Appendix F
Model Configuration, Calibration and Validation

Basin: Susquehanna River

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Watershed Background

Water Body Characteristics

The Susquehanna River drains about 27,500 mi^2 in the states of New York, Pennsylvania, and Maryland and includes a total of 19 HUC8s in HUC 2050 (Figure 1). The watershed makes up 43 percent of the Chesapeake Bay's drainage area and consists of six major subwatersheds (Chemung, Upper Susquehanna, West Branch Susquehanna, Middle Susquehanna, Juniata, and Lower Susquehanna). The Susquehanna River flows about 444 miles from its headwaters at Otsego Lake in Cooperstown, New York to Havre de Grace, Maryland, where the river flows into the Chesapeake Bay. The river is the largest tributary to the Chesapeake Bay, providing 50 percent of its freshwater flows (SRBC 2008).

The Susquehanna River watershed includes three physiographic provinces: the Appalachian Plateau, the Valley and Ridge, and the Piedmont Provinces. The Appalachian Plateau Province is characterized by high, flat-topped hills and deep valleys cut by the Susquehanna River and its tributaries. The Valley and Ridge physiographic province contains steep mountains and ridges separated by valleys. The Piedmont physiographic province consists of uplands and lowlands. The Piedmont physiographic province generally has terrain that is gently rolling to hilly.

Sixty-nine percent of the watershed is forested. However, the well-drained areas with rolling hills and valleys in the southern part of the watershed contain most of the population and some of the most productive agricultural land in the US. Groundwater maintains the base flow of perennial streams during periods of little or no precipitation and constitutes an average of 50 percent of the flow of most streams at other times.

The U.S. Army Corps of Engineers (USACE) operates and maintains 13 dams and reservoirs that are located in all six major subwatersheds. USACE also regulates the operation of a state of Pennsylvania reservoir (George B. Stevenson) in the West Branch Susquehanna subwatershed for the purpose of flood damage reduction. These 14 reservoirs provide most of the floodwater storage in the watershed. The Natural Resources Conservation Service and the state of Pennsylvania have also constructed reservoirs in the watershed that reduce flood damages; however, these reservoirs are typically smaller in scale than the USACE reservoirs.

In addition to the many flood storage dams and reservoirs, there are 20 major electric power generating plants located in the Susquehanna River watershed that use water resources in their operation. Many of these hydroelectric dams are located in the lower Susquehanna watershed. Just below Harrisburg, Pennsylvania the Susquehanna River flows through a series of gorges dammed by hydroelectric power facilities. There are also 13 approved water diversions from the Susquehanna River watershed.

The Susquehanna River basin has a continental type of climate. The average annual temperature in the basin ranges from about 44 degrees in the northern part of the basin to about 53 degrees in the southern part. Average annual precipitation is about 40 inches over the entire basin and ranges from 33 inches in the northern part of the basin to 46 inches in the southern part. Virtually all the major streams experience their highest flows in March, April, and May, when melting snows combine with spring rains. These three months account for about one-half of the yearly runoff. Flows are lowest in these streams during the summer and early fall months, with most streams falling to their lowest levels in September. The Susquehanna River basin is one of the country's most flood prone areas. Generally, floods occur each year somewhere in the basin, and major floods can occur in all seasons of the year, and a major flood occurs on average every 13 years.

Groundwater flow maintains the base flow of perennial streams during periods of little or no precipitation and constitutes an average of 50 percent of the flow of most streams at other times. The use of groundwater resources

in the basin is extensive. Groundwater plays a critical role in supplying drinking water and maintaining economic viability. Outside of the major population centers, drinking water supplies are heavily dependent on groundwater wells. Approximately 20 percent of the basin population is served by public water suppliers that use groundwater as a source.

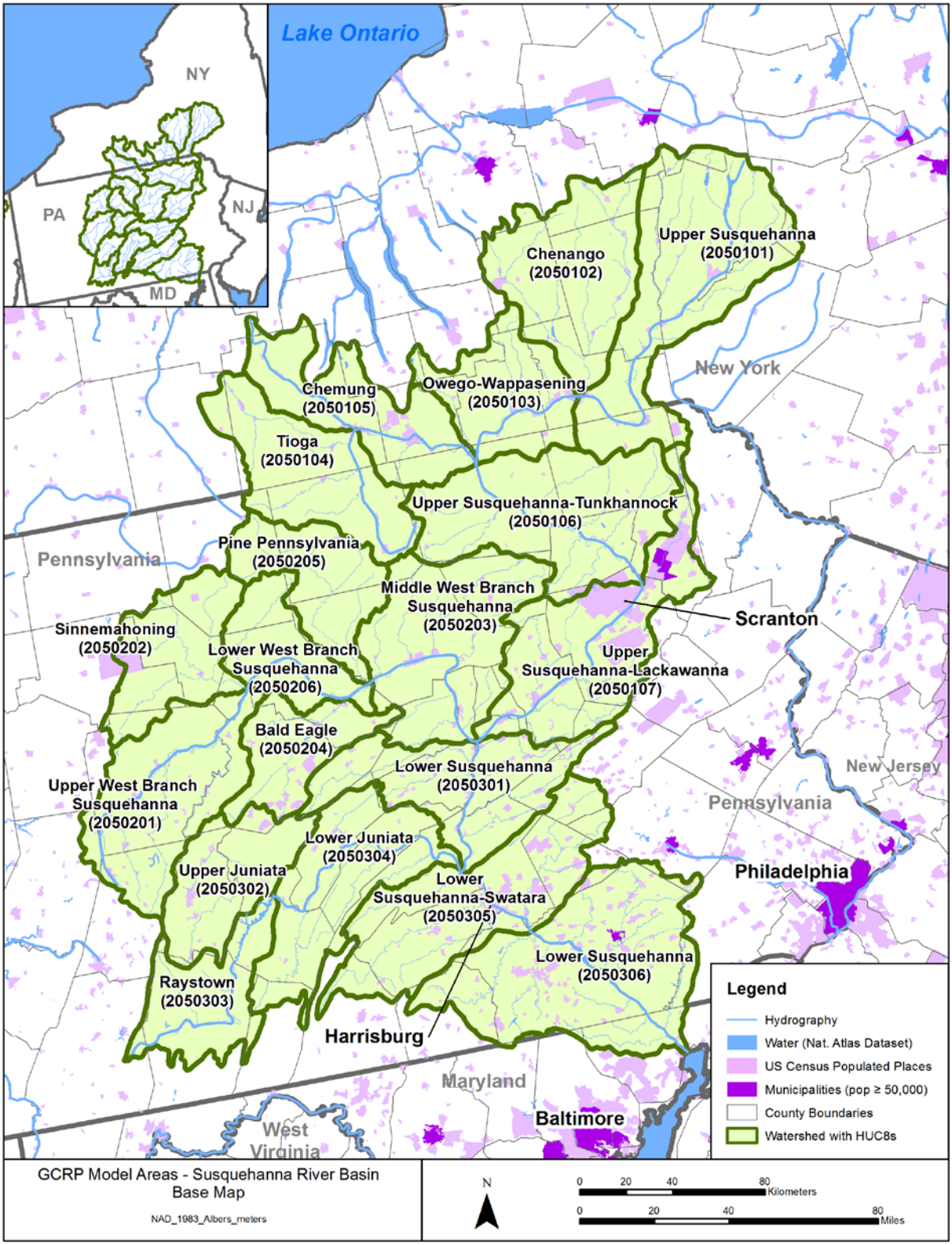

Figure 1. Location of the Susquehanna River watershed.

Soil Characteristics

One of the most important characteristics of soils for watershed modeling is their hydrologic soil group (HSG). The 20 Watershed study utilized STATSGO soil survey HSG information during model set-up. Soils are classified into four hydrologic groups (SCS 1986), separated by runoff potential, as follows:

Group A Soils — Have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B Soils — Have moderate infiltration rates when wet and consist chiefly of soils that are moderately deep to deep, moderately well to well drained, and moderately fine to moderately course textures.

Group C Soils — Have low infiltration rates when thoroughly wetted and consist chiefly of soils having a layer that impedes downward movement of water with moderately fine to fine structure.

Group D Soils — Have high runoff potential, very low infiltration rates and consist chiefly of clay soils with high swelling potential, soils with a permanent water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

The Susquehanna River watershed contains all four HSGs in the watershed. However, soils in the watershed, as described in STATSGO soil surveys, fall primarily into HSGs B (moderately high infiltration capacity) and C (low infiltration capacity). Hydrologic group C soils dominate the northern portion of the watershed while a mixture of B and C soils dominate the southern portion of the watershed.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage and is predominantly forested with some agricultural and developed land (Figure 2). Agriculture and pasture are more predominant in the downstream, eastern portions of the watershed. Urban development is found throughout the watershed; however, the major concentration is in the eastern portions of the watershed.

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. Pervious and impervious lands are specified separately for HSPF, 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 also determined from the NLCD Urban Impervious data coverage. Specifically, percent impervious area was calculated over the whole basin 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. Different developed land classes are specified separately in SWAT. 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.

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

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

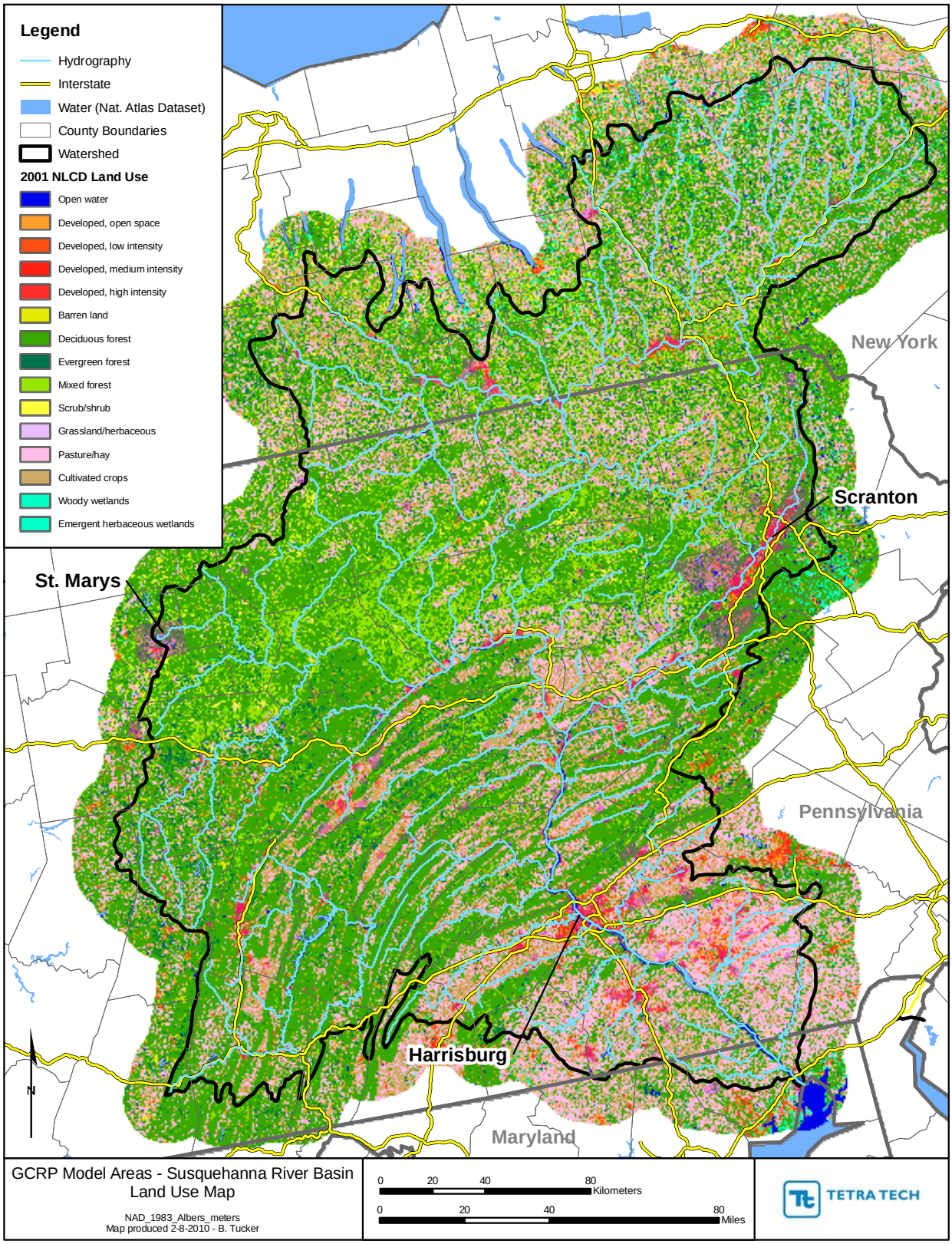

Figure 2. Land use in the Susquehanna River watershed.

Table 2. Land use distribution for the Susquehanna River watershed (2001 NLCD, mi2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
02050101	29.7	89.0	18.1	5.7	1.5	0.5	1,345.3	73.0	459.3	163.0	104.6	2,289.7
02050102	13.2	56.8	14.3	4.8	1.1	1.7	909.5	75.2	319.1	146.5	65.0	1,607.3
02050103	7.8	45.3	18.3	6.9	1.7	0.5	659.5	25.0	200.8	56.5	23.7	1,046.1
02050104	7.3	47.4	7.1	2.5	0.5	2.7	833.2	39.8	299.3	137.3	6.0	1,383.2
02050105	9.2	55.7	18.1	5.9	1.2	1.2	704.5	45.4	196.1	152.5	22.1	1,211.8
02050106	24.3	88.2	9.4	2.9	0.7	1.9	1,177.4	29.0	340.7	314.0	18.1	2,006.7
02050107	32.4	117.5	60.5	42.9	12.1	11.8	1,083.8	23.7	230.2	126.1	22.9	1,764.0
02050201	10.6	90.3	14.7	2.5	0.5	30.1	1,229.8	32.9	147.0	36.2	1.9	1,596.7
02050202	1.4	12.1	1.7	0.5	0.1	2.5	921.2	56.5	27.9	2.8	7.3	1,033.8
02050203	5.6	12.8	2.3	0.9	0.1	2.1	728.9	18.6	21.1	7.7	3.1	803.2
02050204	4.4	45.9	19.0	4.5	1.5	1.4	543.1	0.0	64.8	70.0	0.1	754.6
02050205	2.4	16.9	2.4	0.7	0.2	2.1	816.2	42.0	68.0	25.9	4.3	981.0
02050206	14.1	80.6	23.6	8.5	2.1	2.3	1,170.3	33.1	282.9	184.5	7.8	1,809.9
02050301	32.8	87.1	24.7	7.8	2.4	9.3	860.0	0.0	219.9	201.7	3.0	1,448.7
02050302	3.3	54.4	26.5	8.6	3.5	1.8	688.8	0.0	101.9	102.2	0.1	991.1
02050303	17.3	51.5	12.6	2.9	0.8	1.4	655.6	0.0	140.8	78.8	0.0	961.7
02050304	12.4	72.7	18.0	4.1	1.1	0.3	1,019.2	0.0	185.0	137.2	0.7	1,450.7
02050305	33.5	139.6	113.1	35.6	15.1	3.5	858.3	0.0	391.9	273.5	12.3	1,876.5
02050306	51.5	109.8	99.7	40.4	16.0	23.0	603.5	0.0	1,015.3	489.1	39.4	2,487.5
Total	313.2	1,273.6	504.1	188.6	62.5	100.0	16,808.1	494.4	4,712.1	2,705.6	342.2	27,504.3

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (6.90%), low density (31.26%), medium density (60.90%), and high density (85.41%).

Point Sources

There are numerous point source discharges in the watershed. For the purposes of 20 Watershed modeling, only the 147 major dischargers with a design flow greater than 1 MGD are included in the simulation (Table 3 and Figure 3). The major dischargers account for the majority of the facilities, 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.

Data from 1991-2006 were compiled from the PCS database and the median total nitrogen, total phosphorus, and TSS values were estimated. The facilities that were missing a total nitrogen, total phosphorus, and TSS concentration value were filled with a typical pollutant concentration value from literature (Tetra Tech 1990) based on the SIC classification. The median concentrations for the nutrient species were estimated based on the values reported in the Chesapeake Bay Phase 5 Model documentation (USEPA 2010).

Table 3. Major point source discharges in the Susquehanna River watershed

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
MD0002518	EXELON POWER GENERATION	47.74	0.00
NY0003824	AEROSPACE OPERATIONS	1.35	0.22
NY0003859	AES HICKLING, LLC	77.34	1.10
NY0003867	AES - JENNISON, LLC	65.34	0.03
NY0003875	AES WESTOVER	101.90	0.44
NY0004057	SYSTEMS INTEGRATION - OWEGO	1.61	0.62
NY0004081	MOTOR COMPONENTS, LLC	0.93	3.00
NY0004138	OSG NORWICH PHARMACEUTICALS	0.80	0.08
NY0004146	WOODS CORNER PLANT	0.30	0.07
NY0004243	KERRY BIO-SCIENCE	2.30	0.39
NY0020672	HAMILTON (V) WPCP	0.85	0.53
NY0021423	NORWICH (C) WWTP	2.20	2.14
NY0021431	BATH (V) WWTP	1.00	0.74
NY0022357	ALFRED (V) WWTP	0.98	0.60
NY0022730	OWEGO (T) SD#1	0.50	0.67
NY0023591	COOPERSTOWN (V) STP	0.52	0.65
NY0023647	HORNELL (C) WPCP	4.00	2.94
NY0023906	ERWIN (T) STP	0.80	0.64
NY0024414	BINGHAMTON-JOHNSON (C) JNT STP	20.00	22.20
NY0025712	PAINTED POST (V) STP	0.50	0.25

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
NY0025721	CORNING (C) STP	2.13	1.56
NY0025798	OWEGO WPCP #2	2.00	1.14
NY0027561	LE ROY R SUMMERSON WWTF	10.00	6.96
NY0027669	ENDICOTT (V) WPCP	10.00	7.48
NY0029262	OWEGO (V) STP	1.00	0.57
NY0029271	SIDNEY (V) WWTP	1.70	0.62
NY0031151	ONEONTA (C) WWTP	4.00	2.47
NY0035742	CHEMUNG CO ELMIRA SD STP	12.00	7.49
NY0036986	CHEMUNG CO SD#1 STP	9.50	7.94
PA0007498	WISE FOODS INC	0.59	0.24
PA0007919	CASCADES TISSUE GROUP - PA INC	1.25	1.56
PA0008231	GOLD MILLS INC	2.00	17.94
PA0008265	APPLETON PAPERS INC - SPRING M	4.84	4.45
PA0008281	PPL BRUNNER ISLAND LLC	621.00	6.46
PA0008303	ISG STEELTON LLC	27.60	28.01
PA0008419	MERCK & CO INC	12.20	8.70
PA0008443	PPL MONTOUR LLC	0.46	8.44
PA0008451	SUNBURY GENERATION LLC	3.38	6.50
PA0008508	BURLE BUSINESS PARK LP	0.32	0.11
PA0008575	WIREROPE WORKS INC	0.07	0.05
PA0008869	PH GLATFELTER CO	13.70	28.27
PA0008885	PROCTER & GAMBLE PRODUCTS CO	7.60	7.68
PA0008923	CORNING ASAHI VIDEO PROD CO	1.97	1.27
PA0009024	OSRAM SYLVANIA PRODUCTS INC	1.22	0.93
PA0009164	STANDARD STEEL LLC	1.45	15.56
PA0009202	CERRO METAL PRODUCTS CO	0.23	2.36
PA0009229	NORFOLK SOUTHERN RAILWAY CO -	0.50	0.24
PA0009253	UNITED DEFENSE LP	0.03	0.03
PA0009270	DEL MONTE CORP	0.67	0.41
PA0009733	EXELON GENERATION CO LLC - PEA	0.05	0.12
PA0009920	AMERGEN ENERGY CO LLC - THREE	81.02	20.07
PA0010031	RELIANT ENERGY MID-ATLANTIC PO	0.01	0.70

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
PA0010430	HANOVER FOODS CORP	0.23	0.18
PA0013862	CORIXA CORP	0.32	0.18
PA0020273	MILTON REGIONAL SEW AUTH	3.42	78.54
PA0020320	LITITZ SEW AUTH	3.85	2.62
PA0020486	BELLEFONTE BORO	3.22	2.21
PA0020567	NORTHUMBERLAND SEW AUTH	1.13	11.68
PA0020664	MIDDLETOWN BORO AUTH	2.20	1.32
PA0020826	DOVER TWP	8.00	3.71
PA0020885	MECHANICSBURG BORO	2.08	1.05
PA0020893	MANHEIM BORO	1.14	6.29
PA0020923	NEW OXFORD MUN AUTH	1.79	1.11
PA0021067	MOUNT JOY BORO AUTH	1.53	0.78
PA0021571	MARYSVILLE BORO COUNCIL	1.25	0.80
PA0021687	WELLSBORO MUN AUTH	2.00	1.07
PA0021814	MANSFIELD BORO MUN AUTH	1.00	0.53
PA0021890	NEW HOLLAND BORO	1.34	0.96
PA0022209	BEDFORD BORO MUN AUTH	1.50	0.79
PA0022535	MILLERSBURG AREA AUTH	1.00	0.47
PA0023108	ELIZABETHTOWN BORO	3.00	2.10
PA0023248	BERWICK AREA JNT SEW AUTH	3.70	1.38
PA0023531	DANVILLE BORO	3.62	2.13
PA0023558	ASHLAND BORO	1.30	12.19
PA0023744	NORTHEASTERN YORK CO SEW AUTH	1.70	0.73
PA0024040	HIGHSPIRE BORO	2.00	1.11
PA0024287	PALMYRA BORO STP	1.42	0.83
PA0024325	MUNCY BORO MUN AUTH	1.40	0.76
PA0024406	MOUNT CARMEL MUN AUTH	1.50	1.01
PA0024431	DILLSBURG AREA AUTH	1.53	0.68
PA0024759	CURWENSVILLE MUN AUTH	0.75	0.41
PA0024902	UPPER ALLEN TWP BRD OF COMMRS	1.10	5.81
PA0025933	LOCK HAVEN CITY	3.75	2.29
PA0026077	CARLISLE BORO	4.63	3.34

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
PA0026107	WYOMING VALLEY SAN AUTH	32.00	24.07
PA0026123	COLUMBIA MUN AUTH	2.00	0.80
PA0026191	HUNTINGTON BORO	5.90	2.50
PA0026239	UNIVERSITY AREA JOINT AUTH -	6.00	4.62
PA0026263	YORK CITY SEW AUTH	26.00	10.66
PA0026280	LEWISTOWN BORO	2.82	1.70
PA0026310	CLEARFIELD MUN AUTH	4.50	3.46
PA0026361	LOWER LACKAWANNA VLY SAN AUTH	6.00	3.36
PA0026441	LEMOYNE BORO	2.09	1.72
PA0026484	DERRY TWP MUN AUTH - CLEARWATE	5.00	3.48
PA0026492	SCRANTON CITY SEW AUTH	20.00	13.03
PA0026557	SUNBURY CITY MUN AUTH	4.20	3.40
PA0026620	MILLERSVILLE BORO	1.85	0.65
PA0026654	NEW CUMBERLAND BORO	1.25	3.98
PA0026727	TYRONE BORO	9.00	5.97
PA0026735	SWATARA TWP AUTH	6.30	3.71
PA0026743	LANCASTER CITY	29.73	19.72
PA0026808	SPRINGETTSBURY TWP	15.00	10.04
PA0026875	HANOVER BOROUGH	5.50	4.16
PA0026921	GREATER HAZELTON JNT SEW AUTH	8.90	7.20
PA0027014	ALTOONA CITY AUTH - EAST	8.00	6.77
PA0027022	ALTOONA CITY AUTH - WEST	9.00	8.03
PA0027049	WILLIAMSPORT SAN AUTH-WEST	3.92	2.89
PA0027057	WILLIAMSPORT SAN AUTH-CENTRAL	10.50	7.38
PA0027065	LACKAWANNA RIVER BASIN SEW AUT	6.00	2.78
PA0027090	LACKAWANNA RIVER BASIN SAN AUT	7.00	5.28
PA0027171	BLOOMSBURG MUN AUTH	4.29	2.58
PA0027189	LOWER ALLEN TWP AUTH	6.25	4.38
PA0027197	HARRISBURG AUTHORITY	37.70	25.06
PA0027316	LEBANON CITY	8.00	5.31
PA0027324	SHAMOKIN-COAL TWP JNT SEW AUTH	7.00	3.74
PA0027405	EPHRATA BORO AUTH - WWTP #1	3.80	2.56

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
PA0027553	PINE CREEK MUN AUTH	1.30	39.24
PA0028142	PA NATIONAL GUARD - FORT INDIA	1.00	1.84
PA0028461	MIFFLINBURG BORO	1.40	0.77
PA0028576	CLARKS SUMMIT - S ABINGTON JSA	2.50	2.38
PA0028665	JERSEY SHORE BORO	1.05	0.69
PA0028681	KELLY TWP MUN AUTH	3.75	14.25
PA0028746	HAMPDEN TWP	1.76	1.30
PA0030643	SHIPPENSBURG BORO	3.30	1.79
PA0032883	DUNCANSVILLE BORO	1.22	0.73
PA0034576	TOWANDA MUN AUTH	1.16	0.75
PA0037150	PENN TWP BOARD OF COMMISSIONER	4.20	1.75
PA0037966	MOSHANNON VALLEY JT SEW AUTH	1.73	1.53
PA0038415	EAST PENNSBORO TWP	3.70	3.03
PA0042269	LANCASTER AREA SEW AUTH	15.00	7.52
PA0043257	NEW FREEDOM BORO AUTH	7.20	2.17
PA0043273	HOLLIDAYSBURG SEW AUTH	6.00	3.46
PA0043681	VALLEY JOINT SEW AUTH	2.25	1.04
PA0044661	LEWISBURG AREA JOINT SEW AUTH	2.42	1.30
PA0045985	MOUNTAINTOP AREA JNT SAN AUTH	4.16	2.64
PA0047325	PPL SUSQUEHANNA LLC	0.08	0.11
PA0062219	FRACKVILLE AREA MUN AUTH	1.40	1.05
PA0070041	MAHANOY CITY SEW AUTH	1.38	0.57
PA0070386	SHENANDOAH MUN SEW AUTH	2.00	1.35
PA0080314	HAMPDEN TWP - ROTH LANE	4.65	2.11
PA0083011	NEWBERRY TWP MUN AUTH	1.30	0.53
PA0087181	EPHRATA BORO AUTH - WWTP #2	2.30	1.24
PA0110582	EASTERN SNYDER CO REG AUTH	2.80	1.62
PA0110965	MID-CENTRE COUNTY AUTH	1.00	10.99
PA0111759	CARGILL MEAT SOLUTIONS CORP	0.80	0.56
PA0208779	CLEARFIELD LEATHER INC DBA WIC	0.12	0.13
PA0209228	LYCOMING CO WATER & SEWER AUTH	1.50	0.61
PA0228818	FIRST QUALITY TISSUE LLC	3.95	1.63

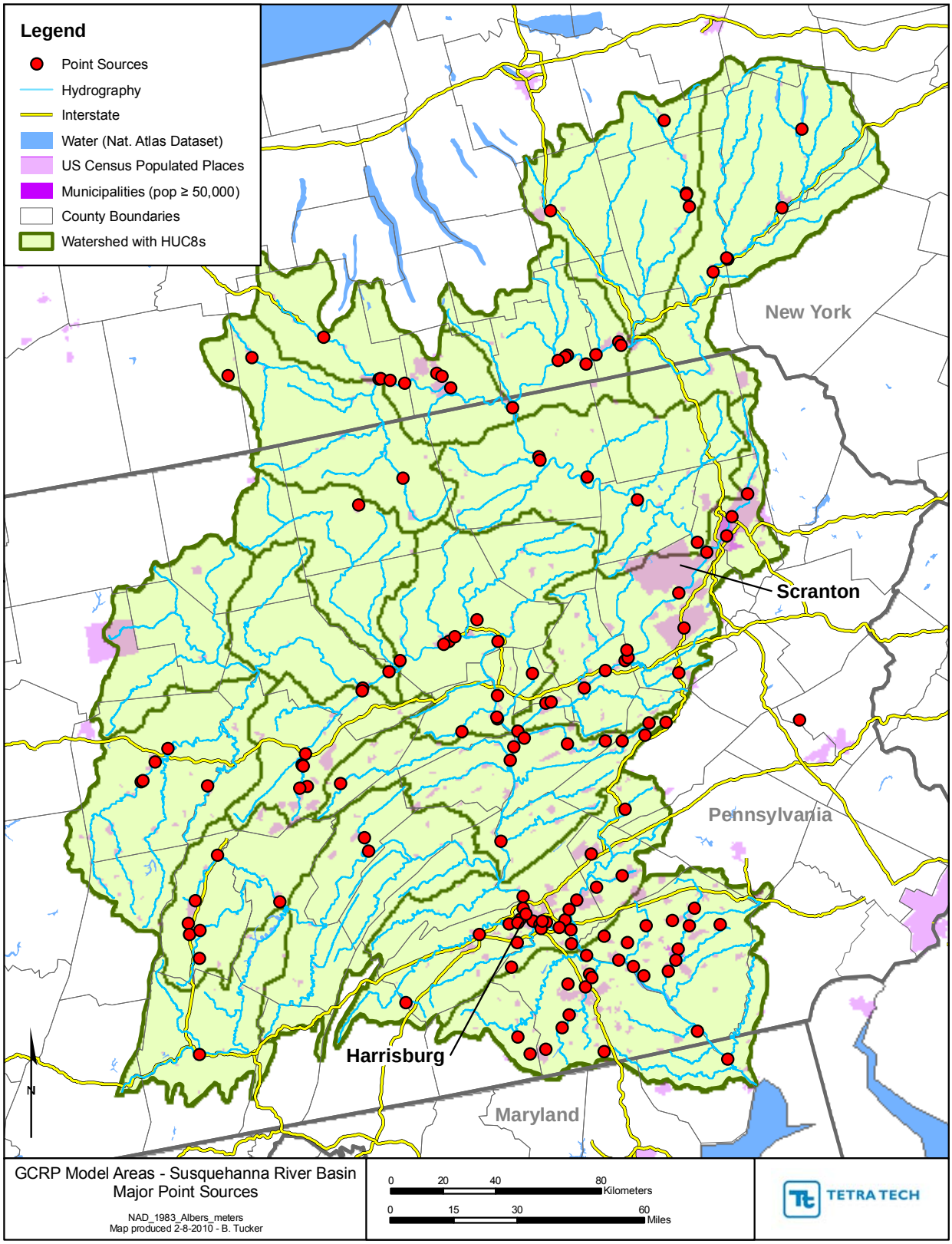

Figure 3. Major point sources in the Susquehanna River watershed.

Meteorological Data

The required meteorological data series for the 20 Watershed model simulations are precipitation, air temperature, and potential evapotranspiration (PET). The 20 Watershed model does not include water temperature or algal simulation and uses a degree-day method for snowmelt, so additional meteorological variables such as solar radiation are needed only for the calculation of PET. 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 62 precipitation stations were identified for use in the Susquehanna River model with a common period of record of 2/1/1972-3/31/2004 for the entire watershed (Table 4 and Figure 4). The majority of the stations are available through at least 9/30/2005. 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.

SWAT uses daily meteorological data for the 20 Watershed model applications, while HSPF requires hourly data. It is important to note that a majority of the meteorological stations available for the Susquehanna 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.

