Appendix O
Model Configuration, Calibration and Validation

Basin: Lake Erie-St. Clair

Contents

Watershed Background **1**
Water Body Characteristics 1
Soil Characteristics 2
Land Use Representation 2
Point Sources 6
Meteorological Data 7
Watershed Segmentation 10
Calibration Data and Locations 10
SWAT Modeling **12**
Assumptions 12
Hydrology Calibration 12
Hydrology Validation 16
Hydrology Results for Larger Watershed 19
Water Quality Calibration and Validation 20
Water Quality Results for Larger Watershed 23
References **25**

Tables

Table 1. Aggregation of NLCD land cover classes 4
Table 2. Land use distribution for the Lake Erie-St. Clair basin (2001 NLCD) (mi^2) 5
Table 3. Major point source discharges in the Lake Erie-St. Clair basin 6
Table 4. Precipitation stations for the Lake Erie-St. Clair watershed model 8
Table 5. Calibration and validation locations in the Lake Erie-St. Clair basin 11
Table 6. Summary statistics at USGS 04208000 Cuyahoga River at Independence, OH – calibration period 16
Table 7. Summary statistics at USGS 04208000 Cuyahoga River at Independence, OH – validation period 19
Table 8. Summary statistics (percent error): all stations - calibration period 20
Table 9. Summary statistics (percent error): all stations - validation period 20
Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 04208000 Cuyahoga River at Independence, OH 21
Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 04208000 Cuyahoga River at Independence, OH 22
Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 04208000 Cuyahoga River at Independence, OH 23
Table 13. Summary statistics for water quality at all stations – calibration period 1990-2000 24
Table 14. Summary statistics for water quality at all stations – validation period 1980-1990 24

Figures

Figure 1. Location of the Lake Erie-St. Clair basin. 2
Figure 2. Land use in the Lake Erie-St. Clair basin. 3
Figure 3. Model segmentation and USGS stations utilized for the Lake Erie-St. Clair basin 10
Figure 4. Mean monthly flow at USGS 04208000 Cuyahoga River at Independence, OH – calibration period. 13
Figure 5. Seasonal regression and temporal aggregate at USGS 04208000 Cuyahoga River at Independence, OH – calibration period. 14
Figure 6. Seasonal medians and ranges at USGS 04208000 Cuyahoga River at Independence, OH – calibration period. 14
Figure 7. Flow exceedance at USGS 04208000 Cuyahoga River at Independence, OH – calibration period. 15
Figure 8. Mean monthly flow at USGS 04208000 Cuyahoga River at Independence, OH – validation period. 17
Figure 9. Seasonal regression and temporal aggregate at USGS 04208000 Cuyahoga River at Independence, OH – validation period. 17
Figure 10. Seasonal medians and ranges at USGS 04208000 Cuyahoga River at Independence, OH – validation period. 18
Figure 11. Flow exceedance at USGS 04208000 Cuyahoga River at Independence, OH – validation period. 18
Figure 12. Fit for monthly Load of TSS at USGS 04208000 Cuyahoga River at Independence, OH. 21
Figure 13. Fit for monthly load of total phosphorus at USGS 04208000 Cuyahoga River at Independence, OH. 22
Figure 14. Fit for monthly load of total nitrogen at USGS 04208000 Cuyahoga River at Independence, OH. 23

Watershed Background

The Lake Erie-St. Clair basin was selected as one of the 15 non-pilot application watersheds for the 20 Watershed study. Watershed modeling for the non-pilot areas is accomplished using the SWAT model only, and model calibration and validation results are presented in abbreviated form.

Water Body Characteristics

The Lake Erie-St. Clair basin are located in areas of northern Ohio, southeastern Michigan, northeastern Indiana, the northern tip of Pennsylvania, and southwestern New York (Figure 1). The study unit drains to the St. Clair River (starting at the outflow of Lake Huron) and to the Detroit River and Lake Erie, which is the 11th-largest freshwater lake in the world. The study unit ends at the Niagara River, the outflow of Lake Erie. Principal streams in the study unit include the Maumee River in Ohio and Indiana, the Sandusky River in Ohio, the River Raisin in Michigan, and Cattaraugus Creek in New York.

