSPF model already exists for the portion of the basin between Lac qui Parle and Minnesota River at Jordan, MN (Tetra Tech 2008). This model, which was developed through a number of iterations to support TMDL development, is calibrated for flow, sediment, and nutrients. A particular focus of the calibration effort was on sediment source attribution, using radionuclide data, including detailed calibration for loading from ravines, in-channel processes, and contributions from bluff collapse where tributaries enter the mainstem at the edges of the old glacial River Warren valley.

The existence of this earlier model provides a firm basis for parameter initialization, and is one of the reasons that the Minnesota River was selected as a pilot site. There are significant differences between the 20 Watershed model and the previous TMDL model. In general, the approach adopted for the 20 Watershed large-scale model applications is intended to provide a basis for comparison across the country. Key characteristics of the 20 Watershed model include the following.

- The model is constrained to the land uses identified by NLCD for consistency with applications to other basins. Supplementary refinements to the land use coverage to incorporate information on conservation tillage and manure application were not used in the 20 Watershed model except as a guide to general spatial trends in model parameters.
- The model makes use of the data present in the BASINS4 meteorological data set, with one station assigned per model subwatershed. Patching and disaggregation of the BASINS4 precipitation data sets generally used a single template station, occasionally resulting in very different interpretation of peak events.
- The model uses Penman-Monteith reference evapotranspiration, based on measured precipitation and temperature combined with solar radiation, wind movement, and relative humidity from the SWAT weather generator.
- The model uses the degree-day approach to simulating snowmelt (because measured values of insolation and wind movement are not available at all stations).

The TMDL model does provide important insights and parameter starting values that are incorporated into the 20 Watershed model. Of particular note are the following:

- Tile drainage is a significant component of hydrology in the basin and exhibits a spatial gradient, with the most intensive tiling in the southeastern portion of the watershed. The TMDL model developed an approach to represent tile drainage through the interflow component of HSPF, with values calibrated by 8-digit HUC. This representation is carried forward into the 20 Watershed model.
- Channel hydraulics in the TMDL model (represented through FTables) was developed through use of existing HEC-RAS models, where available. These channel characteristics were carried forward to the 20 Watershed model (for areas covered by HEC-RAS models) by matching channel segments between the two models and adjusting storage volumes to account for differences in reach length.
- Detailed work on sediment source calibration in the TMDL model was carried forward into the 20 Watershed model, including the representation of tillage and sediment loading from bluffs through the HSPF SPECIAL ACTIONS programming capability.

Changes Made to Base Data Provided

No changes were made to the meteorological or land use base data. For the point source data it was known from previous modeling that there is a rapid loss of phosphorus in the near field immediately downstream of various wastewater treatment plant discharges, likely due to settling of particulate matter. This cannot be accurately represented at the scale of the 20 Watershed model and indeed resulted in overprediction of phosphorus concentrations under low flow conditions. Discounting total phosphorus concentration in the effluent by 50 percent resolved this problem during calibration.

Assumptions

Flow in the upper portions of the Minnesota River is influenced by Lac qui Parle, a U.S. Army Corps of Engineers impoundment near Montevideo, Minnesota. The hydrology of Lac qui Parle is complex, as there is a diversion channel at Watson Sag on the Chippewa River (that naturally discharges to the Minnesota River at Montevideo) that diverts high flows, as well as a portion of base flows, upstream into Lac qui Parle. For the TMDL model, significant efforts were made to simulate the operations of the Watson Sag diversion, while Lac qui Parle itself was taken as a boundary condition. For the 20 Watershed model, the basin upstream of Lac qui Parle is simulated directly, while Watson Sag diversion is not explicitly simulated. The original intent was to ignore Lac qui Parle altogether, as the operations of impoundments are difficult to extrapolate to future climate conditions; however, this proved to be a significant detriment to the simulation of flows in the mainstem of the Minnesota River downstream of Lac qui Parle. Therefore, a reservoir storage-discharge representation (FTable) was constructed to approximate the hydraulic behavior of Lac qui Parle, based on reported lake storage and downstream gaged flows. This FTable provides only an approximation of the actual operations of the Lac qui Parle dam, and, together with the omission of the Watson Sag diversion, introduces uncertainty into the representation of mainstem flows.

The other significant dam in the watershed (Rapidan Reservoir on Blue Earth River) is not represented in the 20 Watershed model because accurate data are lacking and the impoundment's storage capacity is greatly diminished by sediment accumulation behind the dam. The many natural lakes in the watershed are also not explicitly represented, although an approximation of their storage was introduced through representation of the water land use. Specifically, the water "upland" land use was assigned characteristics that approximate storage in small natural ponds by assigning a very low slope and a high surface storage capacity, equivalent to approximately 1 inch of runoff from the surrounding drainage area. Surface storage in HSPF is a function of the slope length (SLSUR) and the roughness coefficient (NSUR). As the program limits NSUR to "reasonable" ranges of Mannings coefficient, additional surface storage capacity can be represented only be artificially increasing slope length to a large value. It is also necessary to represent evaporation from these ponds, but HSPF does not include evaporation from surface storage. This is achieved by specifying some upper zone storage capacity, but near zero infiltration rates out of the upper zone. This effectively routes much of the water to evaporation, except when large rainfall events exceed the surface storage plus upper zone storage capacity – which is how a pothole pond in the Minnesota plains behaves.

Another important characteristic of the basin is the widespread presence of subsurface tile drainage. Installation of tile drainage has converted what were predominantly glacial plain outwash depressional wetlands into productive farmland. The presence of tile drains, which include both surface and subsurface inlets, has radically altered the natural hydrology of the area. Surface inlet tile drains, in particular, may also play a significant role in the transport of sediment and pollutants from agricultural land to the river.

It is not feasible to simulate individual tile drain systems at the large basin scale. Further, neither the location nor the total density of tile drainage is known throughout the basin. In most areas, only the public tile drains and ditches are documented in spatial coverages, and the extent of private tile drains is known only for limited areas.

The HSPF model does not contain any routines for the explicit representation of tile drains. In typical applications of HSPF, surface runoff represents the quick flow storm response; interflow represents an intermediate time-scale hydrologic response; and groundwater discharge represents the base flow hydrologic response. In such applications, interflow represents lateral movement of water through the shallow soil profile.

At a gross or basin scale, the net effect of tile drainage is to move water relatively rapidly out of surface storage without direct surface drainage. Accordingly, it is to be expected that tile drainage is best represented in HSPF as an interflow component, with a response time that is somewhat slower than direct surface runoff, but quicker than groundwater discharge, represented by a relatively fast recession coefficient. Accordingly, tile drainage is

represented through the interflow inflow and interflow recession parameters in HSPF, as was done for the TMDL model (Tetra Tech 2008). USGS successfully implemented a similar approach for the heavily tiled Heron Lake basin, just south of the Minnesota River drainage (Jones and Winterstein 2000).

The tile drain density has a generally decreasing trend from the southeast to the northwest portions of the basin. Accordingly, interflow inflow rates are also scaled across the basin, using the calibrated values determined by Tetra Tech (2008). These parameters, specified monthly, range from a high of 4 in the Le Sueur River basin to a low of 1.1 in the northwestern portions of the watershed. As shown in Tetra Tech (2008), this results in the models representing interflow ranging up to a maximum of 46 percent of total flow in the Le Sueur basin and provides maximum interflow discharge rates that are consistent with typical drainage coefficients for tile drains.

Hydrology Calibration

As noted above, the starting point for calibration of hydrologic parameters was the existing TMDL model (Tetra Tech 2008); however, differences between the models meant that not all parameters were directly transferable. Therefore, the first focus of calibration was on areas of difference between the model formulations. This included calibrating the degree-day snowmelt representation and adjusting factors related to the different representation of PET. In addition, the model parameters were modified to reflect the HRU representation.

The TMDL model divided cropland into areas with conventional tillage, conservation tillage, and manure application. The 20 Watershed model includes a single cropland class (divided by HSG). Therefore, parameter estimates from the TMDL were converted to initial parameters for the 20 Watershed model by developing weighted averages based on the crop management area distribution in the TMDL model. Similar analyses, based on reported soil properties, were used to extend parameter initial values to the portions of the watershed not covered by the TMDL model. Calibration adjustments focused on the following parameters:

- INFILT (nominal infiltration rate parameter): The TMDL model did not distinguish between HSGs, but was adjusted based on watershed averages of reported soil survey infiltration rates. The resulting INFILT values were generally typical of D soils. The 20 Watershed model includes both D and B soils (although, as noted above, the B classification may be influenced by widespread pre-existing tile drainage). During calibration, the D soils were kept at the values derived from the TMDL model while INFILT for the B soils was adjusted upward as needed to match observations. The resulting final values for the B soils are still generally less than are often cited for B soils (USEPA 2000).
- KMELT (degree-day melt factor): The 20 Watershed model switches to a degree-day approach for snowmelt. This depends on the monthly values of KMELT. These were originally set to values recommended by USACE (1956), then adjusted during calibration.
- AGWRC (active groundwater recession constant): The preceding changes along with the modified form of PET required compensating adjustments in AGWRC.
- PET factor: The 20 Watershed model uses Penman-Monteith reference ET estimates consistent with FAO 56 (Allen et al. 1998), whereas the TMDL model used Penman Pan evaporation. The FAO 56 reference ET calculates ET for a well-watered actively growing grass surface and requires crop factors to convert to actual PET. The reference ET is similar to, but generally less than Penman Pan evaporation, for which pan factors, generally in the range around 0.6-0.8, are needed to convert to model PET. Factors on the Penman-Monteith PET are thus expected to be needed in the model, but will be a little higher than those determined in the previous calibration effort. The previous modeling also determined that these factors tend to vary across the watershed, probably reflecting geographic trends in factors like cloud albedo and opacity. Therefore, new PET factors were assigned during calibration on zonal basis, ranging from 0.71 to 0.935.

Initial calibrations were performed for the Cottonwood River, comparing model results to data from USGS 05317000, and are summarized in Figure 6 through Figure 12 and Table 6 and Table 7. The fit is of high quality

for all except the very lowest flows and meets all the recommended criteria – although the fit in the more detailed TMDL model is somewhat better. Potential problems with very low flows likely reflect a combination of factors, including omission of minor point sources and simplified representation of the behavior of small ponds and wetlands.

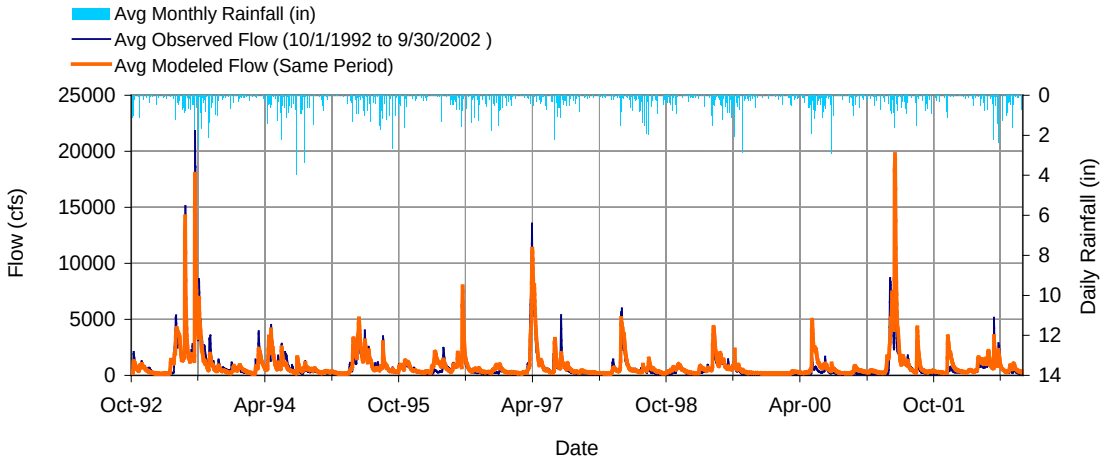

Figure 6. Mean daily flow at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

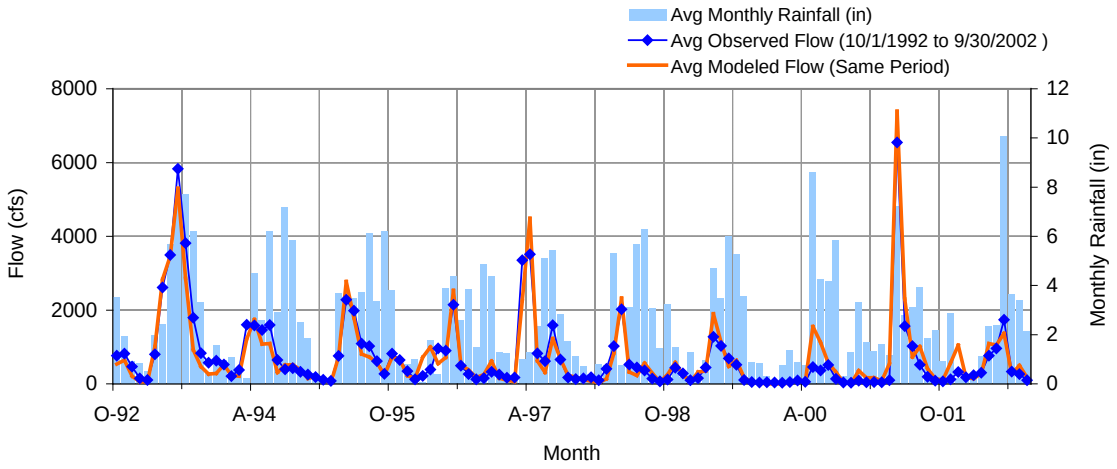

Figure 7. Mean monthly flow at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

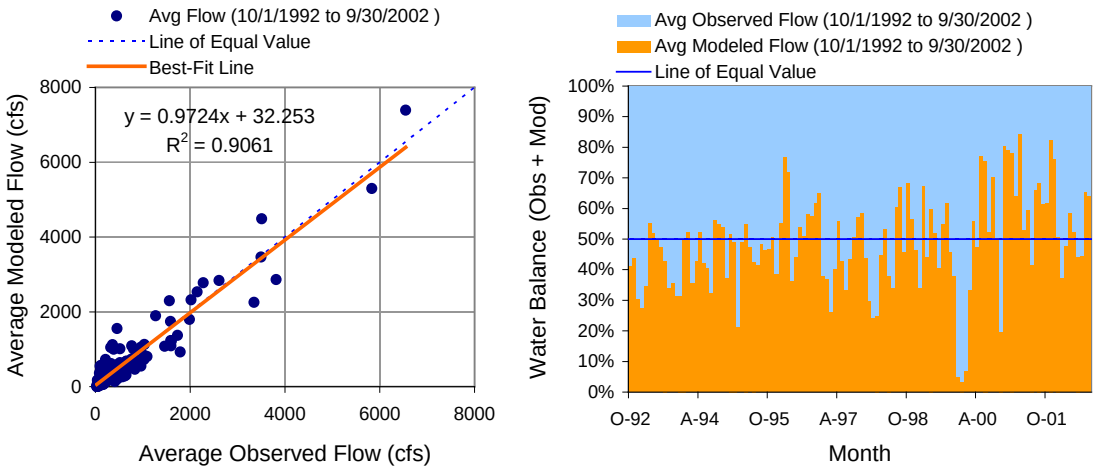

Figure 8. Mean monthly flow regression and temporal variation at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

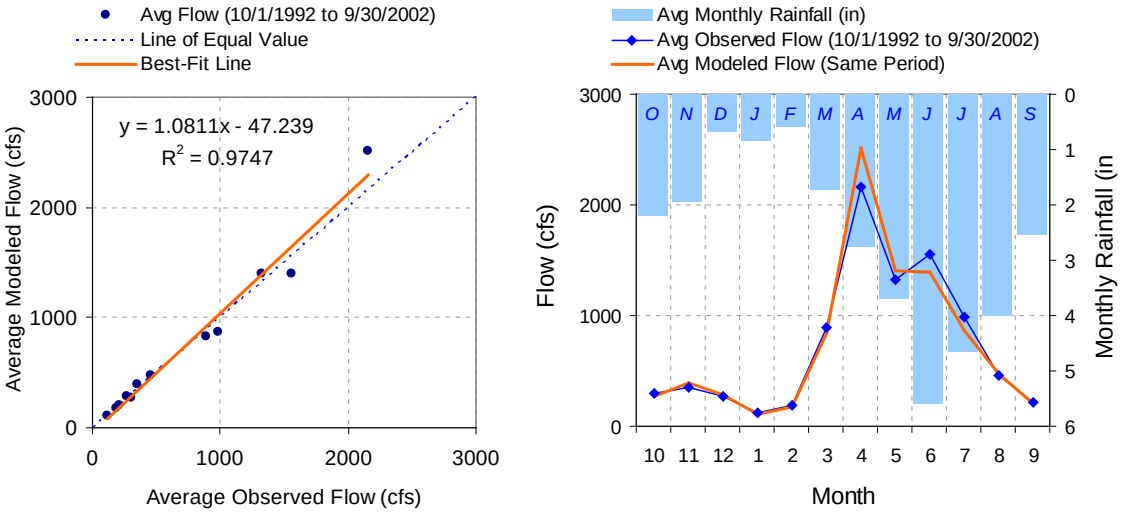

Figure 9. Seasonal regression and temporal aggregate at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

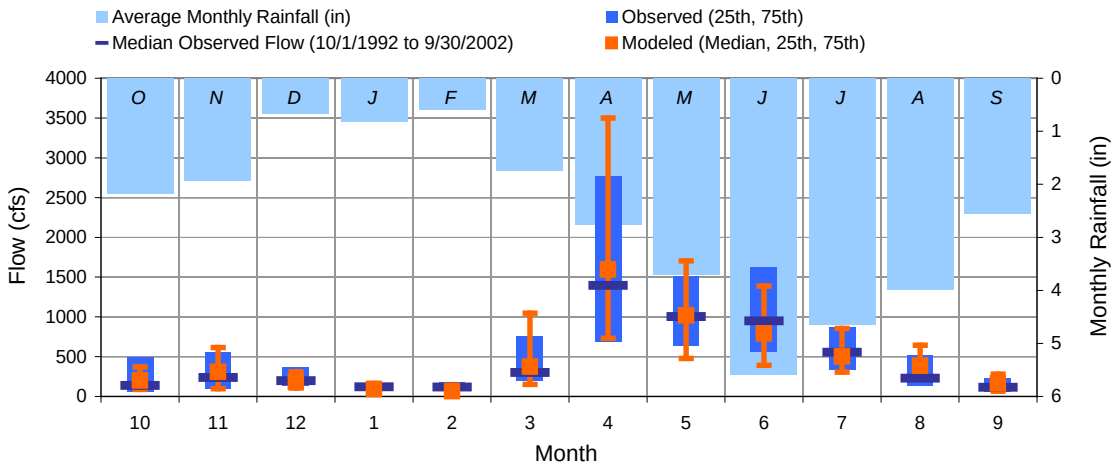

Figure 10. Seasonal medians and ranges at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

Table 6. Seasonal summary at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	301.38	137.50	62.25	499.00	272.97	200.96	89.69	372.11
Nov	350.75	237.50	101.25	562.50	397.77	307.86	98.12	615.44
Dec	264.09	198.00	139.25	369.50	283.83	187.17	104.90	307.50
Jan	120.42	120.00	85.25	169.00	107.44	91.30	39.28	163.40
Feb	183.37	116.00	80.00	174.50	178.50	65.86	24.23	144.26
Mar	885.87	300.00	191.25	755.25	833.50	373.98	150.34	1045.37
Apr	2161.06	1395.00	688.00	2767.50	2514.03	1596.32	730.83	3500.30
May	1320.39	1005.00	638.50	1507.50	1403.31	1018.84	477.76	1705.07
Jun	1552.95	950.00	561.25	1625.00	1395.52	792.72	392.66	1387.65
Jul	981.10	554.50	336.00	877.25	868.51	502.40	306.70	853.99
Aug	455.96	228.00	138.00	519.75	476.75	385.70	237.43	643.06
Sep	216.05	114.00	65.00	234.00	207.22	164.22	67.12	280.86

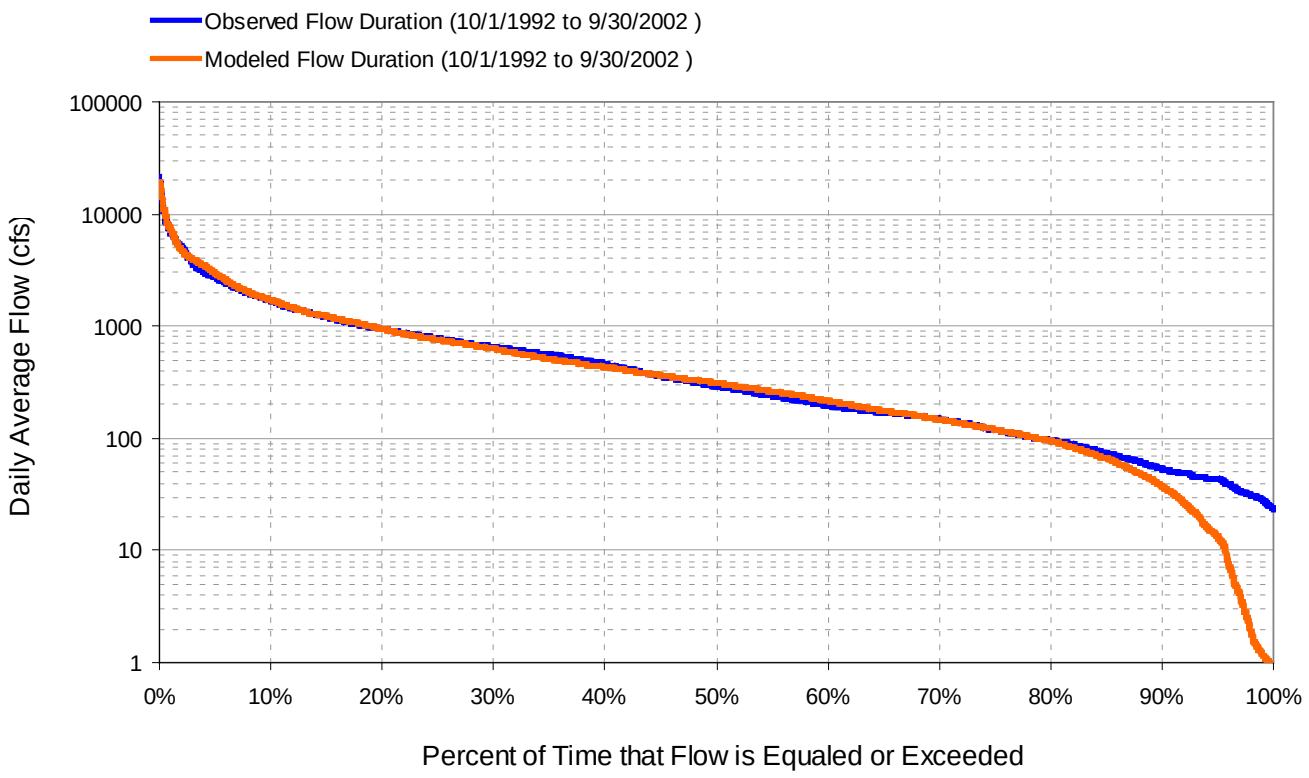

Figure 11. Flow exceedance at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

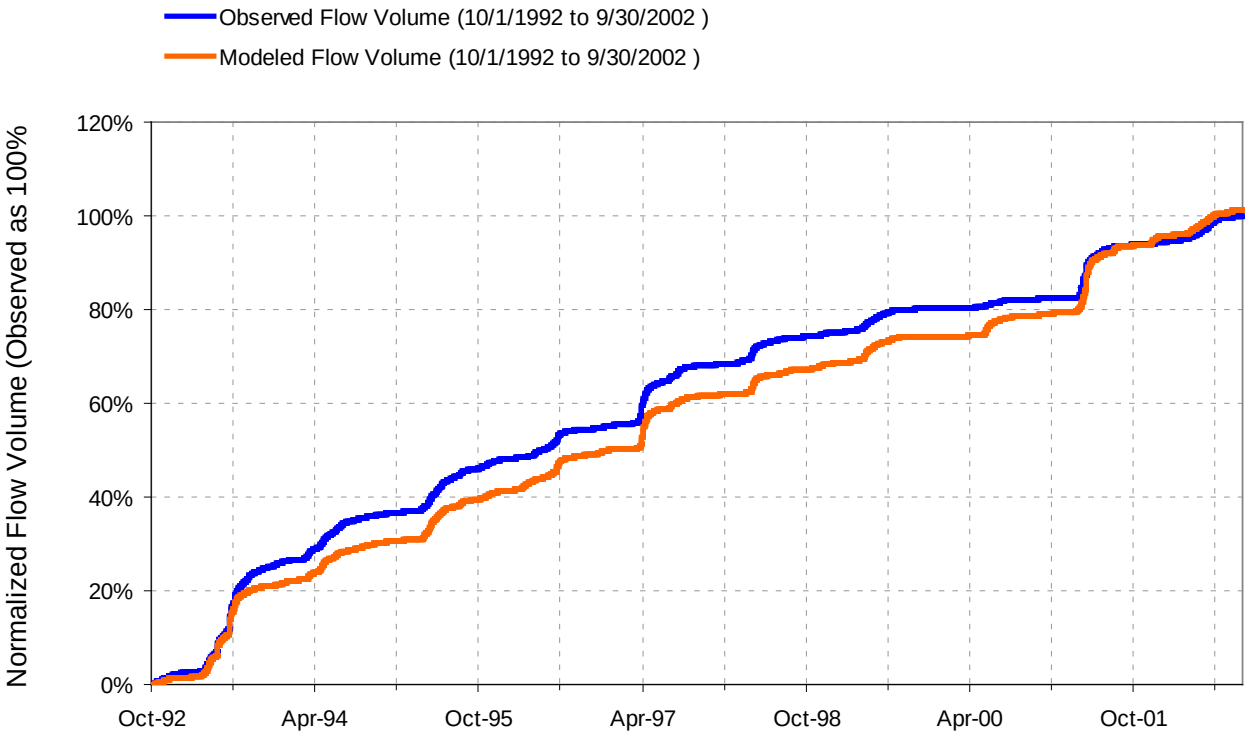

Figure 12. Flow accumulation at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF).