Table 4. Precipitation stations for the Susquehanna River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
NY300085	ALFRED	42.2614	-77.7850	Yes	1,770
NY300270	ARNOT FOREST	42.2670	-76.6330	No	1,200
NY300448	BATH	42.3500	-77.3500	Yes	1,120
NY300687	BINGHAMTON WSO AP	42.2078	-75.9814	Yes	1,600
NY301168	CANDOR 2 SE	42.1947	-76.3133	No	920
NY301173	CANISTEO 1 SW	42.2667	-77.6167	No	1,155
NY301424	CHEPACHET	42.9097	-75.1108	No	1,320
NY301752	COOPERSTOWN	42.7150	-74.9283	Yes	1,200
NY302454	EAST SIDNEY	42.3333	-75.2333	No	1,155
NY302610	ELMIRA	42.1000	-76.8000	Yes	844
NY303979	HORNBY	42.2330	-77.0500	No	1,795
NY303983	HORNELL ALMOND DAM	42.3500	-77.7000	No	1,325
NY304772	LINDLEY 2 N	42.0500	-77.1333	No	1,040
NY305512	MORRISVILLE 6 SW	42.8333	-75.7333	Yes	1,300
NY306085	NORWICH	42.5011	-75.5194	Yes	1,020
NY307195	ROCKDALE	42.3833	-75.4000	No	1,030
NY308498	THURSTON	42.2000	-77.3330	No	1,620
NY309442	WHITNEY POINT DAM	42.3500	-75.9670	No	1,040

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
PA360140	ALTOONA 3 W	40.4950	-78.4667	Yes	1,320
PA360147	ALVIN R BUSH DAM	41.3670	-77.9330	Yes	930
PA360457	BEAR GAP	40.8236	-76.4983	No	900
PA360482	BEAVERTOWN 1 NE	40.7667	-77.1500	No	540
PA360656	BIGLERVILLE	39.9356	-77.2578	Yes	720
PA360725	BLAIN 5SW	40.3000	-77.5833	No	820
PA360763	BLOSERVILLE 1 N	40.2636	-77.3639	Yes	700
PA361087	BUFFALO MILLS	39.9461	-78.6458	No	1,310
PA361480	CLARENCE	41.0456	-77.9453	No	1,390
PA361833	COVINGTON 2 WSW	41.7331	-77.1167	No	1,745
PA361961	CURWENSVILLE LAKE	40.9500	-78.5330	No	1,165
PA362013	DANVILLE	40.9483	-76.6036	No	475
PA362245	DRIFTWOOD	41.3419	-78.1403	No	820
PA362629	EMPORIUM	41.5067	-78.2275	Yes	1,040
PA362721	EVERETT	40.0136	-78.3653	Yes	1,000
PA363130	GALETON	41.7356	-77.6519	No	1,345
PA364047	HONEY BROOK 2 SSE	40.0789	-75.8975	No	665
PA364763	LANCASTER 2 NE FILT PLANT	40.0500	-76.2742	No	270
PA364778	LANDISVILLE 2 NW	40.1167	-76.4333	Yes	360
PA364853	LAURELTON CENTER	40.9017	-77.2139	Yes	800
PA364896	LEBANON 2 W	40.3333	-76.4667	Yes	450
PA364992	LEWISTOWN	40.5869	-77.5697	Yes	460
PA365344	MAHANOY CITY 2 N	40.8344	-76.1353	No	1,710
PA365915	MONTROSE	41.8667	-75.8500	Yes	1,420
PA366289	NEW PARK	39.7350	-76.5061	No	800
PA366916	PHILIPSBURG 8 E	40.9167	-78.0667	No	1,945
PA367409	RENOVO	41.3297	-77.7381	Yes	660
PA367727	RUSHVILLE	41.7833	-76.1167	No	870
PA367730	SABINSVILLE 3 SE	41.8422	-77.4747	No	1,999
PA367931	SELINSGROVE 2 S	40.7831	-76.8611	Yes	420
PA368057	SHICKSHINNY 3 N	41.2000	-76.1500	No	780
PA368073	SHIPPENSBURG	40.0500	-77.5167	Yes	680
PA368449	STATE COLLEGE	40.7933	-77.8672	Yes	1,170

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
PA368491	STILLWATER	41.6830	-75.4830	No	1,650
PA368692	SUSQUEHANNA	41.9483	-75.6050	No	910
PA368905	TOWANDA 1 S	41.7506	-76.4428	Yes	750
PA368959	TROY 1 NE	41.7833	-76.7833	No	1,110
PA369408	WELLSBORO 4 SW	41.7003	-77.3894	Yes	1,818
PA369705	WILKES BARRE SCRANTON WSO AP	41.3389	-75.7267	Yes	930
PA369714	WILLIAMSBURG	40.4667	-78.2000	No	840
PA369728	WILLIAMSPORT RGNL AP	41.2433	-76.9217	Yes	520
PA369823	WOLFSBURG	40.0417	-78.5278	No	1,185
PA369933	YORK 3 SSW PUMP STN	39.9167	-76.7500	Yes	390
PA369950	YORK HAVEN	40.1167	-76.7167	No	310

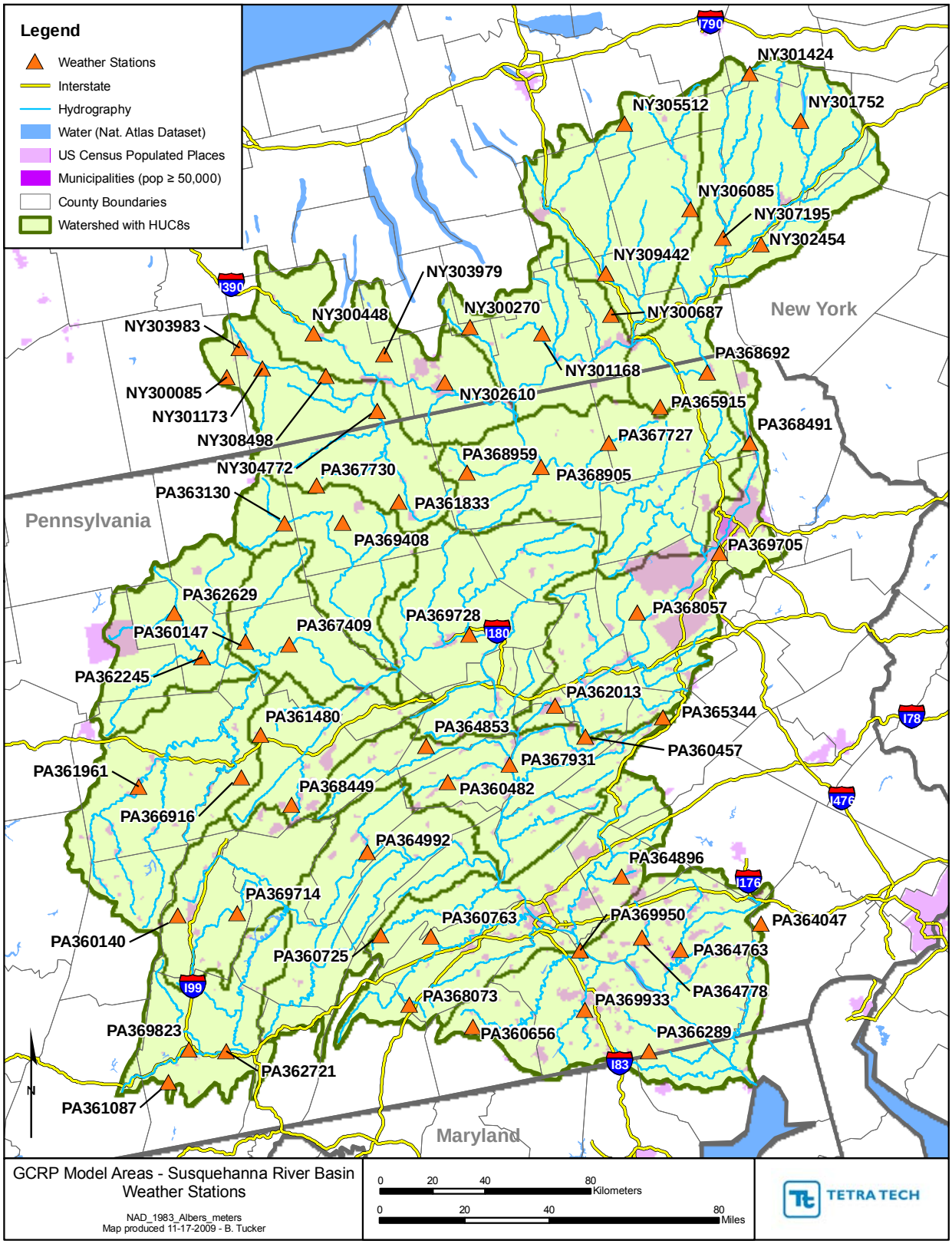

Figure 4. Weather stations for the Susquehanna River watershed model.

Watershed Segmentation

At about 27,000 square miles, the Susquehanna River basin is one of the largest modeling areas considered for the 20 Watershed project. It encompasses a complete drainage area, with no need for upstream boundary conditions. There is also an existing detailed HSPF model of the basin (the Chesapeake Bay Model or CBM; USEPA 2010). Watershed segmentation for the Susquehanna River basin is based on the segmentation used in the CBM, resulting in 278 subbasins for modeling (Figure 5). The initial calibration watershed (Raystown Branch Juniata River) is highlighted.

The model subbasins approximate the HUC-10 scale, but are subdivided as needed to account for the connection of tributaries and location of flow gages. The subbasins range in size from 1.04 to 516 mi^2.

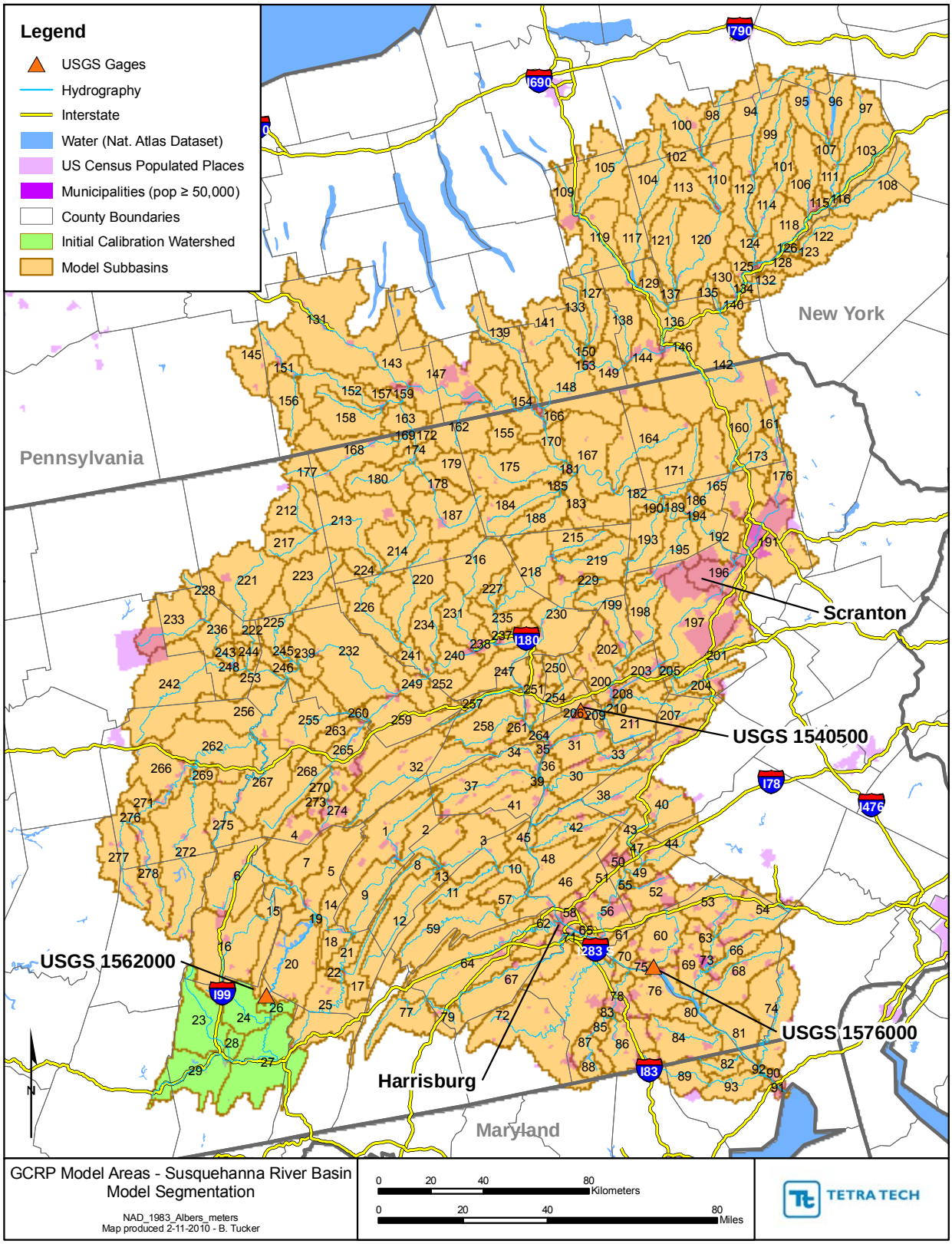

Figure 5. Model segmentation and USGS stations utilized for the Susquehanna River watershed.

Calibration Data and Locations

The Susquehanna River was selected as a pilot site because of extensive previous experience with the CBM. Given the existence of this calibrated model, the approach to the Susquehanna pilot study was to start from parameters derived from the existing model, evaluate the parameterization through detailed application to an initial calibration focus area, then evaluate the quality of the fit through comparison to data at two monitoring points representing the larger watershed. Spatial calibration at multiple locations was not pursued. It should be noted, however, that the 20 Watershed approach is based on a different land use coverage and uses different weather data and, in particular, a different estimator of PET (Penman-Monteith PET using local temperature and weather generator insolation and auxiliary variables for 20 Watershed versus Hamon PET in the Phase 5 CBM and Penman pan evaporation at first-order weather stations in early versions of the CBM). These differences may result in systematic differences in model parameters.

Three sites with known high quality flow gaging and water quality data were selected for both hydrology and water quality calibration (Table 5). The first of these (Raystown Branch Juniata River) was selected for initial calibration, with subsequent adjustments based on comparison to data at two stations on the mainstem Susquehanna.

Table 5. Calibration and validation locations in the Susquehanna River watershed

Station Name	USGS ID	Drainage Area (mi^2)	Hydrology Calibration	Water Quality Calibration
Raystown Branch Juniata River at Saxton, PA	01562000	756	X	X
Susquehanna River at Danville, PA	01540500	11,220	X	X
Susquehanna River at Marietta, PA	01576000	25,990	X	X

The model hydrology calibration period for Raystown Branch Juniata River was set to Water Years 1995-2005, while the mainstem stations use Water Years 1993-2003 to fall within the common period of record of the weather data. Calibration was done on the later data due to concerns that there have been significant changes in land use and agricultural management practices since the 1980s. Hydrologic validation was then performed on the 10 water years prior to the calibration period. The bulk of available water quality data are from the early 1990s. Therefore, water quality calibration used calendar year periods beginning in 1991, with earlier data reserved for validation.

HSPF Modeling

Initial hydrologic parameterization for the Susquehanna River calibration focus area came from the Chesapeake Bay Program's (CBP) model for the Susquehanna River watershed (CBM). The CBM has undergone a series of revisions over many years, with the most current version of the model being known as Phase 5 (USEPA 2010). The Phase 5 parameters were obtained from the CBP and reviewed. Through this process it was identified that the CBM set for Phase 5 was much more complex than that used for a typical HSPF model, with parameters and land use categories provided in a multi-file database, with values changing over the time span of the simulation. In the CBP Phase 5 model, HSPF input sequences are developed through an elaborate scripting scheme, with multiple HSPF input sequences developed for more than 20 land use categories (including various agricultural management practices) and multiple time spans to determine flows and loads on a unit area basis. These unit area flows and loads are then combined through scripts to create input for an in-stream simulation.

The complexity of the Phase 5 model far exceeded the constraints of this study, so rather than using the Phase 5 parameters, it was decided to parameterize Susquehanna River watershed model using the previous version of the CBM, Phase 4. The Phase 4 parameters are readily available, as they are incorporated into the BASINS companion program HSPFParm, and these parameters are available in a format directly akin to that needed by HSPF. The six pervious (forest, high till cropland, low till cropland, pasture, urban, and hay) and two impervious (animal/feedlot and urban) land use categories of the Phase 4 model are more analogous to the categories of the Susquehanna model for this study.

Even using the simpler Phase 4 model from the CBP, there was no one-to-one correlation between land use categories of the CBM and this study. The Phase 4 model of the Susquehanna River watershed consisted of 12 land segments in 4 UCI files, and these parameters needed to be applied to the 21 land uses in this project. Moreover, for this project the land use categories explicitly represented hydrologic soil groups, while the CBM parameters did not. A method was developed for creating the Susquehanna model parameters for this study from these Phase 4 parameters, where approximate average values were applied from the CBP Upper Susquehanna simulations for model section 020501, from the CBP Western Branch Susquehanna simulation for model section 020502, and from the Lower Susquehanna simulation for model section 020503. Since there was no explicit representation of hydrologic soil groups in the CBM, parameter values were assigned the same values across each of the Susquehanna model soil classifications. For example, the CBM forest parameters for the Lower Susquehanna were applied to the land use categories Forest_A through Forest_D in the model parameters for 020503.

The USGS gage on the Raystown Branch of the Juniata River at Saxton, PA (USGS 02050303) was used as the primary calibration location, while the gages on the Susquehanna River at Danville, PA (USGS 01540500), on the West Branch Susquehanna River at Lewisburg, PA (USGS 01553500), and on the Susquehanna River at Marietta, PA (USGS 01576000) were used as additional calibration checks. Calibrated parameters from the Raystown Branch gage were applied to the Lower Susquehanna portion of the study area (020503), while calibration adjustments for the Danville and Lewisburg gages were applied to the Upper and Western sections of the study area respectively (020501 and 020502). The Susquehanna River at Marietta, PA (USGS 01576000), the most downstream of the gages, was used to verify that the calibration parameters applied at the two upstream gages were applicable to the entire watershed.

Once the hydrology calibration was complete for the entire Susquehanna River watershed, the focus turned to sediment and water quality representation. Extracting parameters from the CBP Susquehanna model for sediment and water quality was even less straightforward than that for hydrology parameters, since the CBM used the more complicated NITR and PHOS modules of the HSPF pervious land simulation operations. Initial parameterization for sediment and water quality simulation was taken from the loadings used to set up the Willamette model in this 20 Watershed study, adjusted based on the parameters from the CBP Phase 4 model where available.

Changes Made to Base Data Provided

No changes were made to the meteorological, point source, or land use base data.

Assumptions

Reservoirs

While there are many dams in the study area, their influence was not explicitly included in the study. The largest of the reservoirs are on the Susquehanna River near the outlet of the study area, well below the USGS gage on the Susquehanna River at Marietta. This USGS gage on the Susquehanna River at Marietta was selected for use in calibration because it is the most downstream main stem gage that is still upstream of the influence of the major reservoirs. While one would assume the major main stem reservoirs influence the flow and water quality exiting the Susquehanna River at the outlet, for this model the impacts of these reservoirs are assumed to be implicitly represented through the tabular representation of reach hydrologic response (FTables).

The primary intention of the 20 Watershed simulations is to examine relative changes in response of large watersheds. Information is not available to specify future time series of operations or boundary conditions for these reservoirs. Therefore, representation of the reservoirs through the stage-discharge relationships expressed in the FTables provides the most useful basis for evaluating relative changes in response.

Withdrawals and Point Sources

A variety of water withdrawals occur in the Susquehanna, but these have a relatively small effect on the overall water balance. In addition, future changes in water withdrawals are not known. Therefore, withdrawals were not included in the 20 Watershed model application. In contrast to withdrawals, point sources must be included for model water quality calibration because they represent a significant fraction of nutrient loads in the system. Existing major point source flows and loads are represented in the model, but will be held at current levels for simulation of future conditions to better isolate the potential direct impacts of climate and land use change.

Snow Simulation

The Susquehanna HPSF model includes snow simulation using the degree-day method for snowmelt. The initial values extracted from the Chesapeake Bay Program Model are assumed to be appropriate and the initial parameterization was not adjusted.

Hydrology Calibration

As explained above, the starting parameters for the Susquehanna HSPF model came from a Chesapeake Bay Program model of the Susquehanna River watershed. Once the starting parameters were inserted into the model input files, average annual precipitation and potential evapotranspiration values were computed and compared to published values. Through this process it was determined the input potential evapotranspiration time series should be reduced by multipliers, since the computation of these time series produced more PET on an average annual basis than the published values indicate. The multipliers used for PET were 0.75 for the Lower Susquehanna and Western Branch, and 0.8 for the Upper Susquehanna. Calibration adjustments focused on the following parameters:

- BASETP (ET by riparian vegetation): The model was significantly oversimulating the 50 percent low flows at the primary calibration location. Slightly increasing the BASETP value provided some ET by riparian vegetation and thus improved the simulation of low flows.

- DEEPFR (fraction of groundwater inflow which will enter deep groundwater): Adding a modest amount of DEEPFR above the primary calibration location improved the overall water balance and improved the simulation of low flows.
- INFILT (index to mean soil infiltration rate): In the upper portions of the study area the peak flows were simulating too low, while the low flows were simulating too high. Decreasing INFILT for the upper portions of the watershed shifted flows to a faster response, increasing the peaks and reducing the low flows.
- AGWRC (Groundwater recession rate): Adjusted slightly in order to replicate groundwater recession in the observed data.

Initial calibration was performed at the USGS gage on the Raystown Branch of the Juniata River at Saxton, PA (USGS 02050303), and is summarized in Figures 6 through 12 and Tables 6 and 7. The model fit is of high quality overall, but simulates low on the lowest 10 percent of flows. This could be due to something not accounted for in the model, such as reservoir operations or other discharges. Given that these low flows are not critical to the purposes of this study, the issue is being noted as an area with potential further refinement. None of the metrics fall beyond the range of those set for the 20 Watershed study. The model calibration period was set to the 10 water years from 10/01/1995 to 09/30/2005.

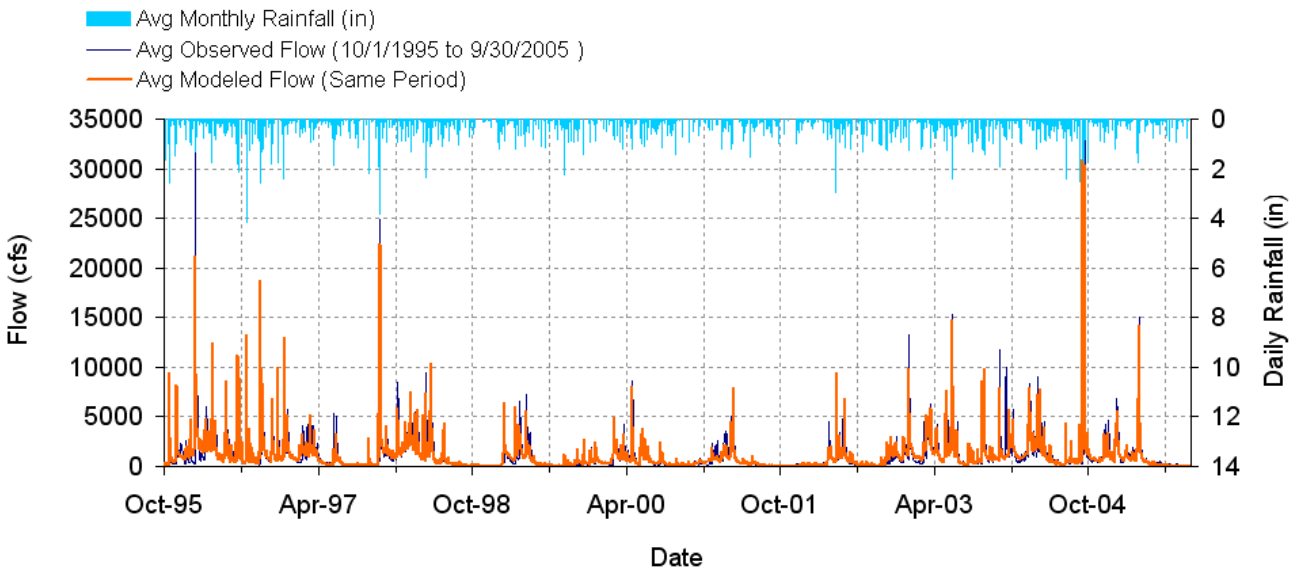

Figure 6. Mean daily flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

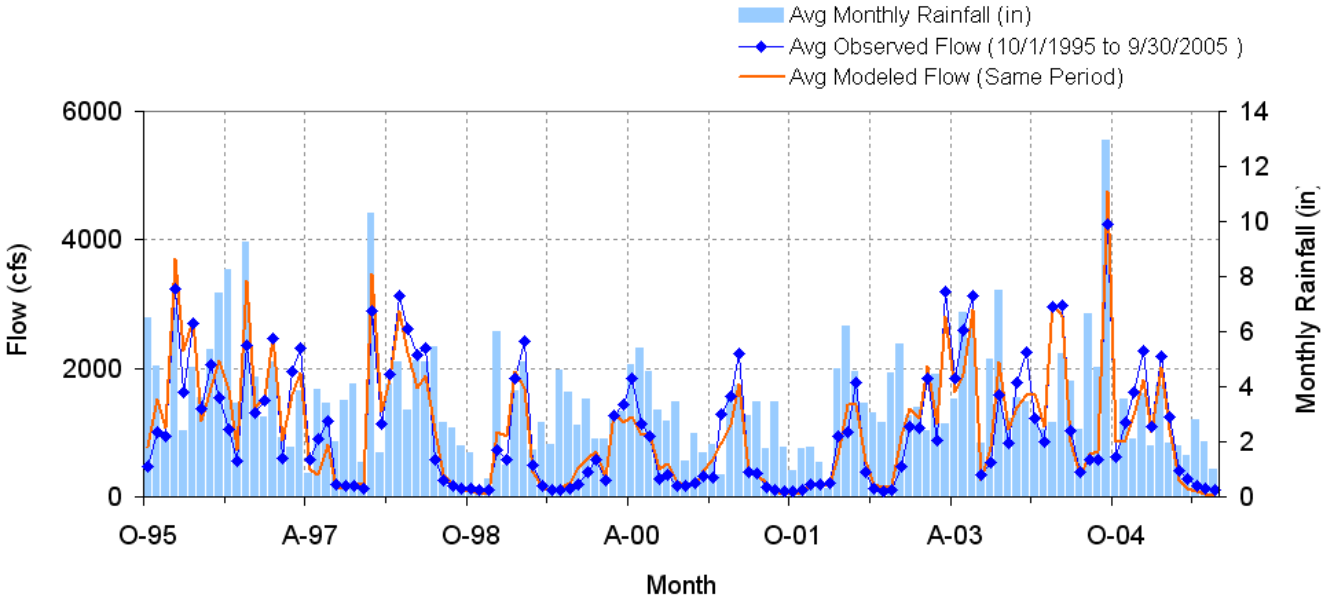

Figure 7. Mean monthly flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

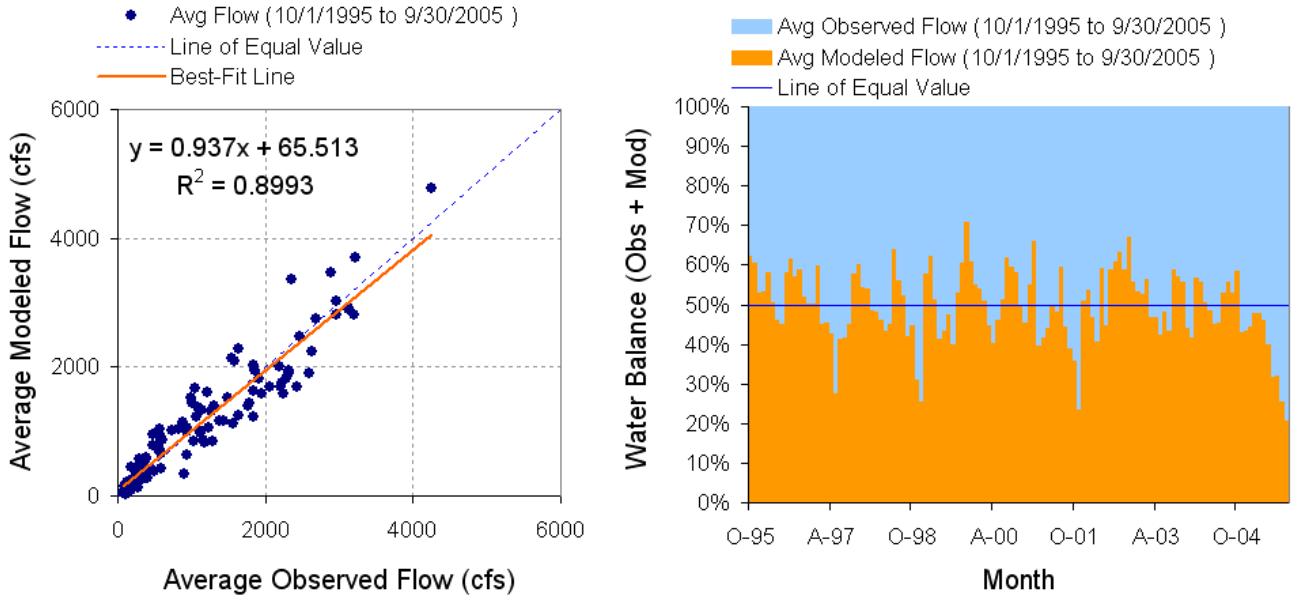

Figure 8. Monthly flow regression and temporal variation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

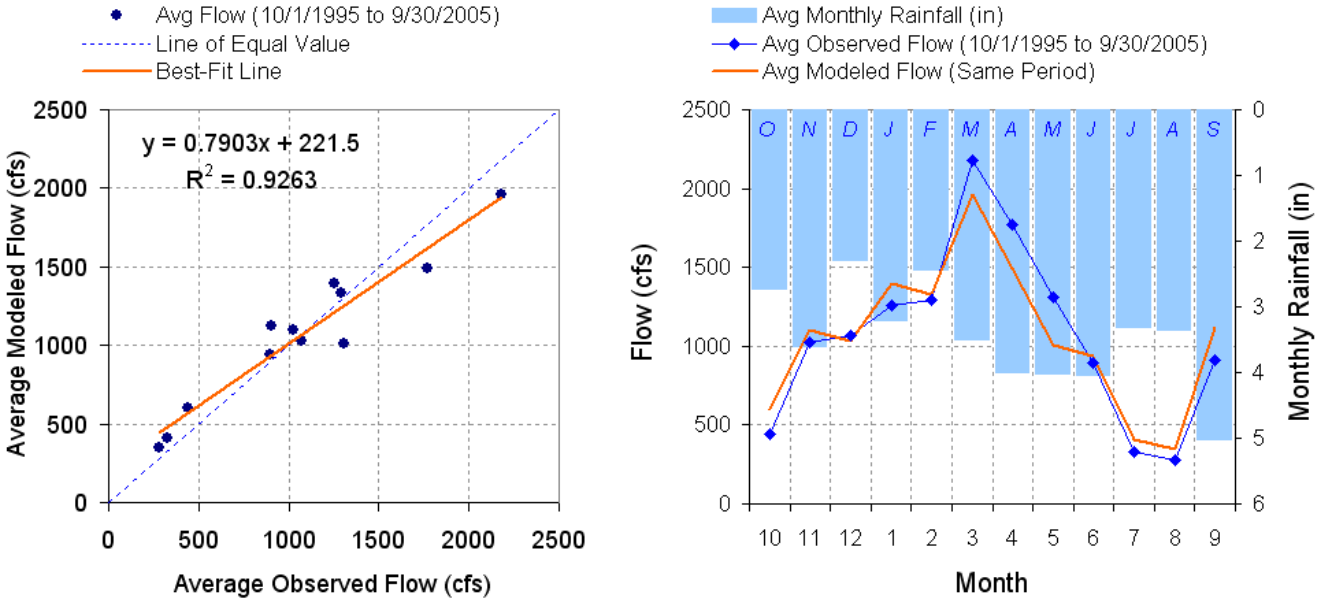

Figure 9. Seasonal regression and temporal aggregate at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