Population density and growth in the Lake Erie basin are among the highest in the Great Lakes basin. About 40 percent of the total population of the Great Lakes basin lives in the Lake Erie basin in 17 urban areas having populations of 50,000 or more. Water resources in the study unit are central to the economy and culture of the region. The surficial deposits of this area consist primarily of ground moraine and end moraine of glacial origin; valleys are filled with glacial outwash. The area is characterized by broad, low ridges with smooth, gentle slopes separated by flat, gently undulating plains. The Eastern Lake Section and the Till Plains Section within the province consist of wide expanses of flat land underlain by clayey till or lake deposits; this flat land is interspersed with sandy ridges that are remnants of glacial-lake beaches. Because soils are fertile and the climate is temperate, the primary land use in this part of the study unit is agricultural, ranging from orchards and vineyards near the Lake Erie shoreline to cropland in corn and soybeans further inland.

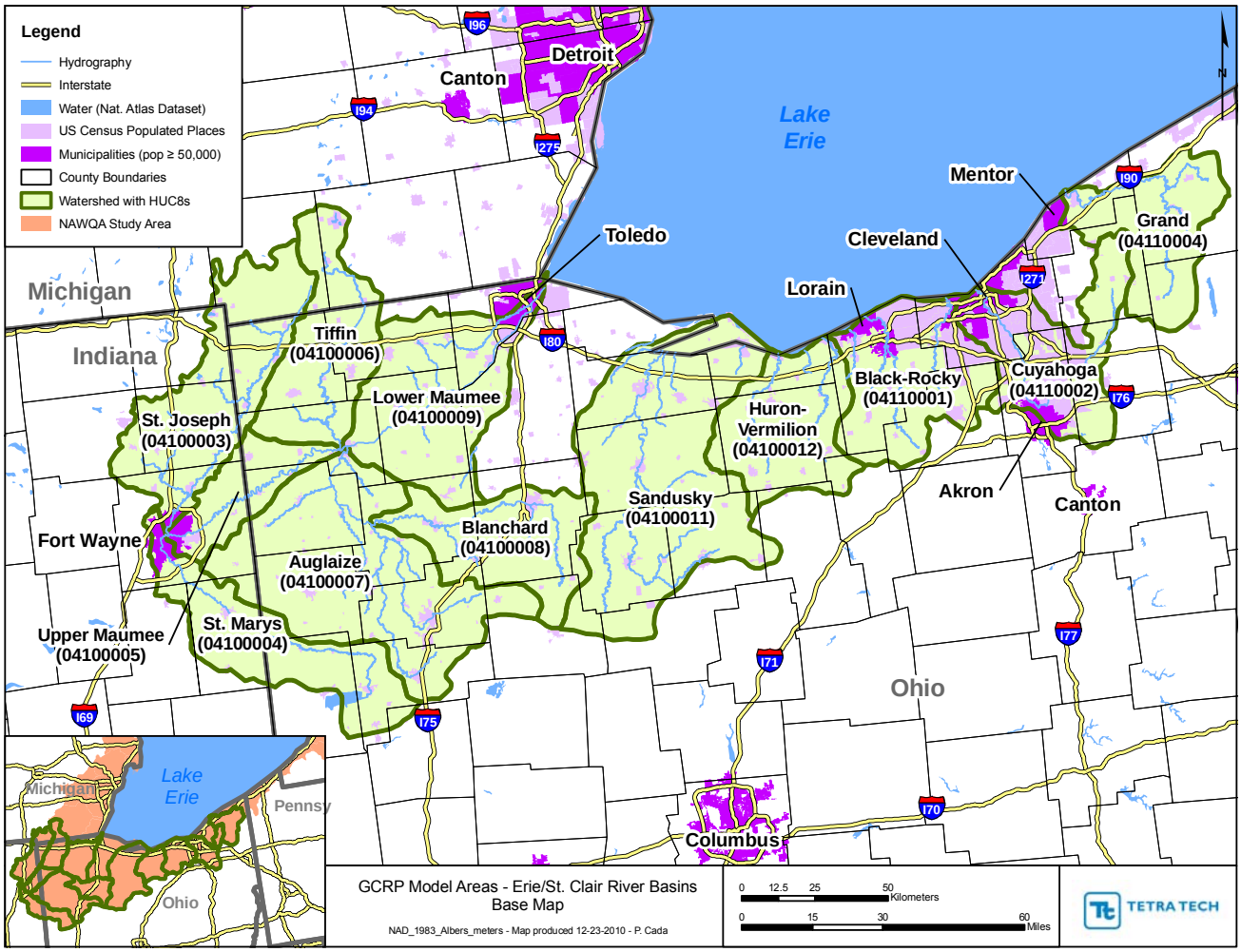

Figure 1. Location of the Lake Erie-St. Clair basin.