Table 7. Summary statistics at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101 10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area UpperMSd, mod Water; PET 0.9		USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Hydrologic Unit Code: 7020008 Latitude: 44.29135177 Longitude: -94.4402495 Drainage Area (sq-mi): 1300	
Total Simulated In-stream Flow:	**7.79**	Total Observed In-stream Flow:	**7.66**
Total of simulated highest 10% flows:	**4.09**	Total of Observed highest 10% flows:	**3.92**
Total of Simulated lowest 50% flows:	**0.67**	Total of Observed Lowest 50% flows:	**0.68**
Simulated Summer Flow Volume (months 7-9):	**1.37**	Observed Summer Flow Volume (7-9):	**1.46**
Simulated Fall Flow Volume (months 10-12):	**0.84**	Observed Fall Flow Volume (10-12):	**0.80**
Simulated Winter Flow Volume (months 1-3):	**0.98**	Observed Winter Flow Volume (1-3):	**1.04**
Simulated Spring Flow Volume (months 4-6):	**4.60**	Observed Spring Flow Volume (4-6):	**4.36**
Total Simulated Storm Volume:	**2.61**	Total Observed Storm Volume:	**2.59**
Simulated Summer Storm Volume (7-9):	**0.44**	Observed Summer Storm Volume (7-9):	**0.50**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	1.61	10	
Error in 50% lowest flows:	-0.73	10	
Error in 10% highest flows:	4.26	15	
Seasonal volume error - Summer:	-6.09	30	
Seasonal volume error - Fall:	4.07	30	
Seasonal volume error - Winter:	-5.95	30	
Seasonal volume error - Spring:	5.54	30	
Error in storm volumes:	0.86	20	
Error in summer storm volumes:	-10.51	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.754	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.589	as E or E' approaches 1.0	

Hydrology Validation

Validation for the Cottonwood watershed model was performed at the same location as calibration but for the period 10/1/1982 through 9/30/1992. Results are presented in Figure 13 through Figure 19 and Table 8 and Table 9. The validation achieves a high coefficient of model fit efficiency, but is over on both total volume and 50% low volume. Inspection of the figures and tables reveals that median flows are generally over-predicted through the spring and summer.

It is important to recognize that the validation uses the 2001 land use and parameters that are calibrated to land management practices of the 1990s. While the basin has remained largely agricultural, there are a number of differences between the earlier and later periods. These differences include the following:

- Developed impervious surface areas have increased.
- The intensity of tile drainage has increased, with more tile lines with greater capacity installed.
- Cropped areas have changed, with a significant amount of land going out of production and into the Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP).
- PET estimates for the 20 Watershed model use SWAT weather generator statistics for solar radiation, cloud cover, wind, and relative humidity – essentially assuming that the central tendency of these factors has not changed over time.

All of these factors may contribute to an increase in the runoff rate for the more recent calibration period, leading to an over-prediction of flows in the validation period.

The TMDL model (Tetra Tech 2008) also included an earlier period validation test, but used a separate land use (ca. 1992) for the earlier period, which accounts for two of these factors, although information was not available on the rate of change in tile drainage intensity. The TMDL model also calculated PET based on observed meteorology, rather than using a weather generator for solar radiation, cloud cover, wind, and relative humidity. Even with these changes it was found in that model that it was necessary to apply higher PET factors for the earlier period to achieve a good hydrologic fit. That adjustment might be compensating for the change in tile drain intensity or it might reflect actual changes in the relationship of actual PET to estimates obtained from solar radiation and cloud cover. Similar discrepancies are found at most other gages in the basin.

Temporal modifications to land use, PET factors, and other parameters were not made for the 20 Watershed model as its purpose is to provide a basis for comparison between current and potential future conditions, where the current condition is characterized by 2001 land use and land management. Therefore, the discrepancies in the validation test are not considered to present a significant bar to application of the model.

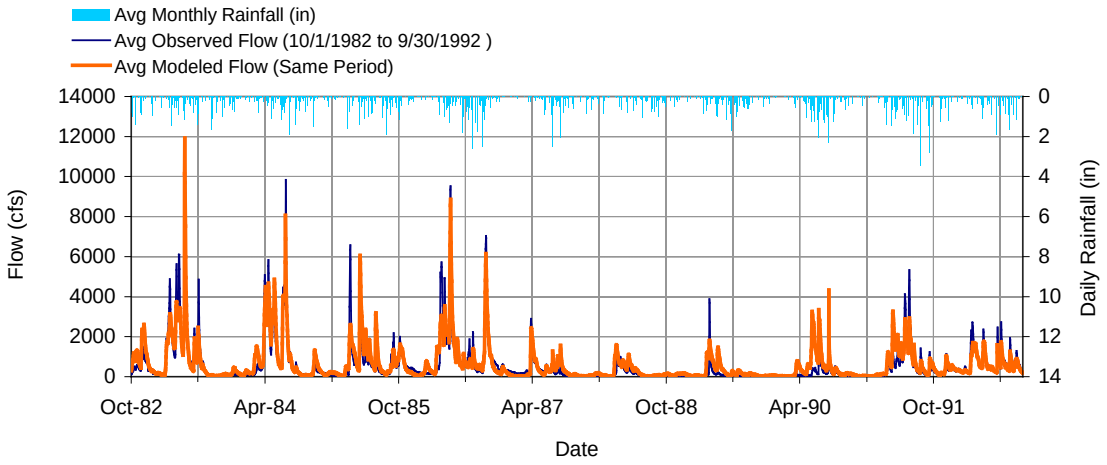

Figure 13. Mean daily flow at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

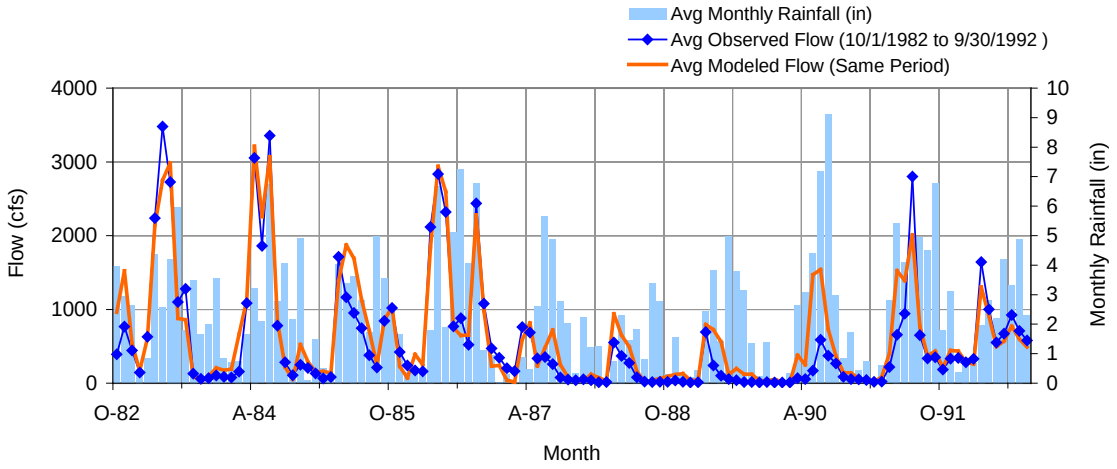

Figure 14. Mean monthly flow at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

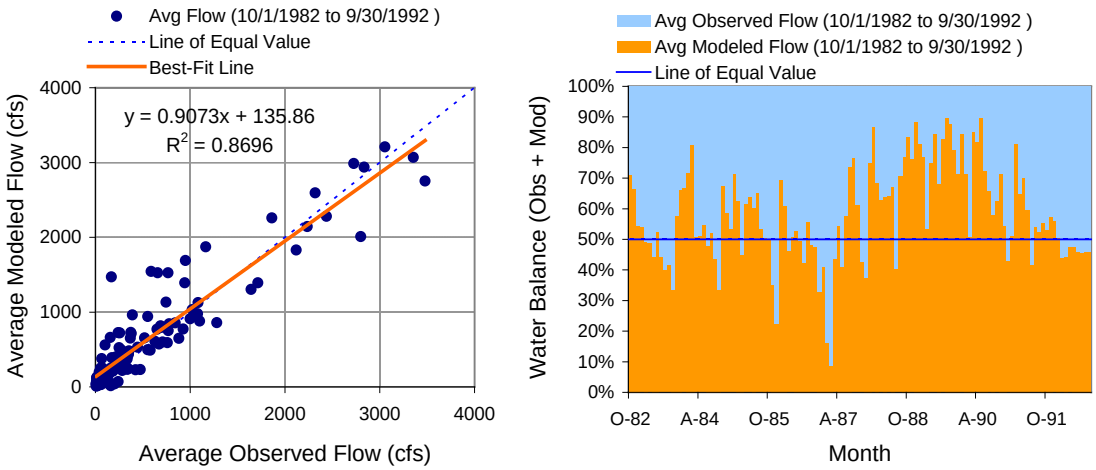

Figure 15. Monthly flow regression and temporal variation at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

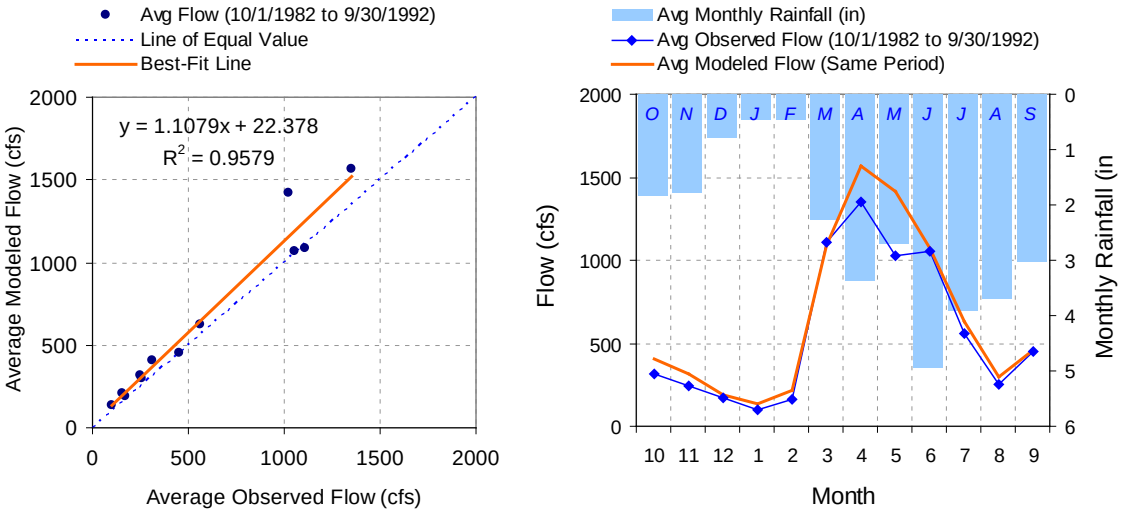

Figure 16. Seasonal regression and temporal aggregate at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

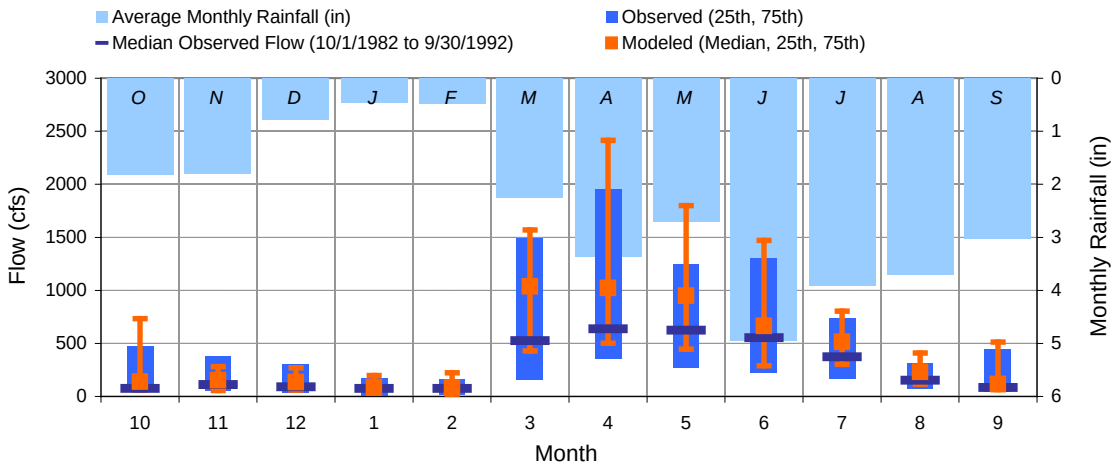

Figure 17. Seasonal medians and ranges at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

Table 8. Seasonal summary at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	311.49	75.50	40.00	467.25	409.43	139.27	59.56	734.36
Nov	246.34	112.00	52.00	380.00	317.71	151.23	54.81	281.15
Dec	170.13	89.00	31.25	300.00	193.45	135.84	60.06	269.57
Jan	98.82	75.00	11.00	172.00	139.56	87.56	30.45	197.78
Feb	158.34	75.00	15.50	166.00	212.14	86.22	21.54	223.51
Mar	1108.68	525.50	162.50	1495.00	1090.13	1037.59	427.82	1570.61
Apr	1354.28	637.50	355.00	1957.50	1565.20	1023.14	501.22	2414.57
May	1023.32	623.00	266.50	1245.00	1417.41	949.90	445.09	1799.84
Jun	1051.98	553.50	222.25	1300.00	1071.80	665.65	289.05	1470.56
Jul	558.86	374.00	160.25	736.50	626.37	514.21	302.17	804.68
Aug	256.15	151.50	71.00	311.50	296.15	231.83	116.57	409.98
Sep	454.86	84.50	46.00	446.00	455.65	117.39	63.86	512.03

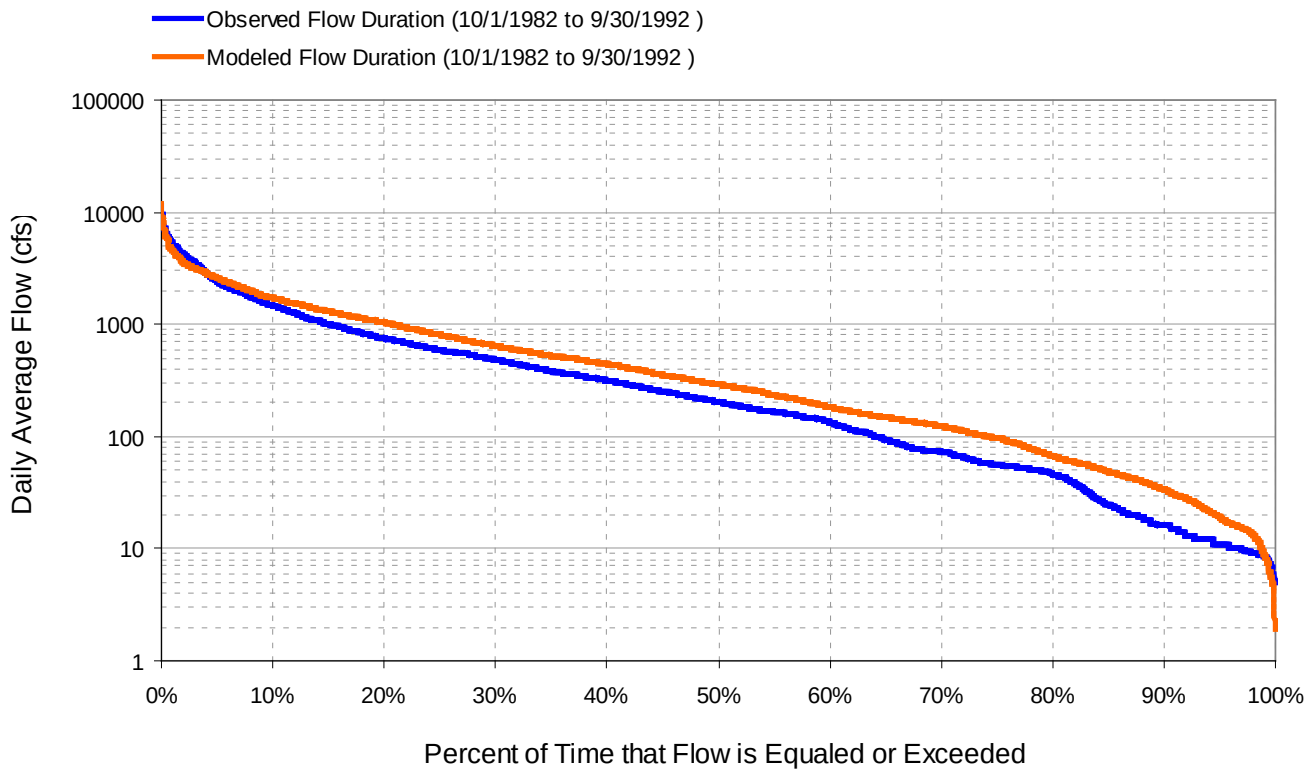

Figure 18. Flow exceedance at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

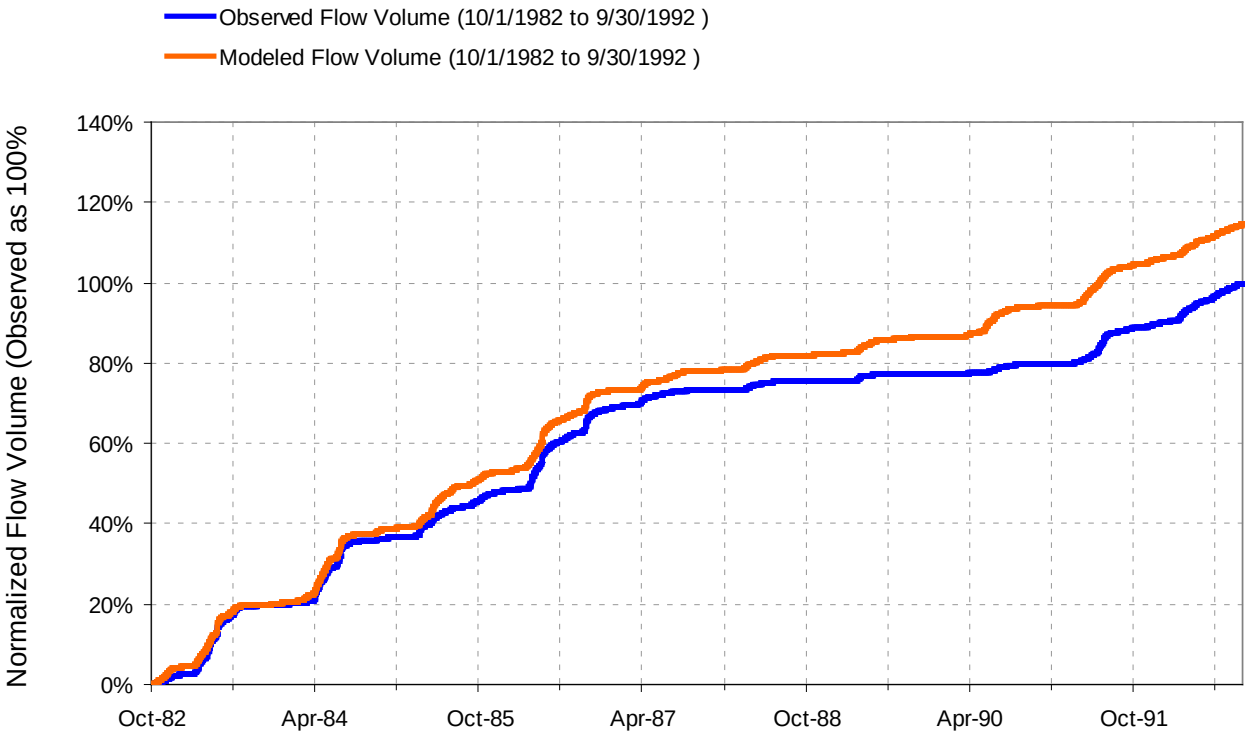

Figure 19. Flow accumulation at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF).

Table 9. Summary statistics at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101 10-Year Analysis Period: 10/1/1982 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Hydrologic Unit Code: 7020008 Latitude: 44.29135177 Longitude: -94.4402495 Drainage Area (sq-mi): 1300	
Total Simulated In-stream Flow:	**6.80**	Total Observed In-stream Flow:	**5.92**
Total of simulated highest 10% flows:	**3.09**	Total of Observed highest 10% flows:	**3.17**
Total of Simulated lowest 50% flows:	**0.57**	Total of Observed Lowest 50% flows:	**0.38**
Simulated Summer Flow Volume (months 7-9):	**1.21**	Observed Summer Flow Volume (7-9):	**1.11**
Simulated Fall Flow Volume (months 10-12):	**0.81**	Observed Fall Flow Volume (10-12):	**0.64**
Simulated Winter Flow Volume (months 1-3):	**1.26**	Observed Winter Flow Volume (1-3):	**1.20**
Simulated Spring Flow Volume (months 4-6):	**3.52**	Observed Spring Flow Volume (4-6):	**2.97**
Total Simulated Storm Volume:	**2.06**	Total Observed Storm Volume:	**2.09**
Simulated Summer Storm Volume (7-9):	**0.40**	Observed Summer Storm Volume (7-9):	**0.45**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	**14.78**	**10**	
Error in 50% lowest flows:	**51.89**	**10**	
Error in 10% highest flows:	-2.54	15	
Seasonal volume error - Summer:	8.63	30	
Seasonal volume error - Fall:	26.43	30	
Seasonal volume error - Winter:	5.27	30	
Seasonal volume error - Spring:	18.42	30	
Error in storm volumes:	-1.37	20	
Error in summer storm volumes:	-11.91	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.779	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.587	as E or E' approaches 1.0	

Hydrology Results for Larger Watershed

As described above, parameters determined for the Cottonwood gage were not fully transferable to other gages in the watershed. Therefore, calibration was pursued at a total of nine gages throughout the watershed, including seven gages at the outlet of 8-digit HUCs and two gages on the mainstem. Calibration results were acceptable at all gages (Table 10). The close match between observed and predicted flow volumes at the most downstream available gage (USGS 05330000, Minnesota River near Jordan) are shown in Figure 20 and Figure 21. Additional calibration results are shown in Figures 22 through 26 and Table 11.

Table 10. Summary statistics (percent error): all stations - calibration period (HSPF)

Station	05311000 Minnesota River at Montevideo	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Error in total volume:	-7.76	-2.49	0.69	1.61	0.88	-4.35	-0.38	-3.80	-4.25
Error in 50% lowest flows:	-6.49	7.14	9.25	-0.73	5.46	1.58	7.09	-3.29	-7.30
Error in 10% highest flows:	-5.98	2.33	4.12	4.26	-1.37	0.30	4.75	-0.94	-1.25
Seasonal volume error - Summer:	-8.31	-19.71	-4.24	-6.09	5.37	4.45	-9.04	-3.11	-3.21
Seasonal volume error - Fall:	-9.09	-12.80	-4.17	4.07	7.25	-12.99	1.53	-5.15	-6.26
Seasonal volume error - Winter:	-16.82	7.94	8.85	-5.95	-12.48	-17.90	33.10	-7.28	-9.55
Seasonal volume error - Spring:	-5.42	1.52	1.47	5.54	0.90	-3.44	-3.36	-3.17	-3.33
Error in storm volumes:	1.81	10.67	7.14	0.86	5.12	8.79	10.76	12.41	8.85
Error in summer storm volumes:	37.17	8.78	9.86	-10.51	-7.13	12.38	6.76	14.66	7.85
Nash-Sutcliffe Coefficient of Efficiency, E:	0.784	0.573	0.673	0.754	0.728	0.811	0.539	0.899	0.916
Baseline adjusted coefficient (Garrick), E':	0.604	0.551	0.596	0.589	0.594	0.657	0.566	0.720	0.720

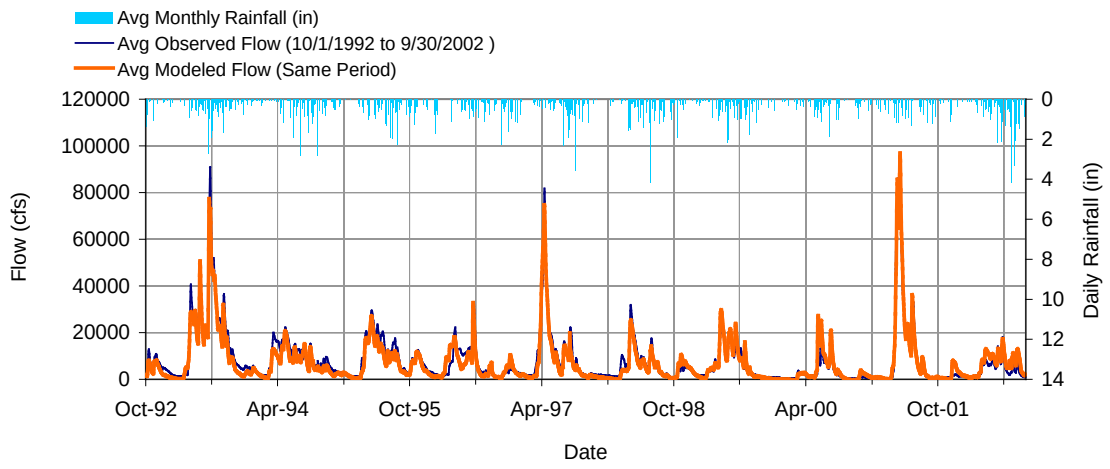

Figure 20. Mean daily flow simulation at USGS 05330000 Minnesota River near Jordan, MN - calibration period (HSPF).