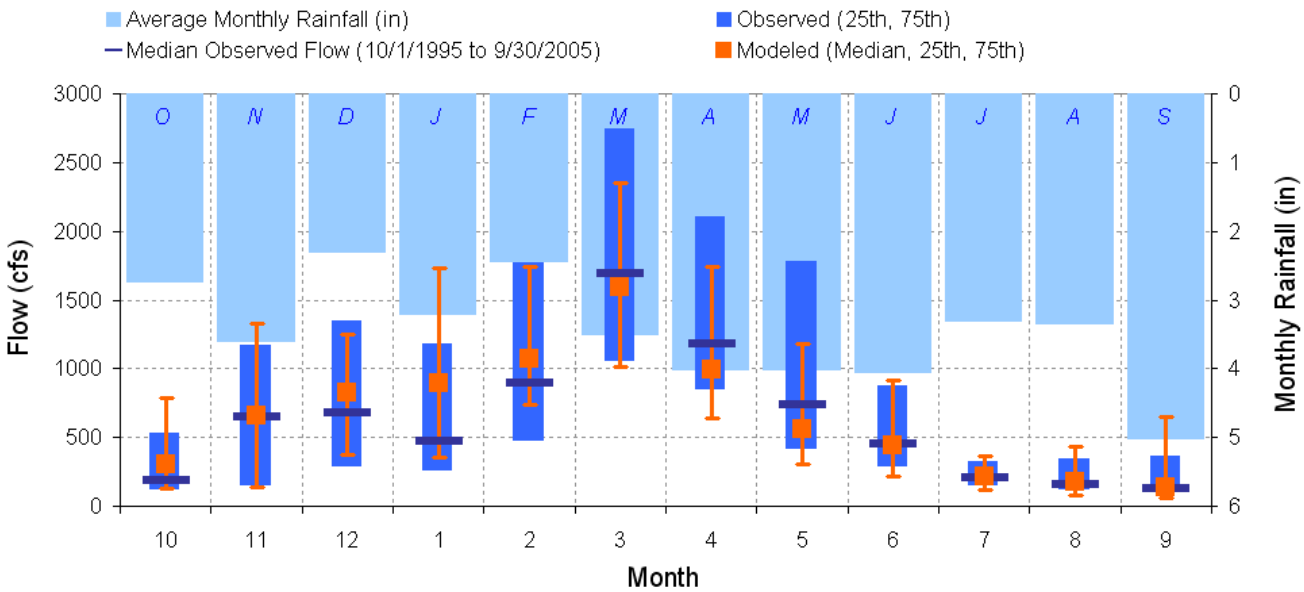

Figure 10. Seasonal medians and ranges at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

Table 6. Seasonal summary at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	438.69	187.00	119.00	530.75	599.79	301.11	128.74	788.27
Nov	1024.44	647.50	149.75	1170.00	1101.45	658.92	138.80	1324.27
Dec	1071.22	682.00	280.75	1350.00	1029.71	830.45	374.78	1250.32
Jan	1255.25	475.00	260.00	1180.00	1394.02	892.68	351.51	1730.37
Feb	1290.35	900.00	470.00	1775.00	1330.42	1074.05	739.83	1743.98
Mar	2177.77	1690.00	1052.50	2742.50	1963.58	1594.05	1008.22	2348.98
Apr	1771.52	1180.00	843.75	2102.50	1490.45	989.11	640.38	1736.15
May	1310.00	739.50	414.00	1777.50	1010.40	563.51	303.89	1180.35
Jun	895.83	448.00	287.50	879.00	939.20	441.19	220.33	910.95
Jul	326.40	207.00	146.00	324.00	407.92	216.08	114.91	368.66
Aug	278.62	157.50	115.25	339.75	345.53	174.23	74.24	430.05
Sep	907.63	124.50	104.00	360.25	1120.57	133.58	62.75	649.56

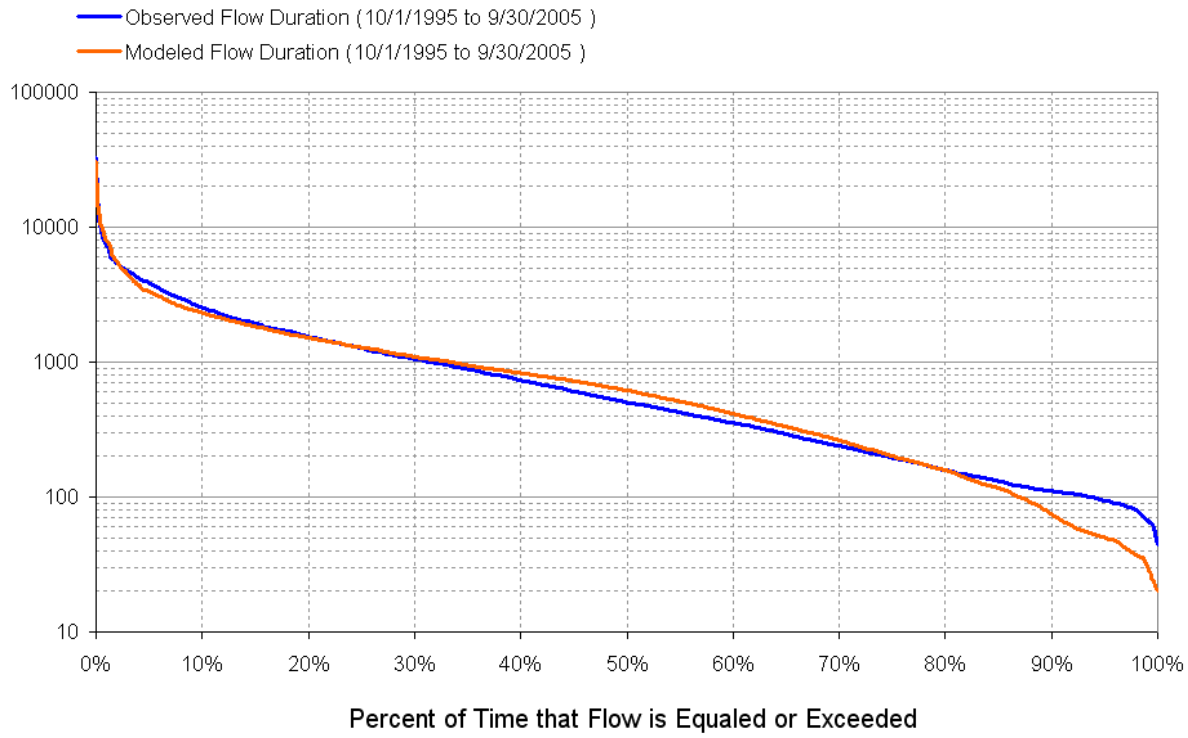

Figure 11. Flow exceedence at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

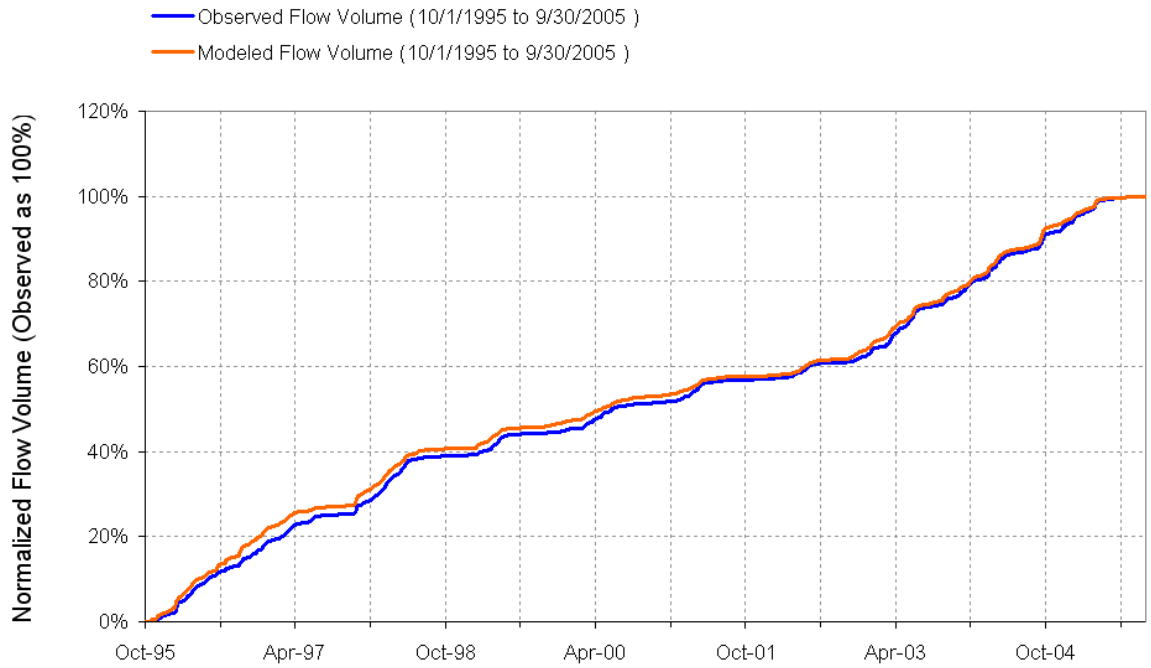

Figure 12. Flow accumulation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

Table 7. Summary statistics at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 01562000 Raystown Branch Juniata River at Saxton, PA Hydrologic Unit Code: 2050303 Latitude: 40.21591249 Longitude: -78.2652901 Drainage Area (sq-mi): 756	
Total Simulated In-stream Flow:	**19.01**	Total Observed In-stream Flow:	**19.04**
Total of simulated highest 10% flows:	**8.15**	Total of Observed highest 10% flows:	**8.48**
Total of Simulated lowest 50% flows:	**2.19**	Total of Observed Lowest 50% flows:	**2.05**
Simulated Summer Flow Volume (months 7-9):	**2.80**	Observed Summer Flow Volume (7-9):	**2.26**
Simulated Fall Flow Volume (months 10-12):	**4.11**	Observed Fall Flow Volume (10-12):	**3.81**
Simulated Winter Flow Volume (months 1-3):	**6.97**	Observed Winter Flow Volume (1-3):	**7.03**
Simulated Spring Flow Volume (months 4-6):	**5.13**	Observed Spring Flow Volume (4-6):	**5.93**
Total Simulated Storm Volume:	**7.78**	Total Observed Storm Volume:	**7.83**
Simulated Summer Storm Volume (7-9):	**1.62**	Observed Summer Storm Volume (7-9):	**1.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-0.16	10	
Error in 50% lowest flows:	6.72	10	
Error in 10% highest flows:	-3.92	15	
Seasonal volume error - Summer:	23.90	30	
Seasonal volume error - Fall:	7.76	30	
Seasonal volume error - Winter:	-0.84	30	
Seasonal volume error - Spring:	-13.61	30	
Error in storm volumes:	-0.63	20	
Error in summer storm volumes:	39.10	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.698	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.552		
Monthly NSE	0.898		

Hydrology Validation

Validation for the Susquehanna River calibration focus was performed at the same gage (USGS 01562000 Raystown Branch Juniata River at Saxton, PA) but for the water years 10/01/1985 to 09/30/1995. Results are presented in Figures 13 through 19 and Tables 8 and 9. Similar to the calibration years, the validation years' model fit is of high quality, although the validation simulates the summer storm volumes somewhat high while undersimulating the overall storm volume. This may in part reflect differences in land use and management practices relative to the 200 NLCD. The remaining metrics fall within the acceptable range set for the 20 Watershed study.

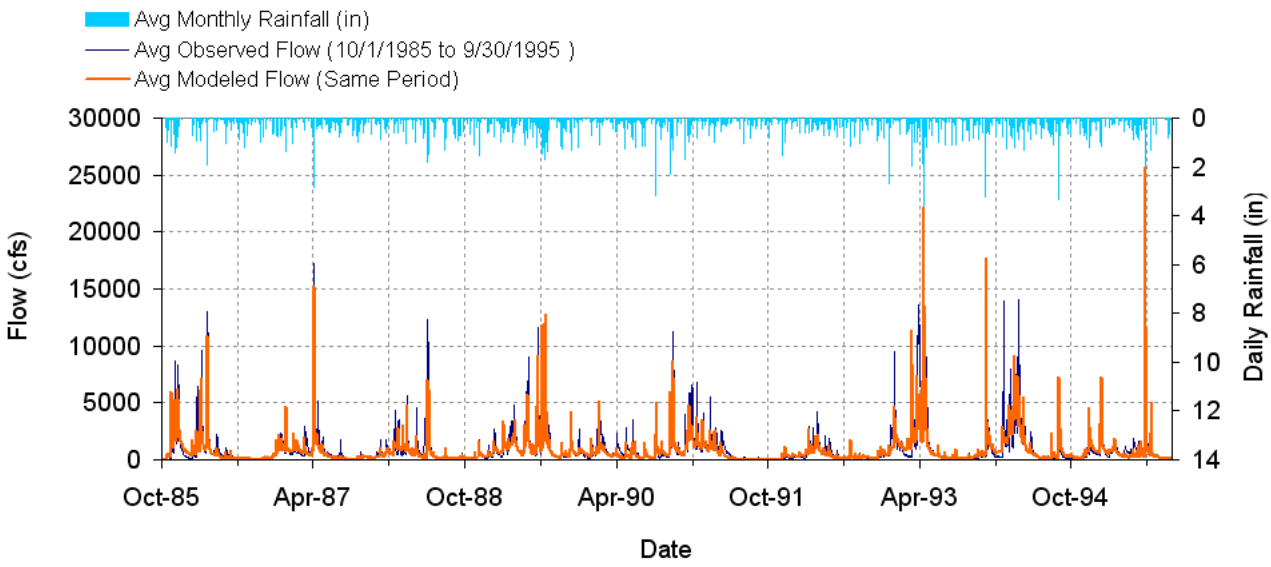

Figure 13. Mean daily flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

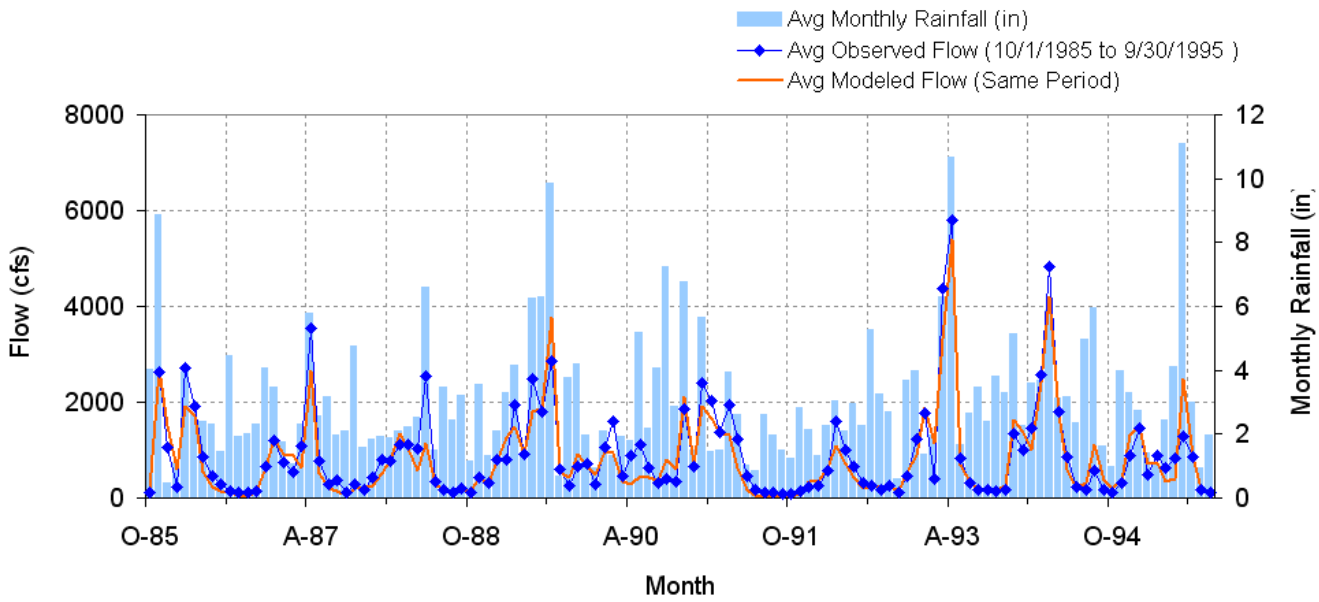

Figure 14. Mean monthly flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

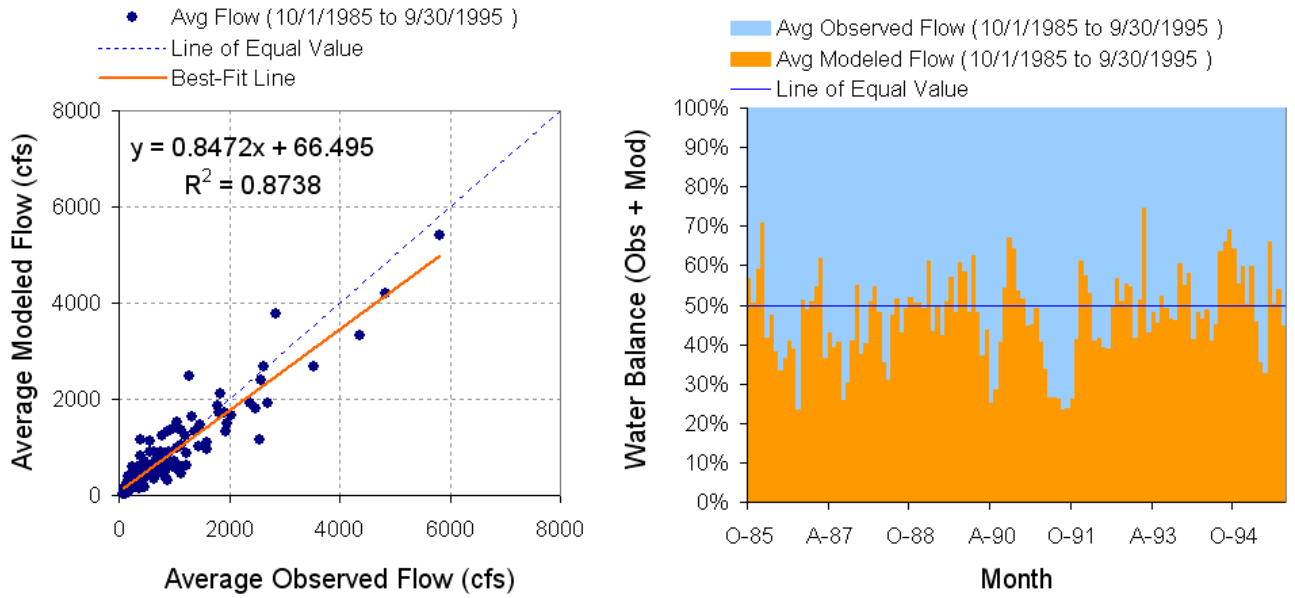

Figure 15. Monthly flow regression and temporal variation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

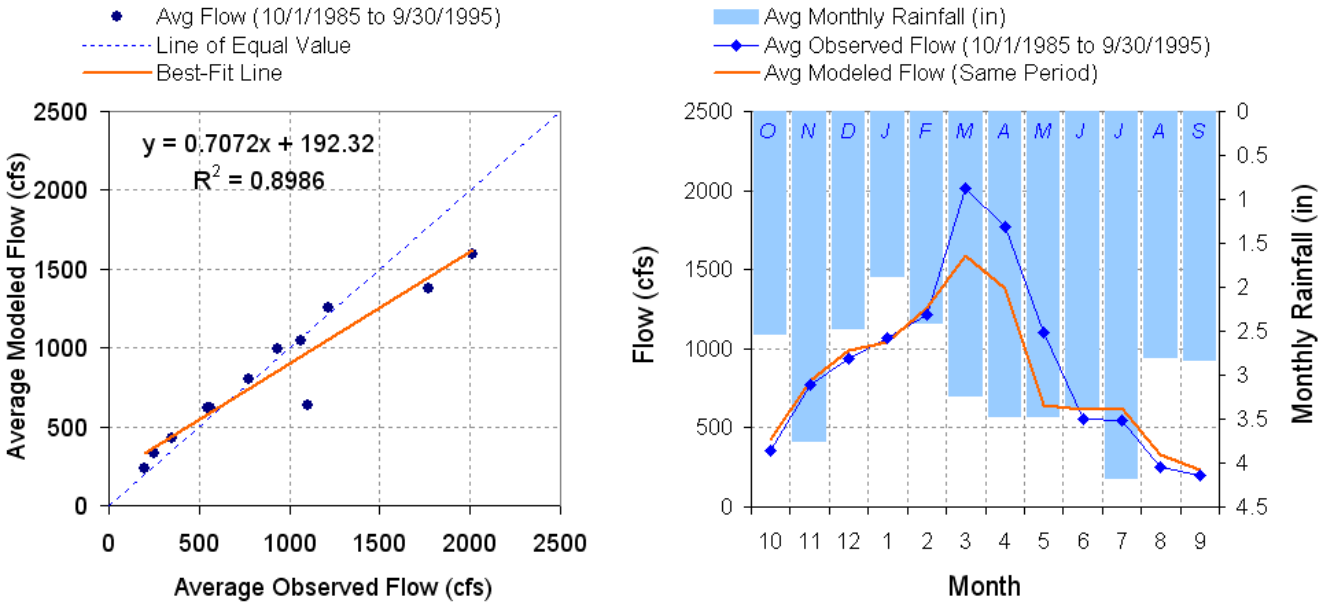

Figure 16. Seasonal regression and temporal aggregate at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

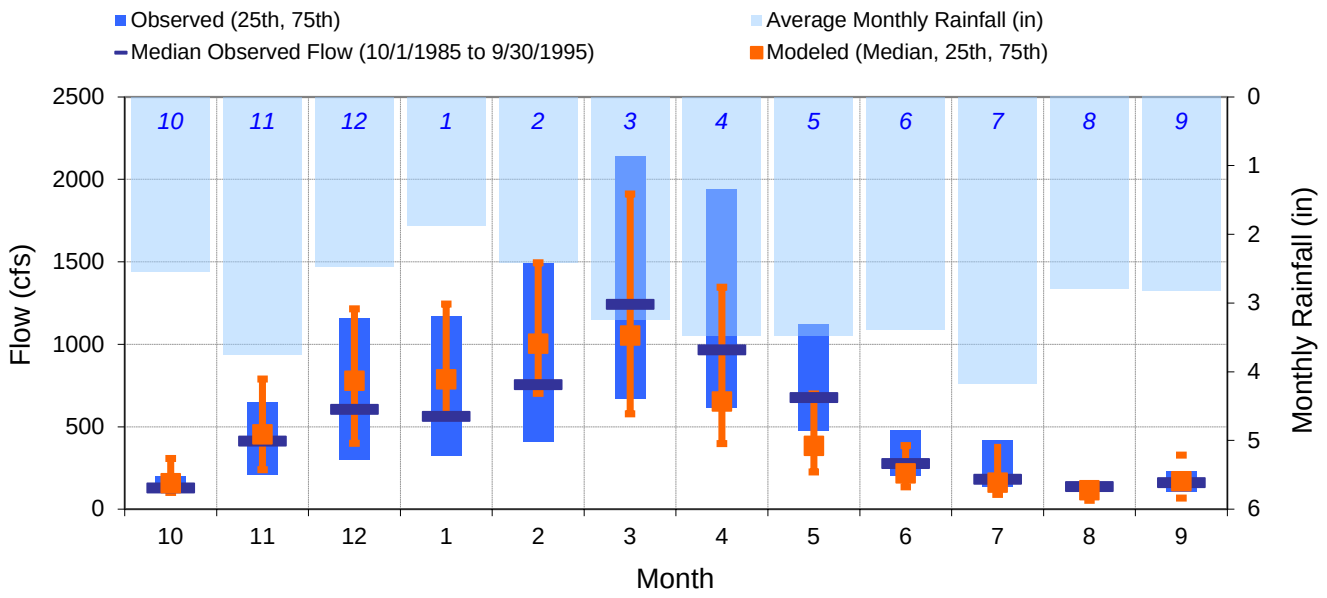

Figure 17. Seasonal medians and ranges at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

Table 8. Seasonal summary at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	351.63	128.00	104.00	200.00	429.02	157.78	101.27	307.10
Nov	771.90	411.00	211.75	649.00	798.12	454.17	239.35	790.07
Dec	936.58	603.50	302.50	1157.50	993.77	779.69	399.19	1215.70
Jan	1063.43	562.00	322.50	1167.50	1044.74	787.94	549.18	1243.93
Feb	1214.57	754.00	410.00	1495.00	1256.37	1003.08	702.93	1494.87
Mar	2016.51	1240.00	670.75	2140.00	1591.71	1053.09	578.34	1910.94
Apr	1772.93	965.00	613.50	1935.00	1379.12	653.23	398.61	1345.43
May	1102.77	676.00	479.25	1122.50	638.99	384.81	225.71	698.65
Jun	559.15	275.50	201.00	479.50	619.87	217.91	135.17	385.61
Jul	545.15	180.00	138.00	418.00	621.12	160.93	89.83	396.62
Aug	252.88	136.00	108.00	216.75	328.81	115.81	54.58	259.23
Sep	195.59	160.00	107.75	233.50	231.64	169.21	67.62	328.28

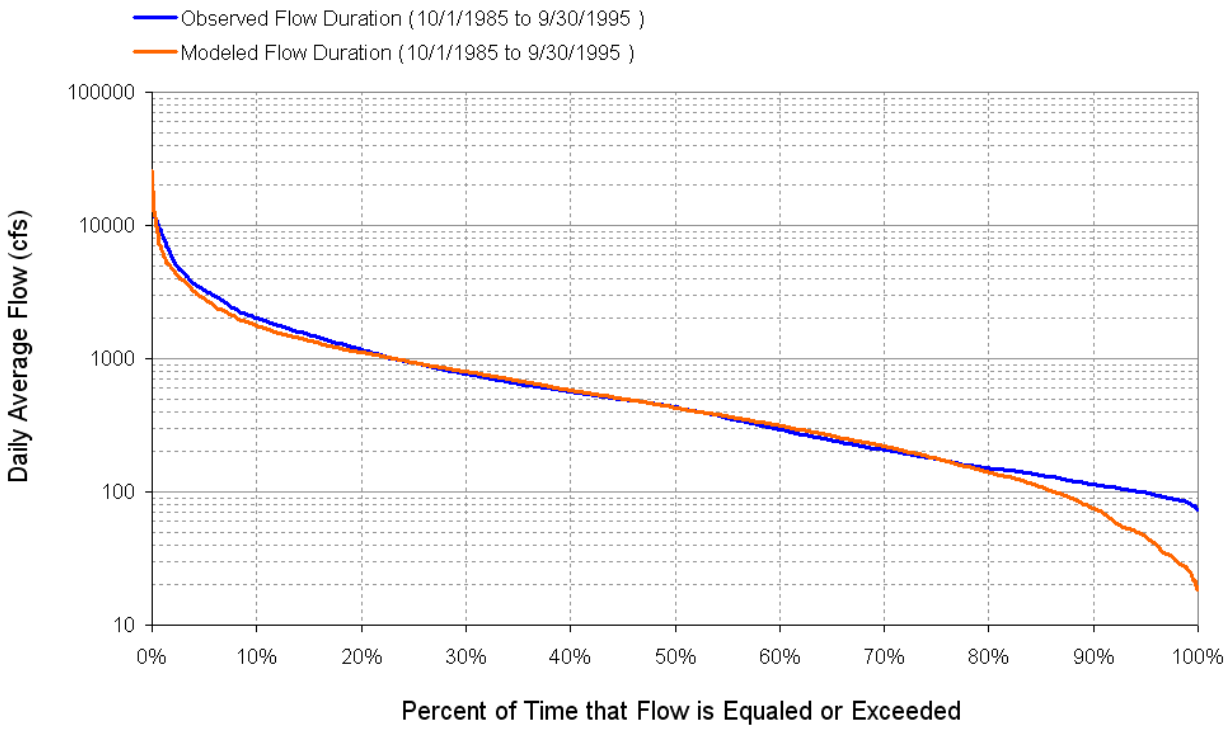

Figure 18. Flow exceedence at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

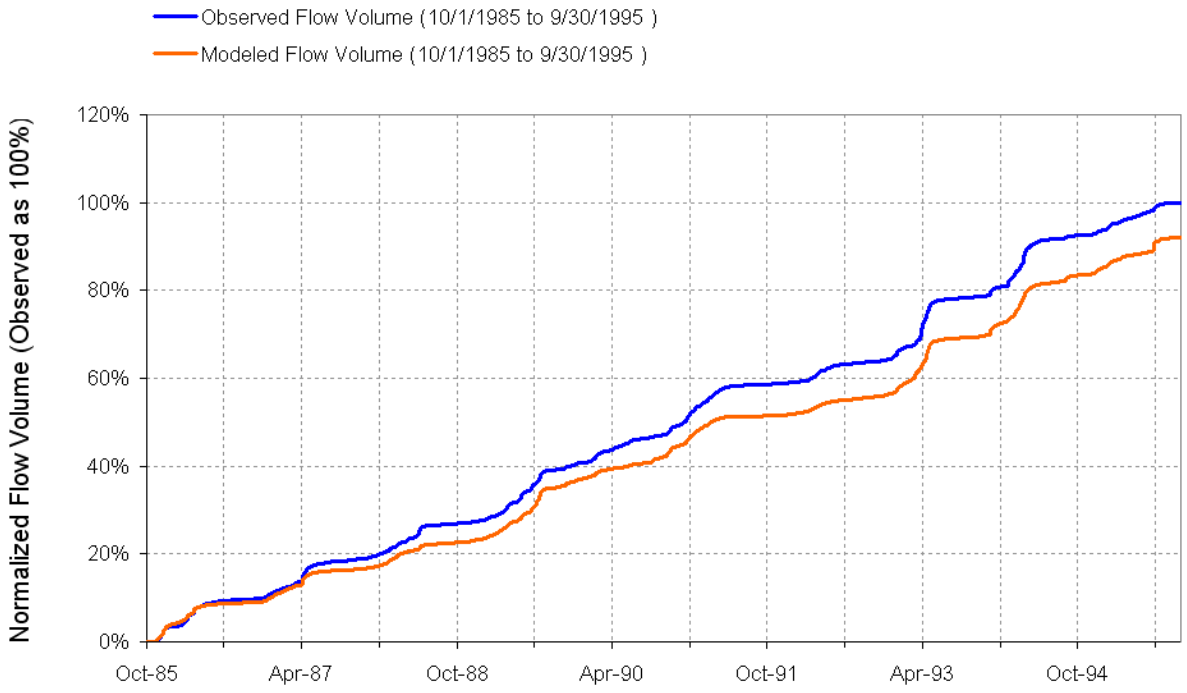

Figure 19. Flow accumulation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

Table 9. Summary statistics at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101 10-Year Analysis Period: 10/1/1985 - 9/30/1995 Flow volumes are (inches/year) for upstream drainage area		USGS 01562000 Raystown Branch Juniata River at Saxton, PA Hydrologic Unit Code: 2050303 Latitude: 40.21591249 Longitude: -78.2652901 Drainage Area (sq-mi): 756	
Total Simulated In-stream Flow:	**14.83**	Total Observed In-stream Flow:	**16.12**
Total of simulated highest 10% flows:	**6.77**	Total of Observed highest 10% flows:	**7.77**
Total of Simulated lowest 50% flows:	**1.74**	Total of Observed Lowest 50% flows:	**1.82**
Simulated Summer Flow Volume (months 7-9):	**1.79**	Observed Summer Flow Volume (7-9):	**1.51**
Simulated Fall Flow Volume (months 10-12):	**3.35**	Observed Fall Flow Volume (10-12):	**3.10**
Simulated Winter Flow Volume (months 1-3):	**5.76**	Observed Winter Flow Volume (1-3):	**6.38**
Simulated Spring Flow Volume (months 4-6):	**3.93**	Observed Spring Flow Volume (4-6):	**5.12**
Total Simulated Storm Volume:	**5.52**	Total Observed Storm Volume:	**6.49**
Simulated Summer Storm Volume (7-9):	**0.85**	Observed Summer Storm Volume (7-9):	**0.54**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-8.00	10	
Error in 50% lowest flows:	-4.61	10	
Error in 10% highest flows:	-12.82	15	
Seasonal volume error - Summer:	18.92	30	
Seasonal volume error - Fall:	7.86	30	
Seasonal volume error - Winter:	-9.69	30	
Seasonal volume error - Spring:	-23.40	30	
Error in storm volumes:	-14.91	20	
Error in summer storm volumes:	**56.16**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.553	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.512		
Monthly NSE	0.868		

Hydrology Results for Larger Watershed

Since the calibration location above represents only a small portion of the drainage area for this project, results near the outlet of the entire watershed were examined at the Susquehanna River at Marietta, PA USGS gage (01576000). The results at this gage look fairly good as well. The simulated output is just a little high on the low flows and a little high on the summer volumes. A few of the metrics were exceeded, but most of the metrics fall within the acceptable range set for the 20 Watershed study including a daily Nash-Sutcliffe of 0.77 at the Marietta gage. The calibration results at the Susquehanna River at Marietta, PA USGS gage (01576000) are presented in Figures 20 through 26 and Tables 10 and 11. The calibration and validation statistical measurements at all USGS gages used in the Susquehanna River watershed for the 20 Watershed project are shown in Tables 12 and 13, respectively.