Soil Characteristics

Soils in the watershed are described in STATSGO soil surveys. SWAT uses information drawn directly from the soils data layer to populate the model.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage (Figure 2). NLCD land cover classes were aggregated according to the scheme shown in

Table 1 for representation in the 20 Watershed model. SWAT uses the built-in hydrologic response unit (HRU) overlay mechanism in the ArcSWAT interface. SWAT HRUs are formed from an intersection of land use and SSURGO major soils. The distribution of land use in the watershed is summarized in Table 2.

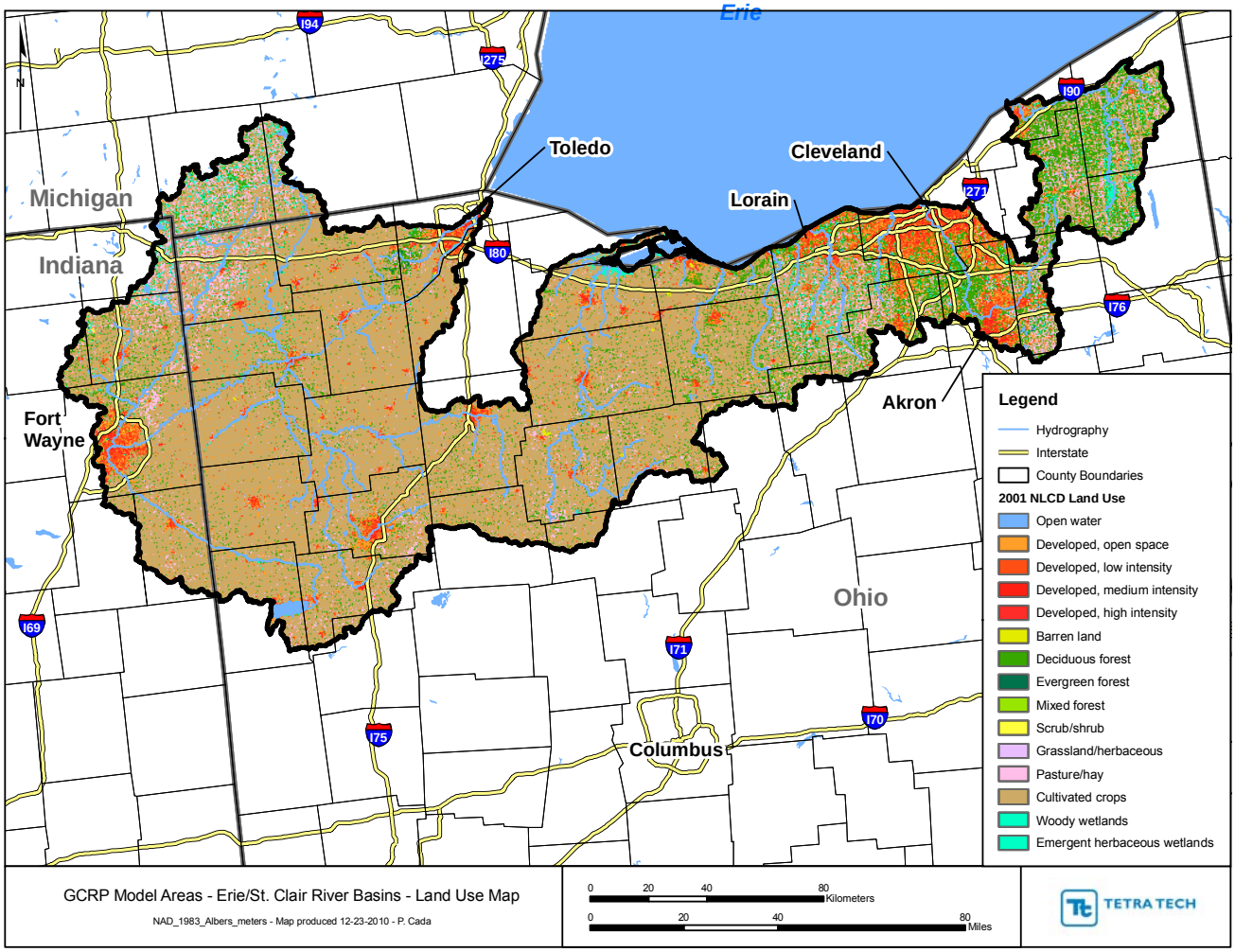

Figure 2. Land use in the Lake Erie-St. Clair basin.