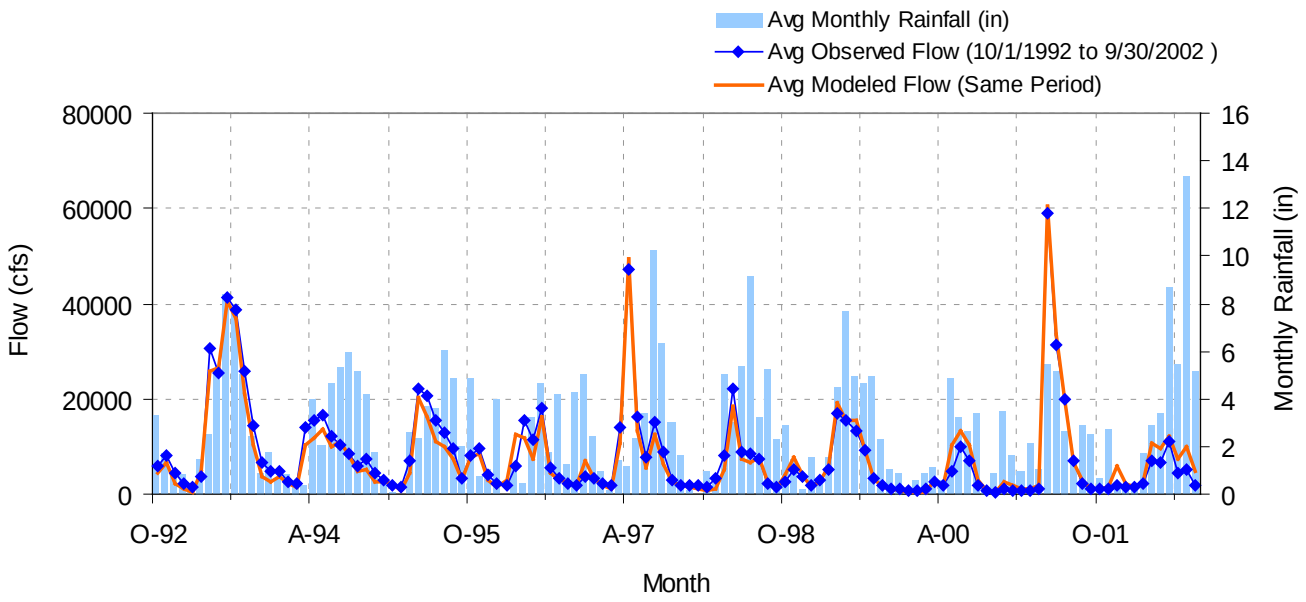

Figure 21. Mean monthly flow simulation at USGS 05330000 Minnesota River near Jordan, MN - calibration period (HSPF).

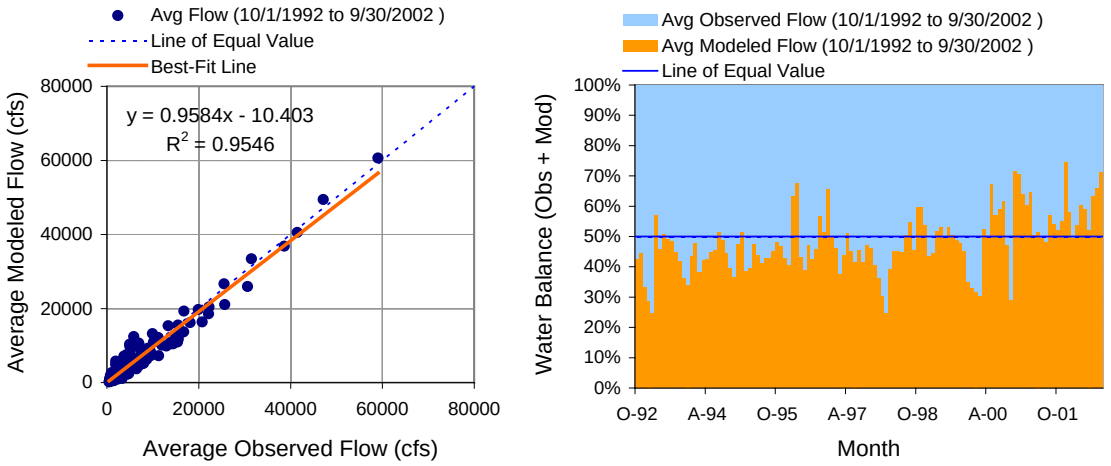

Figure 22. Monthly flow regression and temporal variation at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF).

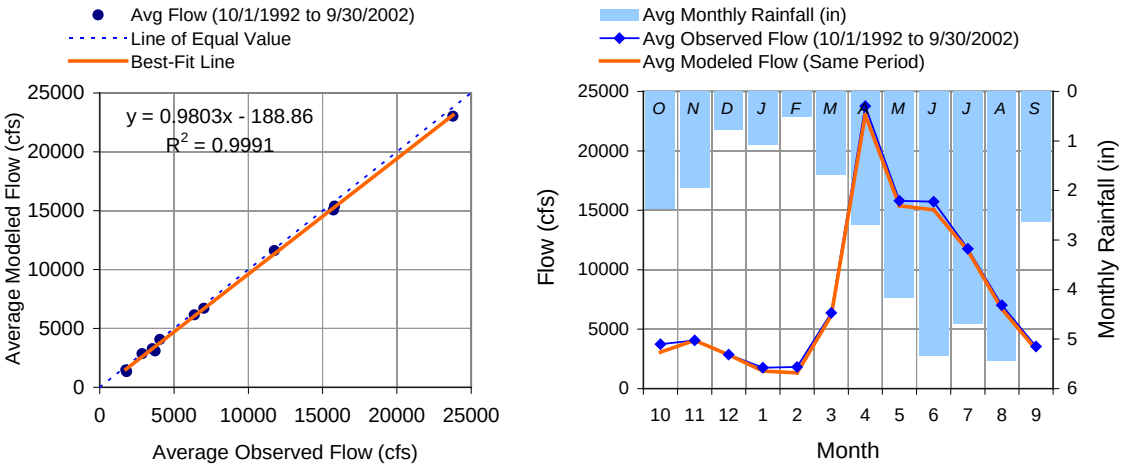

Figure 23. Seasonal regression and temporal aggregate at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF).

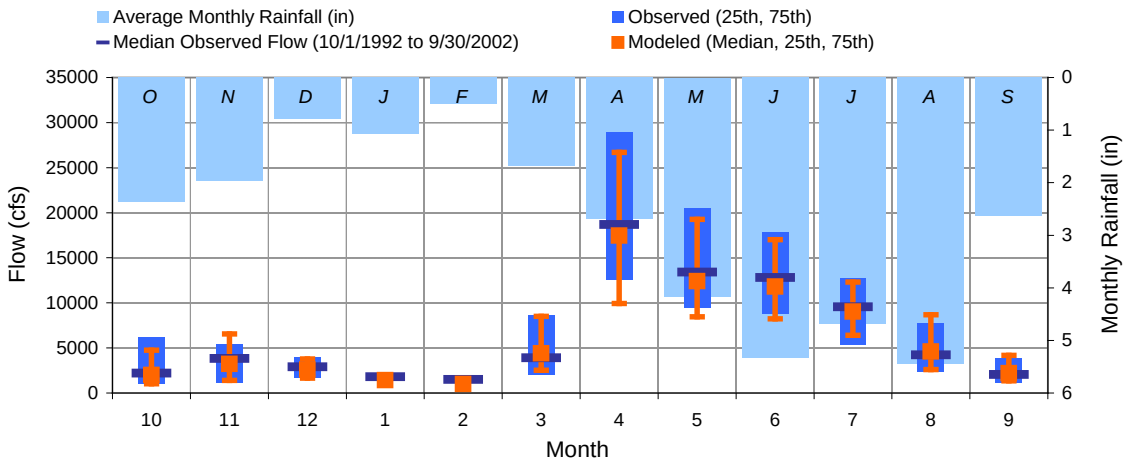

Figure 24. Seasonal medians and ranges at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF).

Table 11. Seasonal summary at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	3732.17	2190.00	1082.50	6237.50	3081.52	2001.01	1032.73	4762.72
Nov	4054.61	3825.00	1210.00	5462.50	4059.50	3234.97	1403.38	6562.34
Dec	2858.86	2900.00	1702.50	4000.00	2846.70	2613.94	1647.86	3784.83
Jan	1757.39	1800.00	1392.50	2200.00	1474.05	1435.78	893.52	1978.66
Feb	1811.52	1500.00	1272.50	1900.00	1327.81	989.91	656.04	1398.81
Mar	6364.40	3910.00	2080.00	8627.50	6154.83	4403.41	2529.67	8517.95
Apr	23775.27	18700.00	12550.00	28925.00	23021.23	17473.36	9942.81	26689.60
May	15802.45	13400.00	9470.00	20500.00	15392.60	12413.48	8451.15	19265.36
Jun	15733.60	12800.00	8805.00	17900.00	15049.13	11811.63	8221.43	17020.20
Jul	11756.52	9565.00	5347.50	12675.00	11613.34	9036.76	6415.22	12314.82
Aug	7020.71	4225.00	2377.50	7782.50	6704.00	4601.26	2608.84	8692.04
Sep	3542.37	2040.00	1205.00	3910.00	3279.92	2191.42	1342.62	4185.19

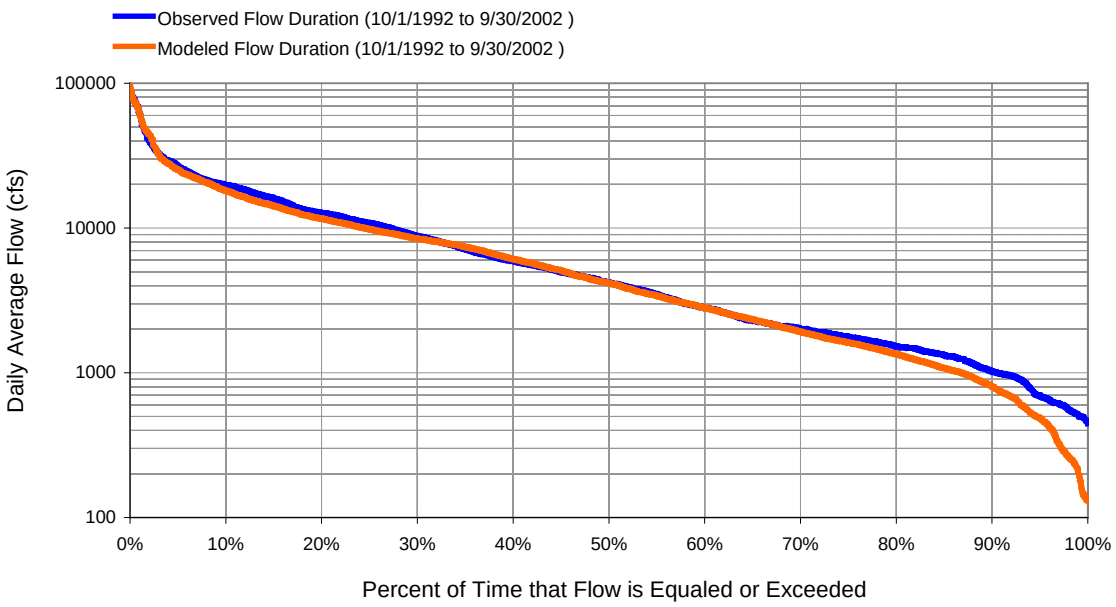

Figure 25. Flow exceedence at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF).

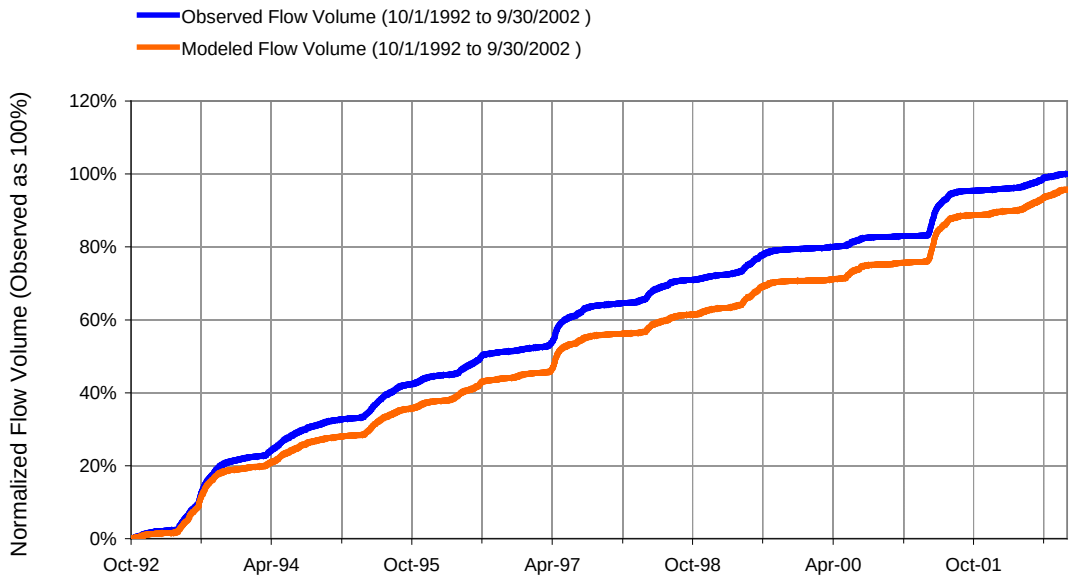

Figure 26. Flow accumulation at USGS 05330000 Minnesota River near Jordan, MN – calibration period (HSPF).

For hydrologic validation, the FTable developed during calibration to represent Lac qui Parle dam did not appear to provide realistic results for the earlier period. Therefore, the model was respecified using gaged flows below Lac qui Parle as a boundary condition. Results of the validation exercise are summarized in Table 12. Problems similar to those experienced on the Cottonwood River were seen at all tributary gages, with overprediction of lower flows in summer. However, as noted above, this is likely due to the use of land use and model parameters that are more reflective of current conditions and is not believed to present a bar to application of the model.

Table 12. Summary statistics: all stations - validation period (HSPF)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Error in total volume:	-3.47	8.55	14.78	13.31	5.11	21.93	-13.43	-9.73
Error in 50% lowest flows:	48.58	74.44	51.89	75.61	67.23	59.34	-2.50	-0.75
Error in 10% highest flows:	-11.24	-11.99	-2.54	-0.33	-7.20	18.94	-17.33	-15.02
Seasonal volume error - Summer:	-20.37	11.63	8.63	29.35	19.13	34.92	-17.07	-13.91
Seasonal volume error - Fall:	22.08	7.22	26.43	21.51	16.11	39.00	-13.92	-11.30
Seasonal volume error - Winter:	-8.64	-1.04	5.27	3.55	-6.63	9.97	-12.26	-9.88
Seasonal volume error - Spring:	-0.22	11.95	18.42	9.93	2.58	19.17	-12.17	-7.27
Error in storm volumes:	5.20	-2.20	-1.37	23.26	12.85	29.98	15.60	14.60
Error in summer storm volumes:	-15.69	-11.47	-11.91	30.61	19.48	61.17	10.28	4.11
Nash-Sutcliffe Coefficient of Efficiency, E:	0.317	0.491	0.779	0.345	0.712	0.374	0.773	0.779
Baseline adjusted coefficient (Garrick), E':	0.483	0.475	0.587	0.458	0.575	0.470	0.597	0.607

Water Quality Calibration and Validation

The 20 Watershed models are designed to provide water quality simulation for TSS, total nitrogen, and total phosphorus. Total suspended solids is simulated with the standard HSPF approach (USEPA 2006), and takes advantage of detailed calibration efforts for the TMDL model (Tetra Tech 2008), which included radionuclide

attribution of sediment sources to field, ravine, and channel sources. However, the segmentation of the 20 Watershed model limits the ability to effectively transfer channel erosion and deposition parameters.

In contrast to TSS, total nitrogen and total phosphorus are simulated in this application in a simplistic fashion, as HSPF general quality constituents (GQUALs) subject to an exponential decay rate during transport. This contrasts with the approach in the TMDL model, where individual nutrient species are simulated along with kinetic transformations and algal uptake/release in the stream reaches using the HSPF NUTRX routines. A significant drawback of the GQUAL approach to nutrients is that it is not readily possible to account for the nutrient content of channel bank erosion, which forms an important component of the total phosphorus load in the TMDL model.

The water quality calibration focuses on the replication of monthly loads, as specified in the project QAPP. Given the approach to water quality simulation in the 20 Watershed model a close match to individual concentration observations cannot be expected. However, comparison to monthly loads presents challenges, as monthly loads are not observed. Instead, monthly loads must be estimated from scattered concentration grab samples and continuous flow records. Such estimation inherently includes uncertainty because it depends on the degree and form in which concentration and flow are correlated with one another. Further, the bulk of the load of sediment and sediment-associated phosphorus is likely to move through the system in a limited number of high flow events, which typically have not been monitored. As a result, the monthly load calibration is inevitably based on the comparison of two uncertain numbers. Nonetheless, calibration is able to achieve a reasonable agreement. Further, the load comparisons were supported by detailed examinations of the relationships of flows to loads and concentrations and the distribution of concentration prediction errors versus flow, time, and season, as well as standard time series plots.

For application on a nationwide basis, the 20 Watershed protocols assume that sediment and phosphorus loads will likely exhibit a strong positive correlation to flow (and associated erosive processes), while total nitrogen loads, which often have a dominant groundwater component, will not. Accordingly, sediment and phosphorus loads were estimated from observations using a flow-stratified log-log regression approach, while total nitrogen loads were estimated using a flow-stratified averaging estimator, consistent with the findings of Preston et al. (1989).

As with hydrology, initial calibration and validation of water quality was done on the Cottonwood River, at USGS gage 05317000, using 1993-2002 for calibration and 1986-1992 for validation. As with hydrology, 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. Initial sediment parameters were transferred from the TMDL model, with area-weighting to account for the change in subwatershed boundaries and the different representation of land use in the 20 Watershed model. It was found that this approach resulted in overestimation of the peak loading at high flows associated with ravine incision. On investigation, it was determined that this was caused by the different methods of processing of rainfall data for the two models. In particular, the approach to disaggregation of daily rainfall totals to hourly rainfall in the BASINS4 meteorological dataset results in greater (and, in some cases, unrealistic) estimates of peak rainfall intensity. As ravine incision depends in a nonlinear fashion on maximum runoff rates this component of the model is highly sensitive to rainfall intensity. This was addressed by reducing the exponent on flow depth (JGER) in the 20 Watershed model and then adjusting the coefficient (KGER) to achieve calibration. Channel scour and deposition critical shear stresses also needed to be adjusted.

Once these changes were made, the sediment model performed well for both the calibration and validation periods. Time series of simulated and estimated sediment loads at the Cottonwood gage for both periods are shown in Figure 27 and statistics for the two periods are provided separately in Table 13. The key statistic in Table 13 (consistent with the QAPP) is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. The table 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 good agreement.

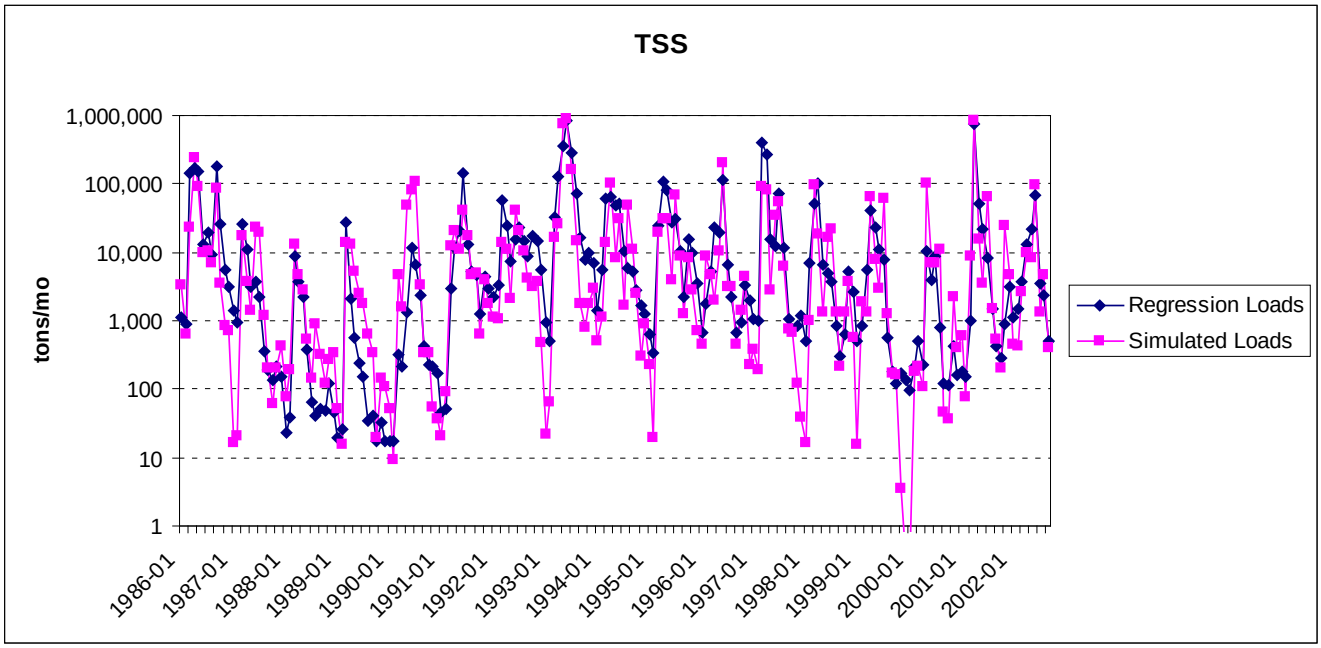

Figure 27. Fit for monthly load of TSS at USGS 05317000 Cottonwood River (HSPF).

Table 13. Model fit statistics (observed minus predicted) for monthly TSS loads using stratified regression (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	7.5%	13.1%
Relative Average Absolute Error	54%	79%
Relative Median Absolute Error	1.7%	9.9%

A variety of other diagnostics were also pursued to ensure agreement between the model and observations. These are available in full in the calibration spreadsheets, but a few examples are provided below. First, load-flow power plots were compared for individual days (Figure 28 and Figure 29). These confirm that the relationship between flow and load is consistent across the entire range of observed flows, for both the calibration and validation periods.

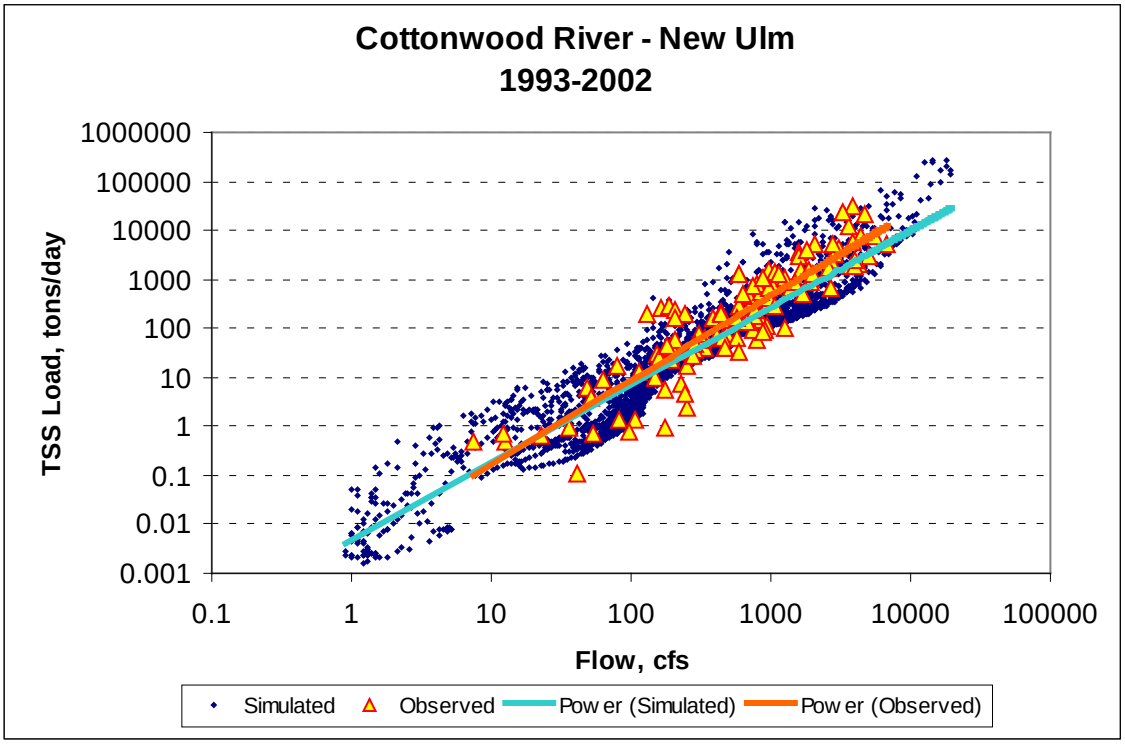

Figure 28. Power plot for observed and simulated TSS at USGS 05317000 Cottonwood River - calibration period (HSPF).