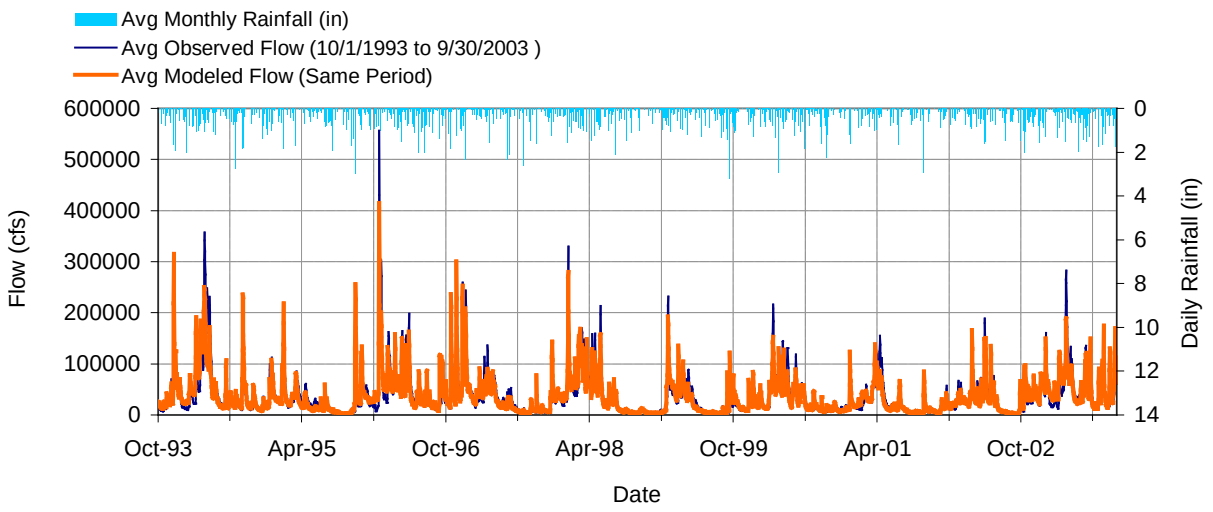

Figure 20. Mean daily flow at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

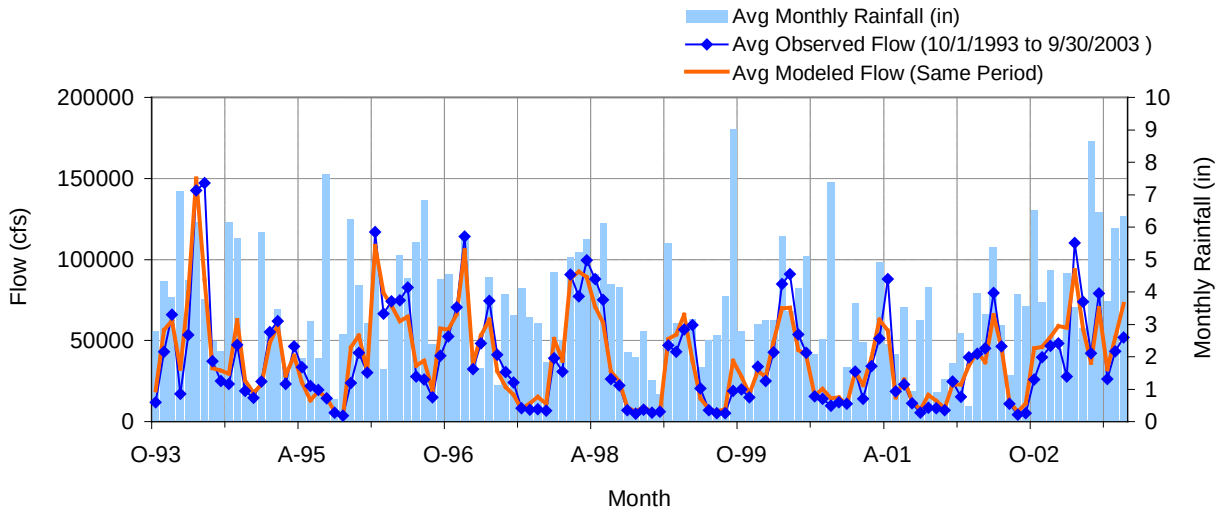

Figure 21. Mean monthly flow at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

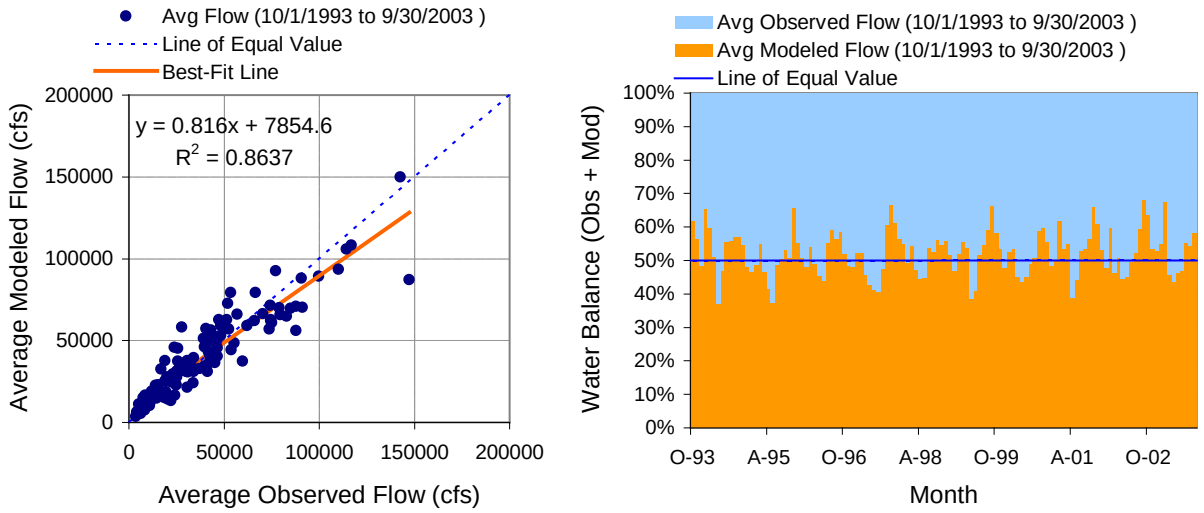

Figure 22. Monthly flow regression and temporal variation at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

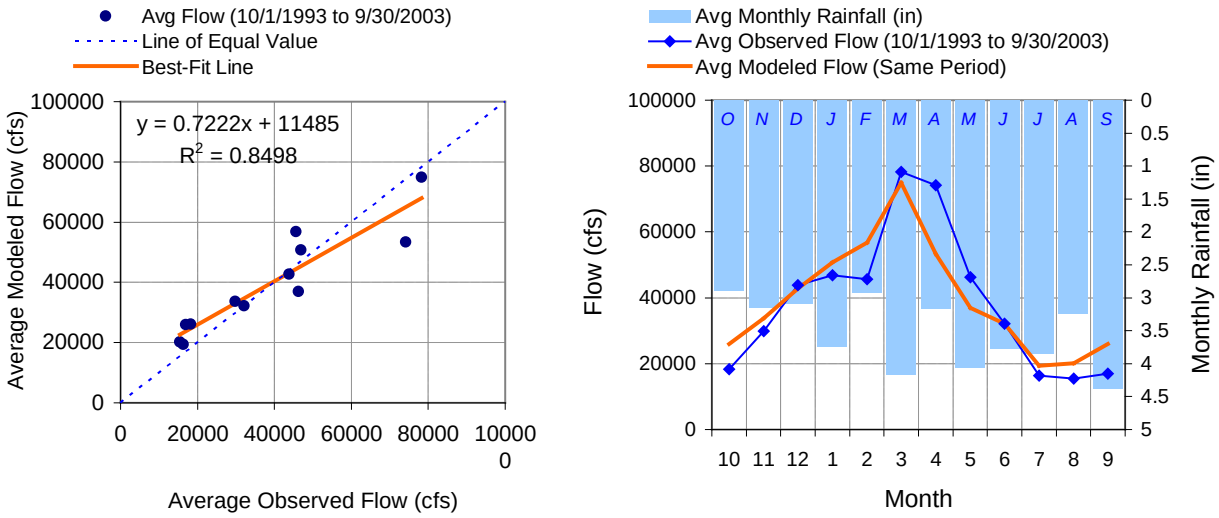

Figure 23. Seasonal regression and temporal aggregate at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

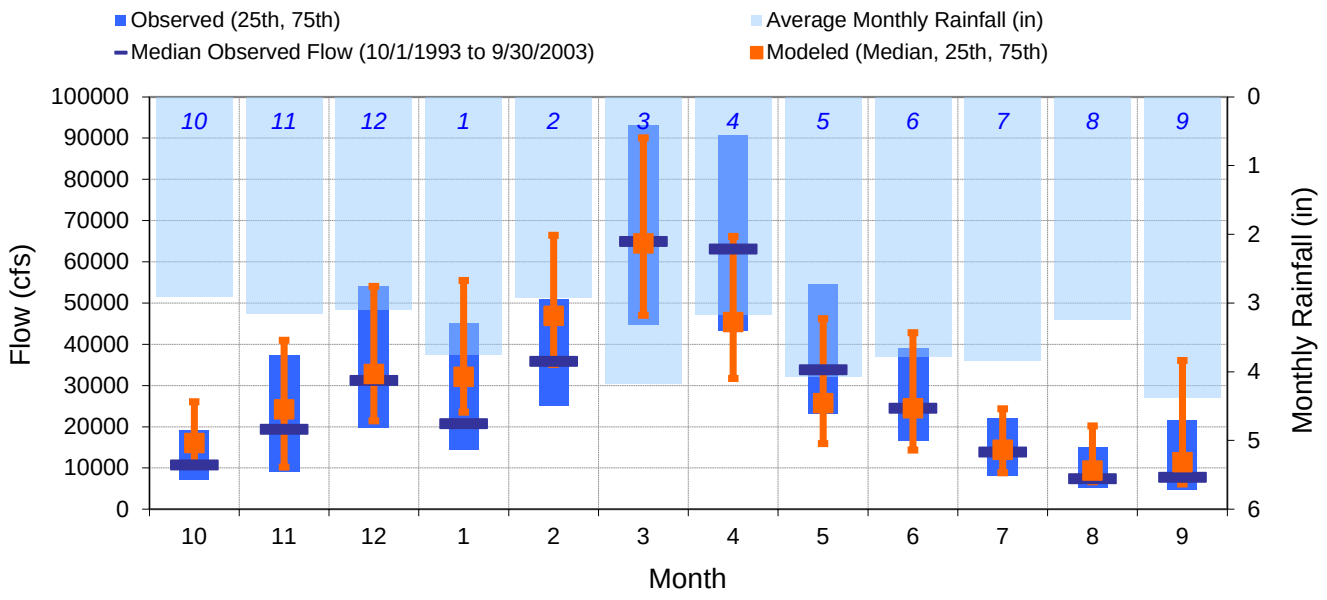

Figure 24. Seasonal medians and ranges at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

Table 10. Seasonal summary at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	18258.39	10650.00	7305.00	19225.00	26039.03	16034.54	11020.63	26062.98
Nov	29811.13	19300.00	9002.50	37325.00	33731.91	24238.21	10179.07	40953.88
Dec	43879.65	31150.00	19700.00	54050.00	42761.05	32769.07	21414.73	54042.56
Jan	46873.61	20700.00	14425.00	45175.00	50733.93	32088.13	23521.55	55480.61
Feb	45647.16	35800.00	25050.00	50975.00	56828.16	46881.28	35098.74	66429.31
Mar	78282.90	64900.00	44725.00	93150.00	74939.27	64475.93	47051.59	90047.35
Apr	74228.00	63000.00	43400.00	90750.00	53288.33	45390.82	31740.68	66146.48
May	46236.13	33750.00	23100.00	54575.00	36901.17	25714.54	15935.99	46244.86
Jun	32080.10	24450.00	16575.00	38925.00	32128.54	24520.57	14349.20	42832.37
Jul	16327.52	13800.00	8122.50	22075.00	19391.00	14448.96	8844.17	24338.26
Aug	15446.55	7330.00	5292.50	15175.00	20184.23	9362.29	6647.42	20176.83
Sep	16977.37	7645.00	4757.50	21650.00	26001.69	11403.96	6133.33	36050.57

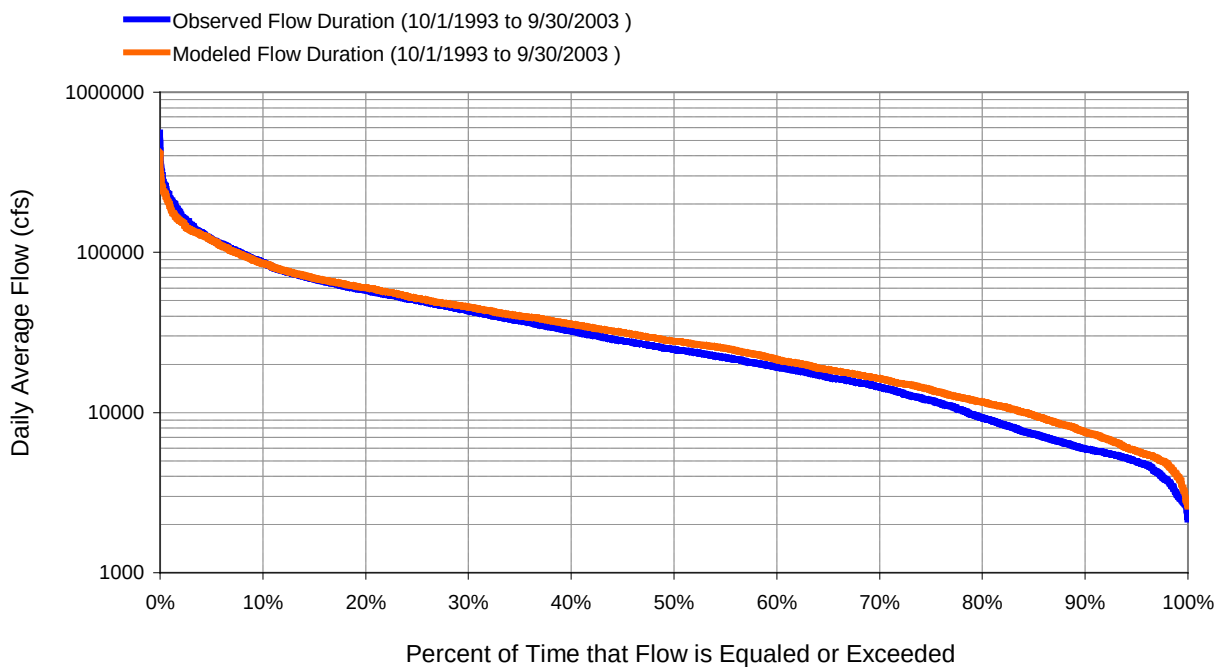

Figure 25. Flow exceedence at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

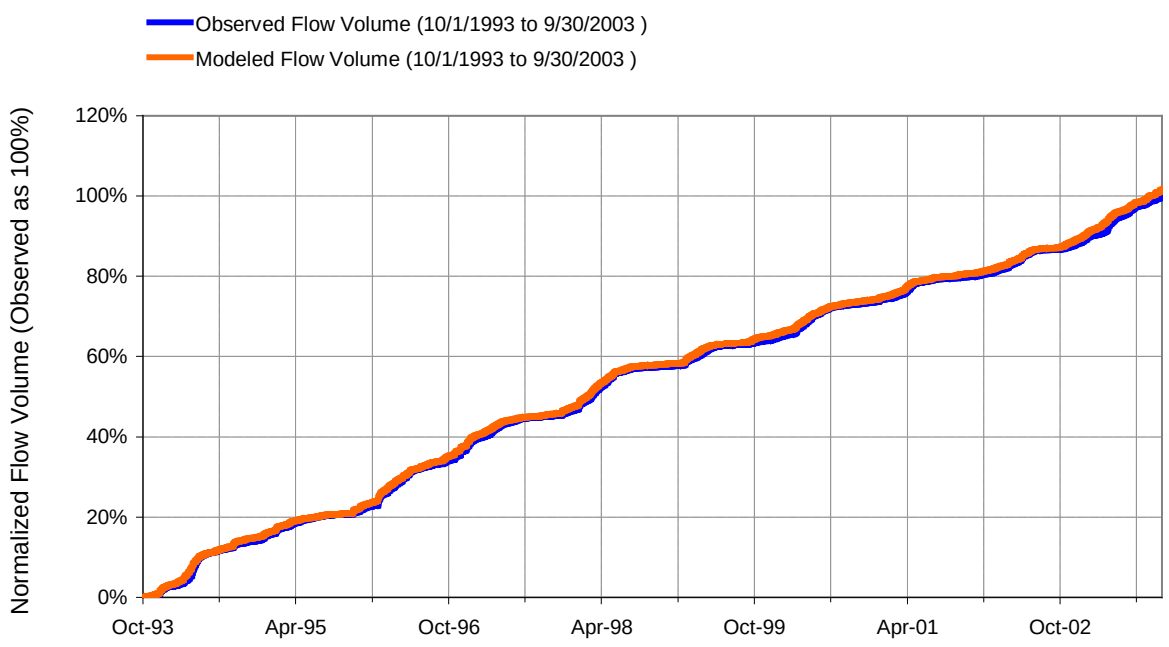

Figure 26. Flow accumulation at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF).

Table 11. Summary statistics at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101		USGS 01576000 Susquehanna River at Marietta, PA	
10-Year Analysis Period: 10/1/1993 - 9/30/2003 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 2050306 Latitude: 40.0545413 Longitude: -76.5307992 Drainage Area (sq-mi): 25990	
Total Simulated In-stream Flow:	**20.55**	Total Observed In-stream Flow:	**20.19**
Total of simulated highest 10% flows:	**6.79**	Total of Observed highest 10% flows:	**7.31**
Total of Simulated lowest 50% flows:	**3.76**	Total of Observed Lowest 50% flows:	**3.27**
Simulated Summer Flow Volume (months 7-9):	**2.87**	Observed Summer Flow Volume (7-9):	**2.14**
Simulated Fall Flow Volume (months 10-12):	**4.50**	Observed Fall Flow Volume (10-12):	**4.04**
Simulated Winter Flow Volume (months 1-3):	**7.87**	Observed Winter Flow Volume (1-3):	**7.39**
Simulated Spring Flow Volume (months 4-6):	**5.30**	Observed Spring Flow Volume (4-6):	**6.62**
Total Simulated Storm Volume:	**7.51**	Total Observed Storm Volume:	**7.32**
Simulated Summer Storm Volume (7-9):	**1.19**	Observed Summer Storm Volume (7-9):	**0.76**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	1.79	10	
Error in 50% lowest flows:	**14.99**	**10**	
Error in 10% highest flows:	-7.21	15	
Seasonal volume error - Summer:	**34.30**	**30**	
Seasonal volume error - Fall:	11.49	30	
Seasonal volume error - Winter:	6.41	30	
Seasonal volume error - Spring:	-19.82	30	
Error in storm volumes:	2.72	20	
Error in summer storm volumes:	**56.64**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.771	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.582	as E or E' approaches 1.0	
Monthly NSE	0.861		

Table 12. Summary statistics (percent error) for all stations – calibration period (HSPF)

Station	01562000 Raystown Branch Juniata River at Saxton, PA (1995-2005)	01540500 Susquehanna River at Danville, PA (1993-2003)	01576000 Susquehanna River at Marietta, PA (1993-2003)
Error in total volume:	-0.16	6.67	1.79
Error in 50% lowest flows:	6.72	25.34	14.99
Error in 10% highest flows:	-3.92	-4.71	-7.21
Seasonal volume error - Summer:	23.9	45.64	34.30
Seasonal volume error - Fall:	7.76	14.79	11.49
Seasonal volume error - Winter:	-0.84	13.54	6.41
Seasonal volume error - Spring:	-13.61	-15.66	-19.82
Error in storm volumes:	-0.63	7.37	2.72
Error in summer storm volumes:	39.10	75.91	56.64
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.698	0.786	0.771
Monthly Nash-Sutcliffe Coefficient of Efficiency, E	0.898	0.837	0.861

Table 13. Summary statistics (percent error) for all stations – validation period (HSPF)

Station	01562000 Raystown Branch Juniata River at Saxton, PA (1985-1995)	01540500 Susquehanna River at Danville, PA (1983-1993)	01576000 Susquehanna River at Marietta, PA (1983-1993)
Error in total volume:	-8.00	2.12	-1.64
Error in 50% lowest flows:	-4.61	30.70	18.99
Error in 10% highest flows:	-12.82	-13.14	-13.32
Seasonal volume error - Summer:	18.92	54.06	35.02
Seasonal volume error - Fall:	7.86	13.13	15.62
Seasonal volume error - Winter:	-9.69	8.76	2.93
Seasonal volume error - Spring:	-23.40	-23.37	-27.27
Error in storm volumes:	-14.91	0.31	-1.26
Error in summer storm volumes:	56.16	85.91	64.86
Nash-Sutcliffe Coefficient of Efficiency, E:	0.553	0.714	0.665
Baseline adjusted coefficient (Garrick), E':	0.868	0.782	0.777

Water Quality Calibration and Validation

The 20 Watershed models are designed to provide water quality simulation for total suspended solids (TSS), total nitrogen, and total phosphorus. TSS is simulated with the standard HSPF approach (USEPA 2006). 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.

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. 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. 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 TSS and total 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, TSS and total 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).

Similar to hydrology, initial calibration of water quality was done on the Raystown Branch Juniata River at Saxton, PA, comparing model results to data from USGS 01562000. The calibration used the time period 1991-2000 and 1990 was used for validation.

Results of the TSS calibration are generally acceptable. Visually, the model is roughly simulating the trends contained in the observed data. 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. Figure 27 presents the monthly load of TSS. Load-flow power plots were compared for individual days (Figures 28 and 29). This confirms that the relationship between flow and load is consistent across the entire range of observed flows, for both the calibration and validation periods. Tables 14 and 15 provide model statistics and relative errors for the TSS calibration and validation periods.

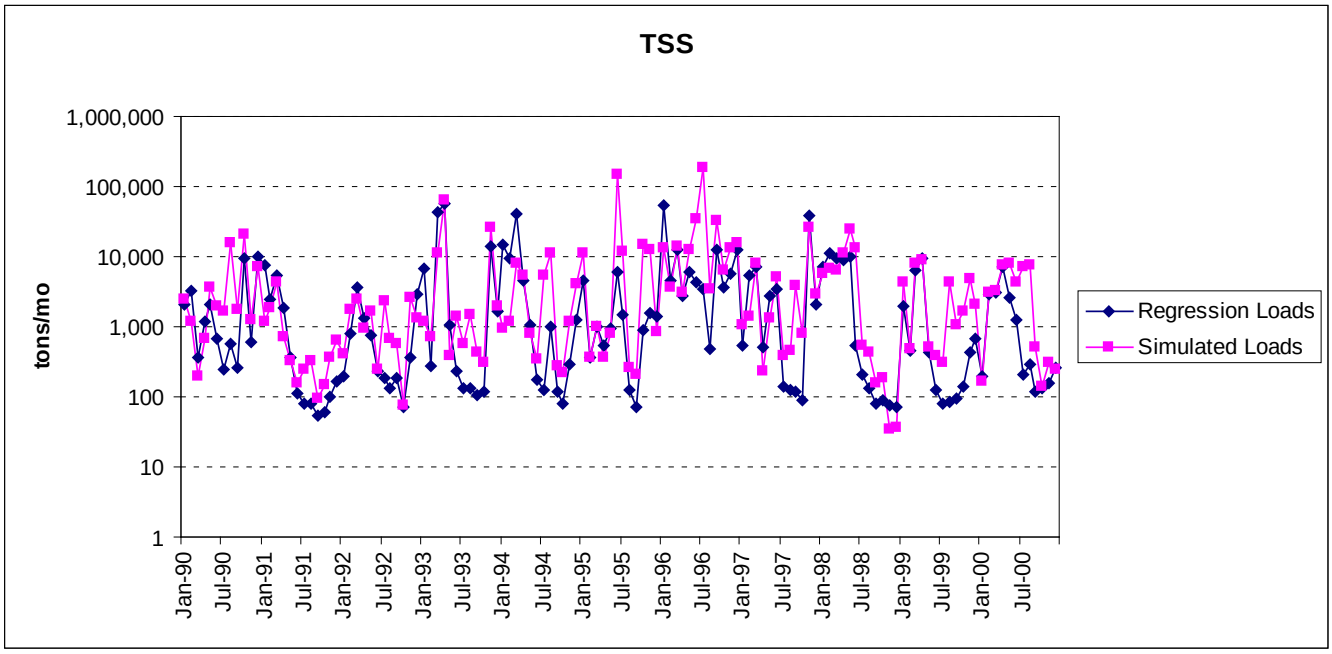

Figure 27. Fit for monthly load of TSS at Raystown Branch Juniata River at Saxton, PA (HSPF).

Table 14. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	-78.2%	-89.7%
Relative Average Absolute Error	146%	124%
Relative Median Absolute Error	20.3%	58.3%

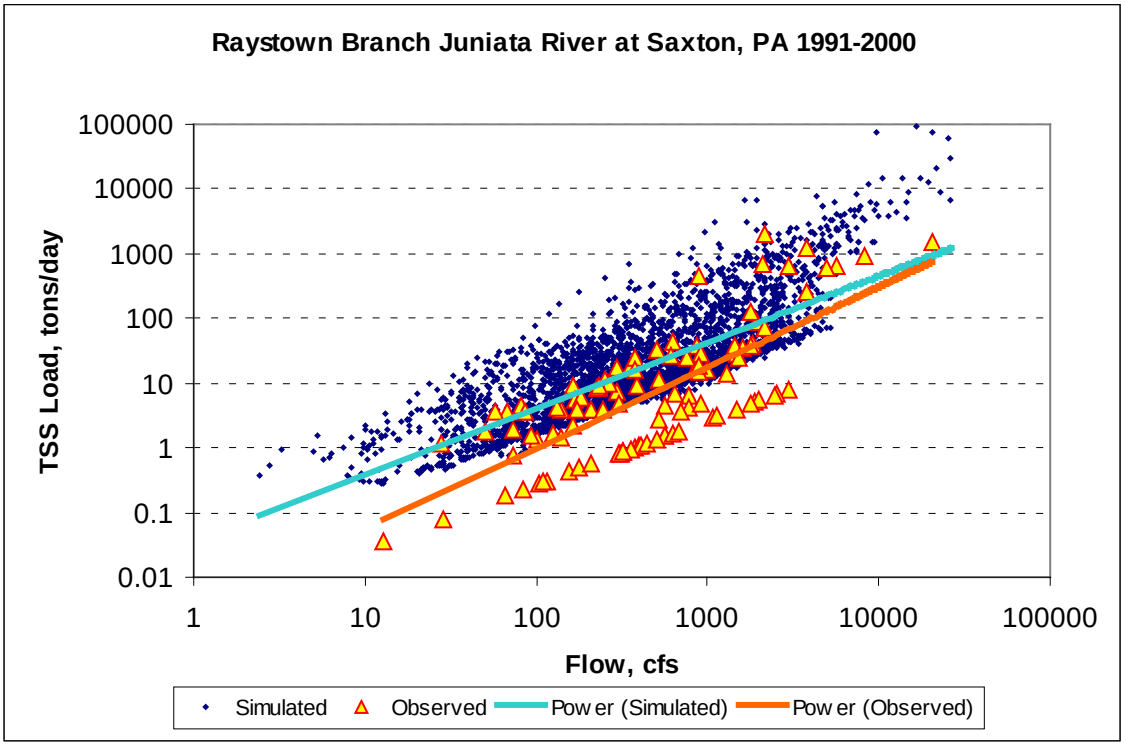

Figure 28. Power plot for observed and simulated TSS at Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

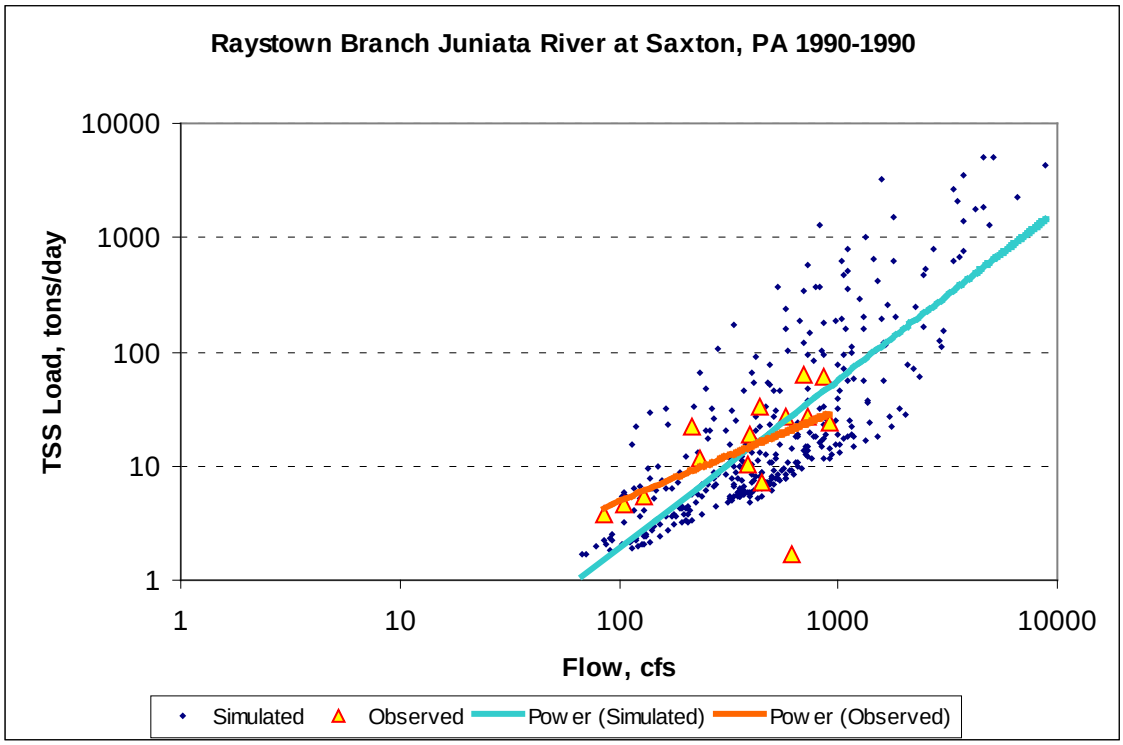

Figure 29. Power plot for observed and simulated TSS at Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

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.

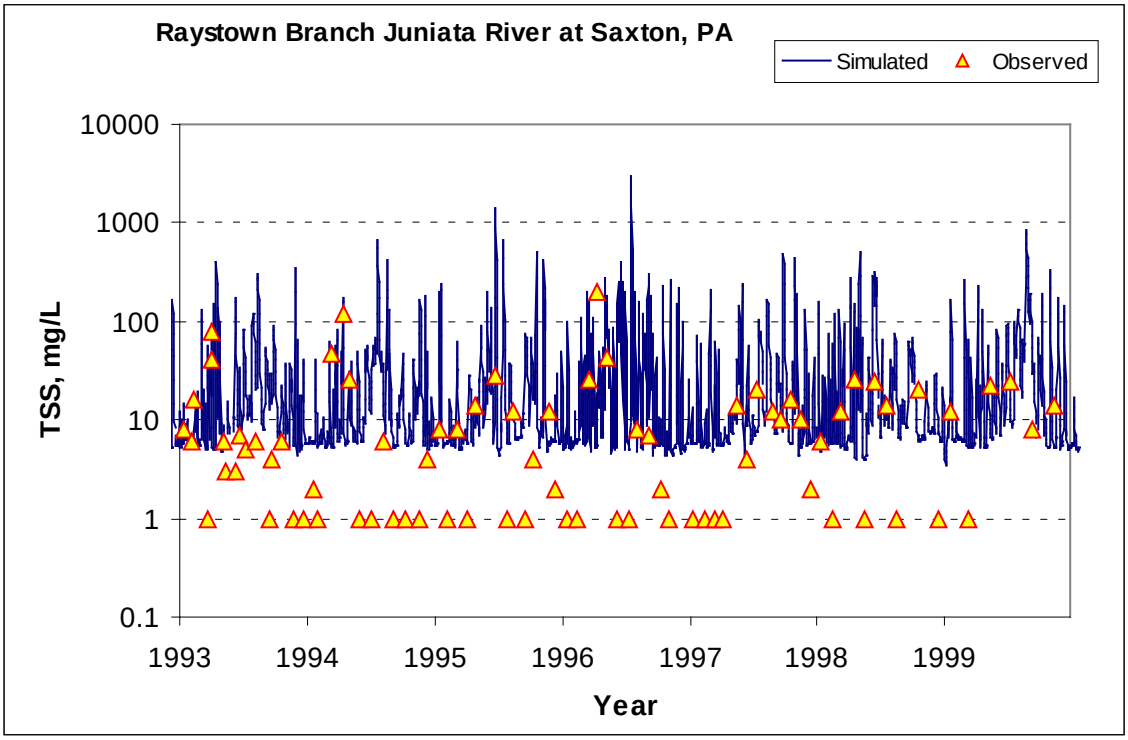

Figure 30. Time series plot of TSS concentration at Raystown Branch Juniata River at Saxton, PA - calibration period (HSPF).