Table 1. Aggregation of NLCD land cover classes

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

Table 2. Land use distribution for the Lake Erie-St. Clair basin (2001 NLCD) (mi^2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
St Joseph **04100003**	12.64	59.39	29.98	6.86	3.15	0.48	116.78	12.92	177.00	548.79	78.87	**1,046.87**
St Marys **04100004**	12.67	59.51	27.74	9.47	4.39	0.01	43.93	11.90	17.01	610.07	4.75	**801.44**
Upper Maumee **04100005**	4.57	30.69	21.75	4.98	2.82	0.10	20.65	2.65	18.08	288.18	4.67	**399.16**
Tiffin **04100006**	5.43	41.62	15.47	3.21	1.78	0.78	54.49	3.60	83.16	522.12	45.77	**777.42**
Auglaize **04100007**	8.99	119.04	43.26	9.28	5.66	1.62	88.15	20.16	28.90	1,356.54	5.41	**1,687.02**
Blanchard **04100008**	3.49	49.53	18.86	4.94	2.34	0.32	40.98	12.10	6.73	603.39	2.46	**745.15**
Lower Maumee **04100009**	14.58	79.68	45.49	16.52	7.81	1.05	71.80	10.53	14.12	792.66	5.46	**1,059.69**
Sandusky **04100011**	14.29	114.36	47.75	14.21	7.02	5.90	143.03	20.77	43.65	1,357.56	30.99	**1,799.51**
Huron-Vermilion **04100012**	6.27	44.88	18.61	4.29	1.90	0.14	145.50	2.26	37.24	487.49	9.03	**757.61**
Black-Rocky **04110001**	6.55	127.18	110.79	27.76	6.21	0.90	220.19	8.06	105.82	211.62	55.12	**880.21**
Cuyahoga **04110002**	19.15	137.17	140.10	55.15	19.73	0.59	243.90	26.75	55.98	60.05	21.70	**780.26**
Grand **04110004**	8.73	41.61	25.50	3.00	0.77	0.06	292.18	39.90	62.44	166.57	43.96	**684.73**
Total	**117.37**	**904.68**	**545.31**	**159.67**	**63.58**	**11.95**	**1,481.58**	**171.59**	**650.11**	**7,005.05**	**308.19**	**11,419.09**

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (7.30%), low density (32.53%), medium density (60.72%), and high density (86.75%).

Point Sources

There are numerous point source discharges in the watershed. Only the major dischargers, generally defined as those with a design flow greater than 1 MGD are included in the simulation (Table 3). The major dischargers are represented at long-term average flows, without accounting for changes over time or seasonal variations.

Table 3. Major point source discharges in the Lake Erie-St. Clair basin

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD)
OH0034223	LUCAS CO COMMISSIONERS	15.00	15.21
OH0002666	GENERAL MOTORS CORPORATION		1.90
OH0003298	CAMPBELL SOUP COMPANY		5.11
OH0020893	CITY OF NAPOLEON	2.50	2.92
OH0024899	CITY OF DEFIANCE	4.00	3.30
OH0025771	VILLAGE OF HICKSVILLE		0.75
OH0027910	CITY OF VAN WERT	2.78	3.39
OH0026921	VILLAGE OF OTTAWA		1.54
OH0027952	CITY OF WAPAKONETA	4.00	2.60
OH0023841	ALLEN COUNTY COMMISSIONERS		1.44
OH0037338	ALLEN CO. COMMISSIONERS		3.17
OH0002615	PCS NITROGEN OHIO, LP		3.50
OH0002623	LIMA REFINING COMPANY		17.70
OH0026069	CITY OF LIMA	18.50	26.33
OH0020851	VILLAGE OF BLUFFTON		2.28
OH0025135	CITY OF FINDLAY	9.00	10.18
OH0020532	CITY OF BRYAN	3.14	2.35
OH0020796	VILLAGE OF ARCHBOLD	1.75	1.36
IN0032191	FORT WAYNE MUNICIPAL WWTP	60.00	88.87
IN0000388	DANA SPICER MANUFACTURING INC.	1.36	0.98
IN0022462	BUTLER MUNICIPAL WWTP	2.00	0.67
IN0020672	AUBURN MUNICIPAL WPCP	4.50	2.70
OH0025291	CITY OF FREMONT	11.00	17.30
OH0052949	CITY OF TIFFIN	6.00	3.27
OH0020001	CITY OF UPPER SANDUSKY	1.50	1.47
OH0020664	CITY OF CRESTLINE		0.95
OH0022659	VILLAGE OF CHARDON		2.35
OH0026948	CITY OF PAINESVILLE	6.00	2.93
OH0000957	ISG CLEVELAND		3.69