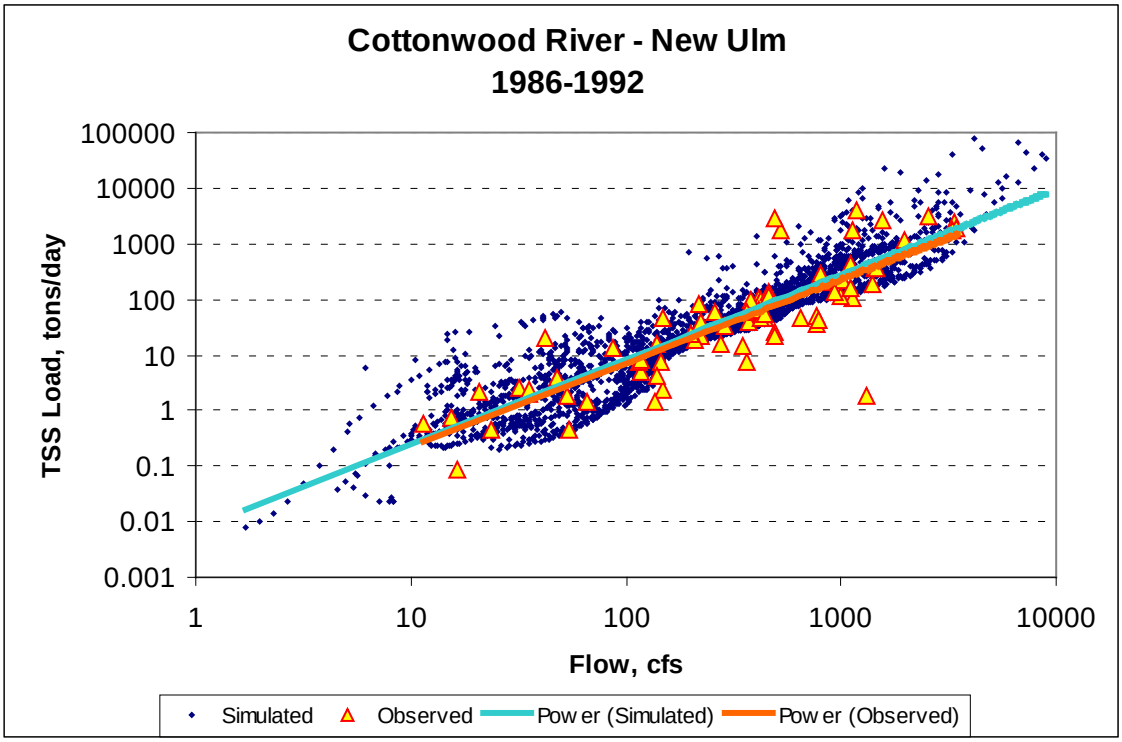

Figure 29. Power plot for observed and simulated TSS at USGS 05317000 Cottonwood River - validation period (HSPF).

Standard time series plots (Figure 30) show that observed and simulated concentrations achieve good agreement, although individual observations may deviate. Plots of concentration error versus flow and versus month (not shown) were used to guard against hydrologic and temporal bias. Finally, statistics on concentration (Table 14) show that low median errors are achieved.

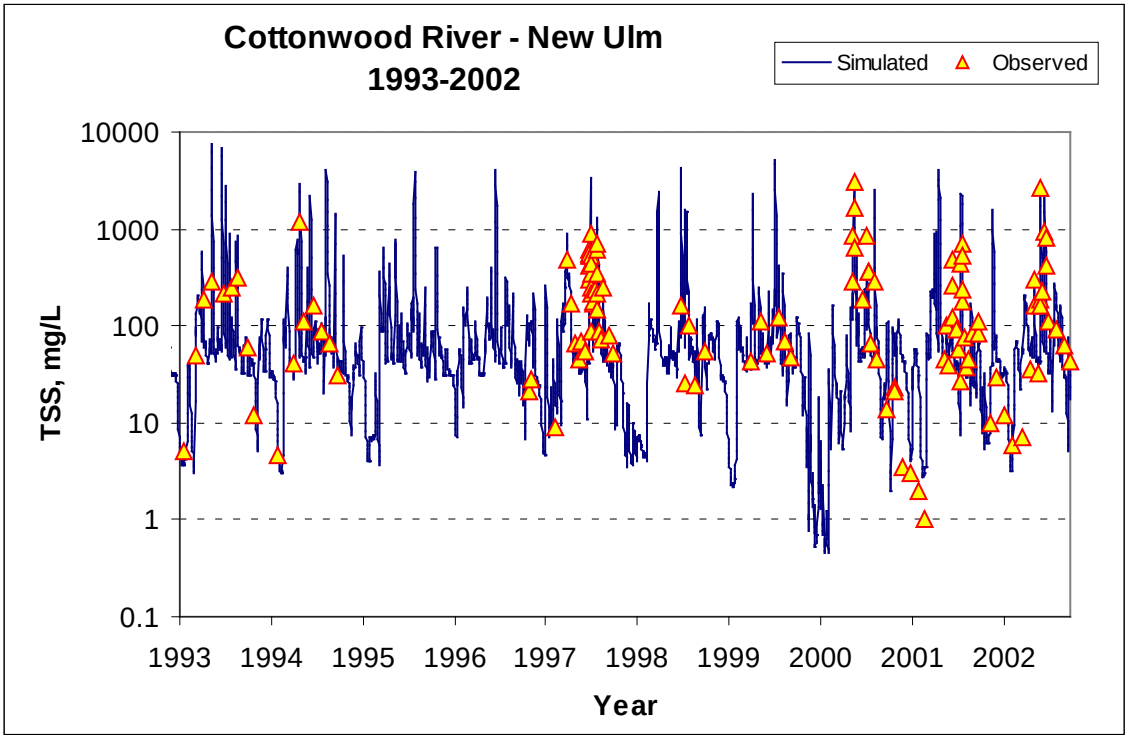

Figure 30. Time series plot of TSS concentration at USGS 05317000 Cottonwood River (HSPF).

Table 14. Relative errors (observed minus predicted), TSS concentration at USGS 05317000 Cottonwood River (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	121	75
Concentration Average Error	-58.8%	13.1%
Concentration Median Error	0.41%	-2.7%

For simulation of total phosphorus and total nitrogen, the TMDL model parameters, which address individual nutrient species separately, were converted to approximately equivalent parameters on total nutrients using area weighting. The model simulates total phosphorus from the uplands as having sediment-associated (both with sheet and rill erosion and ravine incision) and buildup-washoff components on the land surface along with monthly variable interflow and groundwater components. The sediment-associated component of the surface load reflects mineral phosphorus, while the buildup-washoff component addresses the organic phosphorus. Total nitrogen is simulated with a buildup-washoff component for surface loading, plus monthly variable interflow and groundwater components.

The original parameter set derived in this way did not perform well for the Cottonwood River phosphorus simulation – probably because the process of weighting the parameters related to different agricultural land uses

(manured land, conventional tillage, and conservation tillage) assumes linear additivity and independence of hydrologic variation. Calibration was achieved by adjusting downward the sediment potency factors. A similar approach was applied for other subwatersheds, maintaining the spatial variability in loading rates incorporated in the TMDL model.

In-stream, total phosphorus is represented as a simple general quality component, subject to exponential decay. Decay rates were adapted from the most recent version of the SPARROW model (Alexander et al. 2008), which estimates decay coefficients as a function of stream depth, using typical depths for streams of different orders.

Monthly loading series for total phosphorus are shown in Figure 31 and load statistics are summarized in Table 15. In general, the observed and estimated total phosphorus loads attain a good match for both the calibration and validation periods.

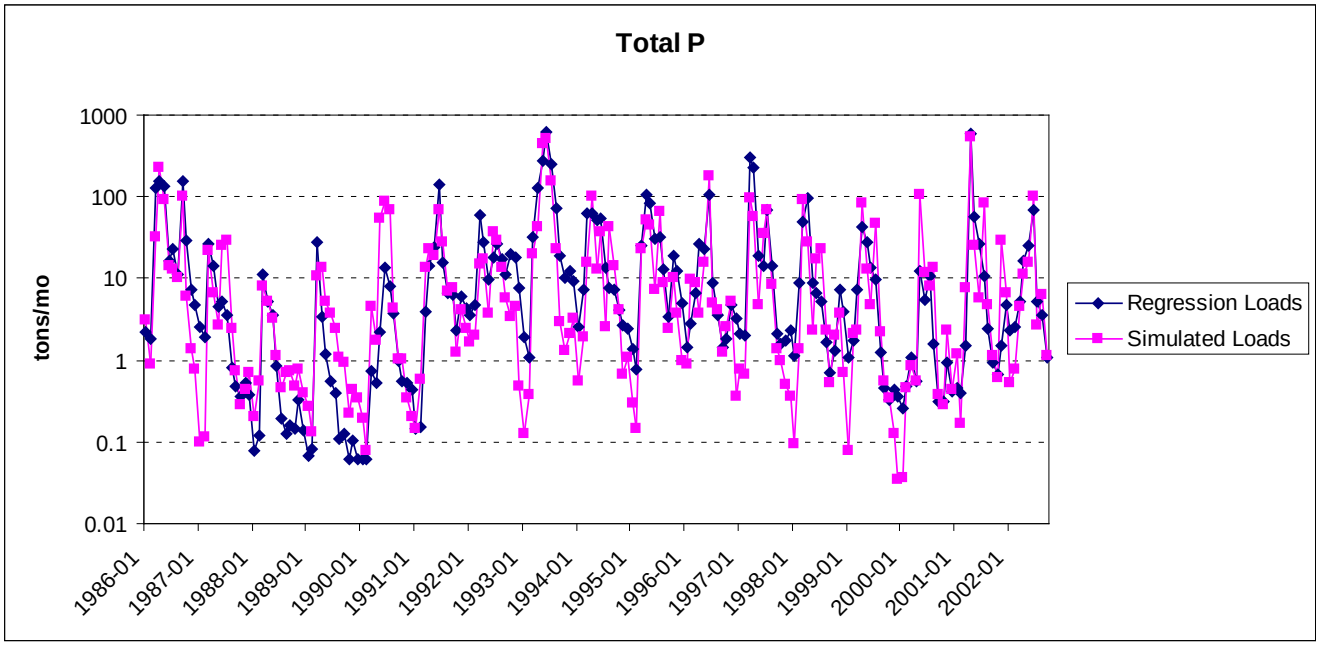

Figure 31. Fit for monthly load of total phosphorus at USGS 05317000 Cottonwood River (HSPF).

Table 15. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	23.0%	15.8%
Average Absolute Error	54%	67%
Median Absolute Error	2.5%	13.5%

As with suspended sediment, additional diagnostics for total phosphorus included flow-load power plots (Figure 32 and Figure 33), time series plots (Figure 34) and analysis of concentration errors (Table 16). All show good agreement.

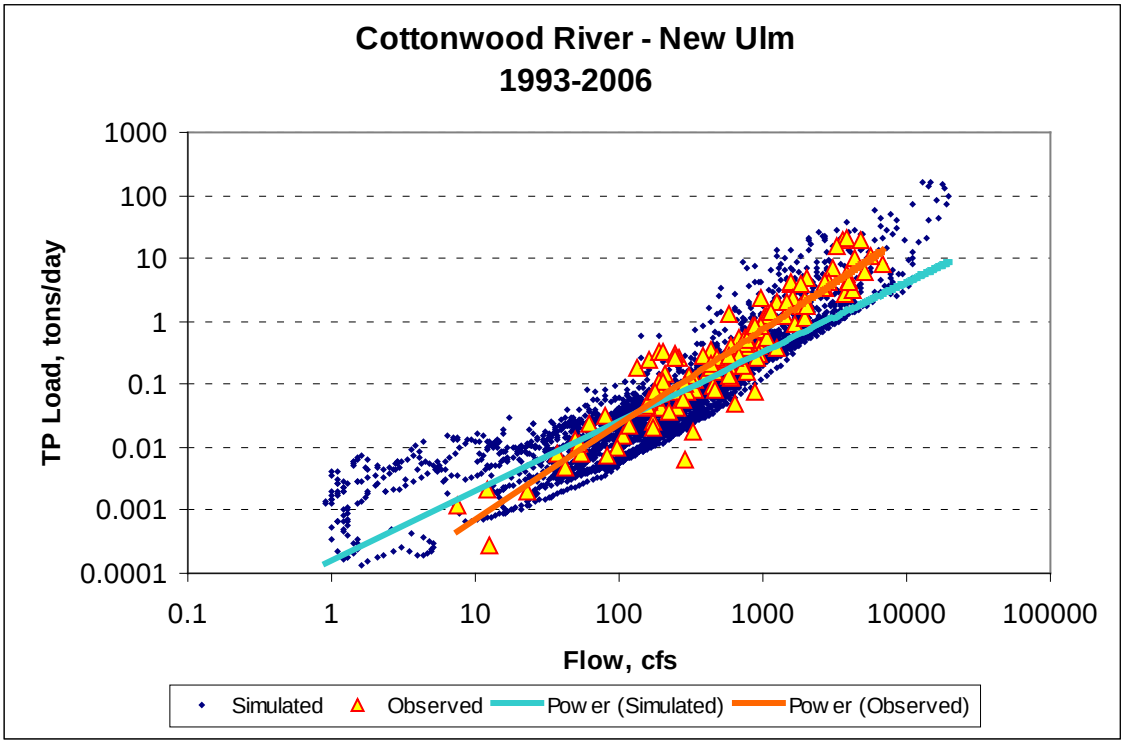

Figure 32. Power plot for observed and simulated total phosphorus at USGS 05317000 Cottonwood River – calibration period (HSPF).

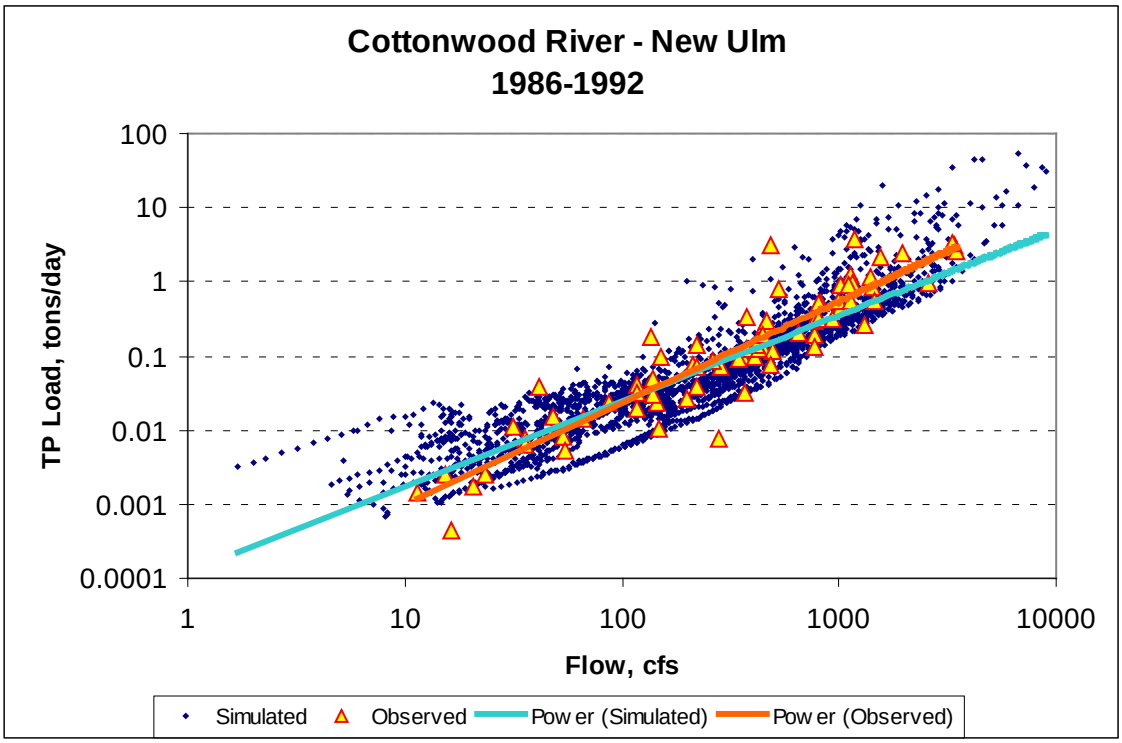

Figure 33. Power plot for observed and simulated total phosphorus at USGS 05317000 Cottonwood River - validation period (HSPF).

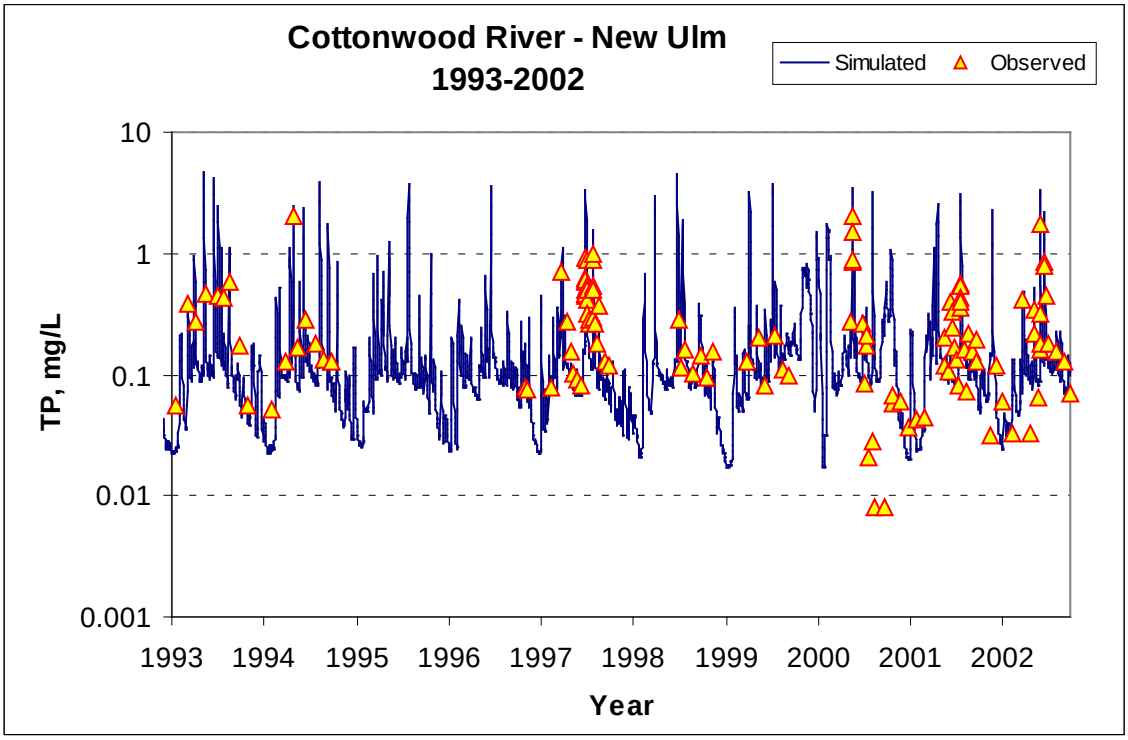

Figure 34. Time series plot of total phosphorus concentration at USGS 05317000 Cottonwood River (HSPF).

Table 16. Relative errors (observed minus predicted), total phosphorus concentration at USGS 05317000 Cottonwood River (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	123	75
Concentration Average Error	-52.9%	18.0%
Concentration Median Error	5.3%	-0.48%

For total nitrogen fewer data are available because many sampling events omitted one or more nitrogen species. This increases the uncertainty of the comparison. However, development of the TMDL model also revealed that there is large temporal variability in observed total nitrogen concentrations, likely related to seasonal differences in the timing and amount of fertilizer application. (In this watershed, the primary fertilizer applications are of subsurface anhydrous ammonia, which can occur in both spring and fall, along with animal manure.)

During calibration for total nitrogen the major change from the original parameter set was scaling down the buildup-washoff factors. Subsurface concentrations, which represent the major loading pathway for nitrogen, were generally acceptable as previously developed, except that the contribution of organic matter to groundwater nitrogen loading was reduced. As with phosphorus, a similar procedure was applied across all model subwatersheds, retaining the spatial variability in nitrogen loading that was identified in the development of the TMDL model.

Results for total nitrogen are summarized in Figure 35 through Figure 38, Table 17, and Table 18, following the same format as total phosphorus. The results are acceptable, although there is clearly greater uncertainty in the prediction of total nitrogen than in the prediction of total phosphorus.

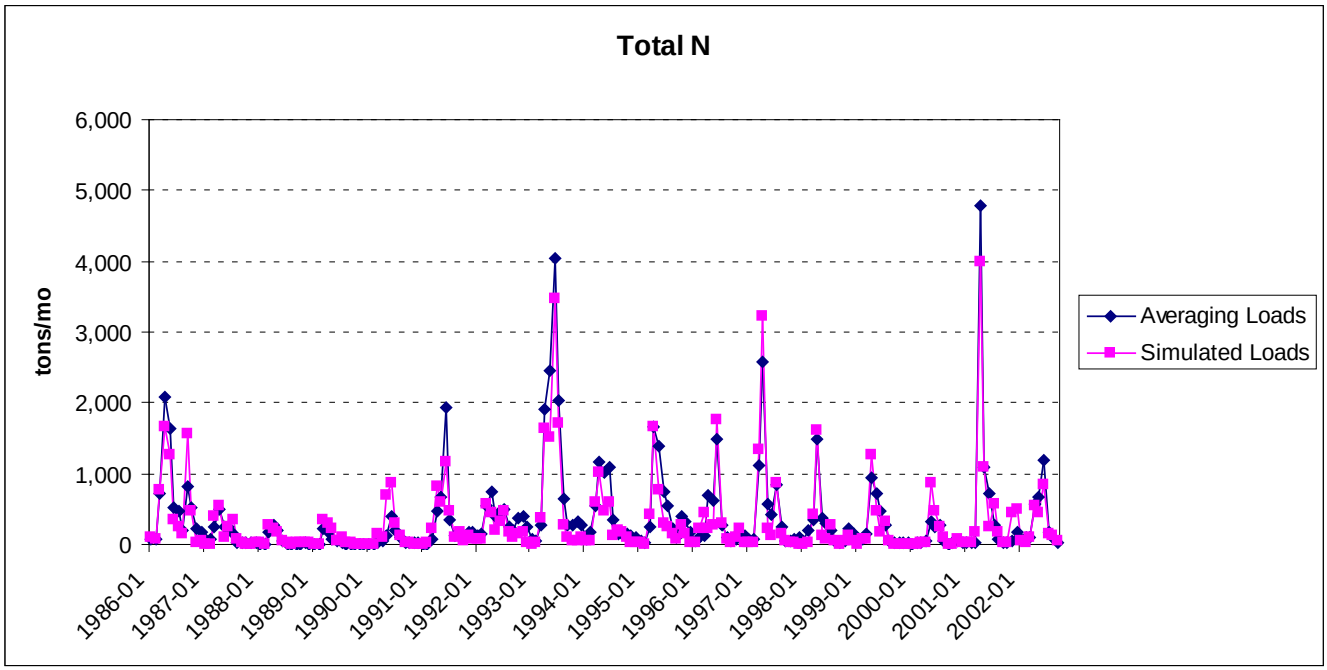

Figure 35. Fit for monthly load of total nitrogen at USGS 05317000 Cottonwood River (HSPF).

Table 17. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	15.4%	16.2%
Average Absolute Error	35%	43%
Median Absolute Error	5.4%	14.5%

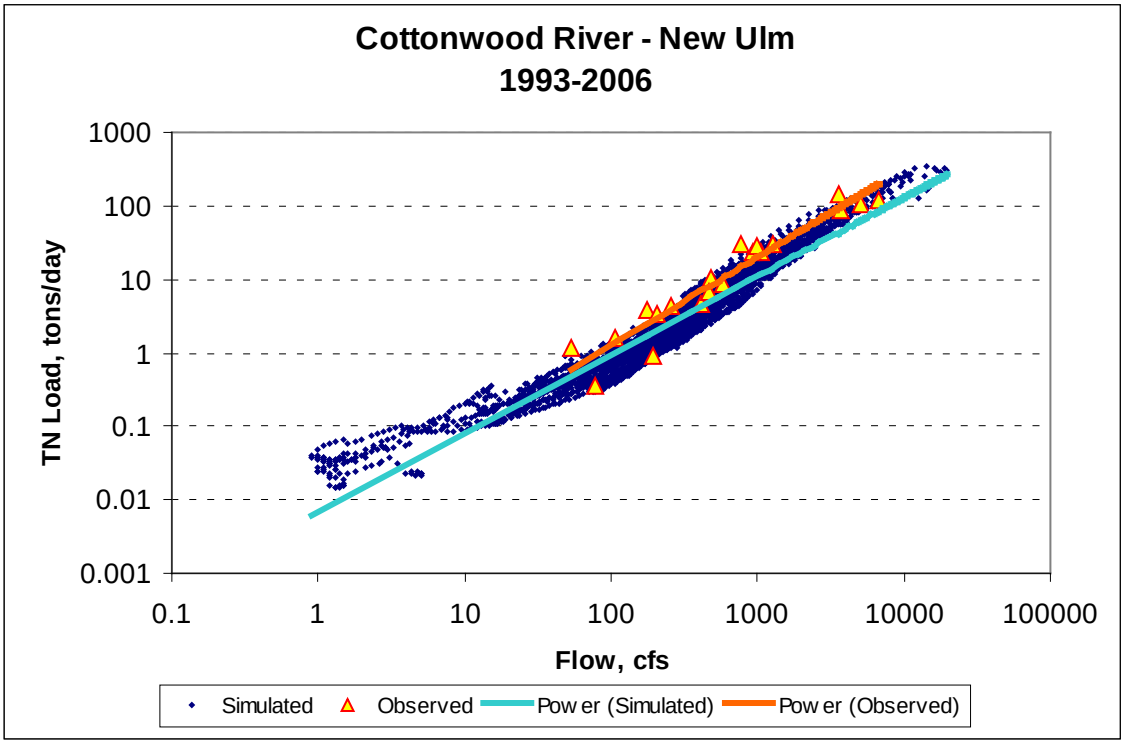

Figure 36. Power plot for observed and simulated total nitrogen at USGS 05317000 Cottonwood River - calibration period (HSPF).