Table 15. Relative errors,(observed minus simulated) for TSS concentrations at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Count	106	15
Concentration Average Error	-138.4%	-30.82%
Concentration Median Error	-29.73%	24.63%

The total phosphorus load calibration performed well for the Susquehanna River watershed calibration focus area. Adjustments were made to the accumulation rate and storage limits for the impervious surfaces. In general, the observed and simulated total phosphorus loads attained an acceptable match for the simulation period (Figure 31). As with TSS, additional diagnostics for total phosphorus included flow-load power plots (Figures 32 and 33) and time series plots (Figure 34). All show acceptable agreement. Tables 16 and 17 provide model statistics and relative errors for the total phosphorus calibration and validation periods. In contrast to load, phosphorus concentrations are generally over-estimated (observed minus simulated concentration less than zero). This is due to an over-estimation of observed phosphorus concentrations at low flows that may be due to the simplistic representation of point source discharges in the model.

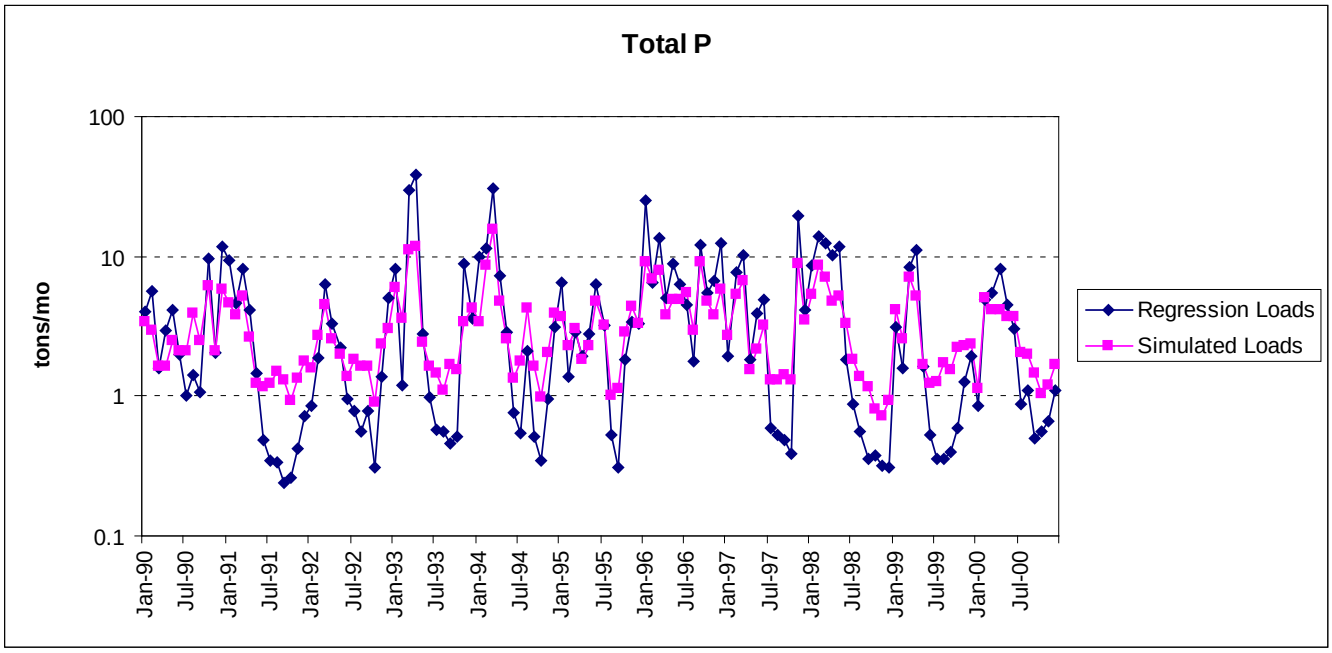

Figure 31. Fit for monthly load of total phosphorus at Raystown Branch Juniata River at Saxton, PA (HSPF).

Table 16. Model fit statistics (observed minus predicted) for monthly total phosphorus loads using stratified regression – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	26.0%	21.5%
Relative Average Absolute Error	49%	45%
Relative Median Absolute Error	22.7%	35.4%

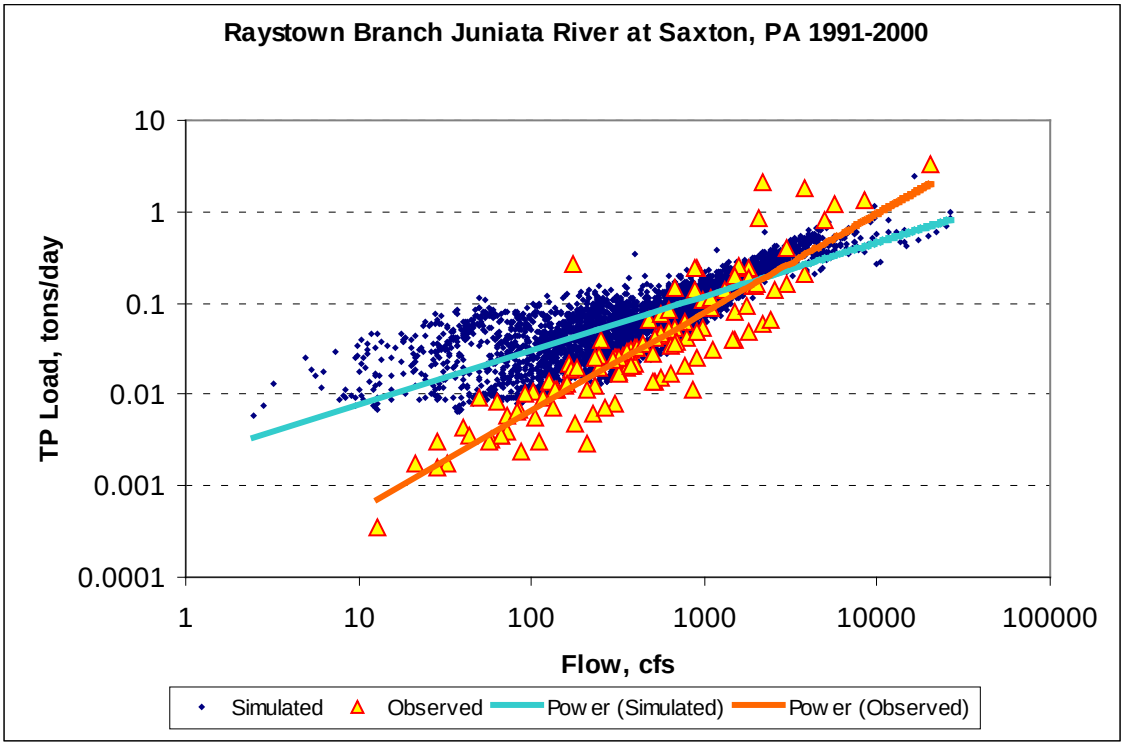

Figure 32. Power plot for observed and simulated total phosphorus at Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

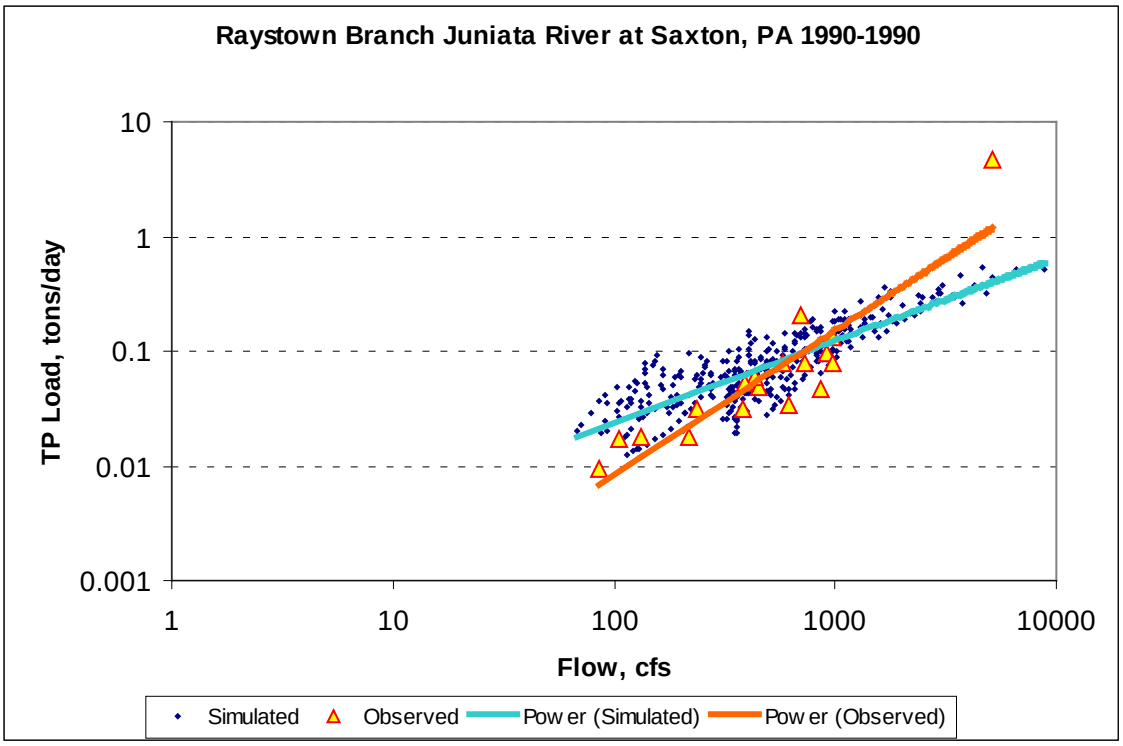

Figure 33. Power plot for observed and simulated total phosphorus at Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

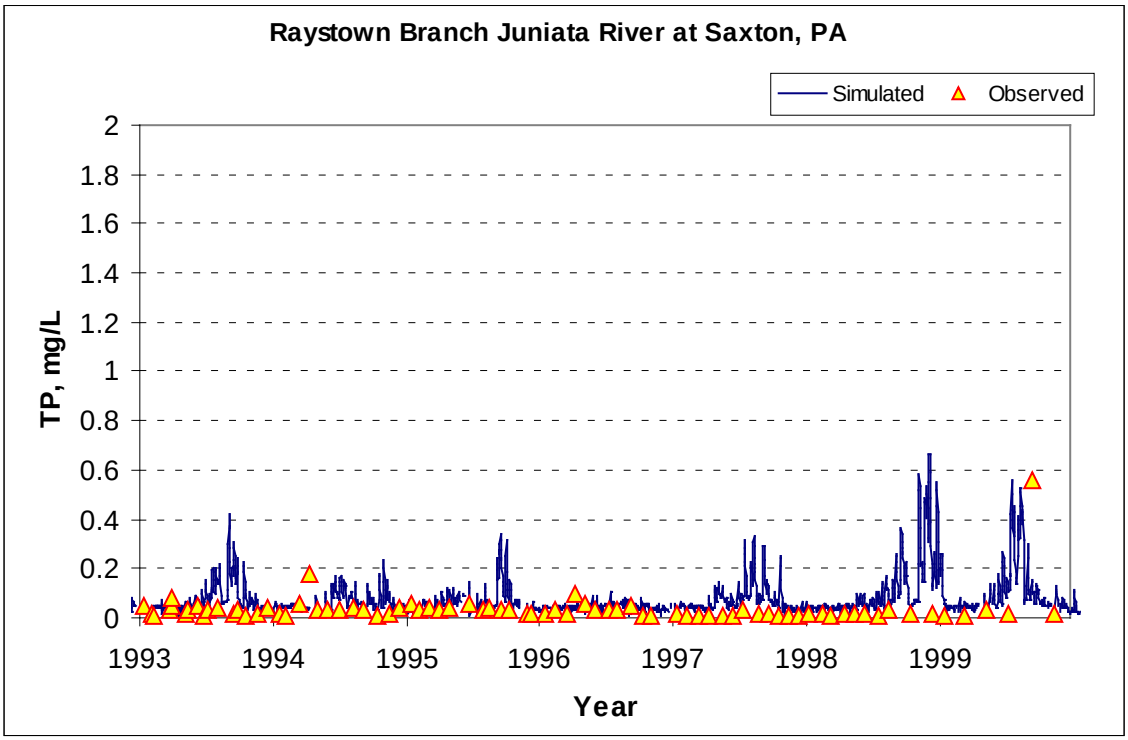

Figure 34. Time series plot of total phosphorus concentration, at Raystown Branch Juniata River at Saxton, PA (HSPF).

Table 17. Relative errors (observed minus simulated) for total phosphorus concentrations at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1990-1990)	Validation period (1990)
Count	122	18
Concentration Average Error	-121.72%	-0.88%
Concentration Median Error	-50.63%	-12.24%

Results for total nitrogen are summarized in Figures 35 through 38. The results are acceptable, and generally better than those for total phosphorus. This is due to total nitrogen not being sediment associated, therefore, problems with sediment are not reflected in the calibration for total nitrogen. Tables 18 and 19 provide model statistics and relative errors for the total nitrogen calibration and validation periods.

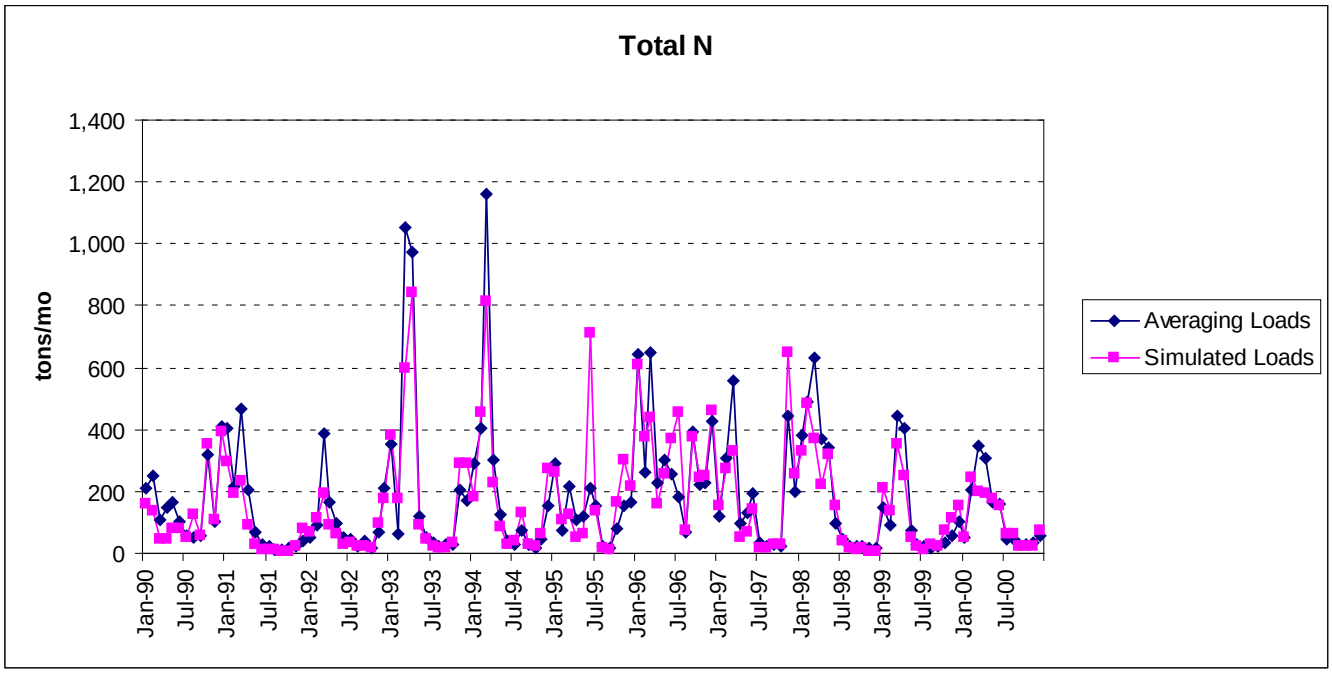

Figure 35. Fit for monthly load of total nitrogen at Raystown Branch Juniata River at Saxton, PA (HSPF).

Table 18. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	7.0%	17.2%
Relative Average Absolute Error	34%	29%
Relative Median Absolute Error	16.8%	26.2%

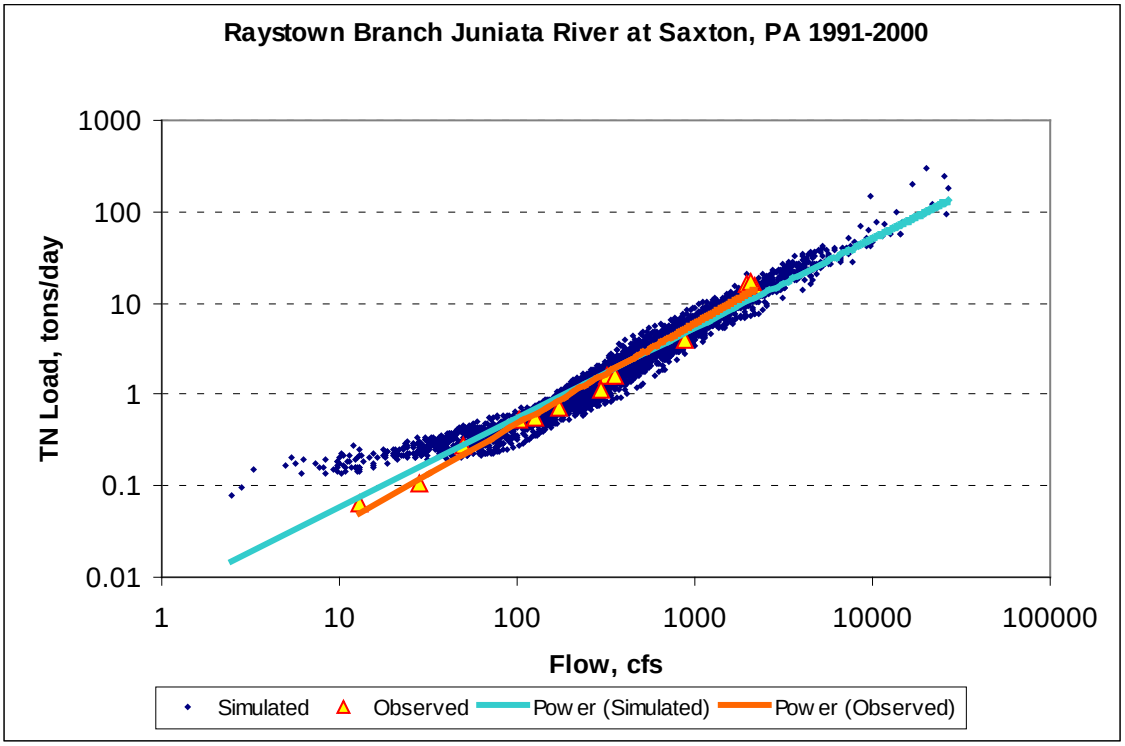

Figure 36. Power plot for observed and simulated total nitrogen at Raystown Branch Juniata River at Saxton, PA – calibration period (HSPF).

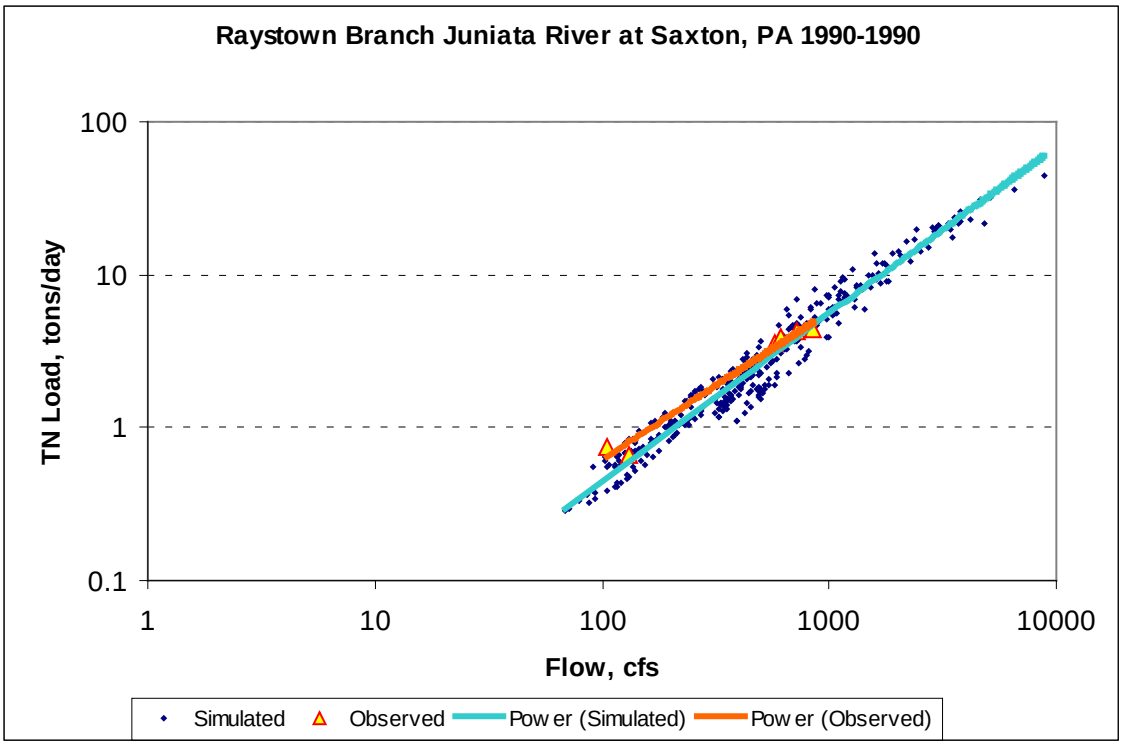

Figure 37. Power plot for observed and simulated total nitrogen at Raystown Branch Juniata River at Saxton, PA – validation period (HSPF).

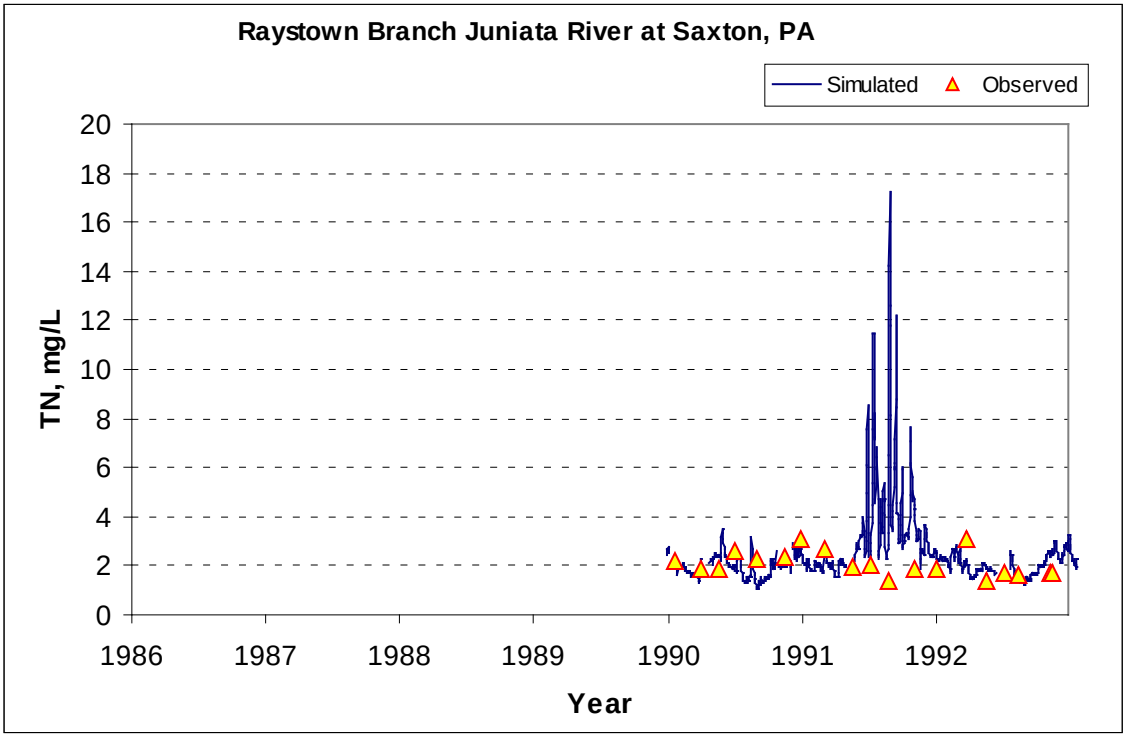

Figure 38. Time series plot of total nitrogen concentration, at Raystown Branch Juniata River at Saxton, PA (HSPF).

Table 19. Relative errors (observed minus simulated) for total nitrogen concentration at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (HSPF)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Count	13	6
Concentration Average Error	-22.89%	11.10%
Concentration Median Error	-22.60%	7.42%

Water Quality Results for Larger Watershed

As with hydrology, the Raystown Branch Juniata River (USGS 01562000) watershed parameters for water quality were directly transferred to other portions of the watershed. Summary statistics for the water quality calibration and validation at other stations in the watershed are provided in Tables 20 and 21, respectively.

Table 20. Summary statistics for water quality for all stations – calibration period (HSPF)

Station	01576000 Susquehanna River at Marietta, PA (1991-1995)	01540500 Susquehanna River at Danville, PA (1991-1994)	01562000 Raystown Branch Juniata River at Saxton, PA (1991-2000)
Relative Percent Error TSS Load	26.5%	27.5%	-78.2%
TSS Concentration Median Error	-24.8%	-6.3%	-29.7%
Relative Percent Error TP Load	44.0%	50.0%	26.0%
TP Concentration Median Error	-1.0%	24.6%	-50.6%
Relative Percent Error TN Load	-14.4%	6.2%	7.0%
TN Concentration Median Error	-34.8%	-4.8%	-22.6%

Table 21. Summary statistics for water quality for all stations – validation period (HSPF)

Station	01576000 Susquehanna River at Marietta, PA (1980-90)	01540500 Susquehanna River at Danville, PA (1986-90)	01562000 Raystown Branch Juniata River at Saxton, PA (1990)
Relative Percent Error TSS Load	-0.6%	-11.1%	-89.7%
TSS Concentration Median Error	-27.3%	-11.2%	24.6%
Relative Percent Error TP Load	38.8%	40.5%	21.5%
TP Concentration Median Error	5.1%	20.7%	-12.2%
Relative Percent Error TN Load	-7.1%	10.0%	17.2%
TN Concentration Median Error	-17.2%	5.9%	7.4%

SWAT Modeling

The SWAT model for the Susquehanna River watershed was set up with the ArcSWAT Version 2.3.3 interface using the subwatersheds and stream network layers obtained from CBP, and other geospatial coverages described above for the HSPF model. The precipitation and temperature data were preprocessed from BASINS Weather Data Management (WDM) files to obtain the daily values.

The SWAT modeling process started with hydrology calibration, followed by calibration of sediment, and then calibration of nitrogen and phosphorous. The USGS gage on the Raystown Branch of the Juniata River at Saxton, PA (USGS 02050303) was used as the initial calibration location. The parameters were then transferred to the entire Susquehanna River watershed and results were evaluated at the gages on the Susquehanna River at Danville, PA (USGS 01540500) and on the Susquehanna River at Marietta, PA (USGS 01576000). While hydrology parameters were readily transferrable, water quality parameters, especially those related to sediment needed some adjustment at the larger watershed scale.

Changes Made to Base Data Provided

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

Assumptions

Though there are a number of reservoirs present in Susquehanna River watershed, they are located below the calibration and validation locations. Hence the information regarding these reservoirs was not specifically addressed in the SWAT model, consistent with the approach used for HSPF.

The point source data were specified for all the major active point sources in the Susquehanna study area. The point source flows and concentrations for each facility in the watershed were assumed to be constant throughout the simulation period. The data from the time period from 1991-2006 were compiled from the PCS database and the median values were estimated. The facilities that were missing a total nitrogen, total phosphorus, and TSS concentration value were filled with a typical pollutant concentration value from literature (Typical Pollutant Concentration for NCPDI Discharge Categories -Improving Point Source Loading Data for Reporting National Water Quality Indicators) prepared for Jim Horne, EPA/OWM (Tetra Tech 1990) based on the SIC classification. All POTWs were assumed to have secondary treatment. The median concentrations for the nutrient species were estimated based on the values reported in Cheaspake Bay Phase 5 Model report for species relationship for point sources and used in the model.

Hydrology Calibration

Similar to HSPF, hydrology calibration was performed at the USGS gage on the Raystown Branch of the Juniata River at Saxton, PA (USGS 01562000). Though some adjustments are made at the major watershed level, a spatial calibration approach was not adopted for Susquehanna River watershed SWAT modeling. The calibration efforts were geared toward getting a closer match between simulated and observed flows at the outlet of the calibration focus area and to limit the error statistics within the acceptable ranges listed in the QAPP.

Land Use / Soil / Slope definition

A 5/10/5 percent threshold was used for land use/soil/slope in the SWAT model while defining the HRUs. Urban (including current and future urban class types) classes were exempt from applying the thresholds.

Elevation Bands

The topographical analysis of Susquehanna River watersheds showed a significant range of elevations within some individual modeling subwatersheds. This is likely to result in orographic variability in precipitation. Eight elevation bands were used to account for the orographic effects on temperature and precipitation.

Calibration Parameters

The initial values of the parameters were set by ArcGIS based on various geospatial datasets and the defaults set in the SWAT database. During the calibration process, adjustments were focused on the following parameters:

- ICN (Daily curve number calculation method) – In order to make the CN less dependent on the soil moisture content and more dependent on the antecedent conditions, the ICN was set to 1 (CN as function or ET)
- FFCB (Initial soil water storage expressed as a fraction of field capacity water content)
- CN_FROZ (Frozen curve number active)
- Tlaps (Temperature laps rate)
- Plaps (Preciptation laps rate)
- ALAI_MIN (Minimum leaf area index for plant during dormant period)
- CurYr_Mat (Current age of trees)
- LAI_Ini (Initial leaf area index)
- EPCO (Plant uptake compensation factor)
- CN (Curve Number)
- TIMP (Snow pack temperature lag factor)
- ESCO (Soil evaporation compensation factor)
- CANMX (Maximum canopy storage)
- Alpha_bf (Baseflow alpha factor)
- GW_Delay (Groundwater delay)
- GWQMN (Threshold depth of water in the shallow aquifer for return flow to occur)
- REVAPMN (Threshold depth of water in the shallow aquifer for revap to occur)
- GW_REVAP (Groundwater revap coefficient)
- SURLAG (Surface runoff lag time)
- CH_K1 (Effective hydraulic conductivity in tributary channel alluvium)
- CH_K2 (Effective hydraulic conductivity in main channel alluvium)
- SFTMP (Snowfall temperature)
- SMTMP (Snow melt base temperature)
- SMFMX (Maximum melt rate for snow during year)
- SMFMN (Minimum melt rate for snow during year)
- CNCOEFF (Plant ET curve number coefficient)
- CH_N2 (Manning's n value for the main channel)
- CH_N1 (Manning's "n" value for the tributary channels)
- HRU_Slope (Average slope steepness)
- Slsubbsn (Average slope length)

Initial calibrations were performed for the Raystown Branch of the Juniata River, comparing model results to data from USGS 01562000 (Raystown Branch Juniata River At Saxton, PA), and are summarized in Figures 39 through 45 and Tables 22 and 23. The model fit is of good quality, but summer volumes are over estimated. The model calibration period was set to the 10 water years from 10/01/1995 to 09/30/2005.