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD)
OH0024651	NEORSD - SOUTHERLY WWTP	175.00	115.67
OH0024040	CITY OF BEDFORD	3.20	2.38
OH0024058	CITY OF BEDFORD HEIGHTS	7.50	2.49
OH0027430	SOLON CITY CENTRAL	3.60	4.00
OH0027863	CITY OF TWINSBURG	3.40	2.92
OH0098043	EARTH TECH	1.40	2.72
OH0025917	CITY OF KENT	5.00	2.59
OH0064009	SUMMIT COUNTY - FISHCREEK #25	4.00	3.92
OH0023221	CITY OF RAVENNA	2.80	2.20
OH0001562	REPUBLIC ENGINEERED PRODUCTS		87.30
OH0023981	AVON LAKE WASTEWATER PLANT	6.50	9.67
OH0026093	CITY OF LORAIN	15.00	13.09
OH0020427	OBERLIN WATER ENV. PROTECTION	1.50	1.27
OH0025372	VILLAGE OF GRAFTON	1.00	3.74
OH0024660	NEORSD - WESTERLY WWTP	50.00	28.50
OH0026794	CITY OF NORTH ROYALTON	1.50	1.55
OH0030503	CITY OF ROCKY RIVER	22.00	11.13
OH0045748	MEDINA COUNTY COMM SD 300	2.00	1.66
OH0043567	MEDINA COUNTY COMM SD 500	10.00	9.04
OH0020125	HURON BASIN STP		0.87
OH0028118	CITY OF WILLARD	1.36	1.80
OH0021628	CITY OF AMHERST	2.00	1.88
OH0020672	CITY OF BELLEVUE	1.20	1.09
OH0024686	CITY OF CLYDE	1.90	1.95

Most of these point sources have reasonably complete monitoring for total suspended solids (TSS). Long term average values of total phosphorus and total nitrogen were assumed based upon the type of point source discharger. The point sources were initially represented in the model with the median of reported values for total phosphorus, total suspended solids and total nitrogen.

Meteorological Data

The required meteorological time series for the 20 Watershed SWAT simulations are precipitation and air temperature. The 20 Watershed simulations do not include water temperature and uses a degree-day method for snowmelt. SWAT estimates Penmann-Monteith potential evapotranspiration using a statistical weather generator for inputs other than temperature and precipitation. These meteorological time series are drawn from the BASINS4 Meteorological Database (USEPA 2008), which provides a consistent, quality-assured set of nationwide data with gaps filled and records disaggregated. Scenario application requires simulation over 30 years, so the available stations are those with a common 30-year period of record (or one that can be filled from

an approximately co-located station) that covers the year 2000. A total of 57 precipitation stations were identified for use in the Lake Erie-St. Clair watershed model with a common period of record of 10/1/1969-9/30/2000 (Table 4). Temperature records are sparser; where these are absent temperature is taken from nearby stations with an elevation correction.

Table 4. Precipitation stations for the Lake Erie-St. Clair watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (m)
IN120200	ANGOLA	41.6397	-84.9899	x	308
IN120676	BERNE	40.6684	-84.9305	x	265
IN122096	DECATUR 1 N	40.8482	-84.9294		250
IN123037	FORT WAYNE WSO AP	41.0062	-85.2056	x	252
IN123206	GARRETT	41.3330	-85.1329		82
IN124497	KENDALLVILLE	41.4428	-85.2613		297
MI200032	ADRIAN 2 NNE	41.9165	-84.0157	x	232
MI203823	HILLSDALE	41.9353	-84.6410	x	329
OH330058	AKRON CANTON WSO AP	40.9167	-81.4333	x	368
OH330059	AKRON WPCS	41.1500	-81.5669		70
OH330061	AKRON	41.0804	-81.5169	x	329
OH330107	ALLIANCE 3 NNW	40.9550	-81.1169		322
OH330256	ASHLAND 2 SW	40.8334	-82.3499	x	386
OH330862	BOWLING GREEN WWTP	41.3831	-83.6110	x	206
OH331042	BRYAN 2 SE	41.4670	-84.5330		68
OH331072	BUCYRUS	40.8129	-82.9693	x	291
OH331390	CELINA 3 NE	40.5695	-84.5364	x	262
OH331458	CHARDON	41.5834	-81.1833	x	344
OH331541	CHIPPEWA LAKE	41.0517	-81.9360	x	360
OH331657	CLEVELAND WSFO AP	41.4051	-81.8528	x	235
OH332098	DEFIANCE	41.2778	-84.3853	x	213
OH332251	DORSET	41.6834	-80.6667	x	299
OH332599	ELYRIA 3 E	41.3833	-82.0499	x	223
OH332786	FINDLAY FAA AIRPORT	41.0136	-83.6685	x	244
OH332791	FINDLAY WPCC	41.0462	-83.6621	x	234
OH332974	FREMONT	41.3334	-83.1166	x	183
OH333021	GALION WATER WORKS	40.7236	-82.7999		357
OH333421	GROVER HILL	41.0184	-84.4724		223
OH333780	HIRAM	41.3000	-81.1500	x	375
OH333874	HOYTVILLE 2 NE	41.2168	-83.7667	x	213