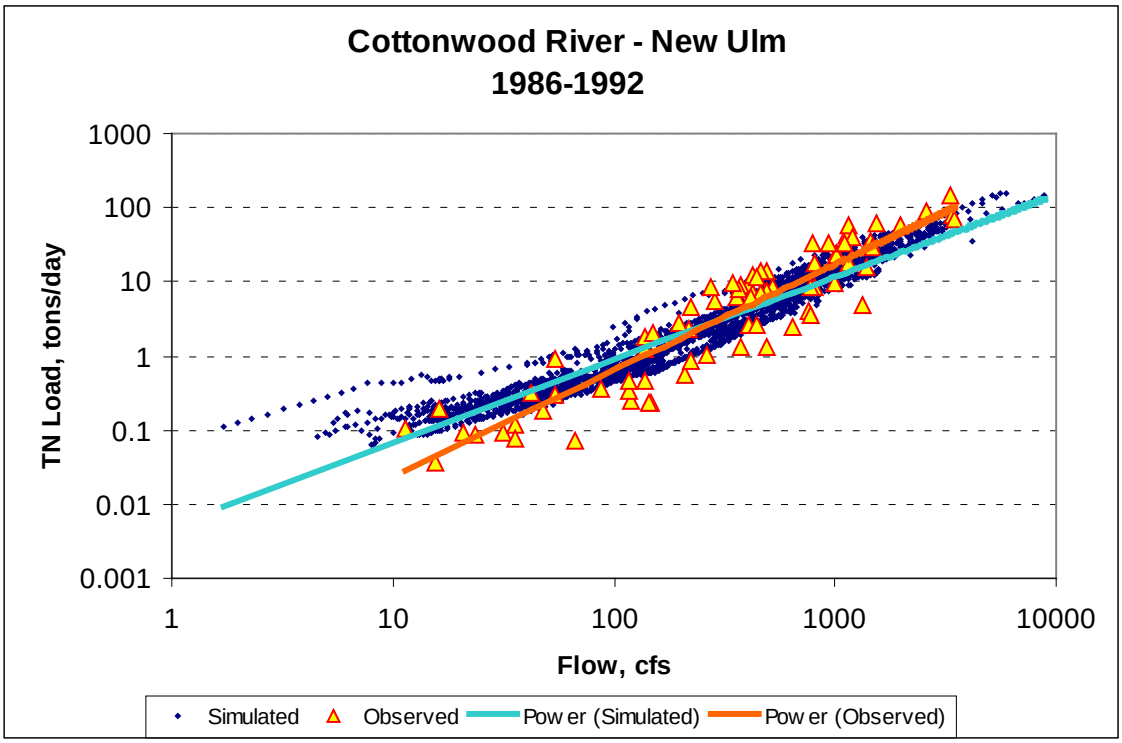

Figure 37. Power plot for observed and simulated total nitrogen at USGS 05317000 Cottonwood River - validation period (HSPF).

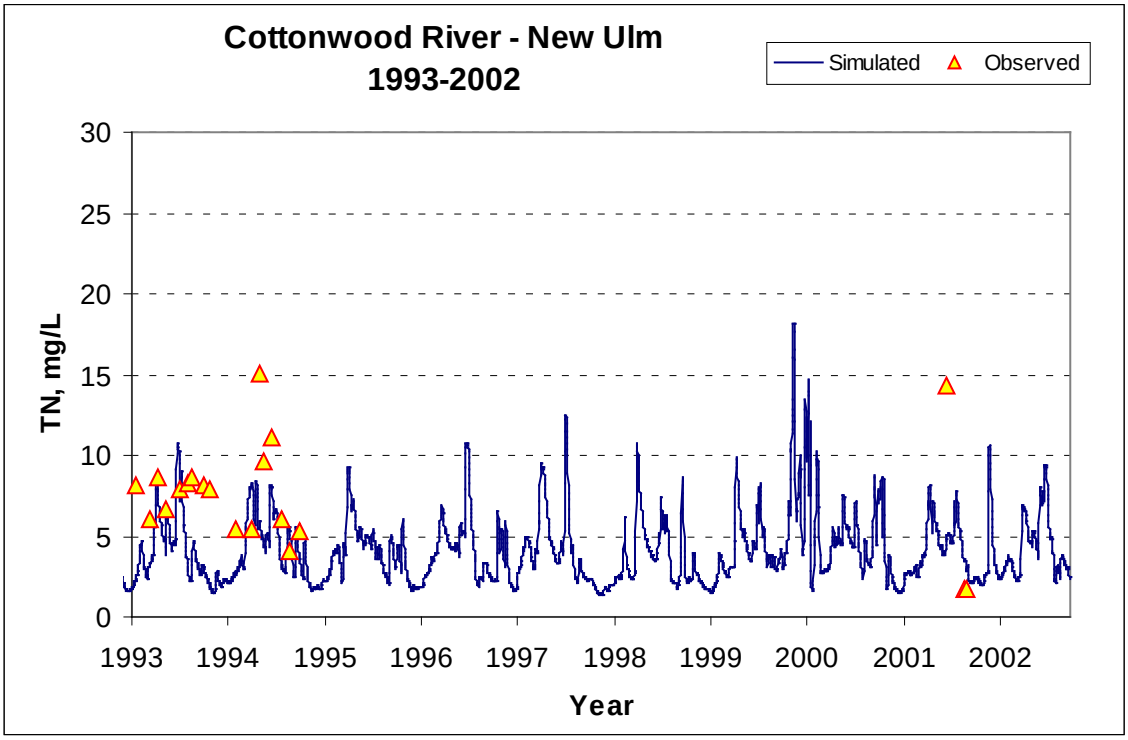

Figure 38. Time series plot of total nitrogen concentration at USGS 05317000 Cottonwood River (HSPF).

Table 18. Relative errors (observed minus predicted), total nitrogen concentration at USGS 05317000 Cottonwood River (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	20	75
Concentration Average Error	36.6%	25.6%
Concentration Median Error	39.4%	22.2%

Water Quality Results for Larger Watershed

As with hydrology, the Cottonwood parameters for water quality are not directly transferable to other portions of the watershed. It is well established that there are strong spatial gradients in ravine and bank erosion of solids, soil test phosphorus, and subsurface loading of nitrogen, with the highest rates generally in the Blue Earth and Le Sueur basins and the lowest rates in the western watersheds. However, a consistent procedure for translating the parameters of the more detailed TMDL model (Tetra Tech 2008) to the 20 Watershed model provided good results, requiring only relatively minor modifications.

Summary statistics for the water quality calibration and validation at other stations in the watershed are provided in Table 19 and Table 20. The relative percent error on the monthly loads is within 26 percent for all parameters at all stations during the calibration period, with the exception of the mainstem station at Mankato. This station is immediately below the confluence of the Minnesota River and the Blue Earth River (a major source of loading) and it is believed that concentration measurements there are influenced by incomplete mixing, which seems to be

borne out by much better fit downstream at Jordan. In contrast, the validation tests underestimate total solids and total phosphorus loads at a number of stations. This is likely due to changes in land use and management over time (including aggressive efforts to increase conservation tillage and decrease erosion), coupled with propagation of errors in the hydrologic simulation.

Table 19. Summary statistics for water quality: all stations - calibration period 1993-2002 (HSPF)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Relative Percent Error TSS Load	-3.8%	2.2%	7.5%	11.4%	-21.6%	2.6%	-3.7%	6.4%
TSS Concentration Median Error	6.5%	8.7%	0.4%	19.5%	4.1%	-1.7%	41.7%	25.8%
Relative Percent Error TP Load	6.9%	10.8%	23.0	2.7%	1.5%	-0.1%	-52.7%	1.3%
TP Concentration Median Error	7.1%	21.2%	5.3%	23.2%	0.53%	1.8%	-6.6%	15.0%
Relative Percent Error TN Load	-21.0%	-7.7%	15.4	-7.2%	-9.0%	14.9%	44.1%	6.5%
TN Concentration Median Error	19.1%	16.7%	39.4%	-4.9%	-10.2%	6.5%	-23.9%	3.1%

Table 20. Summary statistics for water quality: all stations - validation period 1986-1992 (HSPF)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Relative Percent Error TSS Load	-6.4%	-17.0%	13.1%	-46.4%	-25.2%	-36.5%	-37.1%	-6.8%
TSS Concentration Median Error	3.0%	-5.2%	-2.7%	12.7%	ND	11.9%	11.3%	9.1%
Relative Percent Error TP Load	-38.1%	-21.1%	15.8%	-35.0%	-14.0%	-31.7%	-85.3%	-27.3%
TP Concentration Median Error	3.6%	-1.7%	-0.48%	17.6%	ND	-51.9%	-5.1%	29.1%
Relative Percent Error TN Load	-5.0%	-4.9%	6.2%	-14.8%	-19.5%	8.7%	38.6%	-1.2%
TN Concentration Median Error	-43.1%	-12.7%	22.2%	3.2%	ND	29.6%	32.2%	-4.9%

SWAT Modeling

The SWAT model for the Minnesota River basin was set up with the ArcSWAT interface using the same subwatersheds and other geospatial coverages described above for the HSPF model. The SWAT model also uses the same weather data, but at a daily, rather than hourly timestep.

Changes Made to Base Data Provided

No changes were made to the meteorological or land use base data for the SWAT model.

Assumptions

Three major reservoirs occur in the upper portion of the Minnesota River basin. These are Swan Lake, Lac Qui Parle Dam and Big Stone Lake of which only the Lac Qui Parle dam was modeled. Pertinent reservoir information including surface area and storage at principal (normal) and emergency spillway levels for the reservoirs modeled were obtained from the National Inventory of dams (NID) database. 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, it was assumed that the best representation of the reservoirs was to simulate them without supplying time series of outflow records. Therefore, target release approach was used in the GCRP-SWAT model.

Another important characteristic of the watershed is the widespread presence of subsurface tile drainage. Installation of tile drainage has converted what were predominantly glacial plain outwash depressional wetlands into productive farmland. The presence of tile drains, which include both surface and subsurface inlets, has radically altered the natural hydrology of the area. Surface inlet tile drains, in particular, may also play a significant role in the transport of sediment and pollutants from agricultural land to the river. It is not feasible to simulate individual tile drain systems at the large basin scale. Further, neither the location nor the total density of tile drainage is known throughout the watershed. In most areas, only the public tile drains and ditches are documented in spatial coverages, and the extent of private tile drains is known only for limited areas.

The SWAT model allows for some representation of tile drains in the form of three parameters: depth to the tile drains, time to drain soil to field capacity and tile drain lag time.

Hydrology Calibration

A spatial calibration approach was not adopted for GCRP-SWAT modeling for Upper Mississippi River basin, unlike the HSPF application. However, 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. The cropland HRUs were split into corn and soybean in the ratio 1:1. Further these classes and the urban (including current and future urban class types) classes were exempt from applying the thresholds.

The calibration focus area (Cottonwood River) represents 7 subwatersheds, which together consists of 349 HRUs. The calibration focus area well represented the general land use characteristics of the overall watershed. Since the

Minnesota River basin has predominantly an agricultural land use, there is essentially one set of parameters for the entire 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 Minnesota River basin predicted by the SWAT model is as follows:

```
PRECIP =    689.0 MM
SNOW FALL = 102.36 MM
SNOW MELT =    98.01 MM
SUBLIMATION =     4.58 MM
SURFACE RUNOFF Q =    50.96 MM
LATERAL SOIL Q =    1.12 MM
TILE Q =    31.59 MM
GROUNDWATER (SHAL AQ) Q =    67.14 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    3.08 MM
DEEP AQ RECHARGE =     3.70 MM
TOTAL AQ RECHARGE =   73.91 MM
TOTAL WATER YLD =   148.19 MM
PERCOLATION OUT OF SOIL =   71.32 MM
ET =    533.9 MM
PET =   1239.2MM
TRANSMISSION LOSSES =     2.62 MM
```

As is consistent with earlier studies (Tetra Tech, 2008), the baseflow (i.e., the groundwater and the tile Q) component accounts for more than 50 percent of the total water yield.

Calibration adjustments focused on the following parameters:

- FFCB
- SURLAG (surface runoff lag coefficient)
- CNCOEFF
- Baseflow factor
- GW_DELAY (groundwater delay time)
- Manning's "n" value for main channels, and tributary channels
- Sol_AWC (available water capacity of the soil layer, mm water/mm of soil)
- Heat Units to maturity for corn and soybean
- Depth to impervious surface
- BLAI for corn
- Snow parameters SMTMP, SMFMX and SMFMN
- Tile drain parameters (DDRAIN, TDRAIN and GDRAIN)

Initial calibrations were performed for the Cottonwood River, comparing model results to data from USGS 05317000, and are summarized in Figures 39 through 45 and Table 21 and Table 22.

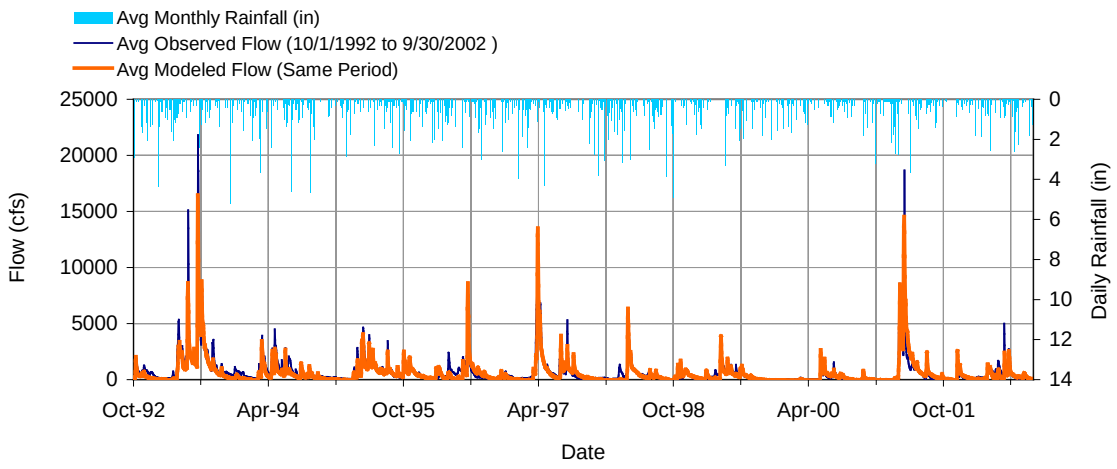

Figure 39. Mean daily flow at USGS 05317000 Cottonwood River near New Ulm, MN – calibration period (SWAT).

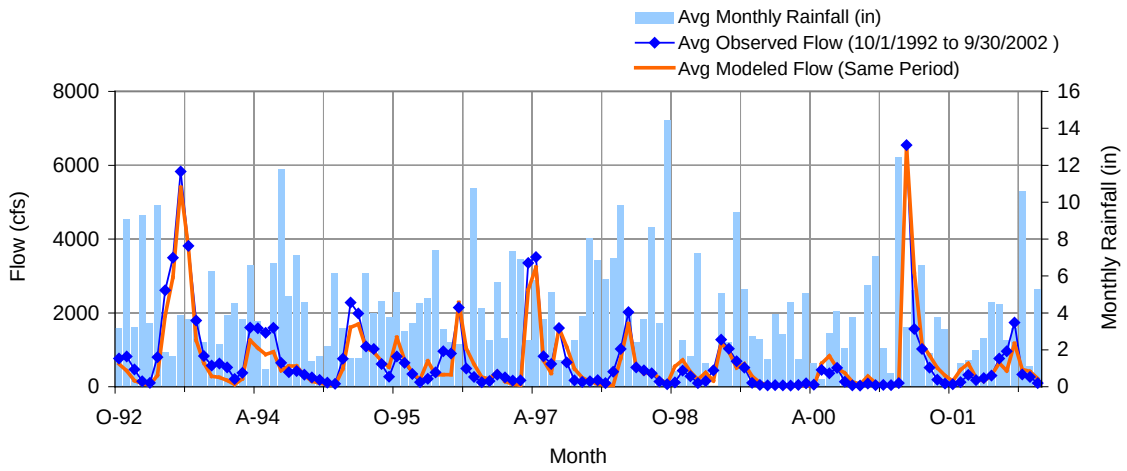

Figure 40. Mean monthly flow at USGS 05317000 Cottonwood River near New Ulm, MN – calibration period (SWAT).

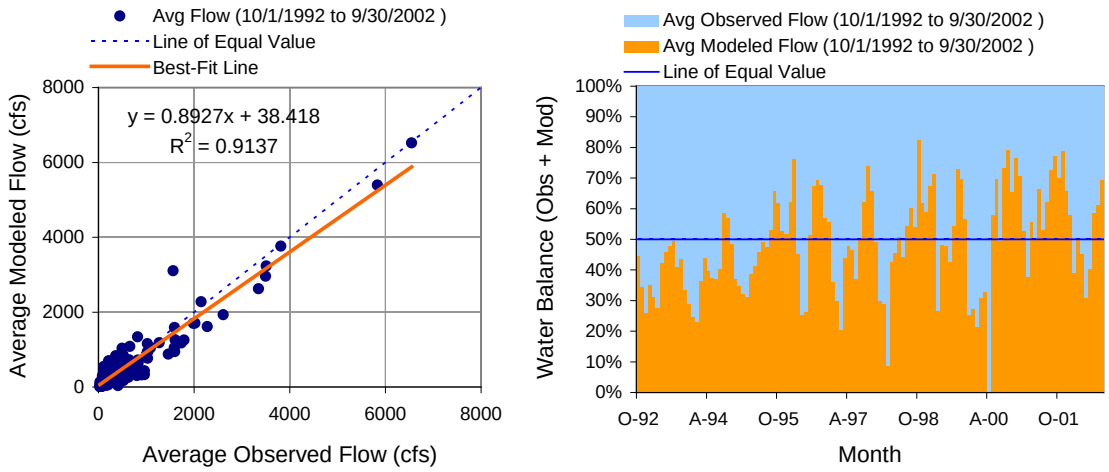

Figure 41. Monthly flow regression and temporal variation at USGS 05317000 Cottonwood River near New Ulm, MN – calibration period (SWAT).

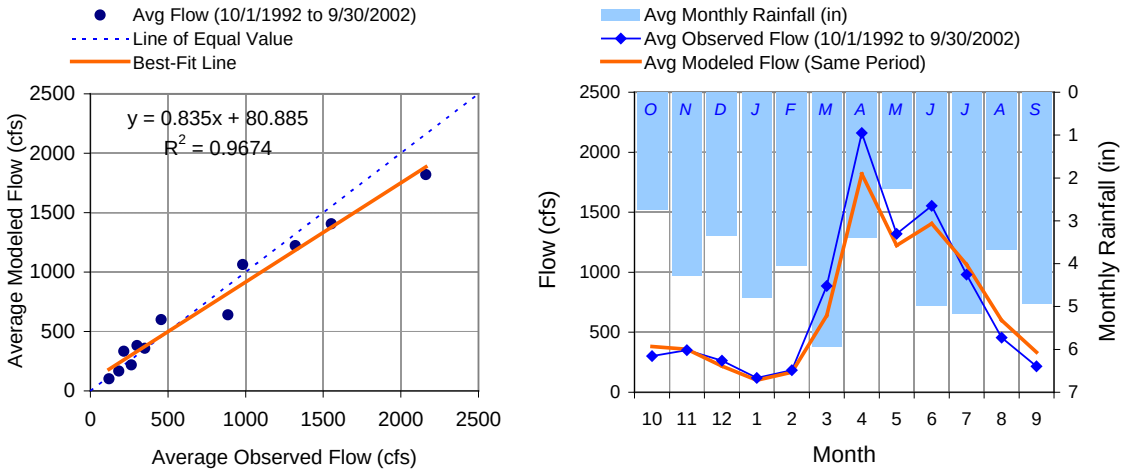

Figure 42. Seasonal regression and temporal aggregate at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (SWAT).

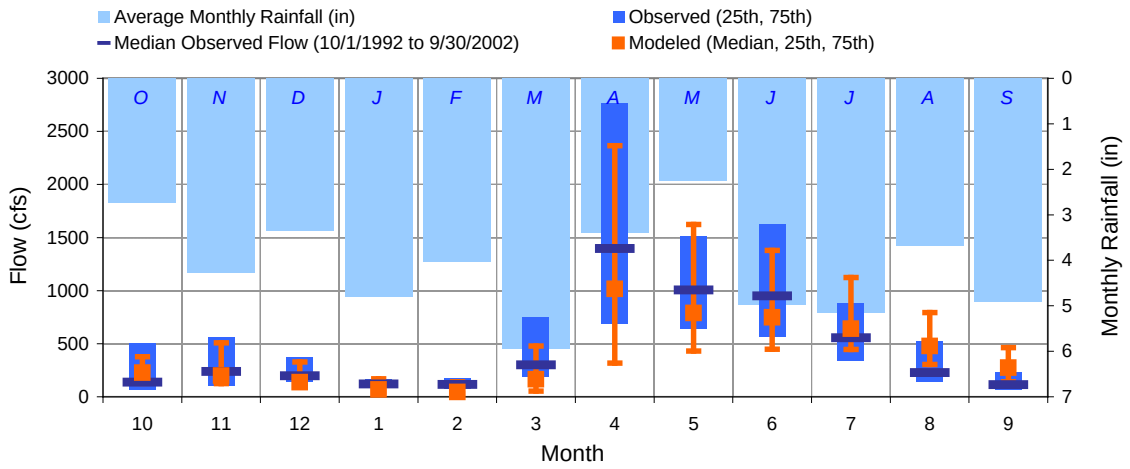

Figure 43. Seasonal medians and ranges at USGS 05317000 Cottonwood River near New Ulm, MN – calibration period (SWAT).

Table 21. Seasonal summary at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	301.38	137.50	62.25	499.00	381.46	227.46	126.33	377.43
Nov	350.75	237.50	101.25	562.50	359.14	199.53	125.15	508.97
Dec	264.09	198.00	139.25	369.50	218.04	138.01	90.43	328.58
Jan	120.42	120.00	85.25	169.00	101.28	67.56	44.06	168.76
Feb	183.37	116.00	80.00	174.50	167.59	45.34	27.41	141.13
Mar	885.87	300.00	191.25	755.25	639.79	164.53	53.07	478.34
Apr	2161.06	1395.00	688.00	2767.50	1819.87	1015.47	316.98	2365.55
May	1320.39	1005.00	638.50	1507.50	1222.77	788.58	430.93	1623.50
Jun	1552.95	950.00	561.25	1625.00	1406.00	747.96	448.05	1379.83
Jul	981.10	554.50	336.00	877.25	1064.17	641.49	445.58	1123.71
Aug	455.96	228.00	138.00	519.75	599.42	477.98	304.94	792.46
Sep	216.05	114.00	65.00	234.00	333.14	275.54	142.37	463.77

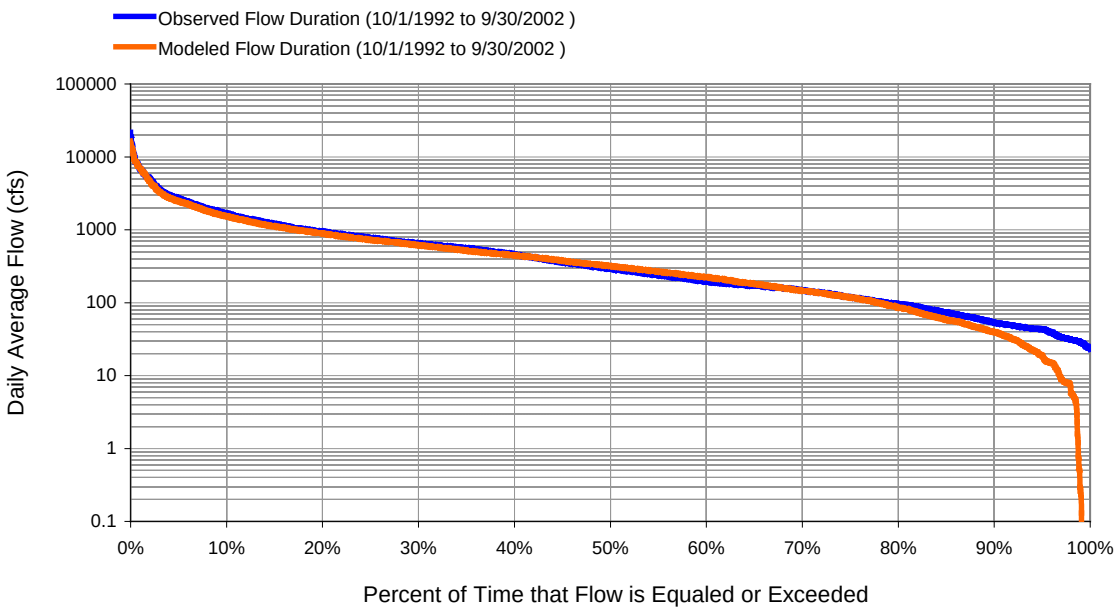

Figure 44. Flow exceedance at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (SWAT).