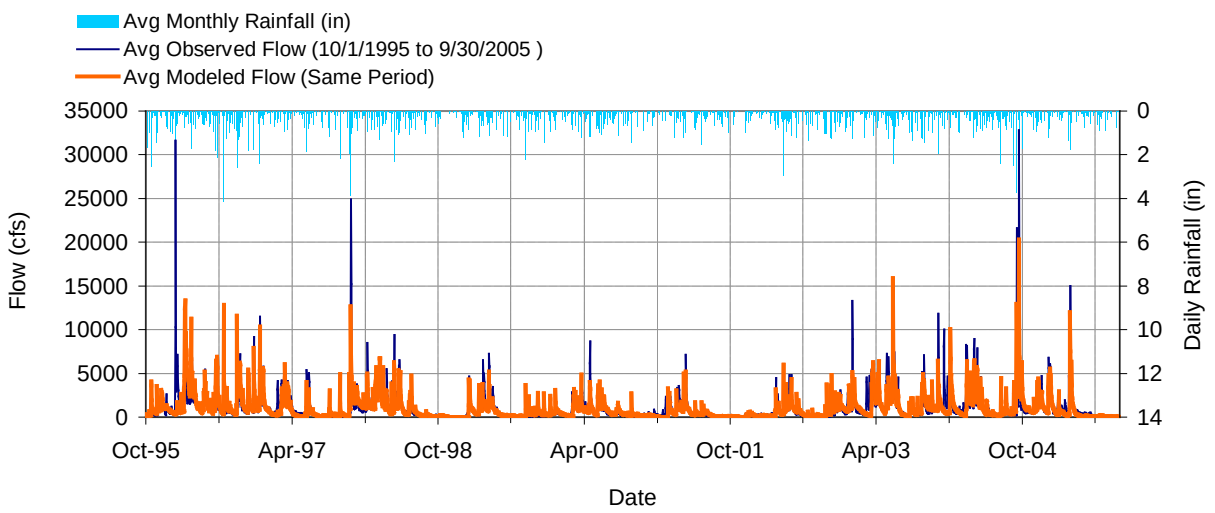

Figure 39. Mean daily flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

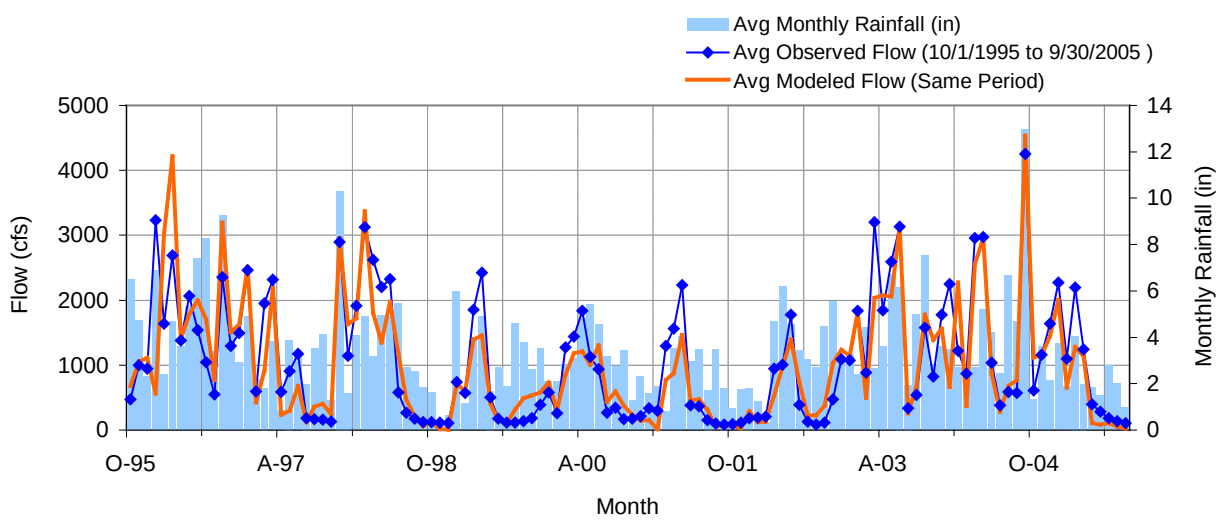

Figure 40. Mean monthly flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

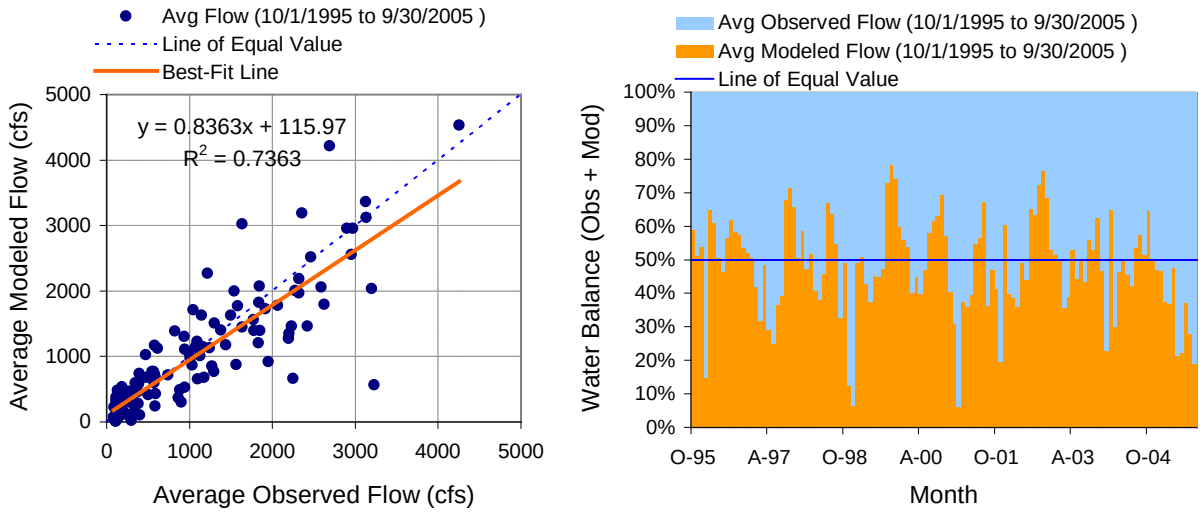

Figure 41. Monthly flow regression and temporal variation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

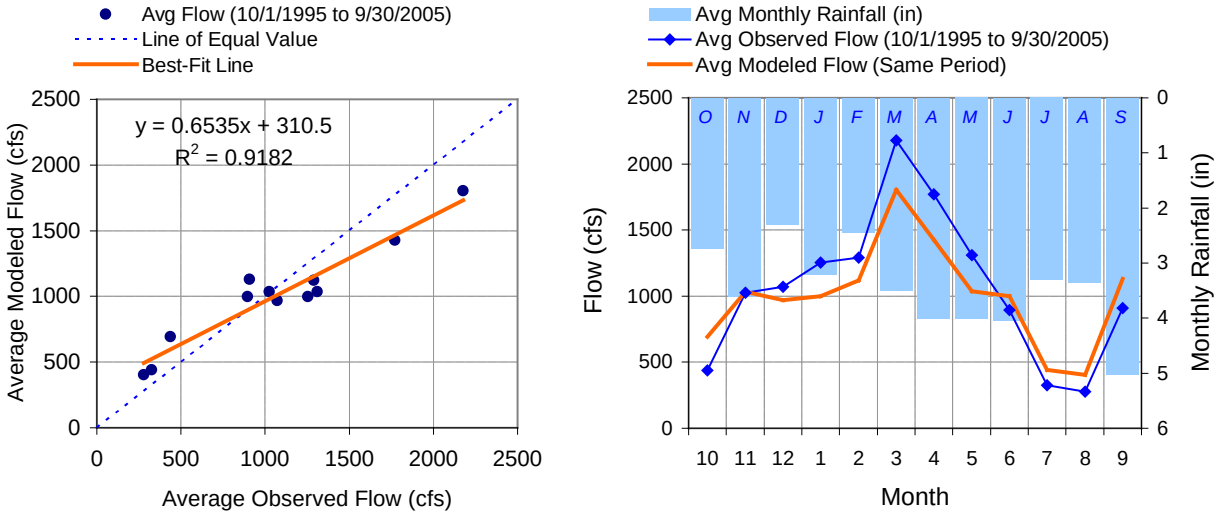

Figure 42. Seasonal regression and temporal aggregate at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

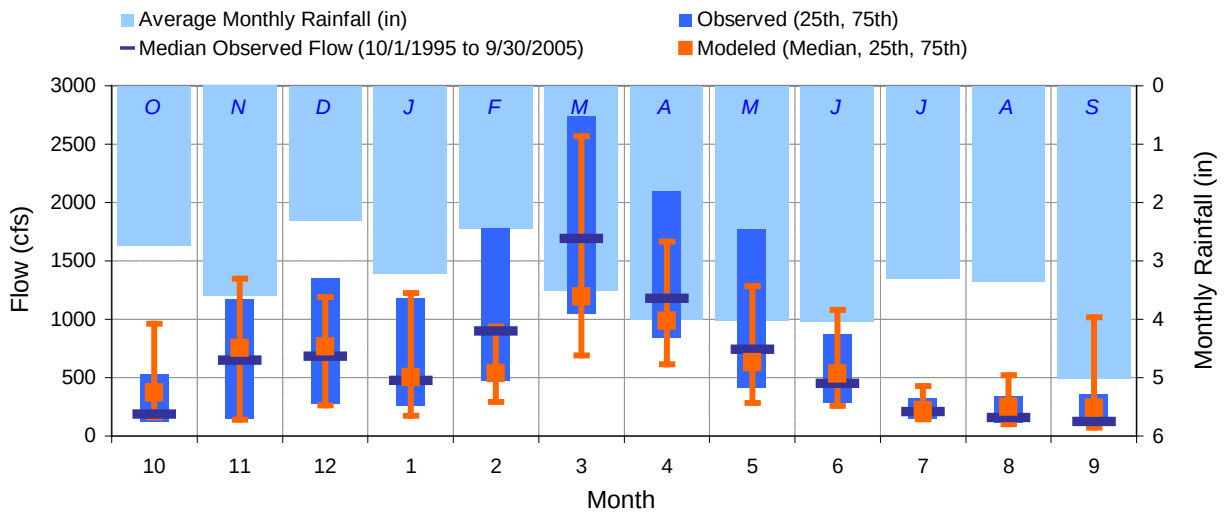

Figure 43. Seasonal medians and ranges at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

Table 22. Seasonal summary at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	438.69	187.00	119.00	530.75	692.82	371.51	162.66	959.94
Nov	1024.44	647.50	149.75	1170.00	1034.60	754.67	141.71	1346.72
Dec	1071.22	682.00	280.75	1350.00	969.20	765.27	263.19	1190.02
Jan	1255.25	475.00	260.00	1180.00	998.54	505.18	171.86	1224.18
Feb	1290.35	900.00	470.00	1775.00	1120.65	539.96	290.45	935.31
Mar	2177.77	1690.00	1052.50	2742.50	1804.98	1195.40	691.99	2568.17
Apr	1771.52	1180.00	843.75	2102.50	1425.47	986.87	613.33	1666.15
May	1310.00	739.50	414.00	1777.50	1035.99	630.37	283.51	1281.83
Jun	895.83	448.00	287.50	879.00	999.51	535.90	258.19	1082.22
Jul	326.40	207.00	146.00	324.00	440.54	222.43	144.38	426.51
Aug	278.62	157.50	115.25	339.75	404.37	249.52	100.82	519.83
Sep	907.63	124.50	104.00	360.25	1129.77	239.93	73.81	1015.30

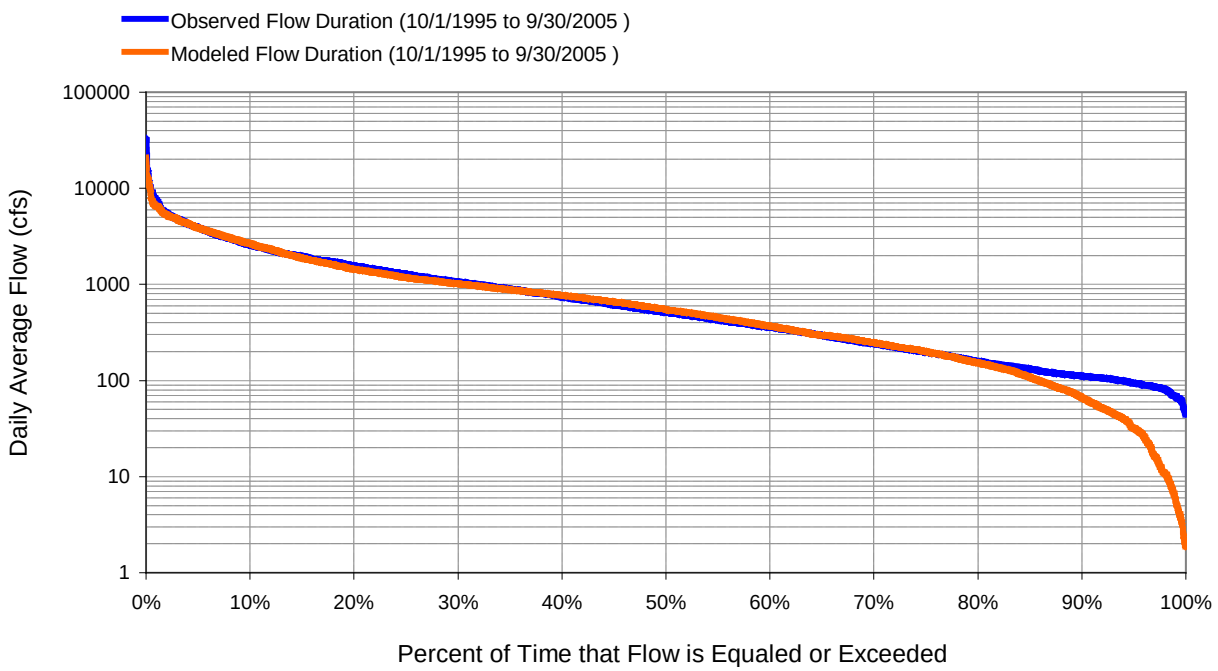

Figure 44. Flow exceedence at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

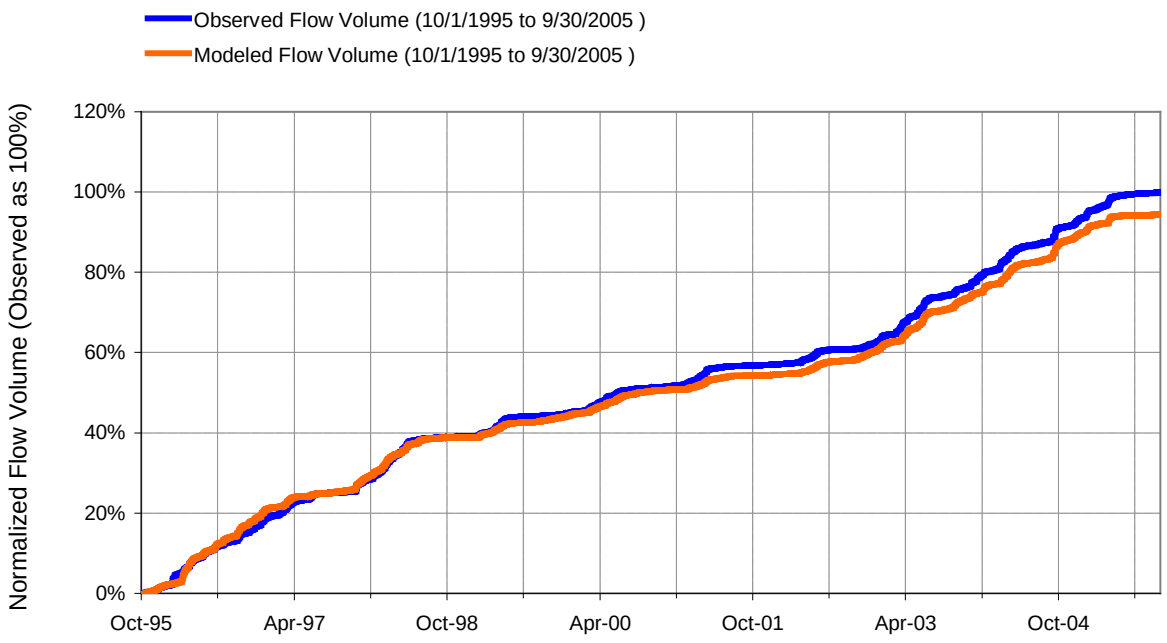

Figure 45. Flow accumulation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

Table 23. Summary statistics at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 26 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 01562000 Raystown Branch Juniata River at Saxton, PA Hydrologic Unit Code: 2050303 Latitude: 40.21591249 Longitude: -78.2652901 Drainage Area (sq-mi): 756	
Total Simulated In-stream Flow:	**18.01**	Total Observed In-stream Flow:	**19.04**
Total of simulated highest 10% flows:	**7.87**	Total of Observed highest 10% flows:	**8.48**
Total of Simulated lowest 50% flows:	**1.94**	Total of Observed Lowest 50% flows:	**2.05**
Simulated Summer Flow Volume (months 7-9):	**2.96**	Observed Summer Flow Volume (7-9):	**2.26**
Simulated Fall Flow Volume (months 10-12):	**4.06**	Observed Fall Flow Volume (10-12):	**3.81**
Simulated Winter Flow Volume (months 1-3):	**5.83**	Observed Winter Flow Volume (1-3):	**7.03**
Simulated Spring Flow Volume (months 4-6):	**5.16**	Observed Spring Flow Volume (4-6):	**5.93**
Total Simulated Storm Volume:	**6.86**	Total Observed Storm Volume:	**7.83**
Simulated Summer Storm Volume (7-9):	**1.30**	Observed Summer Storm Volume (7-9):	**1.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-5.41	10	
Error in 50% lowest flows:	-5.67	10	
Error in 10% highest flows:	-7.15	15	
Seasonal volume error - Summer:	**30.66**	**30**	
Seasonal volume error - Fall:	6.47	30	
Seasonal volume error - Winter:	-17.01	30	
Seasonal volume error - Spring:	-13.07	30	
Error in storm volumes:	-12.43	20	
Error in summer storm volumes:	11.80	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.294	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.395		
Monthly NSE	0.669		

Hydrology Validation

Hydrology validation for the Susquehanna River watershed model was performed at the same gage location but for the period 10/1/1985 through 9/30/1995. Results are presented in Figure 49 through 52 and Tables 24 and 25. The validation achieves a reasonable coefficient of model fit efficiency, but many of statistics show that simulated values were underestimated compared to the observed values.

In general, the sign of the errors in the validation period are similar to those in the calibration period, but the discrepancies are larger. Additional factors that may have contributed to the difference in the flows between the calibration and validation period are:

- Drainage area of the observed USGS gage is about 6% higher than that of the calibration watershed.
- Increase in urban impervious surface areas between the 1980s and present.

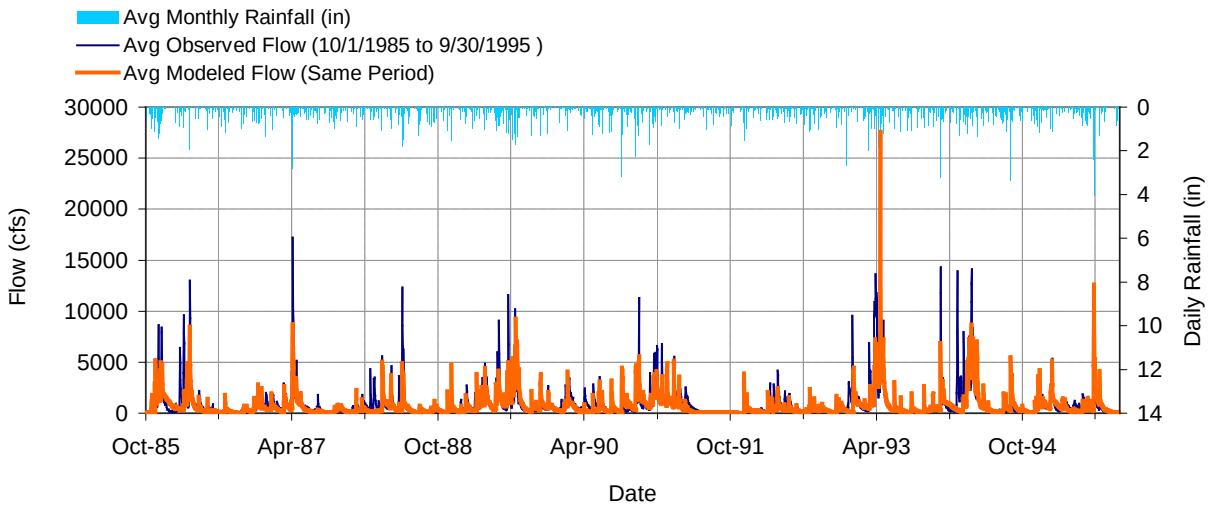

Figure 46. Mean daily flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

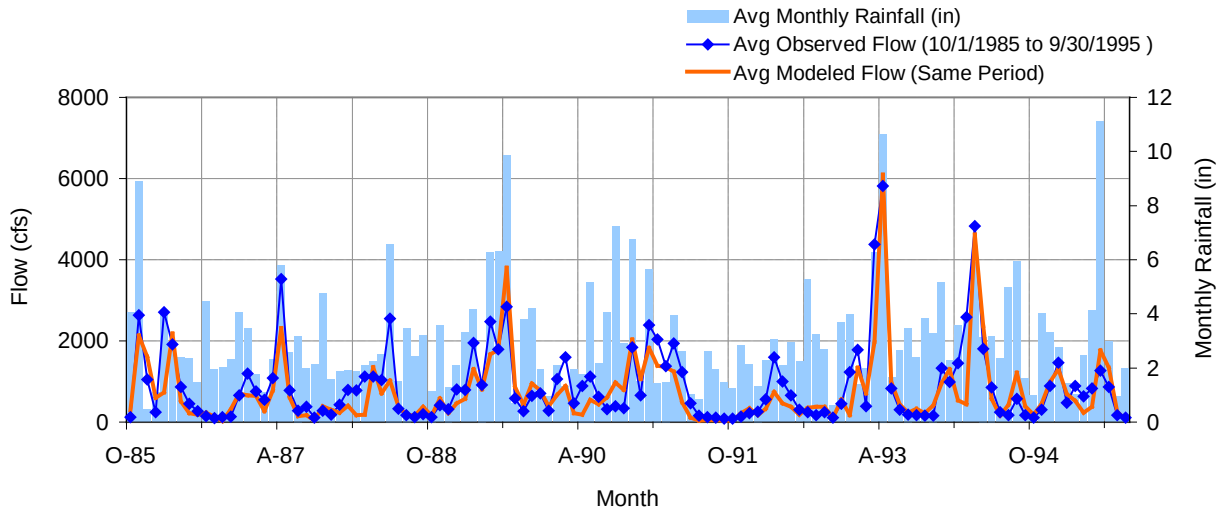

Figure 47. Mean monthly flow at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

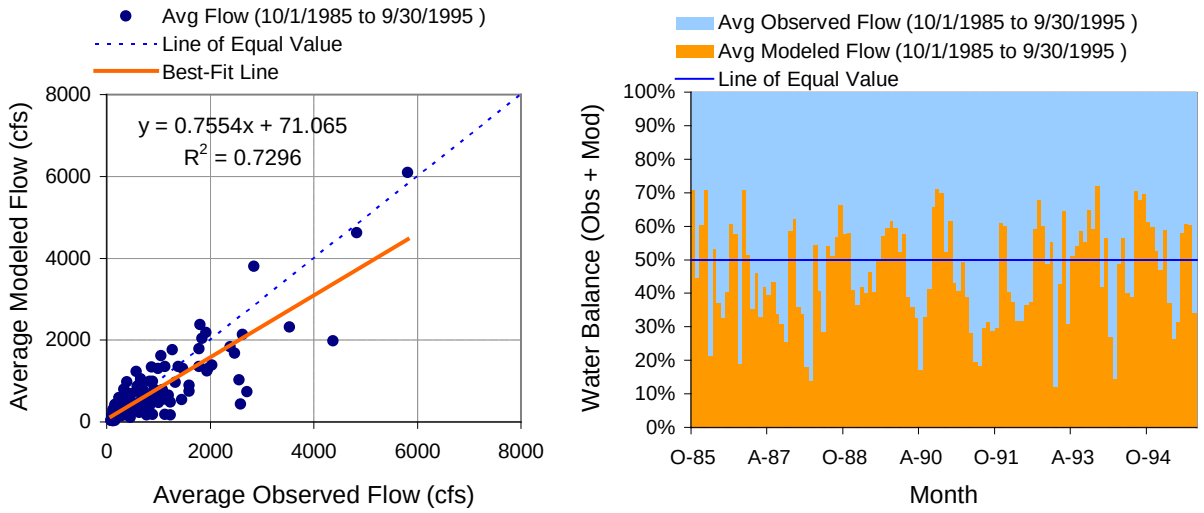

Figure 48. Monthly flow regression and temporal variation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

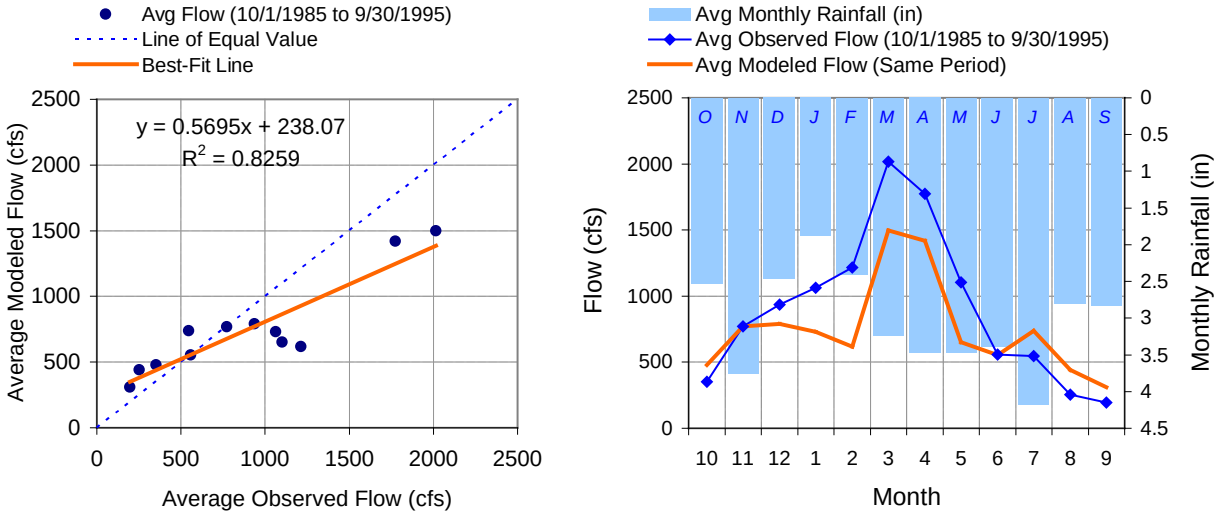

Figure 49. Seasonal regression and temporal aggregate at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

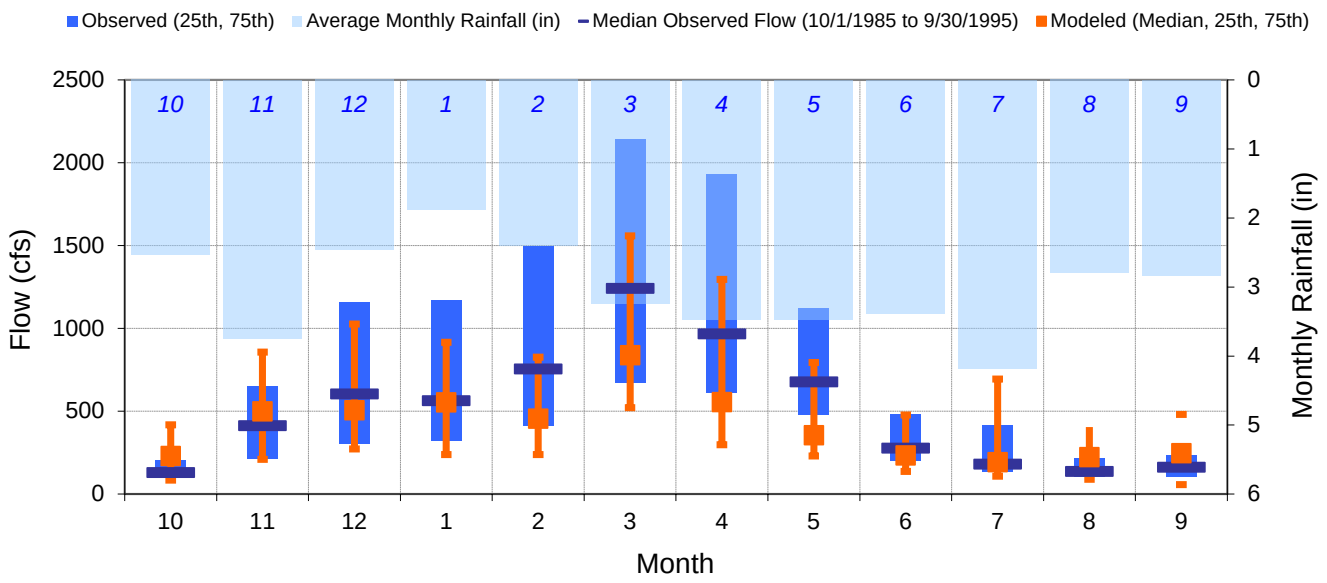

Figure 50. Seasonal medians and ranges at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

Table 24. Seasonal summary at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	351.63	128.00	104.00	200.00	479.66	229.97	83.68	417.42
Nov	771.90	411.00	211.75	649.00	769.29	500.41	209.87	857.53
Dec	936.58	603.50	302.50	1157.50	790.68	506.59	271.91	1027.22
Jan	1063.43	562.00	322.50	1167.50	731.64	553.91	238.23	916.06
Feb	1214.57	754.00	410.00	1495.00	615.95	454.68	238.94	827.25
Mar	2016.51	1240.00	670.75	2140.00	1497.03	838.37	522.30	1559.50
Apr	1772.93	965.00	613.50	1935.00	1417.56	554.79	298.14	1296.67
May	1102.77	676.00	479.25	1122.50	652.39	355.80	230.15	793.79
Jun	559.15	275.50	201.00	479.50	552.94	232.64	136.75	476.75
Jul	545.15	180.00	138.00	418.00	739.08	192.13	108.06	694.82
Aug	252.88	136.00	108.00	216.75	441.53	223.70	89.30	404.09
Sep	195.59	160.00	107.75	233.50	310.53	246.34	56.63	481.69

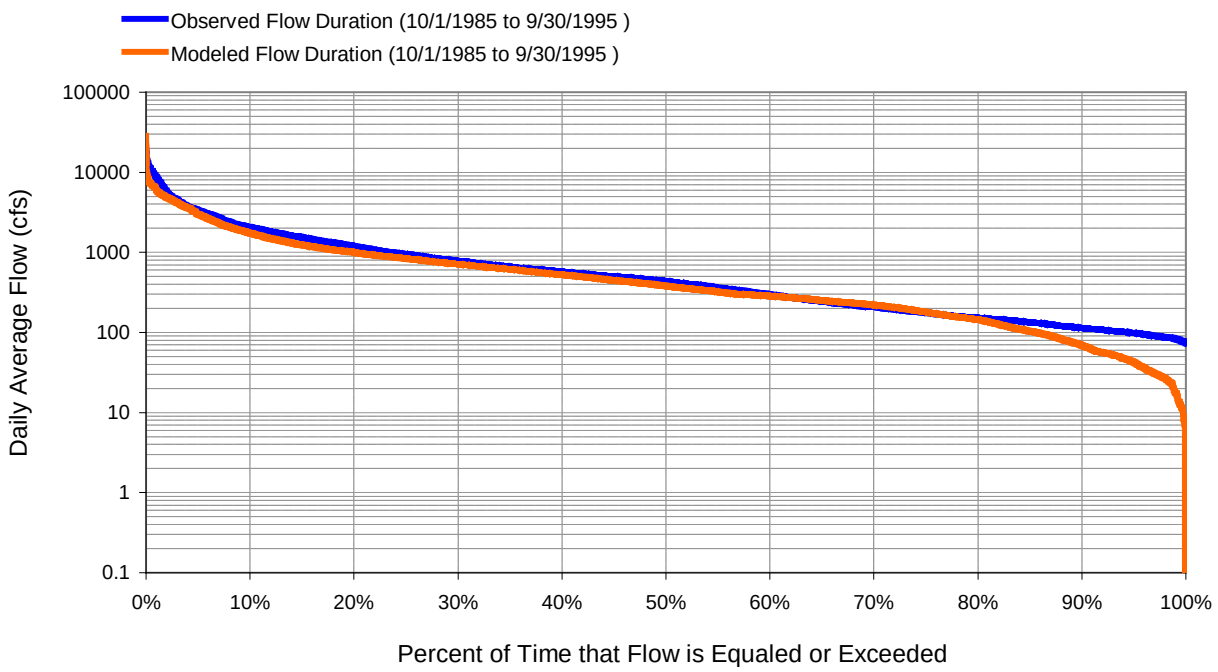

Figure 51. Flow exceedence at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