OH333915	HUNTSVILLE 3 N	40.4803	-83.8131		314
OH334189	KENTON	40.6489	-83.6060	x	303
OH334551	LIMA WWTP	40.7247	-84.1294	x	259
OH334865	MANSFIELD WSO AP	40.8204	-82.5177	x	395
OH334874	MANSFIELD 5 W	40.7668	-82.6166	x	411
OH334942	MARION 2 N	40.6168	-83.1333	x	294
OH335438	MONTPELIER	41.5804	-84.6077	x	262
OH335505	MOSQUITO CREEK LAKE	41.3000	-80.7667		277
OH335669	NAPOLEON	41.3940	-84.1144	x	208
OH336118	NORWALK WWTP	41.2668	-82.6166	x	204
OH336196	OBERLIN	41.2668	-82.2167	x	249
OH336342	OTTAWA	41.0318	-84.0528		223
OH336389	PAINESVILLE 4 NW	41.7500	-81.2999	x	183
OH336405	PANDORA	40.9543	-83.9616	x	235
OH336465	PAULDING	41.1245	-84.5922	x	221
OH336949	RAVENNA 2 S	41.1333	-81.2832		337
OH337383	ST MARYS 3 W	40.5447	-84.4374		267
OH337447	SANDUSKY	41.4501	-82.7167	x	178
OH337698	SIDNEY HIGHWAY DEPT	40.2983	-84.1633		314
OH338110	STRYKER	41.5057	-84.4300		213
OH338313	TIFFIN	41.1168	-83.1667	x	226
OH338357	TOLEDO EXPRESS WSO AP	41.5886	-83.8014	x	204
OH338534	UPPER SANDUSKY	40.8334	-83.2832	x	260
OH338539	UPPER SANDUSKY WATER WK	40.8167	-83.2832		250
OH338609	VAN WERT 1 S	40.8495	-84.5807	x	241
OH338769	WARREN 3 S	41.2001	-80.8166	x	274
OH338822	WAUSEON WATER PLANT	41.5184	-84.1453	x	229

Watershed Segmentation

The Lake Erie-St. Clair basin was divided into 100 subwatersheds for the purposes of modeling (Figure 3). The model encompasses the complete watershed and does not require specification of any upstream boundary conditions for application.