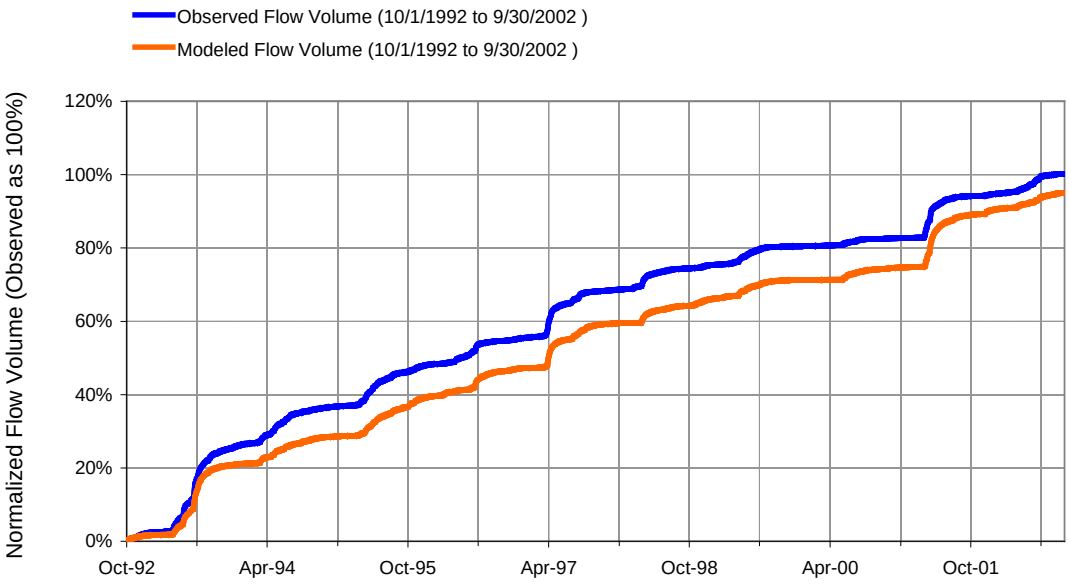

Figure 45. Flow accumulation at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (SWAT).

Table 22. Summary statistics at USGS 05317000 Cottonwood River near New Ulm, MN - calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 16 10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Hydrologic Unit Code: 7020008 Latitude: 44.29135177 Longitude: -94.4402495 Drainage Area (sq-mi): 1300	
Total Simulated In-stream Flow:	**7.25**	Total Observed In-stream Flow:	**7.66**
Total of simulated highest 10% flows:	**3.66**	Total of Observed highest 10% flows:	**3.92**
Total of Simulated lowest 50% flows:	**0.68**	Total of Observed Lowest 50% flows:	**0.68**
Simulated Summer Flow Volume (months 7-9):	**1.76**	Observed Summer Flow Volume (7-9):	**1.46**
Simulated Fall Flow Volume (months 10-12):	**0.84**	Observed Fall Flow Volume (10-12):	**0.80**
Simulated Winter Flow Volume (months 1-3):	**0.79**	Observed Winter Flow Volume (1-3):	**1.04**
Simulated Spring Flow Volume (months 4-6):	**3.85**	Observed Spring Flow Volume (4-6):	**4.36**
Total Simulated Storm Volume:	**2.42**	Total Observed Storm Volume:	**2.59**
Simulated Summer Storm Volume (7-9):	**0.43**	Observed Summer Storm Volume (7-9):	**0.50**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-5.41	10	
Error in 50% lowest flows:	0.30	10	
Error in 10% highest flows:	-6.65	15	
Seasonal volume error - Summer:	20.65	30	
Seasonal volume error - Fall:	4.66	30	
Seasonal volume error - Winter:	-23.83	30	
Seasonal volume error - Spring:	-11.60	30	
Error in storm volumes:	-6.50	20	
Error in summer storm volumes:	-13.60	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.794	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.580	as E or E' approaches 1.0	

Hydrology Validation

Validation for the Cottonwood model was performed at the same location but for the period 10/1/1982 through 9/30/1992. Results are presented in Figures 46 through 52 and Tables 23 and 24. The validation achieves a high coefficient of model fit efficiency, but is under on 50 percent low volume and over on seasonal volumes for summer and fall.

Factors that may have contributed to the difference in the flows between the calibration and validation period are:

- Increase in urban impervious surface areas.
- Increase in the intensity of tile drainage.
- Cropped areas have changed.
- PET estimates for the 20 Watershed model use SWAT weather generator statistics for solar radiation, cloud cover, wind, and relative humidity – essentially assuming that the central tendency of these factors has not changed over time.

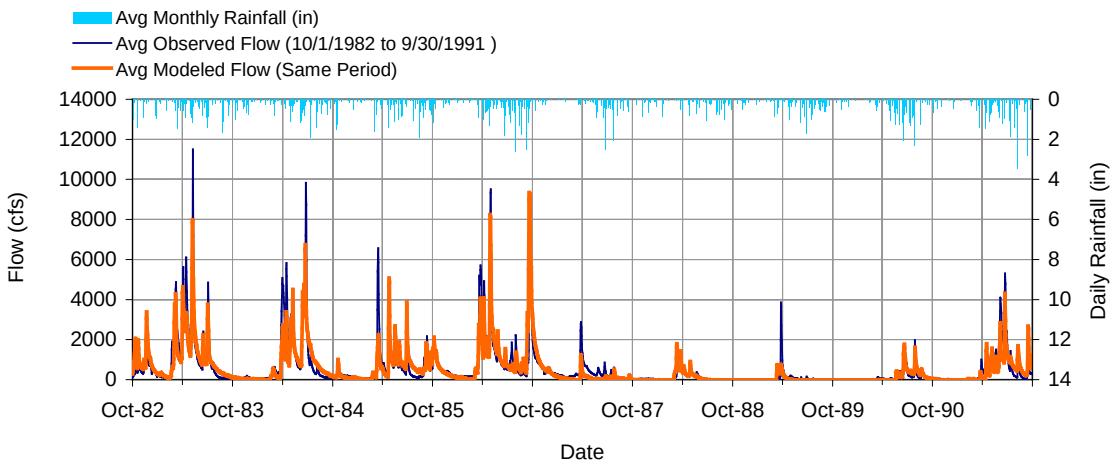

Figure 46. Mean daily flow at USGS 05317000 Cottonwood River near New Ulm, MN – validation period (SWAT).

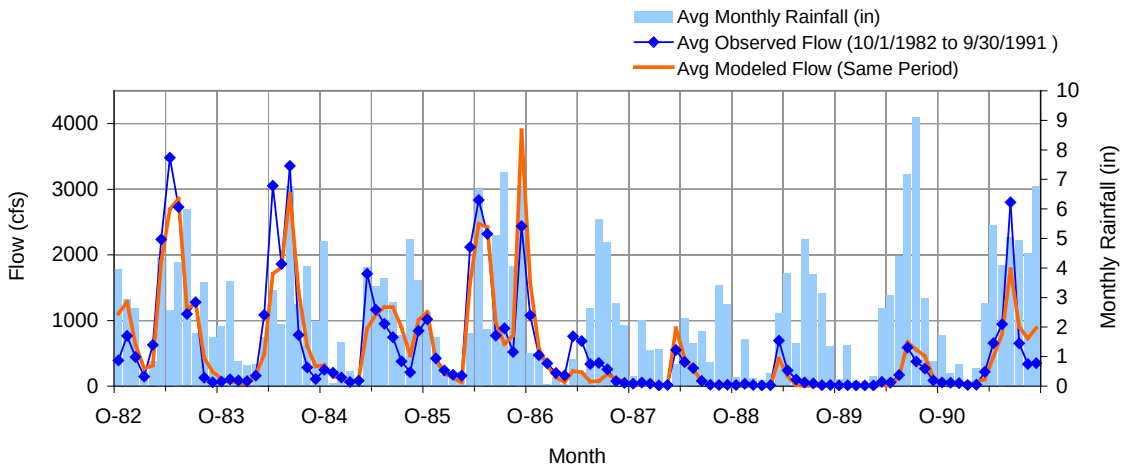

Figure 47. Mean monthly flow at USGS 05317000 Cottonwood River near New Ulm, MN – validation period (SWAT).

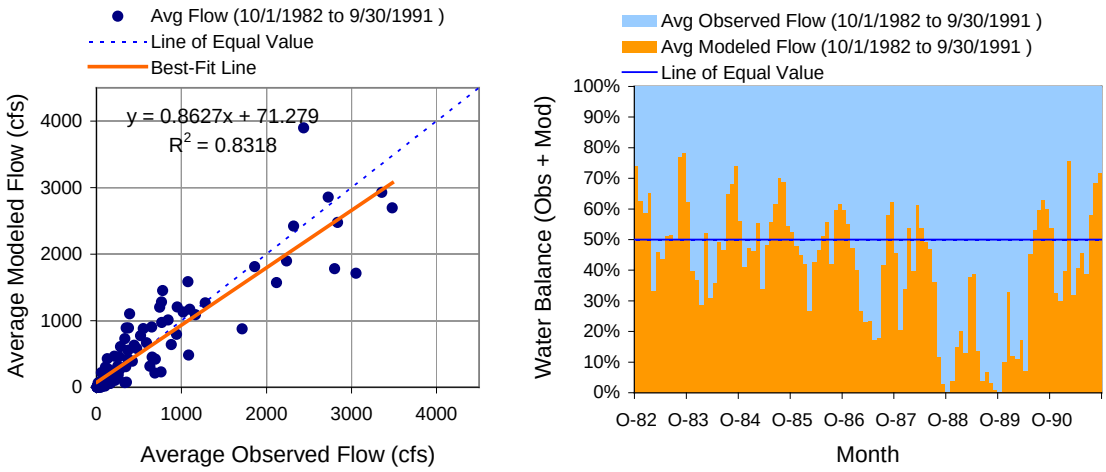

Figure 48. Monthly flow regression and temporal variation at USGS 05317000 Cottonwood River near New Ulm, MN – validation period (SWAT).

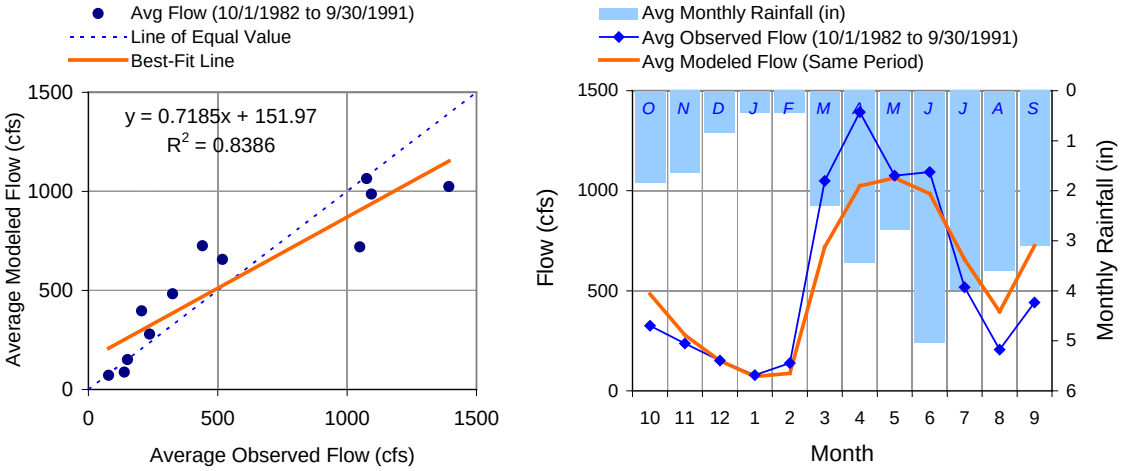

Figure 49. Seasonal regression and temporal aggregate at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (SWAT).

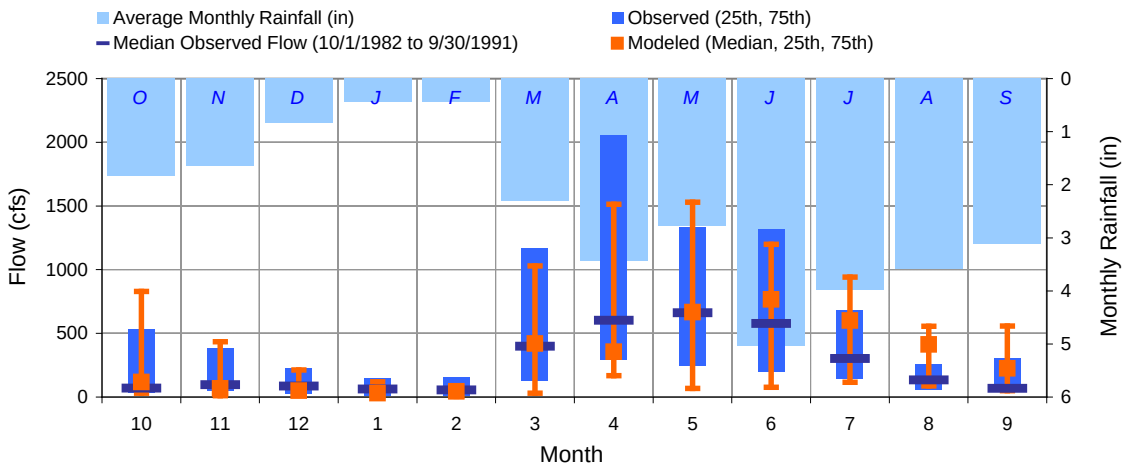

Figure 50. Seasonal medians and ranges at USGS 05317000 Cottonwood River near New Ulm, MN – validation period (SWAT).

Table 23. Seasonal summary at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	325.44	70.00	30.00	530.00	483.16	117.35	29.73	828.48
Nov	236.81	97.00	49.00	378.25	279.00	68.79	11.44	434.99
Dec	151.12	85.00	26.50	231.00	150.35	50.61	14.60	212.47
Jan	78.47	63.00	11.00	148.00	71.41	31.16	8.80	118.92
Feb	138.70	56.00	13.00	158.00	87.25	44.67	5.29	78.17
Mar	1049.35	399.00	128.00	1165.00	719.49	419.19	30.22	1029.60
Apr	1393.56	602.50	293.75	2057.50	1024.55	354.91	168.44	1513.23
May	1075.69	662.00	244.50	1330.00	1064.03	667.09	67.73	1529.65
Jun	1094.19	576.50	198.75	1317.50	985.89	767.21	77.69	1199.11
Jul	518.17	302.00	146.50	684.00	656.53	600.00	116.11	942.20
Aug	205.90	134.00	62.50	260.00	396.61	412.12	87.85	556.21
Sep	441.19	68.50	43.00	305.75	725.22	225.34	49.80	556.82

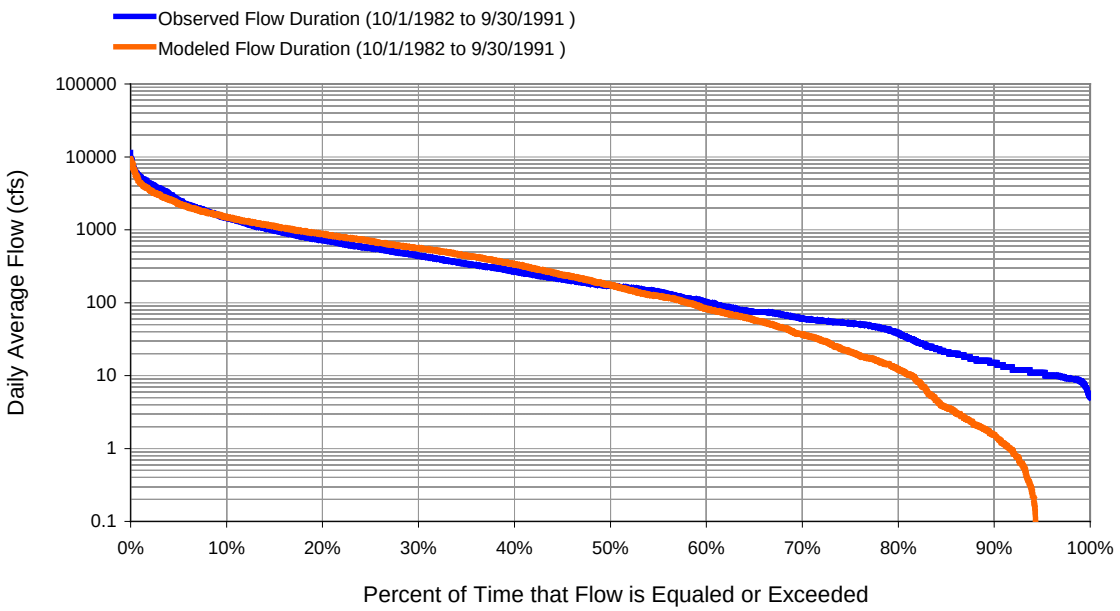

Figure 51. Flow exceedance at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (SWAT).

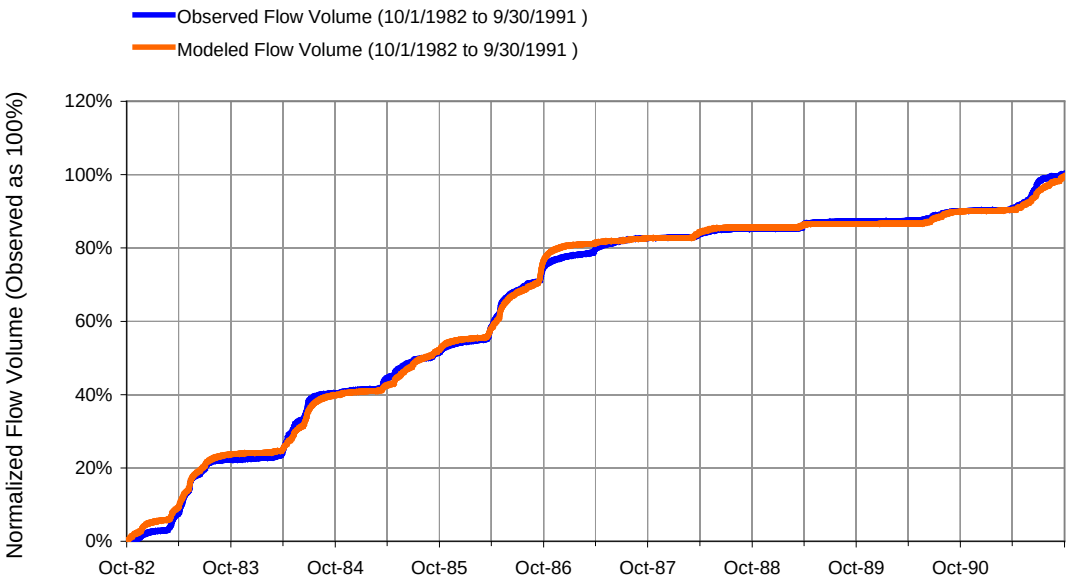

Figure 52. Flow accumulation at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (SWAT).

Table 24. Summary statistics at USGS 05317000 Cottonwood River near New Ulm, MN - validation period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 16 9-Year Analysis Period: 10/1/1982 - 9/30/1991 Flow volumes are (inches/year) for upstream drainage area		USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Hydrologic Unit Code: 7020008 Latitude: 44.29135177 Longitude: -94.4402495 Drainage Area (sq-mi): 1300	
Total Simulated In-stream Flow:	**5.80**	Total Observed In-stream Flow:	**5.85**
Total of simulated highest 10% flows:	**2.94**	Total of Observed highest 10% flows:	**3.30**
Total of Simulated lowest 50% flows:	**0.22**	Total of Observed Lowest 50% flows:	**0.32**
Simulated Summer Flow Volume (months 7-9):	**1.56**	Observed Summer Flow Volume (7-9):	**1.02**
Simulated Fall Flow Volume (months 10-12):	**0.80**	Observed Fall Flow Volume (10-12):	**0.63**
Simulated Winter Flow Volume (months 1-3):	**0.77**	Observed Winter Flow Volume (1-3):	**1.11**
Simulated Spring Flow Volume (months 4-6):	**2.67**	Observed Spring Flow Volume (4-6):	**3.09**
Total Simulated Storm Volume:	**1.89**	Total Observed Storm Volume:	**2.10**
Simulated Summer Storm Volume (7-9):	**0.44**	Observed Summer Storm Volume (7-9):	**0.41**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-0.84	10	
Error in 50% lowest flows:	**-29.79**	**10**	
Error in 10% highest flows:	-10.88	15	
Seasonal volume error - Summer:	**52.47**	**30**	
Seasonal volume error - Fall:	28.02	30	
Seasonal volume error - Winter:	**-30.60**	**30**	
Seasonal volume error - Spring:	-13.60	30	
Error in storm volumes:	-9.94	20	
Error in summer storm volumes:	6.14	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.740	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.599	as E or E' approaches 1.0	

Hydrology Results for Larger Watershed

As described above, parameters determined for the Cottonwood gage were fully transferable to other gages in the watershed. In addition, calibration and validation was pursued at a total of nine gages throughout the watershed, including seven gages at the outlet of 8-digit HUCs and two gages on the mainstem. Calibration results were acceptable at most gages, as summarized in Table 25. The match between observed and predicted flow volumes at the most downstream available gage (USGS 05330000, Minnesota River near Jordan) are shown in Figures 53 through 58 and Tables 26 and 27.

Table 25. Summary statistics (percent error): all stations - calibration period (SWAT)

Station	05311000 Minnesota River at Montevideo	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Error in total volume:	-7.70	19.10	25.84	-5.41	-2.88	-6.46	12.11	16.69	7.89
Error in 50% lowest flows:	22.21	98.49	48.26	0.30	-30.14	-1.22	38.42	40.12	21.60
Error in 10% highest flows:	-15.93	9.44	23.39	-6.65	19.60	-0.02	8.82	14.57	8.10
Seasonal volume error - Summer:	30.78	59.05	56.54	20.65	20.56	25.26	25.23	55.02	38.77
Seasonal volume error - Fall:	15.65	37.01	53.30	4.66	11.22	1.28	32.44	32.84	21.31
Seasonal volume error - Winter:	-19.05	26.86	26.65	-23.83	-9.86	-20.62	52.98	25.76	18.03
Seasonal volume error - Spring:	-23.84	4.67	10.93	-11.60	-12.94	-18.60	-4.87	-2.83	-9.25
Error in storm volumes:	-11.85	13.55	43.78	-6.50	72.02	18.65	20.92	48.13	43.49
Error in summer storm volumes:	23.67	-8.32	31.94	-13.60	34.92	6.89	0.02	45.88	35.70
Nash-Sutcliffe Coefficient of Efficiency, E:	0.637	0.638	0.641	0.794	0.381	0.724	0.688	0.653	0.633
Baseline adjusted coefficient (Garrick), E':	0.479	0.481	0.495	0.580	0.372	0.535	0.528	0.508	0.502

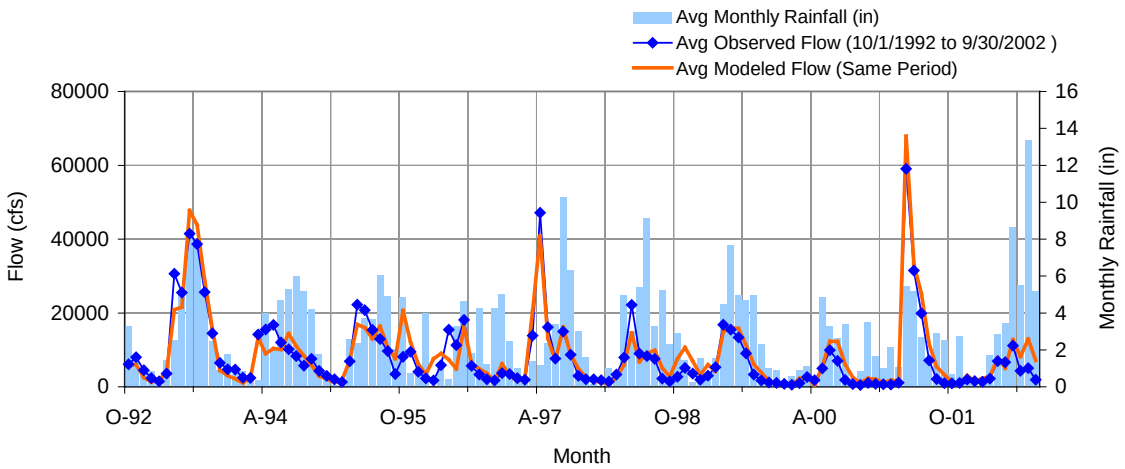

Figure 53. Monthly flow simulation: USGS 05330000 Minnesota River near Jordan, MN - calibration period (SWAT).