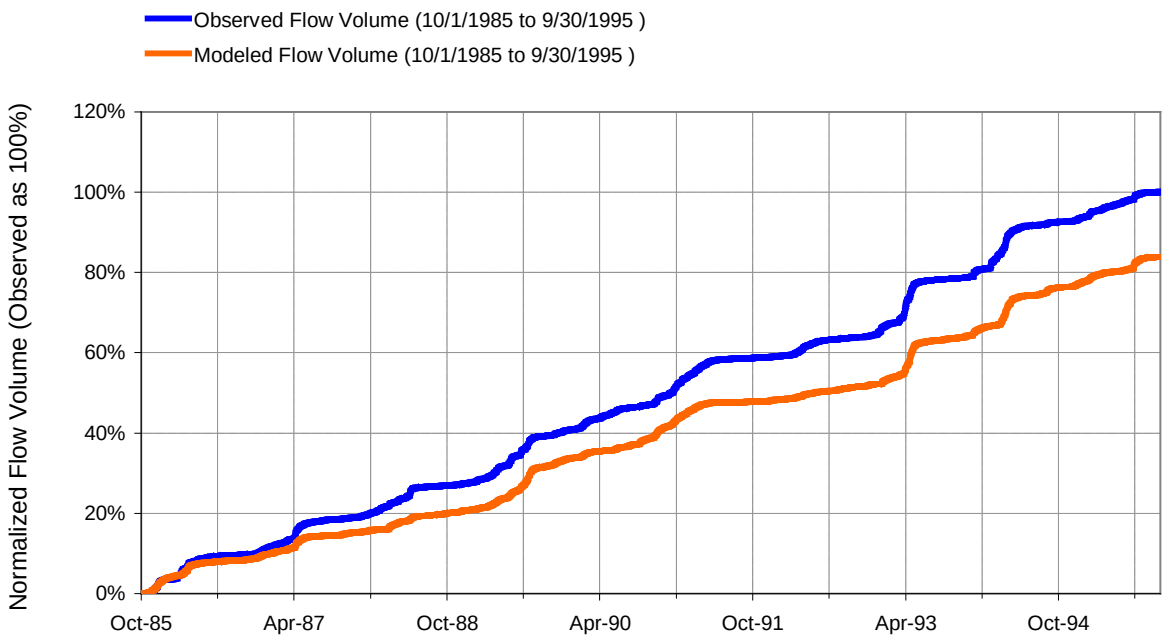

Figure 52. Flow accumulation at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

Table 25. Summary statistics at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 26 10-Year Analysis Period: 10/1/1985 - 9/30/1995 Flow volumes are (inches/year) for upstream drainage area		USGS 01562000 Raystown Branch Juniata River at Saxton, PA Hydrologic Unit Code: 2050303 Latitude: 40.21591249 Longitude: -78.2652901 Drainage Area (sq-mi): 756	
Total Simulated In-stream Flow:	**13.49**	Total Observed In-stream Flow:	**16.12**
Total of simulated highest 10% flows:	**6.35**	Total of Observed highest 10% flows:	**7.77**
Total of Simulated lowest 50% flows:	**1.59**	Total of Observed Lowest 50% flows:	**1.82**
Simulated Summer Flow Volume (months 7-9):	**2.26**	Observed Summer Flow Volume (7-9):	**1.51**
Simulated Fall Flow Volume (months 10-12):	**3.07**	Observed Fall Flow Volume (10-12):	**3.10**
Simulated Winter Flow Volume (months 1-3):	**4.25**	Observed Winter Flow Volume (1-3):	**6.38**
Simulated Spring Flow Volume (months 4-6):	**3.90**	Observed Spring Flow Volume (4-6):	**5.12**
Total Simulated Storm Volume:	**4.60**	Total Observed Storm Volume:	**6.49**
Simulated Summer Storm Volume (7-9):	**0.77**	Observed Summer Storm Volume (7-9):	**0.54**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	**-16.30**	**10**	
Error in 50% lowest flows:	**-12.87**	**10**	
Error in 10% highest flows:	**-18.30**	**15**	
Seasonal volume error - Summer:	**50.02**	**30**	
Seasonal volume error - Fall:	-1.00 >>	30	Clear
Seasonal volume error - Winter:	**-33.35**	**30**	
Seasonal volume error - Spring:	-23.82	30	
Error in storm volumes:	**-29.17**	**20**	
Error in summer storm volumes:	42.83	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.415	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.383		
Monthly NSE	0.664		

Hydrology Results for Larger Watershed

The parameters determined for the Raystown Branch of the Juniata River gage were transferred to the remainder of the watershed without detailed spatial calibration. Tests of calibration and validation were pursued at a total of three gages throughout the watershed, all of them at the outlet of 8-digit HUCs. Calibration results were generally acceptable at all gages, as summarized in Table 26. The match between observed and predicted flow corresponding to the largest watershed of the three gages (USGS 01576000, Susquehanna River at Marietta) is shown in Figures 53 through 59 and Tables 27 and 28. Validation results were also generally in the acceptable range for all the gages, as summarized in Table 29. It appears, however, that there are some systematic biases in the model, including under-prediction of the 10 percent highest flows and winter flows, coupled with over-prediction of summer flows

Table 26. Summary statistics (percent error) for all stations – calibration period (SWAT)

Station	01576000 Susquehanna River at Marietta, PA (1993-2003)	01540500 Susquehanna River at Danville, PA (1993-2003)	01562000 Raystown Branch Juniata River at Saxton, PA (1995-2005)
Error in total volume:	-9.74	-4.51	-5.41
Error in 50% lowest flows:	2.03	5.90	-5.67
Error in 10% highest flows:	-19.80	-11.24	-7.15
Seasonal volume error - Summer:	15.58	11.96	30.66
Seasonal volume error - Fall:	-2.46	-4.24	6.47
Seasonal volume error - Winter:	-31.54	-38.92	-17.01
Seasonal volume error - Spring:	1.99	26.18	-13.07
Error in storm volumes:	-22.08	-29.54	-12.43
Error in summer storm volumes:	9.52	-12.84	11.80
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.451	0.327	0.294
Monthly Nash-Sutcliffe Coefficient of Efficiency,	0.669	0.573	0.669

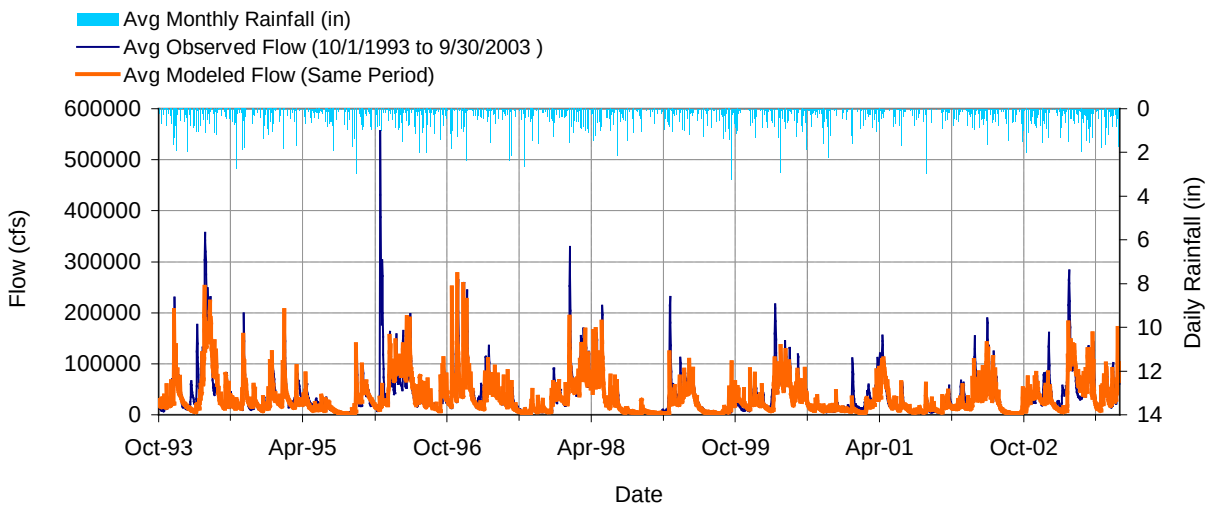

Figure 53. Mean daily flow at USGS 01576000 Susquehanna River At Marietta, PA – calibration period (SWAT).

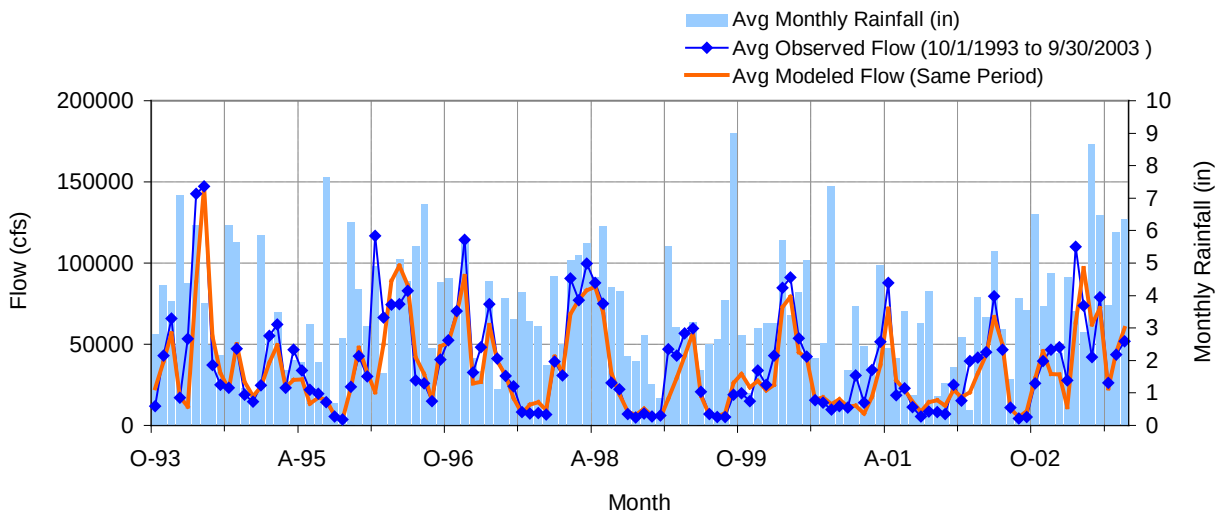

Figure 54. Mean monthly flow at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

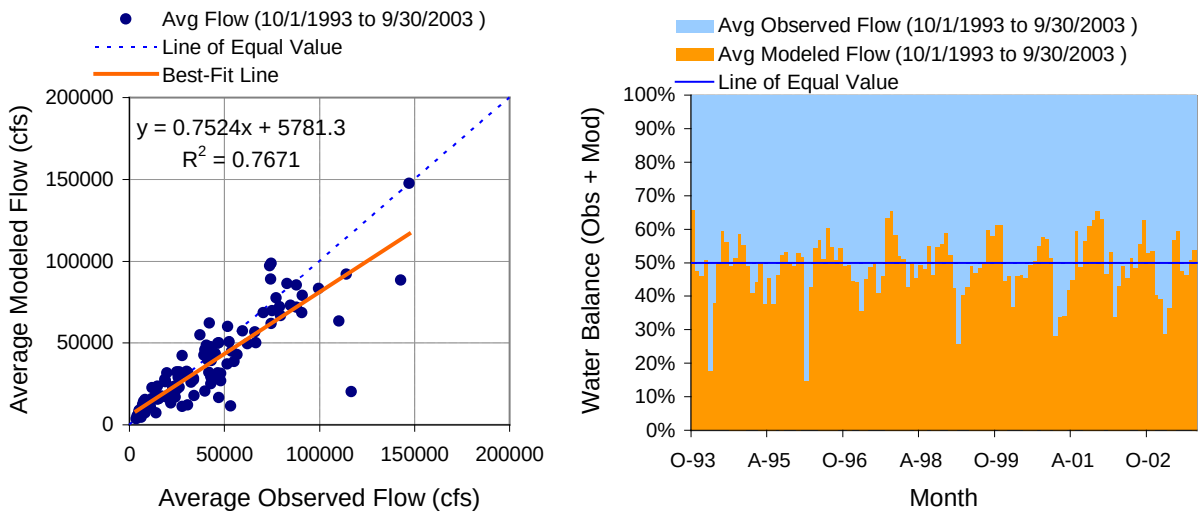

Figure 55. Monthly flow regression and temporal variation at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

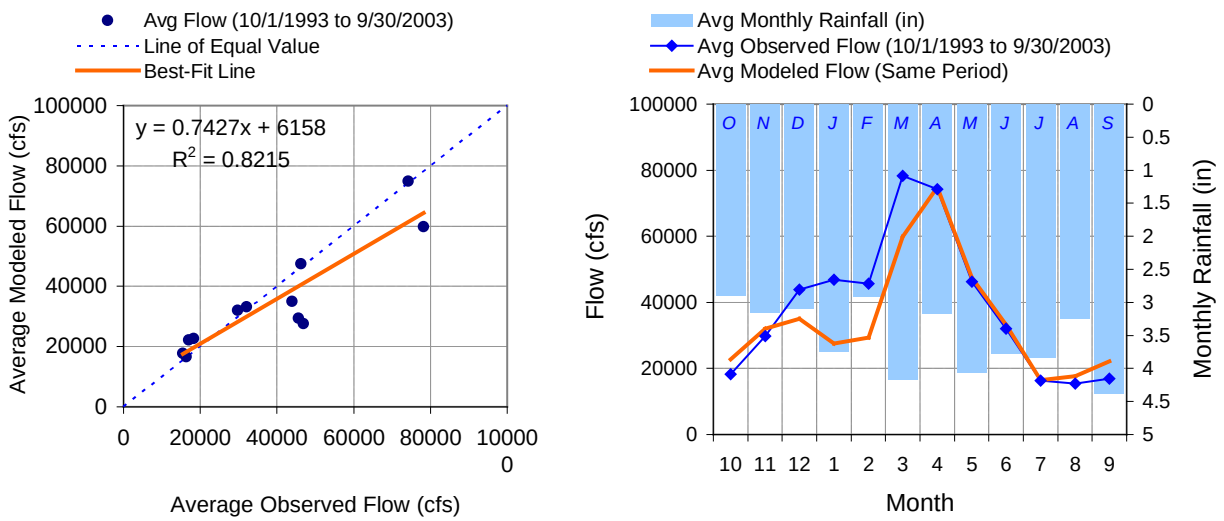

Figure 56. Seasonal regression and temporal aggregate at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

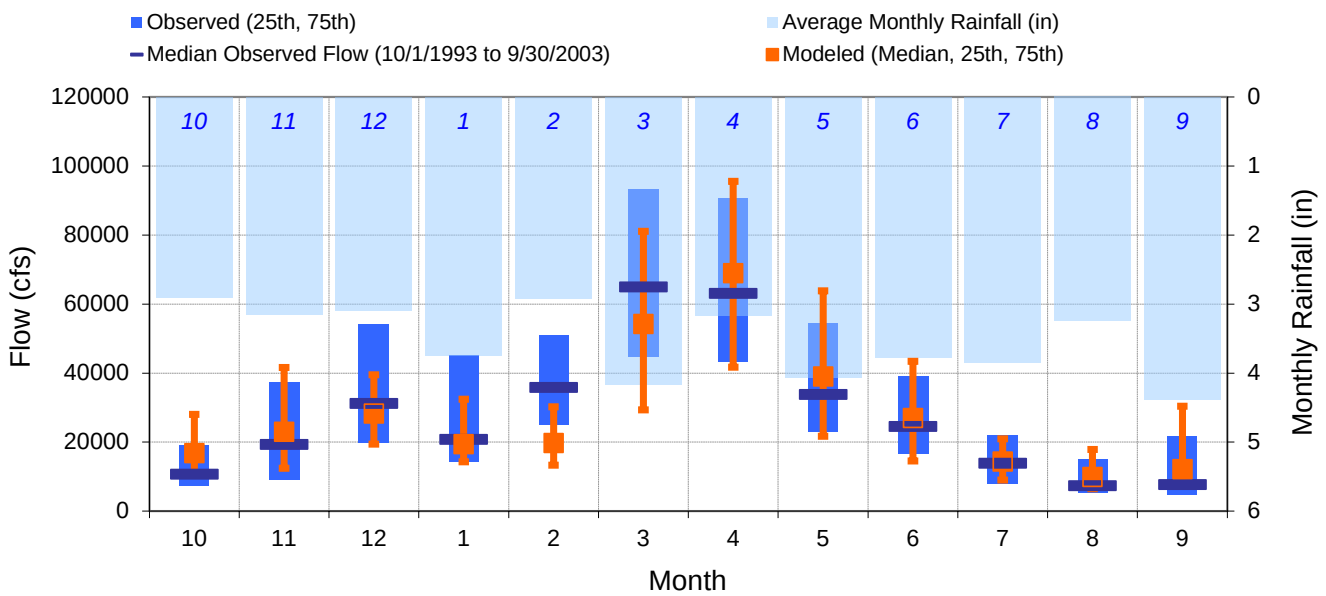

Figure 57. Seasonal medians and ranges at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

Table 27. Seasonal summary at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	18258.39	10650.00	7305.00	19225.00	22700.72	16857.46	11114.41	28029.25
Nov	29811.13	19300.00	9002.50	37325.00	32093.73	22972.19	12402.51	41600.68
Dec	43879.65	31150.00	19700.00	54050.00	34985.85	28272.92	19425.72	39499.45
Jan	46873.61	20700.00	14425.00	45175.00	27590.78	19412.47	14285.67	32425.04
Feb	45647.16	35800.00	25050.00	50975.00	29342.81	19732.07	13347.18	30222.29
Mar	78282.90	64900.00	44725.00	93150.00	59826.28	54243.33	29365.91	81082.47
Apr	74228.00	63000.00	43400.00	90750.00	74819.70	68934.23	41733.11	95561.49
May	46236.13	33750.00	23100.00	54575.00	47504.67	39005.05	21727.35	63884.23
Jun	32080.10	24450.00	16575.00	38925.00	33247.00	26980.41	14564.65	43437.04
Jul	16327.52	13800.00	8122.50	22075.00	16522.99	14343.05	8986.70	20941.60
Aug	15446.55	7330.00	5292.50	15175.00	17697.63	9907.53	6522.62	17877.17
Sep	16977.37	7645.00	4757.50	21650.00	22211.19	12176.50	7015.26	30420.94

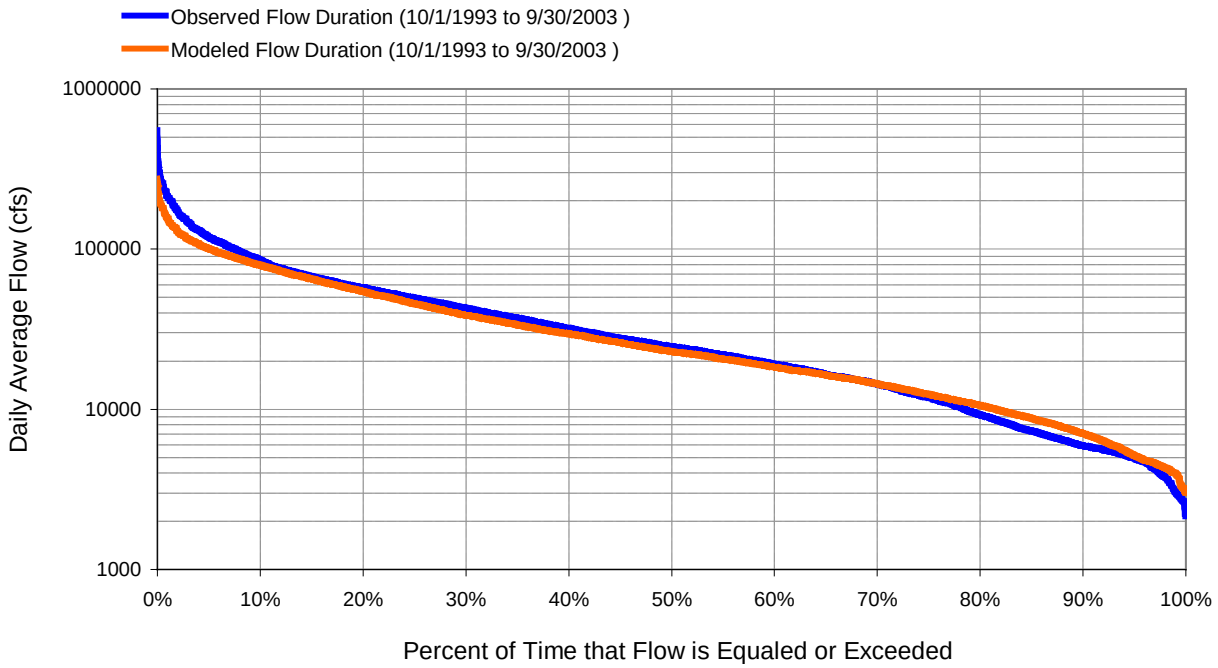

Figure 58. Flow exceedence at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

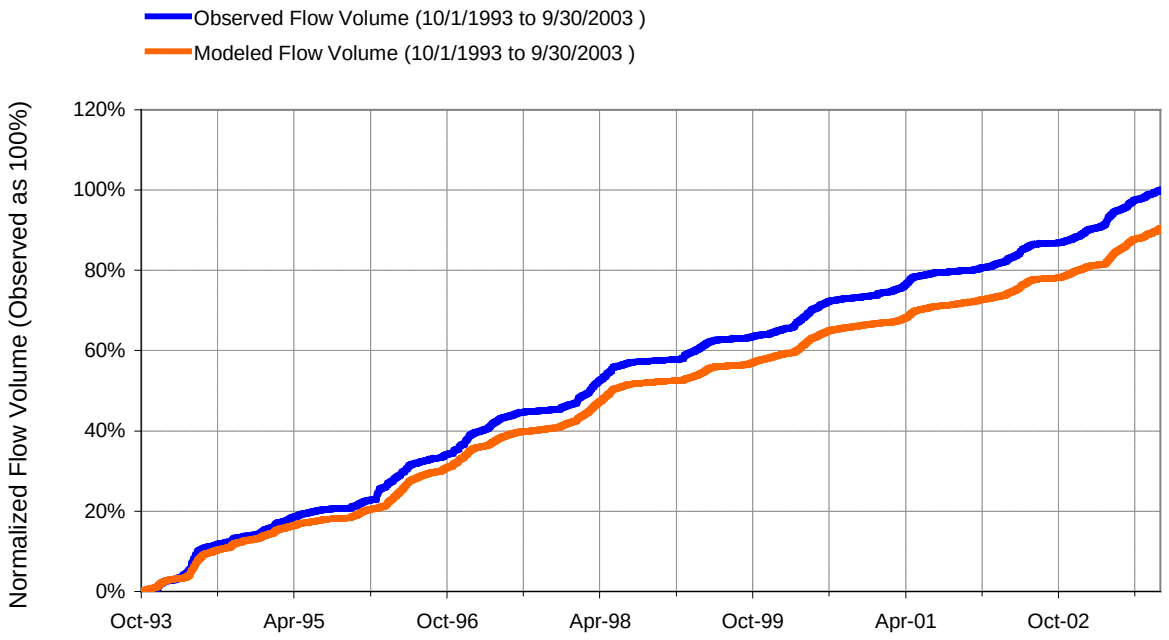

Figure 59. Flow accumulation at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT).

Table 28. Summary statistics at USGS 01576000 Susquehanna River at Marietta, PA – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 75		USGS 01576000 Susquehanna River at Marietta, PA	
10-Year Analysis Period: 10/1/1993 - 9/30/2003 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 2050306 Latitude: 40.0545413 Longitude: -76.5307992 Drainage Area (sq-mi): 25990	
Total Simulated In-stream Flow:	**18.22**	Total Observed In-stream Flow:	**20.19**
Total of simulated highest 10% flows:	**5.86**	Total of Observed highest 10% flows:	**7.31**
Total of Simulated lowest 50% flows:	**3.34**	Total of Observed Lowest 50% flows:	**3.27**
Simulated Summer Flow Volume (months 7-9):	**2.47**	Observed Summer Flow Volume (7-9):	**2.14**
Simulated Fall Flow Volume (months 10-12):	**3.94**	Observed Fall Flow Volume (10-12):	**4.04**
Simulated Winter Flow Volume (months 1-3):	**5.06**	Observed Winter Flow Volume (1-3):	**7.39**
Simulated Spring Flow Volume (months 4-6):	**6.75**	Observed Spring Flow Volume (4-6):	**6.62**
Total Simulated Storm Volume:	**5.70**	Total Observed Storm Volume:	**7.32**
Simulated Summer Storm Volume (7-9):	**0.84**	Observed Summer Storm Volume (7-9):	**0.76**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-9.74	10	
Error in 50% lowest flows:	2.03	10	
Error in 10% highest flows:	**-19.80**	**15**	
Seasonal volume error - Summer:	15.58	30	
Seasonal volume error - Fall:	-2.46	30	
Seasonal volume error - Winter:	**-31.54**	**30**	
Seasonal volume error - Spring:	1.99	30	
Error in storm volumes:	**-22.08**	**20**	
Error in summer storm volumes:	9.52	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.451	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.443		
Monthly NSE	0.641		

Table 29. Summary statistics (percent error) for all stations – validation period (SWAT)

Station	01576000 Susquehanna River at Marietta, PA (1983-1993)	01540500 Susquehanna River at Danville, PA (1983-1993)	01562000 Raystown Branch Juniata River at Saxton, PA (1985-1995)
Error in total volume:	-15.17	-10.17	-16.30
Error in 50% lowest flows:	1.37	1.84	-12.87
Error in 10% highest flows:	-24.62	-17.11	-18.30
Seasonal volume error - Summer:	22.63	17.20	50.02
Seasonal volume error - Fall:	-8.86	-11.29	-1.00
Seasonal volume error - Winter:	-34.95	-40.55	-33.35
Seasonal volume error - Spring:	-12.26	9.55	-23.82
Error in storm volumes:	-28.54	-36.20	-29.17
Error in summer storm volumes:	29.42	-15.18	42.83
Nash-Sutcliffe Coefficient of Efficiency, E:	0.485	0.372	0.415
Baseline adjusted coefficient (Garrick), E':	0.657	0.573	0.664

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done on data from the Raystown Branch Juniata River at Saxton (USGS 01562000), using 1991-2000 for calibration and 1990 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:

- SPCON (Linear parameters for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- SPEXP (Exponent parameter for calculating sediment re-entrained in channel sediment routing)
- CH_COV (Channel cover factor)
- CH_EROD (Channel erodibility factor)

Various plots that compare TSS simulated by SWAT against the observed data are shown in Figures 60 through 63. The comparison statistics are provided in Tables 30 and 31. The fit to monthly sediment loads is generally better than that obtained with the HSPF model. However, the correlation between observed and predicted concentrations is weak – in part because many of the observed data are reported as less than a detection limit of 2 mg/L (plotted at 1 mg/L in Figure 63).

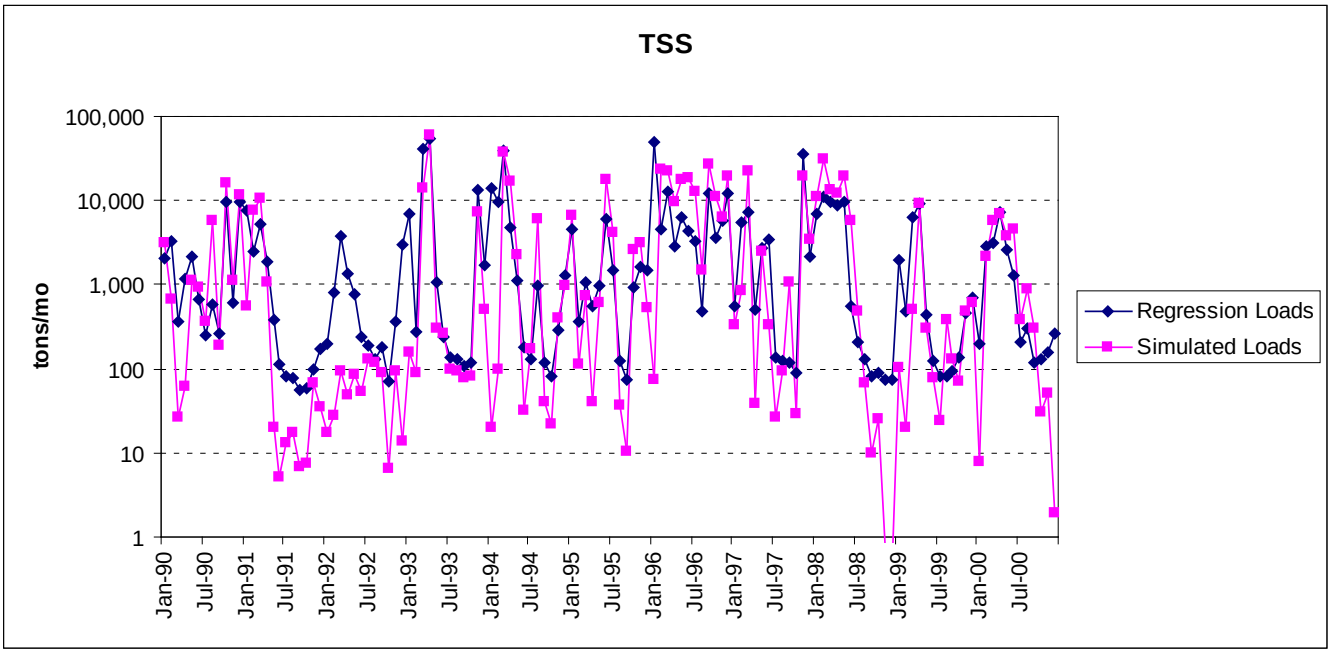

Figure 60. Fit for monthly load of TSS at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT).