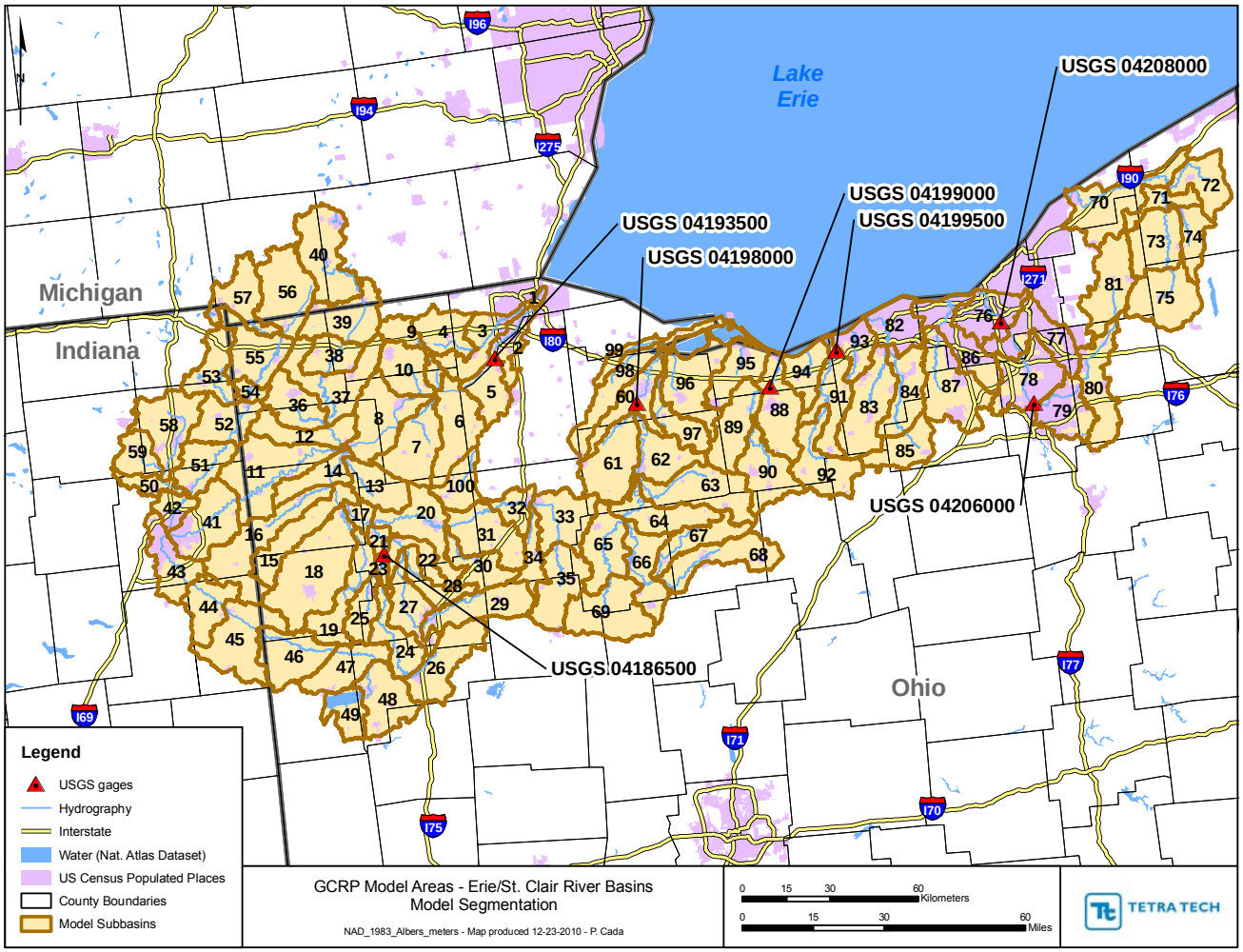

Figure 3. Model segmentation and USGS stations utilized for the Lake Erie-St. Clair basin

Calibration Data and Locations

The specific site chosen for initial calibration was the Cuyahoga River at Independence (USGS 04208000), a flow and water quality monitoring location that approximately coincides with the mouth of an 8-digit HUC. The Cuyahoga River watershed was selected because there is a good set of flow and water quality data available and the watershed lacks major point sources and impoundments. Additional calibration and validation was pursued at multiple locations (Table 5). Parameters derived on the Cuyahoga River were not fully transferable to other portions of the Lake Erie-St. Clair basin, and additional calibration was conducted at multiple gage locations.

Table 5. Calibration and validation locations in the Lake Erie-St. Clair basin

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Auglaize River near Fort Jennings OH	04186500	332	x	
Maumee River at Waterville OH	04193500	6,330	x	x
Sandusky River near Fremont OH	04198000	1,251	x	x
Huron River at Milan OH	04199000	371	x	
Black River at Elyria OH	04200500	396	x	
Cuyahoga River at Old Portage OH	04206000	404	x	
Cuyahoga River at Independence OH	04208000	707	x	x

The model hydrology calibration period was set to Water Years 1990-2000 (within the 32-year period of record for modeling). Hydrologic validation was then performed on Water Years 1980-1990. Water quality calibration used calendar years 1990-2000, while validation used 1980-1990.

SWAT Modeling

Assumptions

There were no significant impoundments and/or diversions that needed representation in the watershed model for the Lake Erie-St. Clair basin.

Hydrology Calibration

A spatial calibration approach was adopted for GCRP-SWAT modeling for the Lake Erie-St. Clair basin. A systematic adjustment of parameters has been adopted and some adjustments are applied throughout the basin. Most of the calibration efforts were geared towards getting a closer match between simulated and observed flows at the outlet of calibration focus area.

Land Use / Soil / Slope Definition

A 5/10/5 percent threshold was used for land use/soil/slope in the SWAT model while defining the HRUs. Urban land use classes were exempted from the HRU overlay thresholds.

The calibration focus area (Cuyahoga River) includes six subwatersheds and is generally representative of the general land use characteristics of the overall watershed with the exception of a higher percentage of cultivated lands. The parameters were adjusted within the practical range to obtain reasonable fit between the simulated and measured flows in terms of Nash-Sutcliffe modeling efficiency and the high flow and low flow components as well as the seasonal flows.