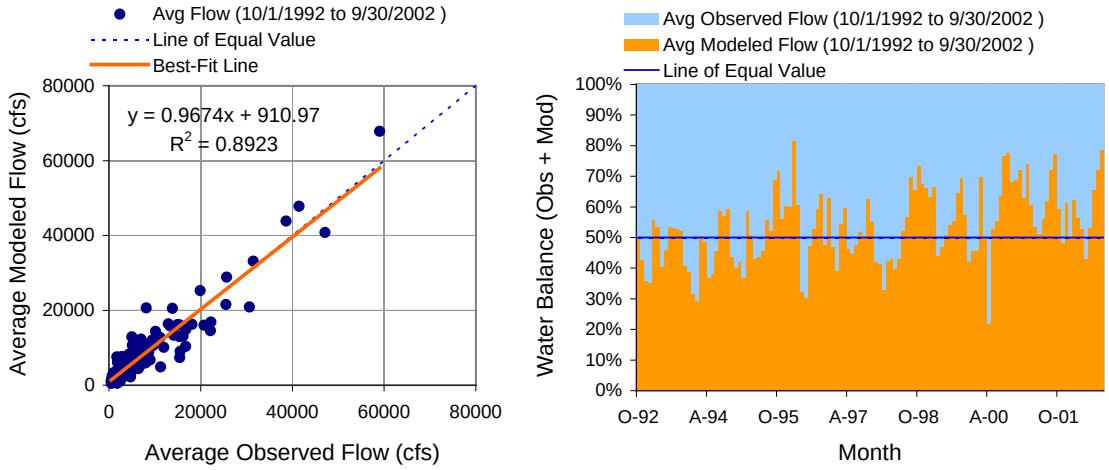

Figure 54. Monthly flow regression and temporal variation at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

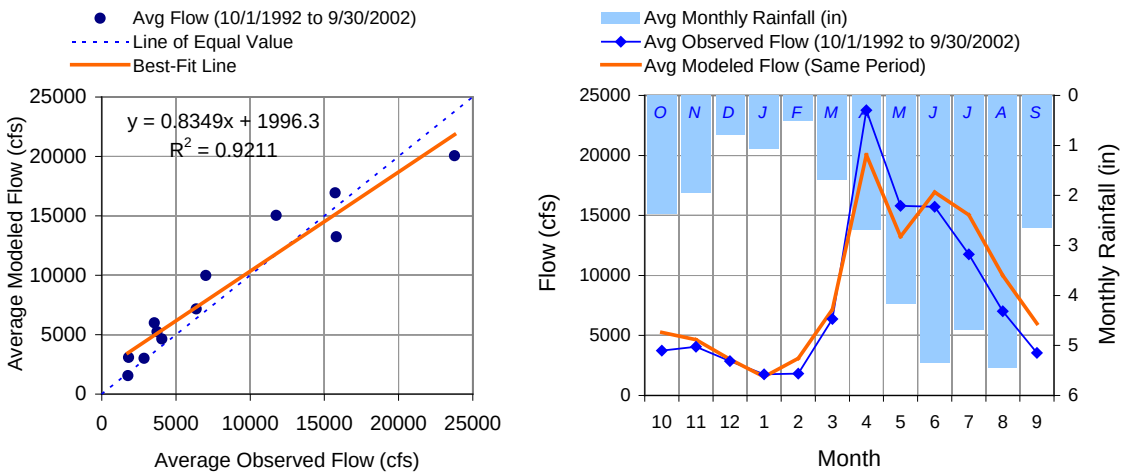

Figure 55. Seasonal regression and temporal aggregate at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

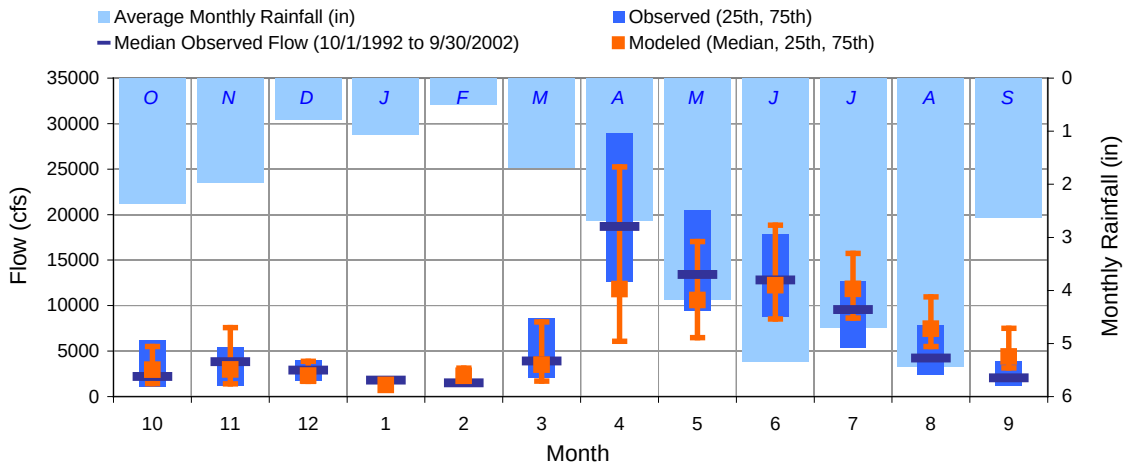

Figure 56. Seasonal medians and ranges at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

Table 26. Seasonal summary at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	3732.17	2190.00	1082.50	6237.50	5253.33	2954.43	1425.65	5515.27
Nov	4054.61	3825.00	1210.00	5462.50	4640.70	2973.49	1405.61	7576.76
Dec	2858.86	2900.00	1702.50	4000.00	3010.99	2304.81	1684.51	3881.96
Jan	1757.39	1800.00	1392.50	2200.00	1555.88	1265.15	892.75	1712.94
Feb	1811.52	1500.00	1272.50	1900.00	3090.56	2277.97	1606.91	3129.50
Mar	6364.40	3910.00	2080.00	8627.50	7164.26	3503.74	1705.43	8215.07
Apr	23775.27	18700.00	12550.00	28925.00	20056.78	11800.40	6084.72	25252.64
May	15802.45	13400.00	9470.00	20500.00	13244.86	10601.46	6478.48	17027.85
Jun	15733.60	12800.00	8805.00	17900.00	16930.06	12234.77	8519.66	18846.55
Jul	11756.52	9565.00	5347.50	12675.00	15032.51	11823.35	8634.44	15728.27
Aug	7020.71	4225.00	2377.50	7782.50	9987.30	7453.16	5505.56	10963.44
Sep	3542.37	2040.00	1205.00	3910.00	5986.83	4391.38	3145.48	7497.30

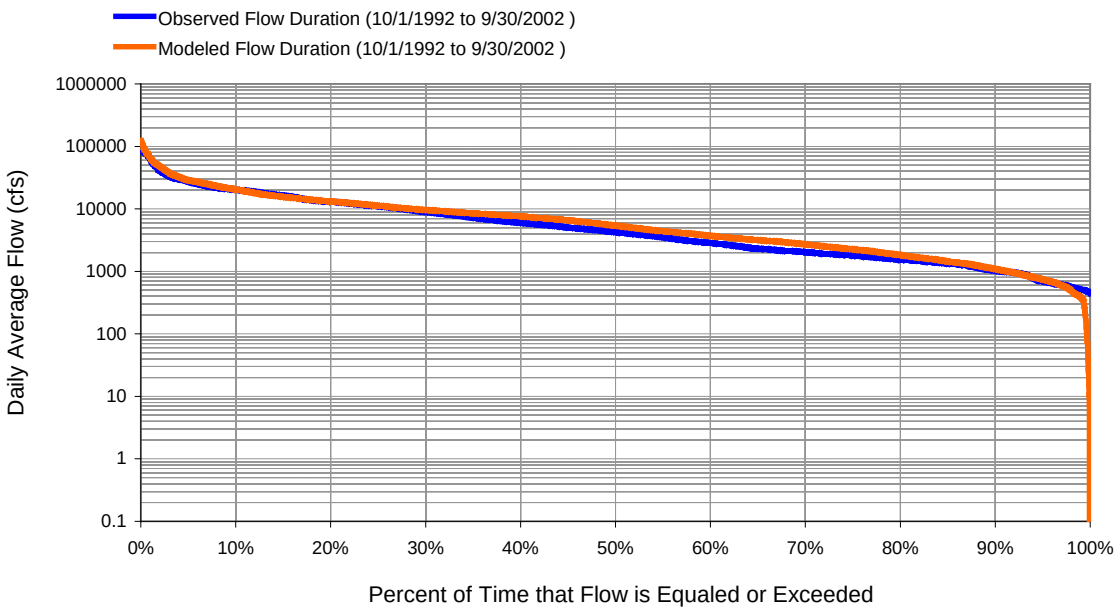

Figure 57. Flow exceedence at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

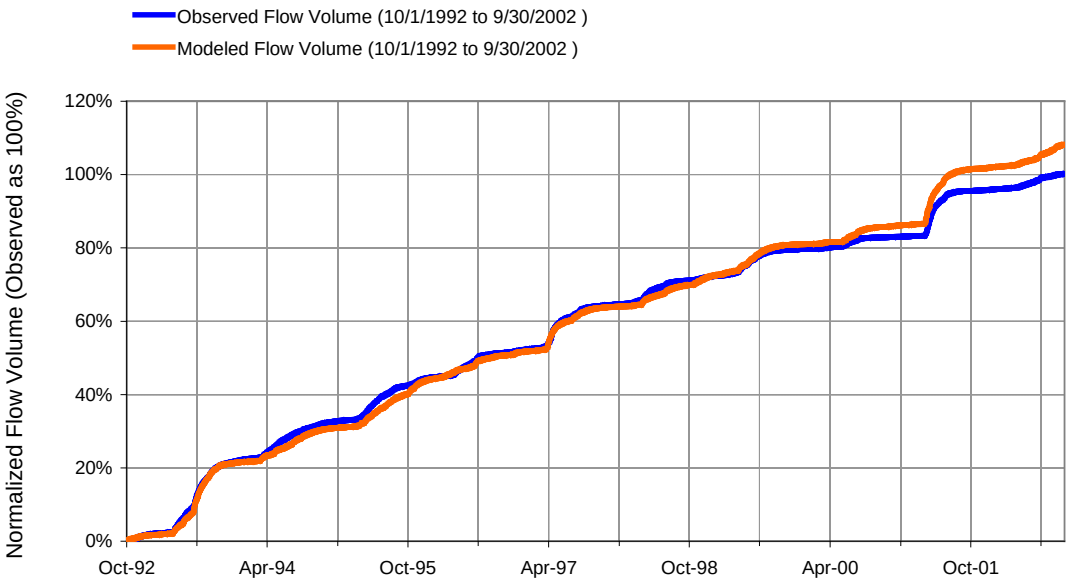

Figure 58. Flow accumulation at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

Table 27. Summary statistics at USGS 05330000 Minnesota River near Jordan, MN – calibration period (SWAT).

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 4 10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		USGS 05330000 MINNESOTA RIVER NEAR JORDAN, MN Hydrologic Unit Code: 7020012 Latitude: 44.69301845 Longitude: -93.641902 Drainage Area (sq-mi): 16200	
Total Simulated In-stream Flow:	**7.41**	Total Observed In-stream Flow:	**6.87**
Total of simulated highest 10% flows:	**3.01**	Total of Observed highest 10% flows:	**2.79**
Total of Simulated lowest 50% flows:	**0.99**	Total of Observed Lowest 50% flows:	**0.81**
Simulated Summer Flow Volume (months 7-9):	**2.19**	Observed Summer Flow Volume (7-9):	**1.58**
Simulated Fall Flow Volume (months 10-12):	**0.91**	Observed Fall Flow Volume (10-12):	**0.75**
Simulated Winter Flow Volume (months 1-3):	**0.82**	Observed Winter Flow Volume (1-3):	**0.70**
Simulated Spring Flow Volume (months 4-6):	**3.49**	Observed Spring Flow Volume (4-6):	**3.85**
Total Simulated Storm Volume:	**2.06**	Total Observed Storm Volume:	**1.43**
Simulated Summer Storm Volume (7-9):	**0.44**	Observed Summer Storm Volume (7-9):	**0.32**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	7.89	10	
Error in 50% lowest flows:	**21.60**	**10**	
Error in 10% highest flows:	8.10	15	
Seasonal volume error - Summer:	**38.77**	**30**	
Seasonal volume error - Fall:	21.31	30	
Seasonal volume error - Winter:	18.03	30	
Seasonal volume error - Spring:	-9.25	30	
Error in storm volumes:	**43.49**	**20**	
Error in summer storm volumes:	35.70	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.633	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.502	as E or E' approaches 1.0	

Results of the validation exercise are summarized in Table 28. Problems similar to those experienced on the Cottonwood gage were seen at all the tributary gages, with overprediction of seasonal flows in summer and fall. However, as noted above, this is likely due to the use of land use and model parameters that are more reflective of current conditions and is not believed to present a bar to application of the model.

Table 28. Summary statistics: all stations - validation period (SWAT)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Error in total volume:	11.24	31.84	-0.84	-1.10	-2.66	32.01	38.66	28.58
Error in 50% lowest flows:	20.06	65.19	-29.79	-68.25	13.13	48.38	60.68	34.93
Error in 10% highest flows:	-4.84	10.80	-10.88	23.45	-5.64	24.34	28.42	22.70
Seasonal volume error - Summer:	71.72	127.37	52.47	59.14	50.15	92.70	98.32	72.78
Seasonal volume error - Fall:	54.63	43.60	28.02	22.81	23.23	42.94	57.68	40.65
Seasonal volume error - Winter:	-25.13	1.06	-30.60	-18.95	-24.39	11.05	26.20	18.12
Seasonal volume error - Spring:	-0.75	15.22	-13.60	-18.56	-16.18	19.79	15.14	10.04
Error in storm volumes:	8.05	45.17	-9.94	90.61	25.30	45.02	77.61	74.72
Error in summer storm volumes:	2.96	62.49	6.14	135.92	36.86	59.70	81.05	60.81
Nash-Sutcliffe Coefficient of Efficiency, E:	0.517	0.439	0.740	-0.245	0.636	0.513	0.423	0.421
Baseline adjusted coefficient (Garrick), E':	0.440	0.427	0.599	0.327	0.535	0.465	0.418	0.441

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done on the Cottonwood River (USGS 05317000), using 1993-2002 for calibration and 1986-1992 for validation. As with hydrology, 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:

- BIOMIX

- SPCON (Linear parameters 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-C (Land surface cover factor).

Simulated and estimated sediment loads at the Cottonwood station for both the calibration and validation periods are shown in Figures 59 through 62 and statistics for the two periods are provided separately in Tables 29 and 30. The key statistic in Table 29 is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. The table 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 good agreement.

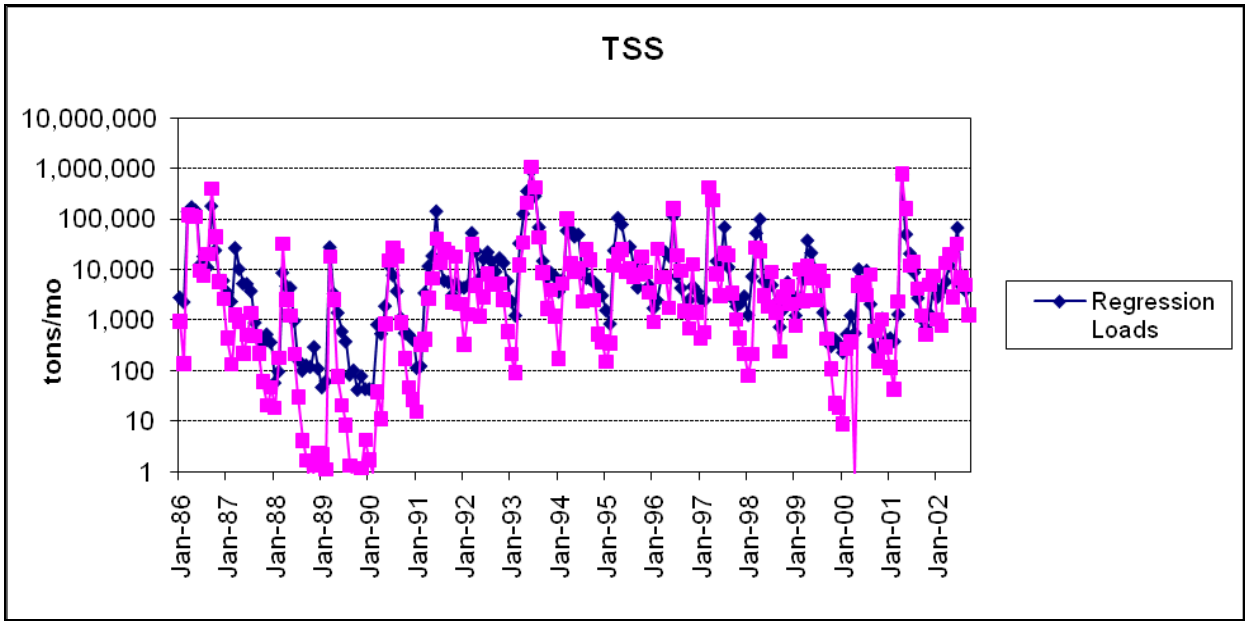

Figure 59. Fit for monthly load of TSS at USGS 05317000 Cottonwood River (SWAT).

Table 29. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	9.2%	9.0%
Relative Average Absolute Error	36%	65%
Relative Median Absolute Error	9.1%	14.3%

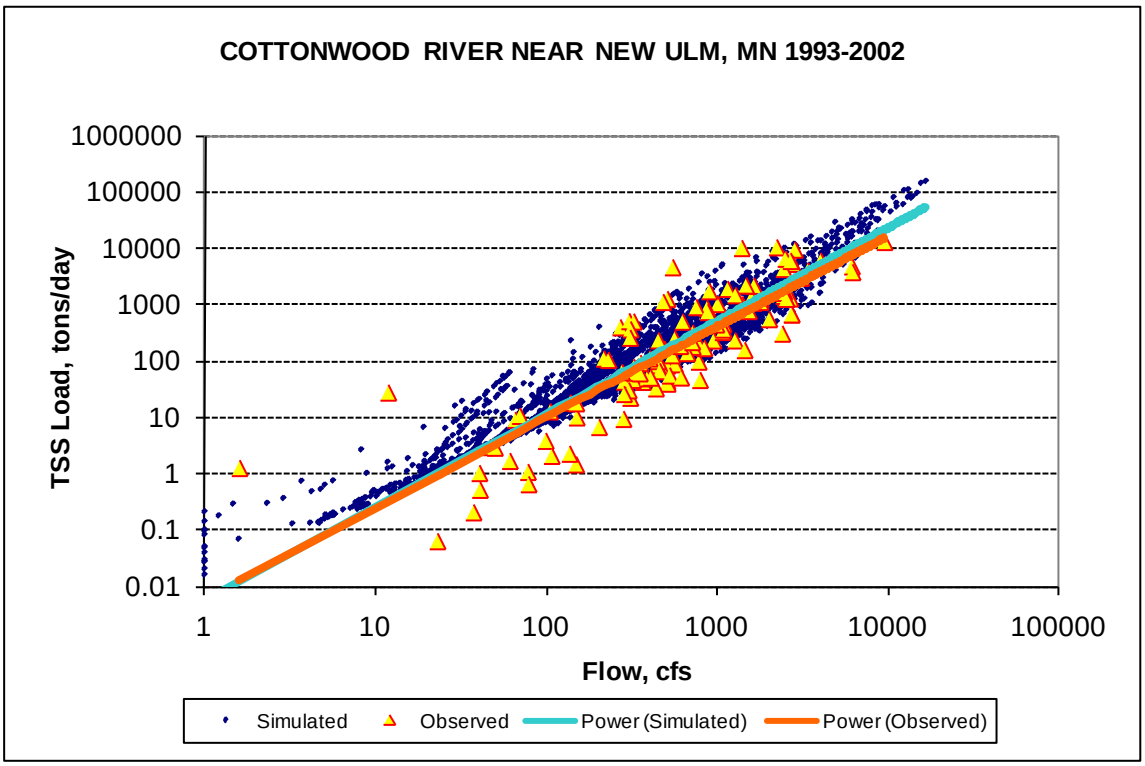

Figure 60. Power plot for observed and simulated TSS at USGS 05317000 Cottonwood River - calibration period (SWAT).

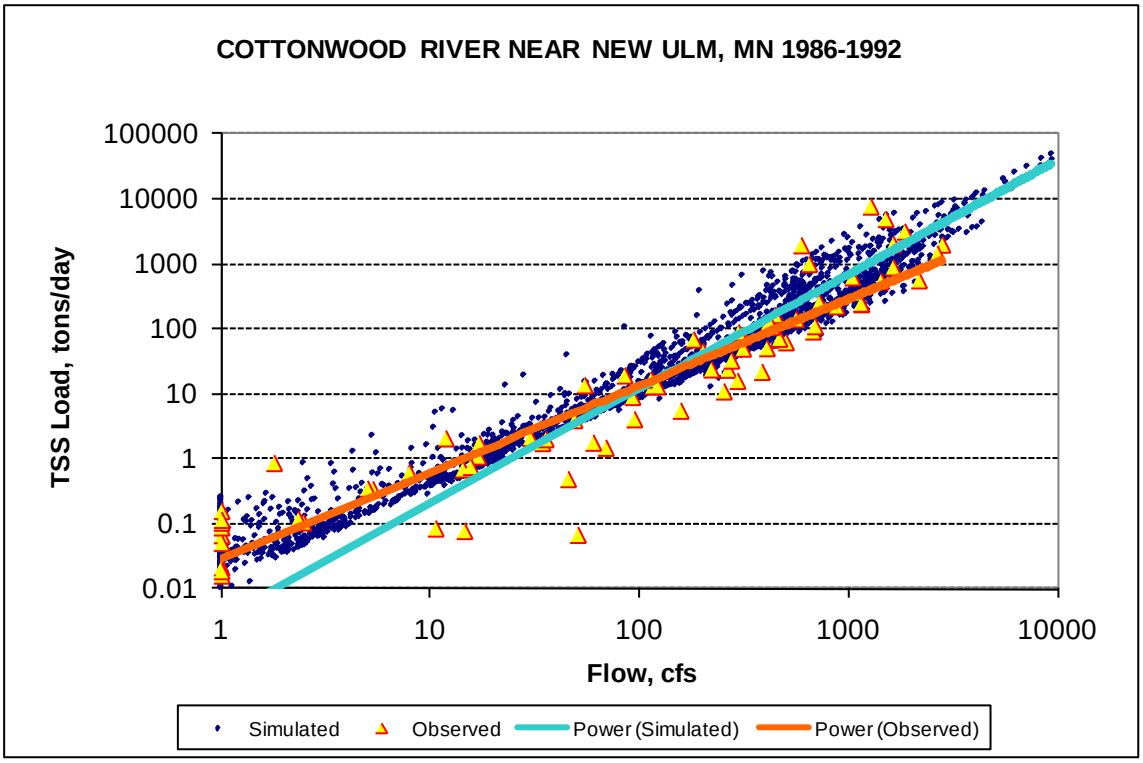

Figure 61. Power plot for observed and simulated TSS at USGS 05317000 Cottonwood River - validation period (SWAT).

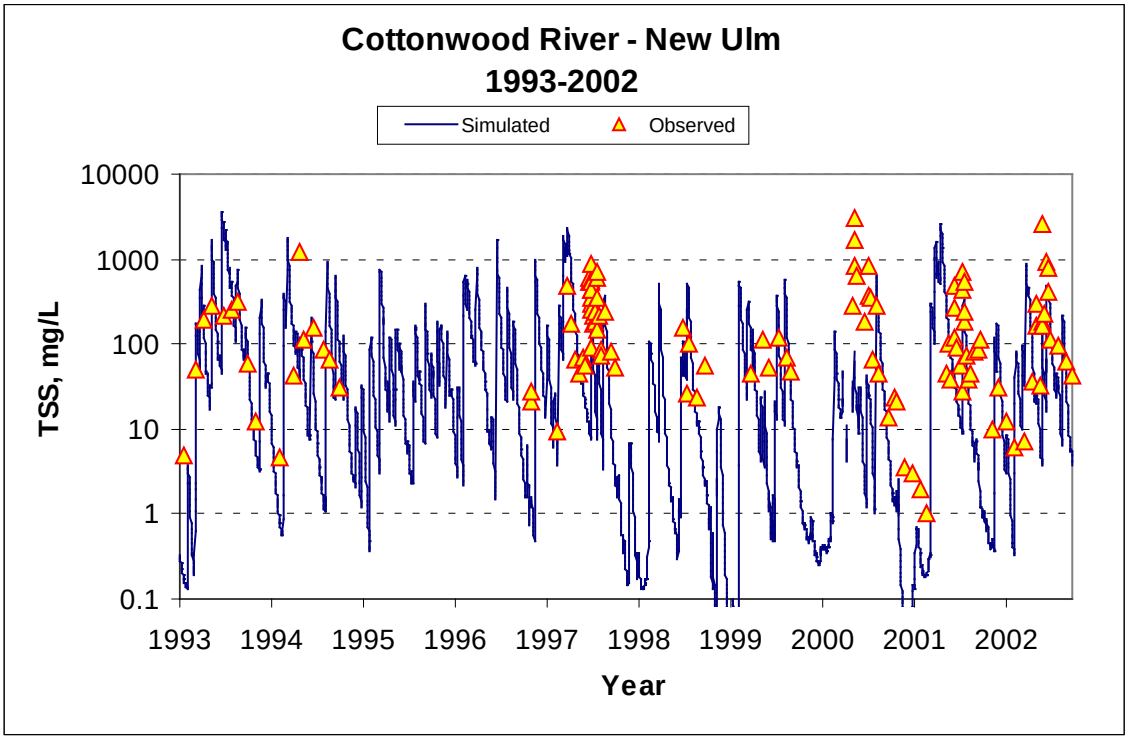

Figure 62. Time series plot of TSS concentration at USGS 05317000 Cottonwood River (SWAT).

Table 30. Relative errors (observed minus predicted), TSS concentration at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	121	75
Concentration Average Error	27.69%	13.61%
Concentration Median Error	-2.52%	-4.04%

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

- PHOSKD (Phosphorus soil partitioning coefficient)
- RS4
- PSP
- BC3 and BC4
- SOL_CBN1 (Organic carbon in the first soil layer)
- Michaelis-Menton half-saturation constant for nitrogen and phosphorus
- MUMAX

Results for the phosphorus simulation are shown in Figures 63 through 66 and Tables 31 and 32. Results for the nitrogen simulation are shown in Figures 67 through 70 and Tables 33 and 34. The SWAT fit is generally good, with calibration and validation error statistics similar to those obtained from the HSPF model.