Table 30. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	-10.1%	-33.6%
Relative Average Absolute Error	80%	67%
Relative Median Absolute Error	11.1%	41.1%

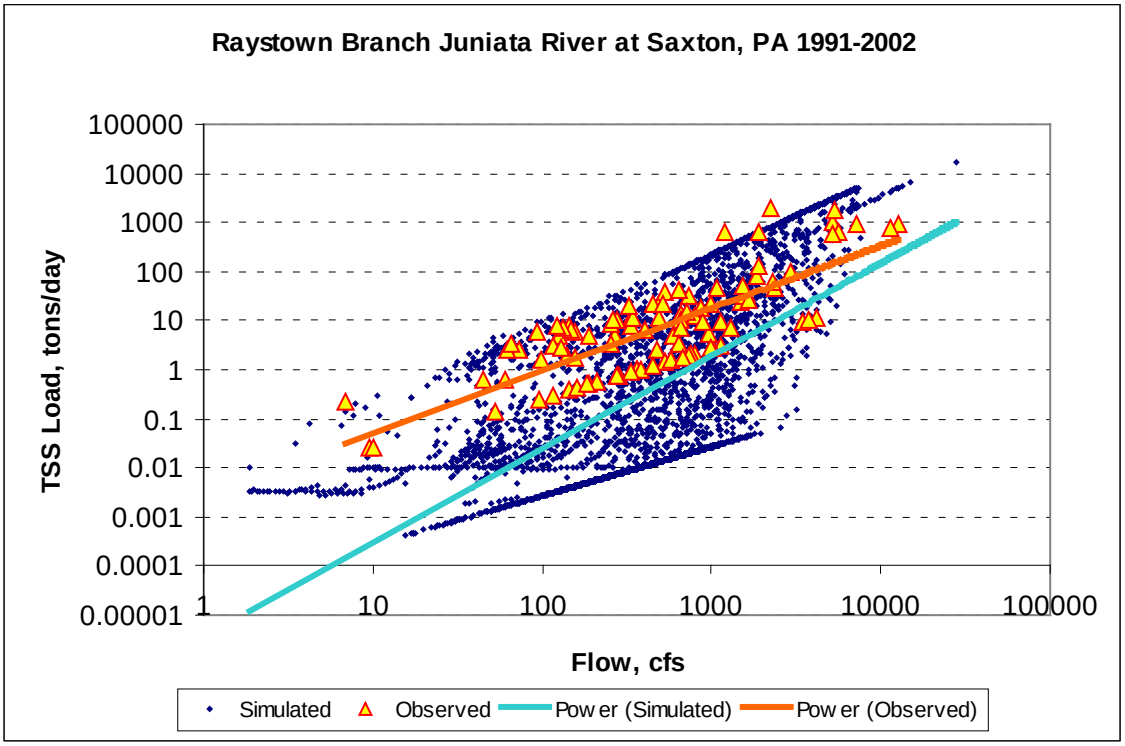

Figure 61. Power plot for observed and simulated TSS at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

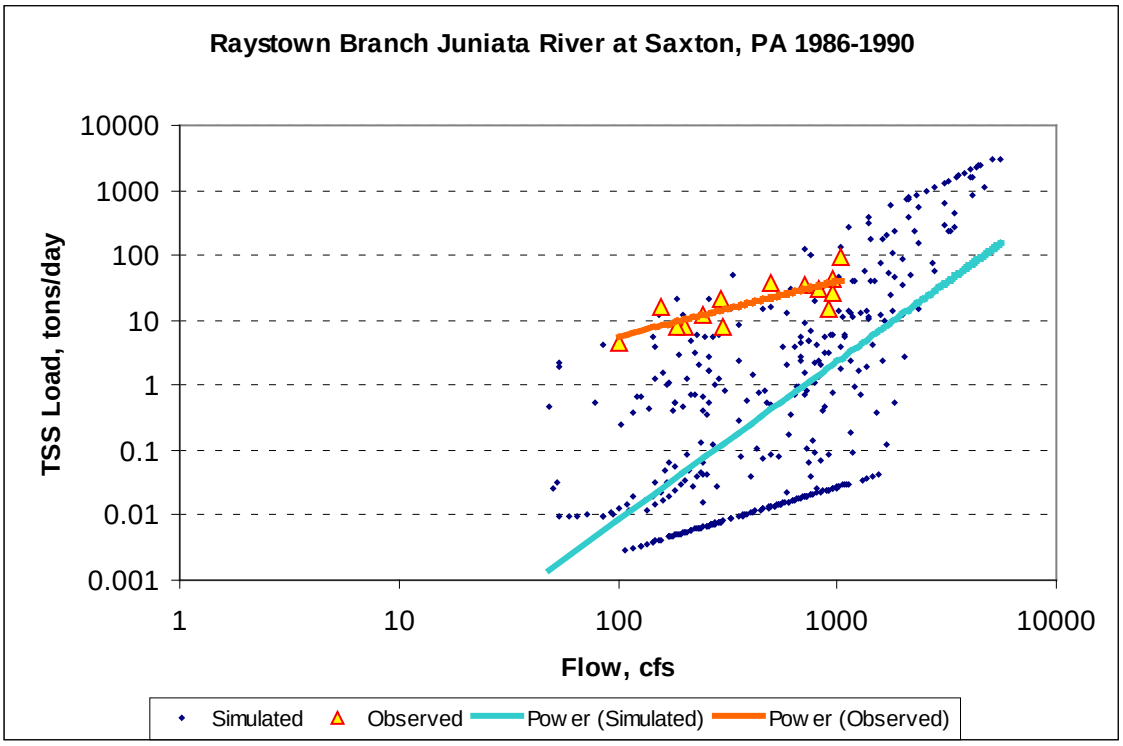

Figure 62. Power plot for observed and simulated TSS at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

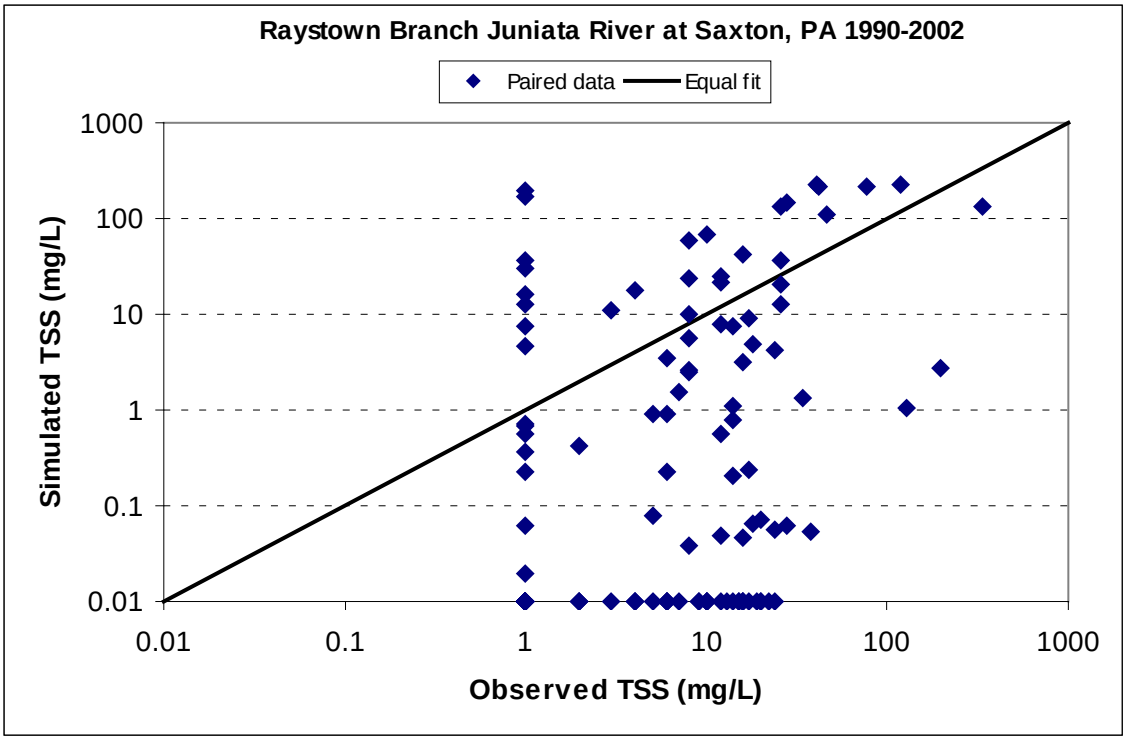

Figure 63. Correlation between observed and predicted TSS concentration at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT).

Table 31. Relative errors (observed minus simulated) for TSS concentrations at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Count	106	14
Concentration Average Error	-26.49%	73.88%
Concentration Median Error	12.04%	73.84%

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

- PHOSKD (phosphorus soil partitioning coefficient)
- NPERCO (nitrogen percolation coefficient)
- PPERCO (phosphorus percolation coefficient)
- SOL_NO3 (initial nitrate concentration in soil layers)
- SOL_ORGN (initial organic nitrogen concentration in soil layers)
- SOL_SOLP (initial soluble phosphorus concentration in soil layers)
- SOL_ORGP (initial organic phosphorus concentration in soil layers)

Various plots that compare total phosphorous simulated by SWAT against the observed data are shown in Figures 64 through 67. The comparison statistics are provided in Tables 32 and 33. Similarly, the results corresponding to total nitrogen are shown in Figures 68 though 71 and Tables 34 and 35. The model representation of total load is generally acceptable, although better for phosphorus than for nitrogen. As with the HSPF application, phosphorus

loads and concentrations tend to be overestimated at lower flows, likely as a result of the simplified representation of point sources.

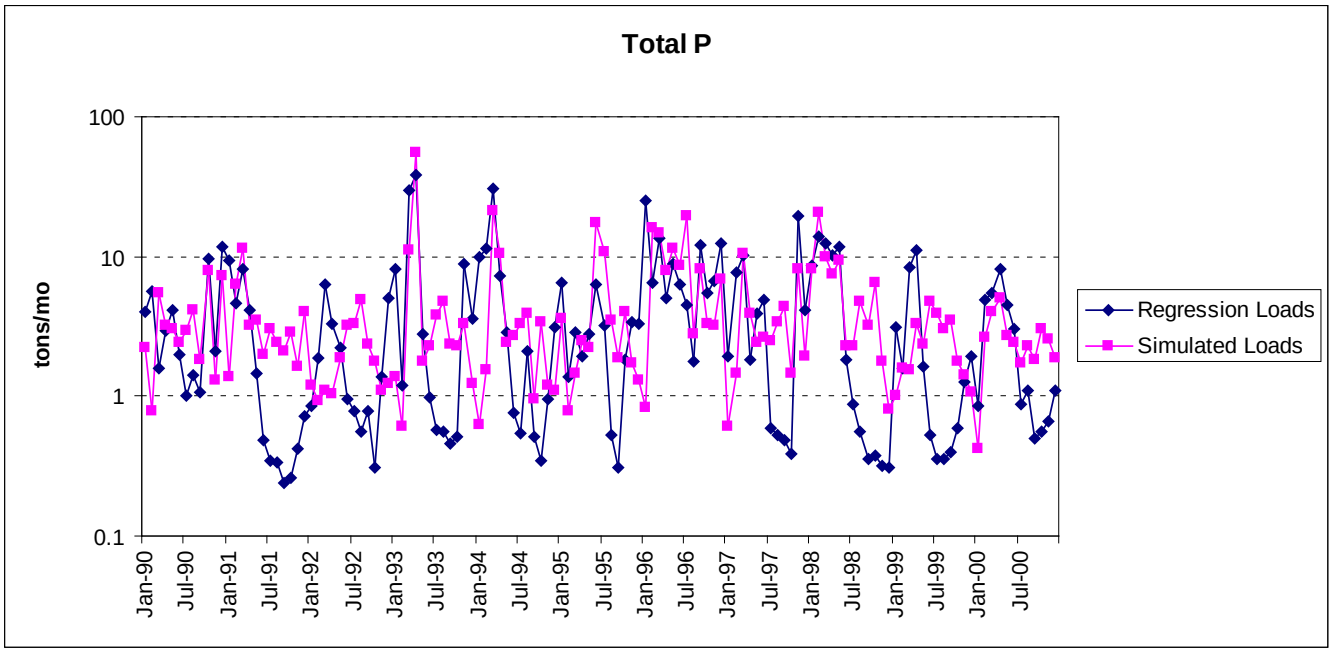

Figure 64. Fit for monthly load of total phosphorous at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT).

Table 32. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	-0.5%	9.2%
Average Absolute Error	73%	54%
Median Absolute Error	48.6%	44.6%

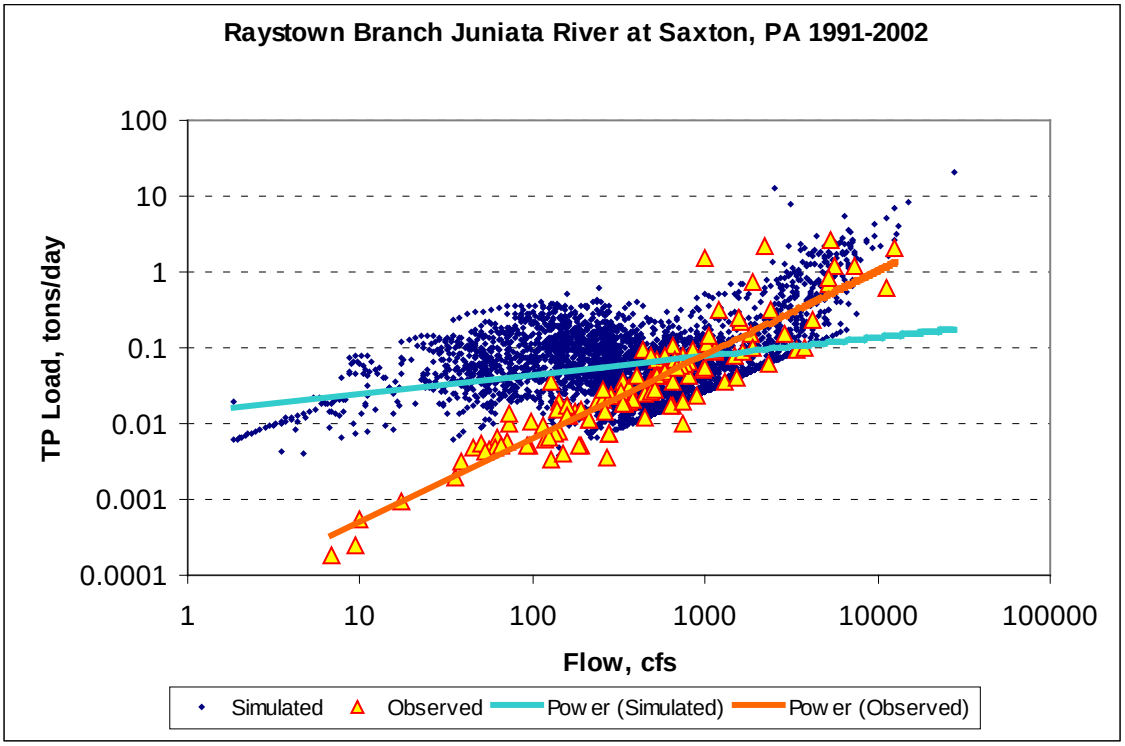

Figure 65. Power plot for observed and simulated total phosphorus at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT)

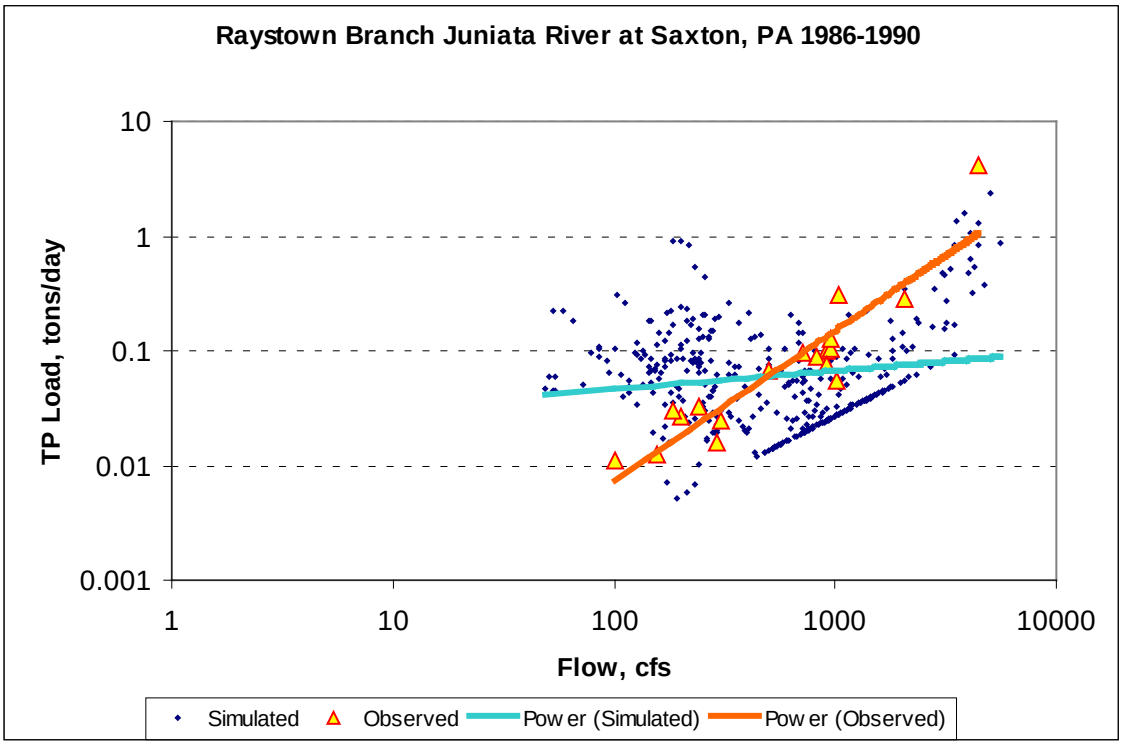

Figure 66. Power plot for observed and simulated total phosphorus at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT)

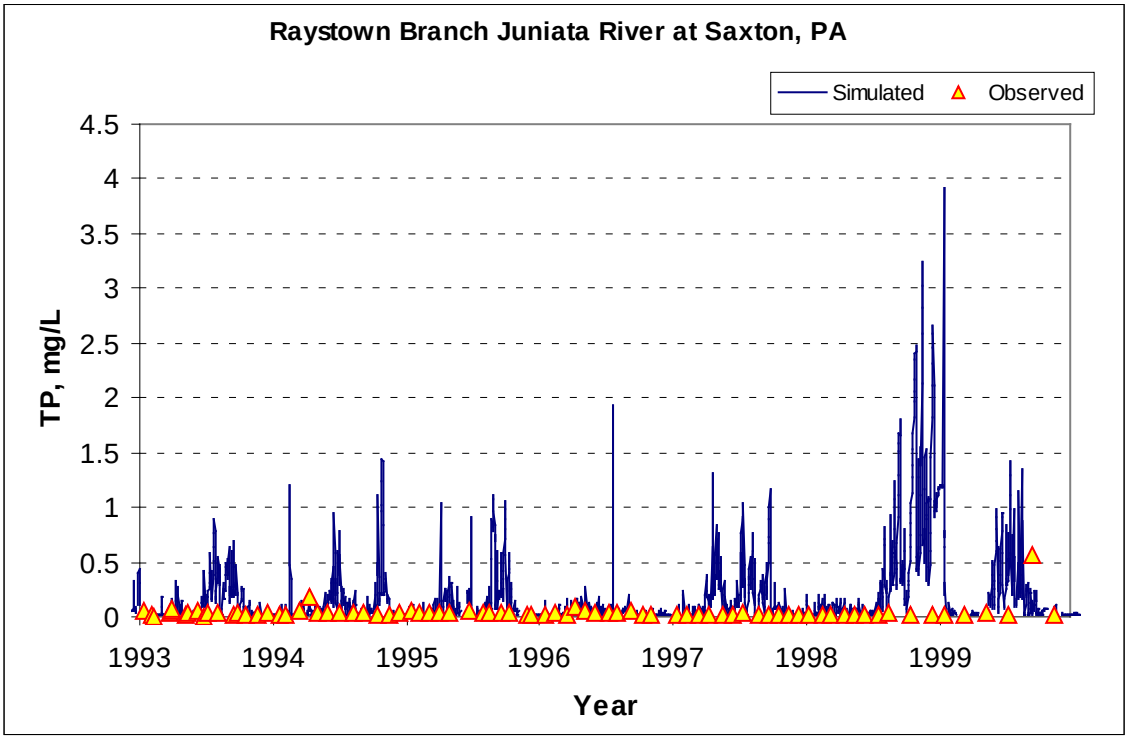

Figure 67. Time series plot of total phosphorus concentration at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT).

Table 33. Relative errors (observed minus predicted), total phosphorus concentration, USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Count	122	18
Concentration Average Error	-377.89%	-58.65%
Concentration Median Error	-71.74%	-9.69%

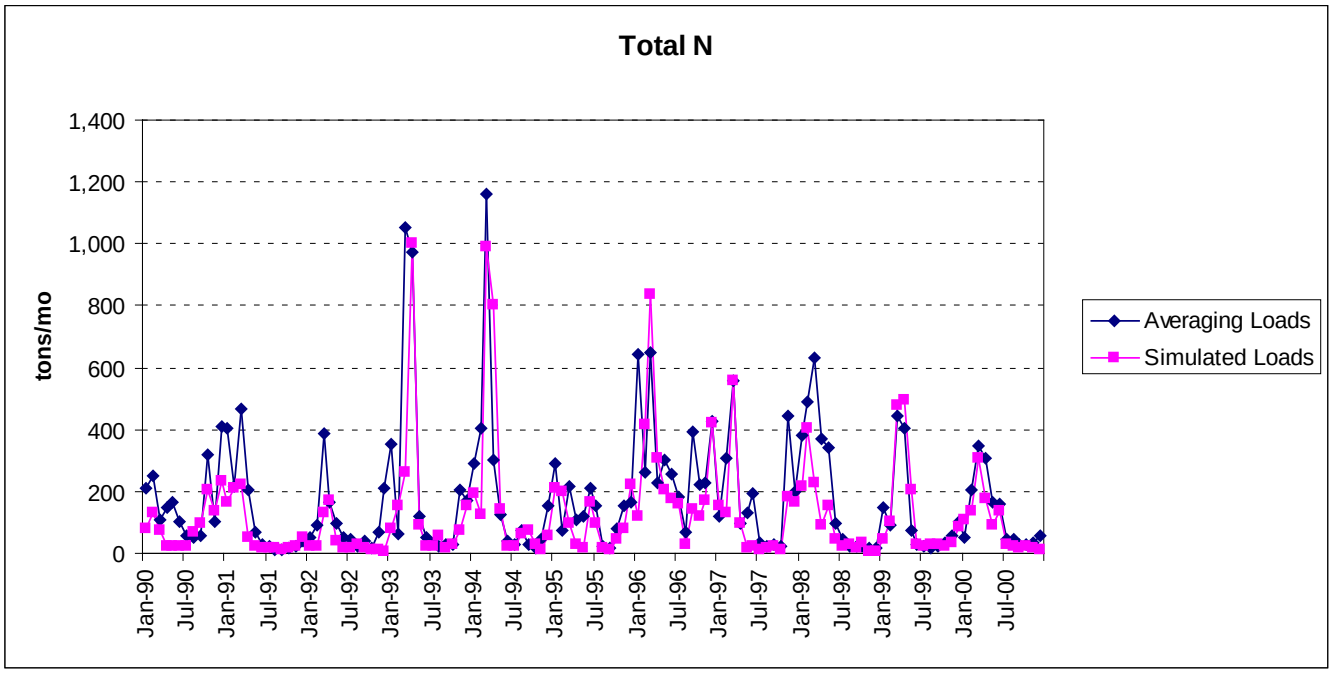

Figure 68. Fit for monthly load of total nitrogen at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Table 34. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator – USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2000)	Validation period (1990)
Relative Percent Error	28.6%	43.9%
Average Absolute Error	45%	53%
Median Absolute Error	19.7%	58.3%

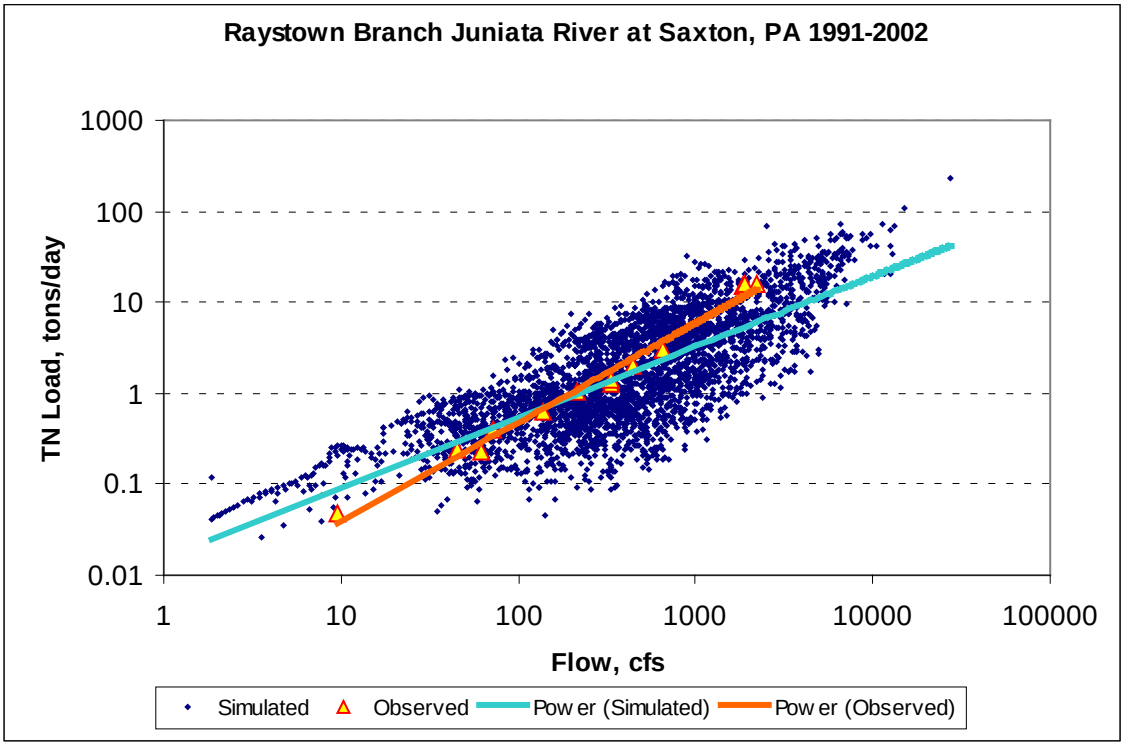

Figure 69. Power plot for observed and simulated total nitrogen at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – calibration period (SWAT).

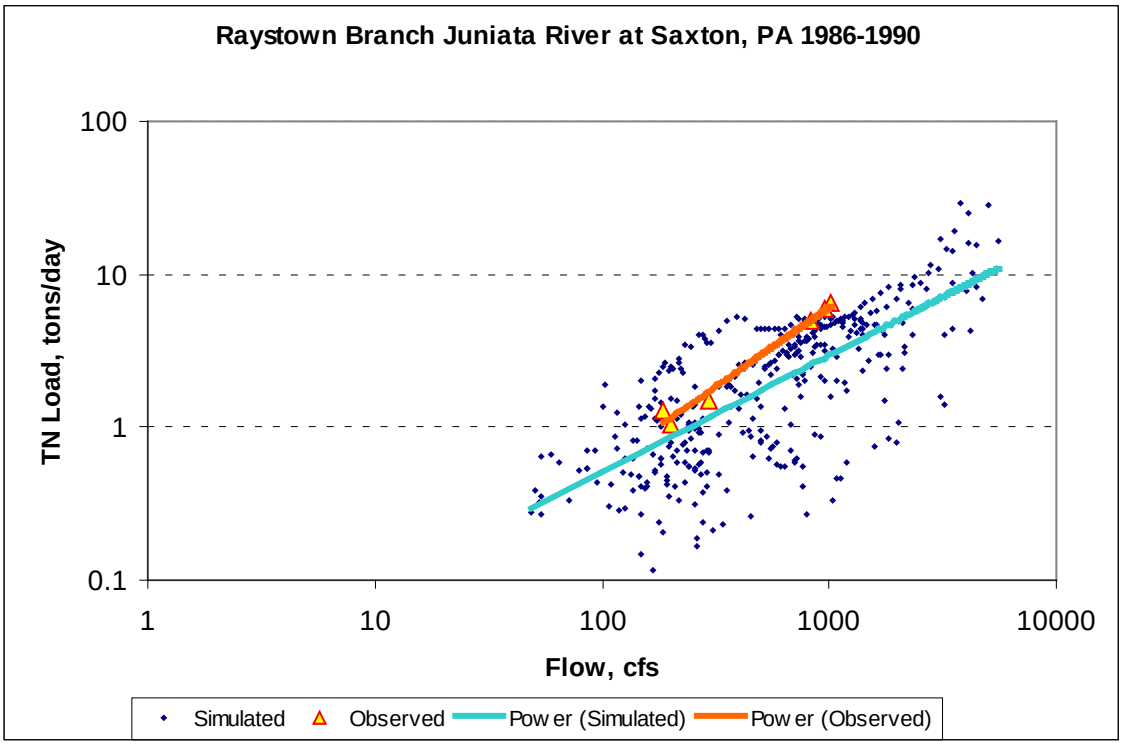

Figure 70. Power plot for observed and simulated total nitrogen at USGS 01562000 Raystown Branch Juniata River at Saxton, PA – validation period (SWAT).

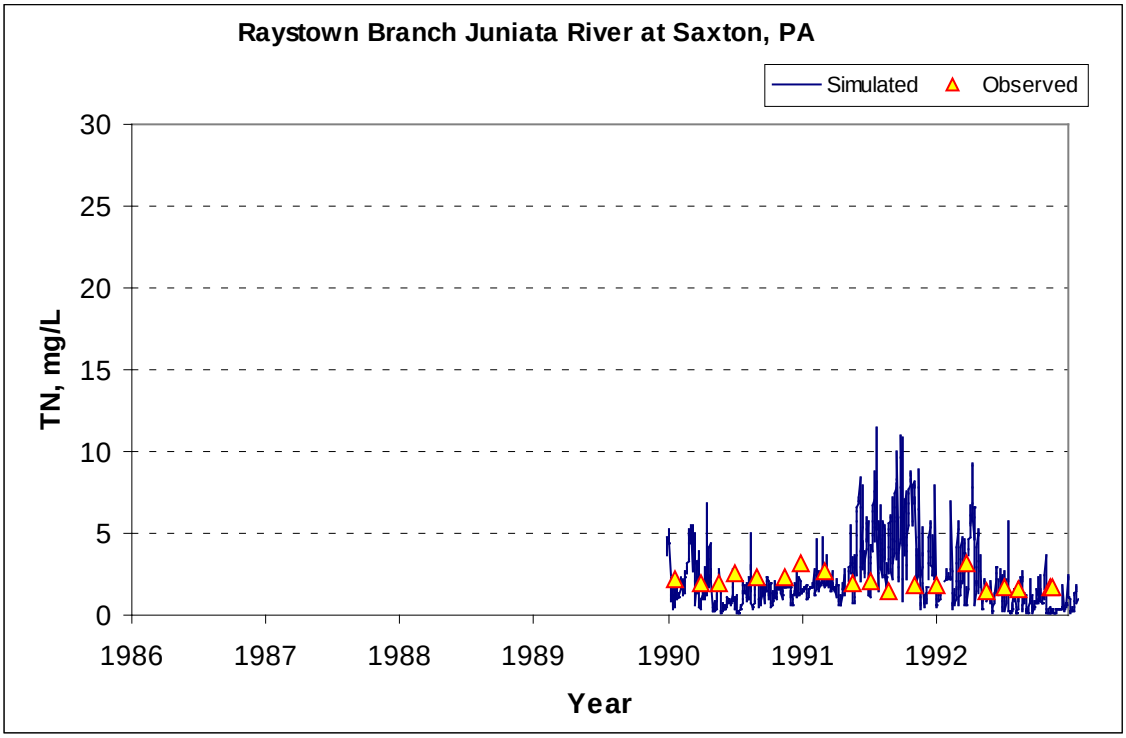

Figure 71. Time series plot of total nitrogen concentration at USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT).

Table 35. Relative errors (observed minus predicted), total nitrogen concentration, USGS 01562000 Raystown Branch Juniata River at Saxton, PA (SWAT)

Statistic	Calibration period (1991-2002)	Validation period (1990)
Count	13	6
Concentration Average Error	-13.82%	32.07%
Concentration Median Error	21.58%	36.92%

Water Quality Results for Larger Watershed

Similar to hydrology calibration, water quality results were compared at other gages. Note that in contrast to the HSPF model, water quality for the SWAT model for Susquehanna River at Marietta, PA was calibrated to the stratified regression monthly load estimates for the entire 1991-2005 period, although the observed data stop with 1995. Summary statistics for the water quality calibration and validation at other stations in the watershed are provided in Tables 36 and 37.

Table 36. Summary statistics for water quality for all stations – calibration period (SWAT)

Station	01576000 Susquehanna River at Marietta, PA (1991-1995)	01540500 Susquehanna River at Danville, PA (1991-1994)	01562000 Raystown Branch Juniata River at Saxton, PA (1991-2000)
Relative Percent Error TSS Load	25.2%	28.4%	-10.1%
TSS Concentration Median Error	-34.0%	-19.9%	12.04%
Relative Percent Error TP Load	-11.4%	22.6%	-0.5%
TP Concentration Median Error	-23.2%	-2.4%	71.74%
Relative Percent Error TN Load	-14.0%	-1.6%	28.6%
TN Concentration Median Error	-39.2%	-7.8%	21.6%

Table 37. Summary statistics for water quality for all stations – validation period (SWAT)

Station	01576000 Susquehanna River at Marietta, PA (1980-1990)	01540500 Susquehanna River at Danville, PA (1986-1990)	01562000 Raystown Branch Juniata River at Saxton, PA (1990)
Relative Percent Error TSS Load	15.2%	17.1%	-33.6%
TSS Concentration Median Error	-22.8%	-3.4%	-73.8%
Relative Percent Error TP Load	0.9%	10.9%	9.2%
TP Concentration Median Error	-21.2%	-21.9%	9.7%
Relative Percent Error TN Load	-0.1%	15.7%	43.9%
TN Concentration Median Error	-16.6%	16.0%	36.9%

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