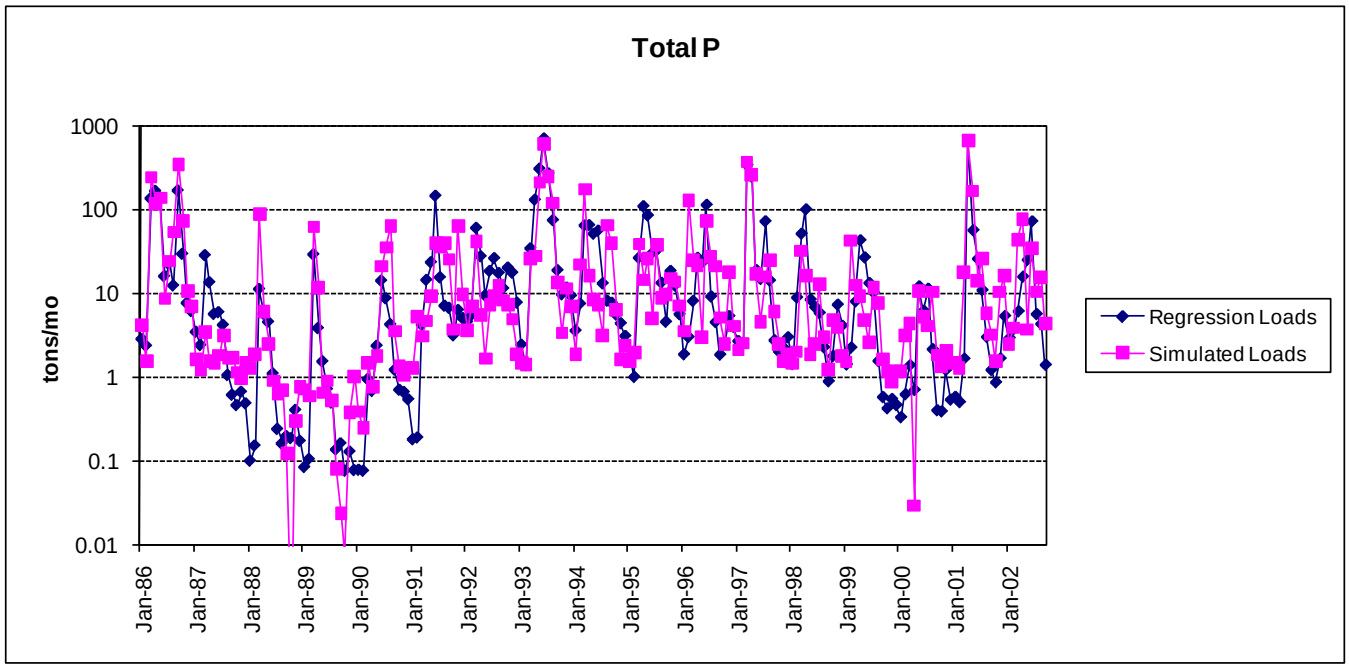

Figure 63. Fit for monthly load of total phosphorus at USGS 05317000 Cottonwood River (SWAT).

Table 31. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	9.3%	-21.6
Average Absolute Error	46%	80%
Median Absolute Error	11.2%	9.3%

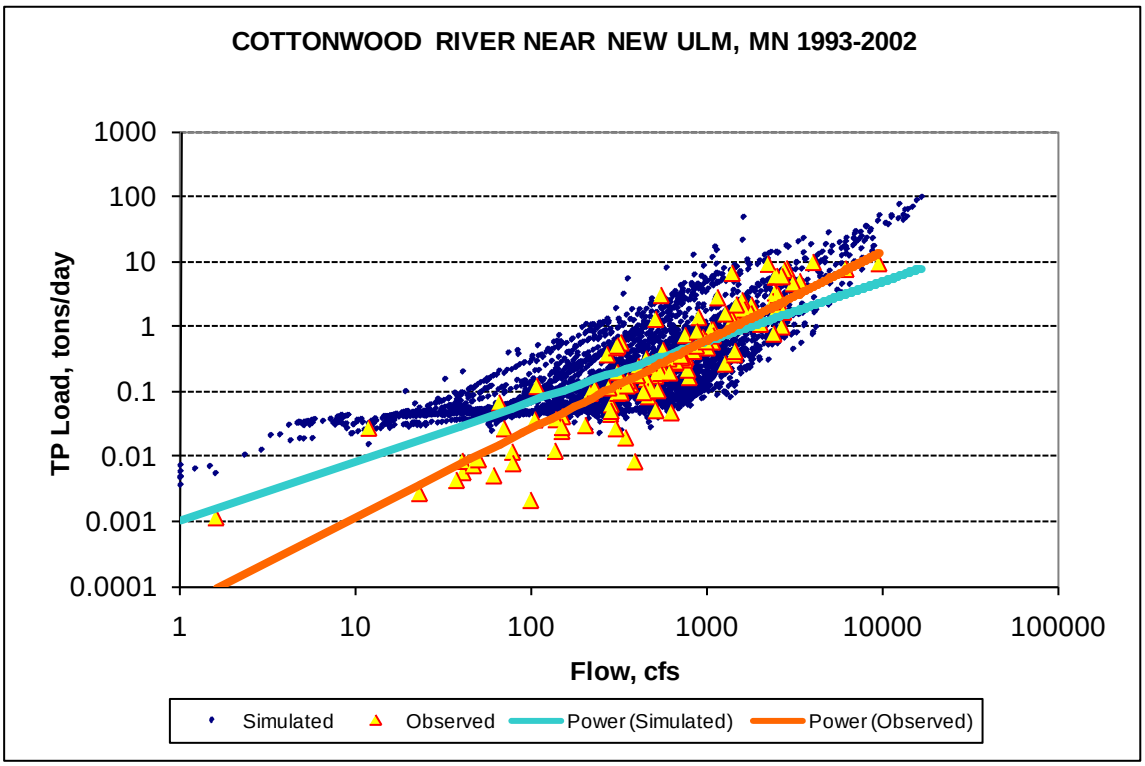

Figure 64. Power plot for observed and simulated total phosphorus at USGS 05317000 Cottonwood River - calibration period (SWAT).

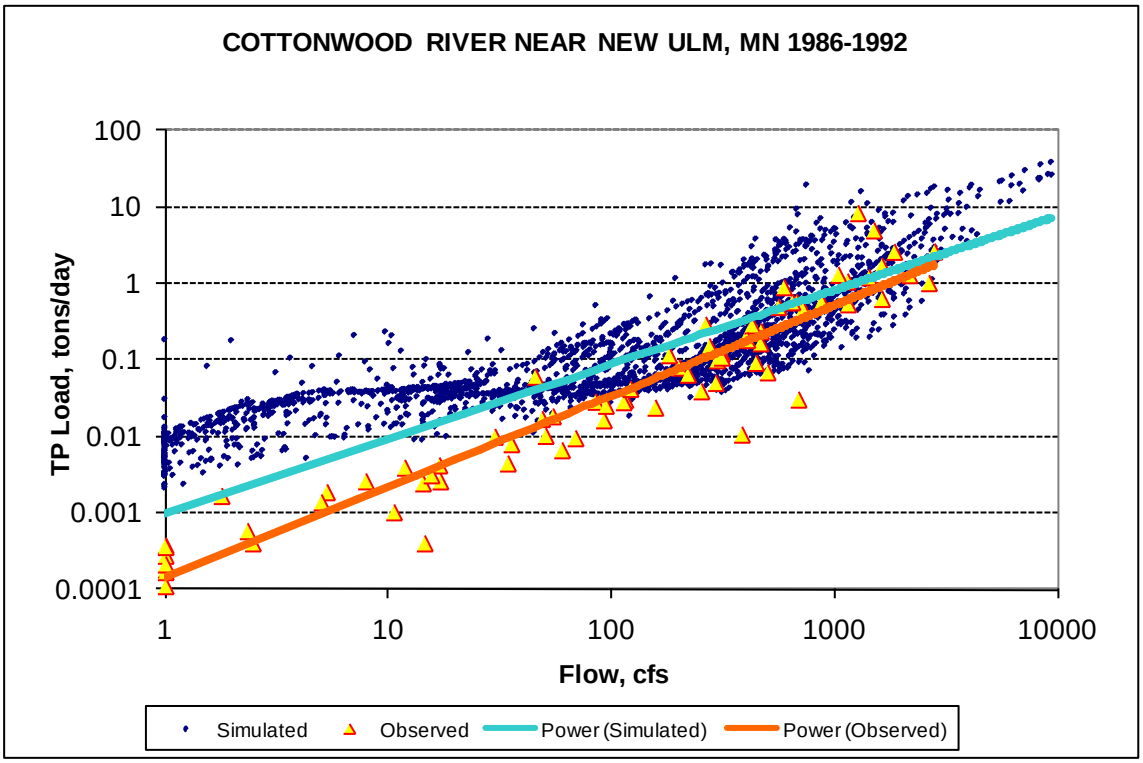

Figure 65. Power plot for observed and simulated total phosphorus at USGS 05317000 Cottonwood River – validation period (SWAT).

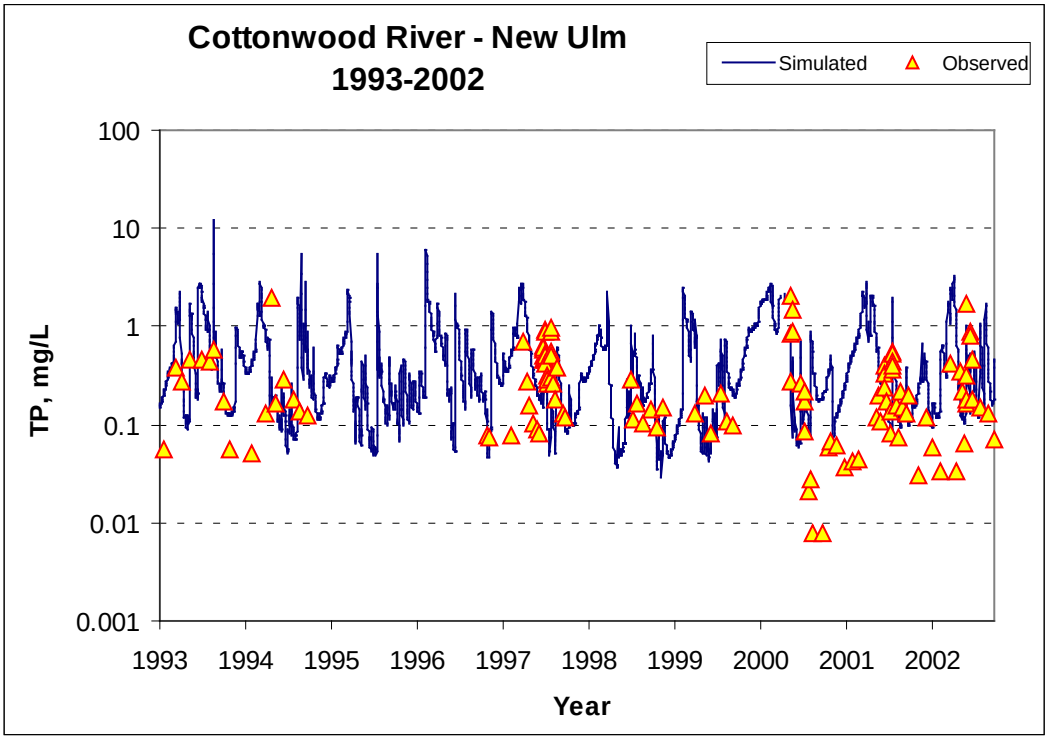

Figure 66. Time series plot of total phosphorus concentration at USGS 05317000 Cottonwood River (SWAT).

Table 32. Relative errors (observed minus predicted), total phosphorus concentration at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	123	75
Concentration Average Error	-20.45%	-707.00%
Concentration Median Error	-0.25%	-87.32%

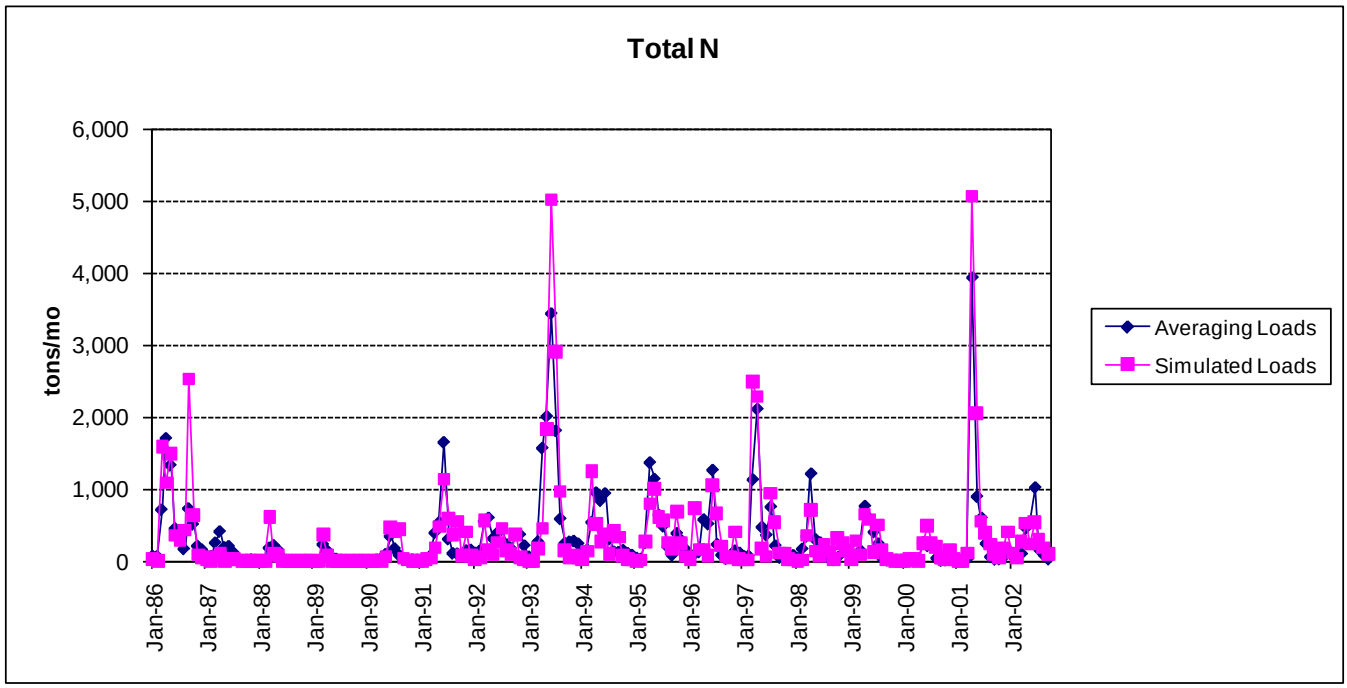

Figure 67. Fit for monthly load of total nitrogen at USGS 05317000 Cottonwood River (SWAT).

Table 33. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	-8.9%	-1.3%
Average Absolute Error	54%	65%
Median Absolute Error	24.4%	28.7%

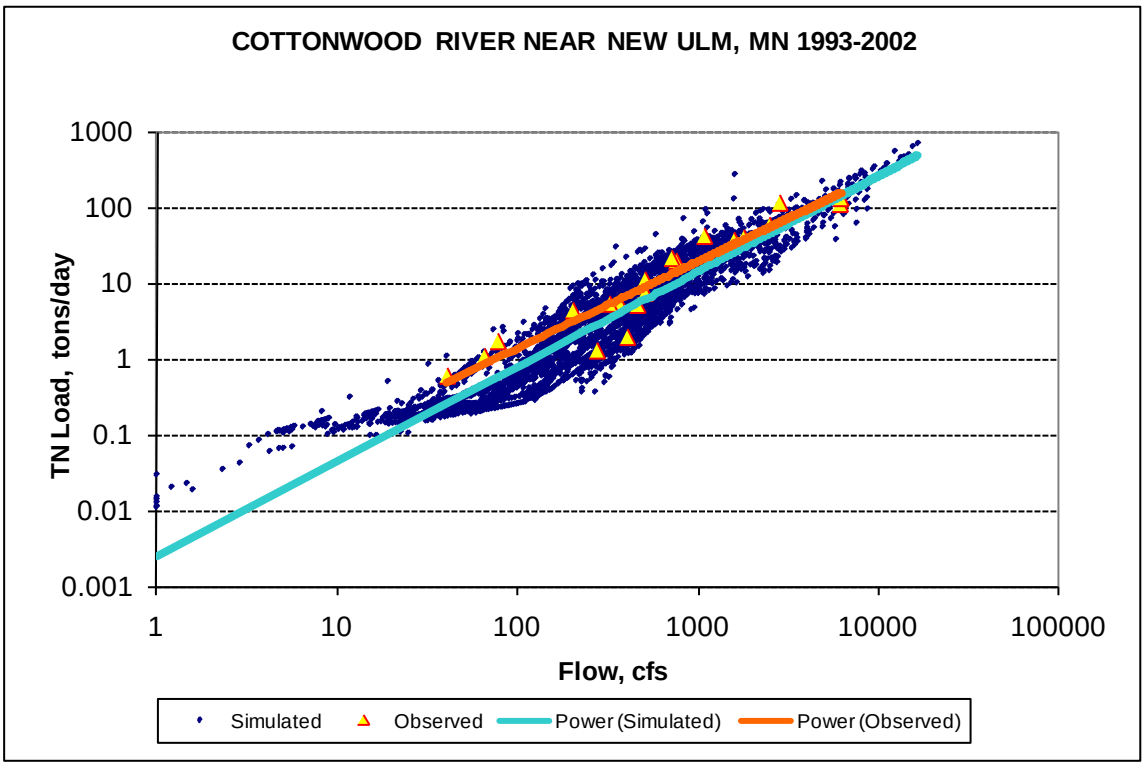

Figure 68. Power plot for observed and simulated total nitrogen at USGS 05317000 Cottonwood River – calibration period (SWAT).

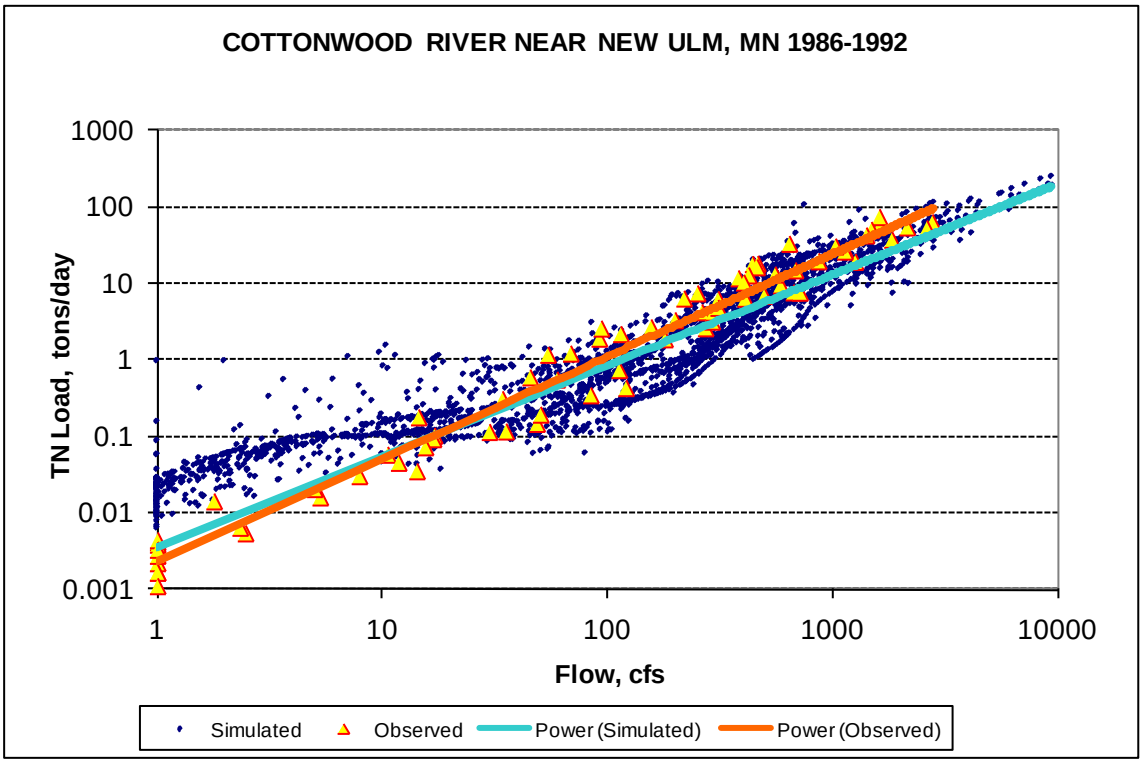

Figure 69. Power plot for observed and simulated total nitrogen at USGS 05317000 Cottonwood River – validation period (SWAT).

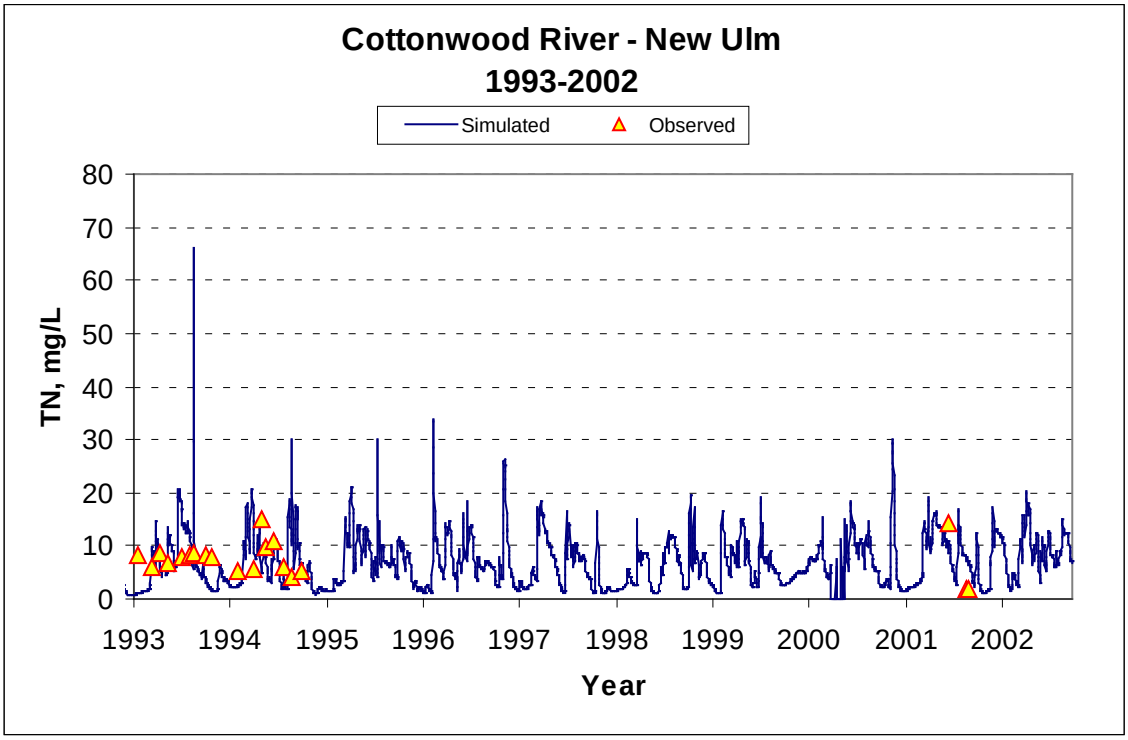

Figure 70. Time series plot of total nitrogen concentration at USGS 05317000 Cottonwood River (SWAT).

Table 34. Relative errors (observed minus predicted), total nitrogen concentration at USGS 05317000 Cottonwood River (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	20	75
Concentration Average Error	12.65%	-78.90%
Concentration Median Error	31.42%	12.33%

Water Quality Results for Larger Watershed

Water quality results from the larger watershed from the SWAT model appear to be much less precise than those obtained with the HSPF model. This is believed to be largely a result of the calibration strategy adopted for the SWAT application: As with hydrology, the Cottonwood River watershed SWAT model parameters for water quality were directly transferred to other portions of the watershed. In contrast, the HSPF model used a spatial calibration approach. Application of the SWAT model without spatial adjustments resulted in relatively large errors in predicting loads and concentrations at some stations.

Summary statistics for the SWAT water quality calibration and validation at other stations in the watershed are provided in Tables 35 and 36.

Table 35. Summary statistics for water quality at all stations – calibration period 1993-2002 (SWAT)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Relative Percent Error TSS Load	-97.8%	-96.0%	9.2%	-166.7%	-145.1%	-139.8%	-73.1%	-40.7%
TSS Concentration Median Error	7.10%	-3.0%	-2.84%	-11.14%	-31.85%	-28.91%	-41.2%	-20.48%
Relative Percent Error TP Load	-38.3%	-84.0%	9.3%	-58.1%	-54.7%	-65.7%	-13.1%	-5.0%
TP Concentration Median Error	19.53%	-52.87%	-0.25%	-16.19%	-23.38%	-13.37%	-5.65%	-5.99%
Relative Percent Error TN Load	-22.9%	-44.3%	-8.9%	-17.9%	-10.9%	13.4%	9.5%	18.20%
TN Concentration Median Error	29.17%	19.87%	31.42%	38.06%	31.66%	28.4%	42.39%	47.64%

Table 36. Summary statistics for water quality at all stations – validation period 1986-1992 (SWAT)

Station	05313500 Yellow Medicine River	05316500 Redwood River nr Redwood Falls	05317000 Cottonwood River near New Ulm	05319500 Watonwan River nr Garden City	05320000 Blue Earth River nr Rapidan	05320500 LeSueur River nr Rapidan	05325000 Minnesota River at Mankato	05330000 Minnesota River nr Jordan
Relative Percent Error TSS Load	-56.8%	-75.1%	9.0%	-227.1%	-136.3%	-199.8%	-95.1%	-43.2%
TSS Concentration Median Error	-8.60%	-14.87%	-4.04%	-24.78%	-65.75%	-51.33%	-91.48%	-39.50%
Relative Percent Error TP Load	-27.4%	-1142.6%	-21.6%	-174.3%	-60.4%	-143.7%	-39.6%	-31.0%
TP Concentration Median Error	10.04%	-275.32%	-87.32%	-74.48%	-80.91%	-91.5%	-76.07%	-80.93%
Relative Percent Error TN Load	-28.0%	-68.7%	-1.3%	-69.9%	-15.3%	-43.1%	-4.8%	4.2%
TN Concentration Median Error	24.09%	-3.37%	12.33%	21.14%	10.54%	5.29%	10.57%	12.33%

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