The water balance of the whole Lake Erie-St. Clair basin predicted by the SWAT model over the 32-year simulation period is as follows:

```
PRECIP =    934.7 MM
SNOW FALL = 125.69 MM
SNOW MELT =   122.44 MM
SUBLIMATION =     1.95 MM
SURFACE RUNOFF Q =   233.68 MM
LATERAL SOIL Q =    1.40 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    92.63 MM
REVAP (SHAL AQ => SOIL/PLANTS) =    4.67 MM
DEEP AQ RECHARGE =    13.62 MM
TOTAL AQ RECHARGE = 110.90 MM
TOTAL WATER YLD =   327.70 MM
PERCOLATION OUT OF SOIL = 110.91 MM
ET =    583.7 MM
PET =   1152.4MM
TRANSMISSION LOSSES =     0.00 MM
```

Hydrologic calibration adjustments focused on the following parameters:

- CN2 (initial SCS runoff curve number for moisture condition II)
- ESCO (soil evaporation compensation factor)
- SURLAG (surface runoff lag coefficient)
- SOL_AWC (available water capacity of the soil layer, mm water/mm of soil)

- ALPHA_BF (baseflow alpha factor, days)
- GW_DELAY (groundwater delay time, days)
- GWQMIN (threshold depth of water in the shallow aquifer required for return flow to occur, mm)
- GW_REVAP (groundwater "revap" coefficient)
- CH_N1 (Manning's "n" value for tributary channels)
- CH_N2 (Manning's "n" value for main channels)
- CH_K1 (Effective hydraulic conductivity in tributary channel alluvium)
- CH_K2 (Effective hydraulic conductivity in main channel alluvium)
- SFTMP (Snowfall temperature)
- SMTMP (Snowmelt base temperature)
- SMFMX (Maximum melt rate for snow during the year)
- SMFMN (Minimum melt rate for snow during the year)

The calibration achieves a moderately high coefficient of model fit efficiency, but is below on 50 percent lowest flow volume. Calibration results for the Cuyahoga River are summarized in Figure 4, Figure 5, Figure 6, Figure 7 and Table 6.

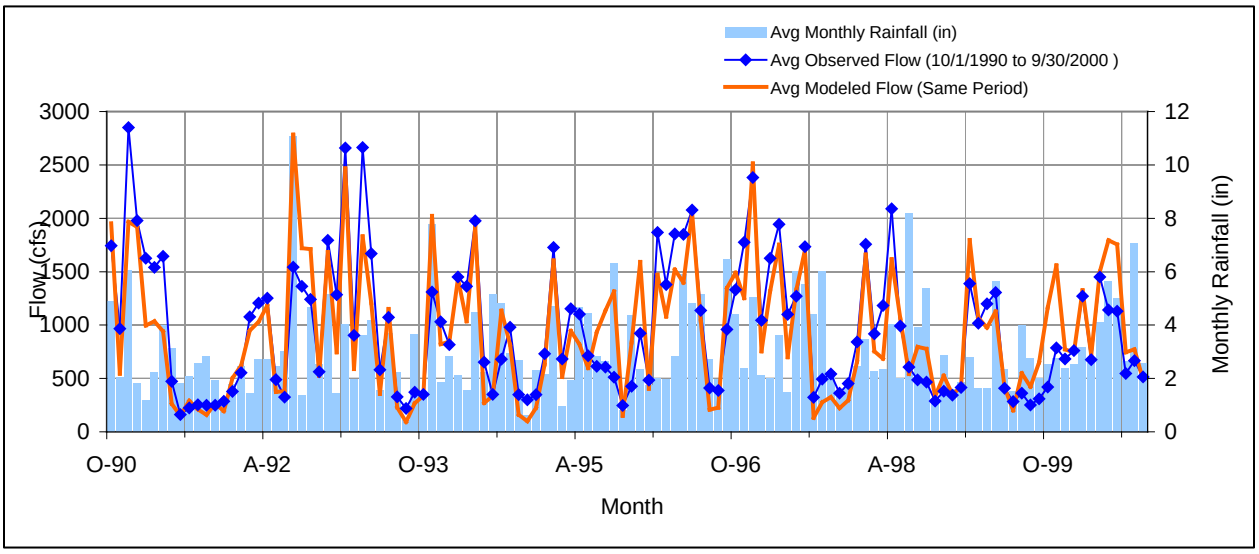

Figure 4. Mean monthly flow at USGS 04208000 Cuyahoga River at Independence, OH – calibration period.

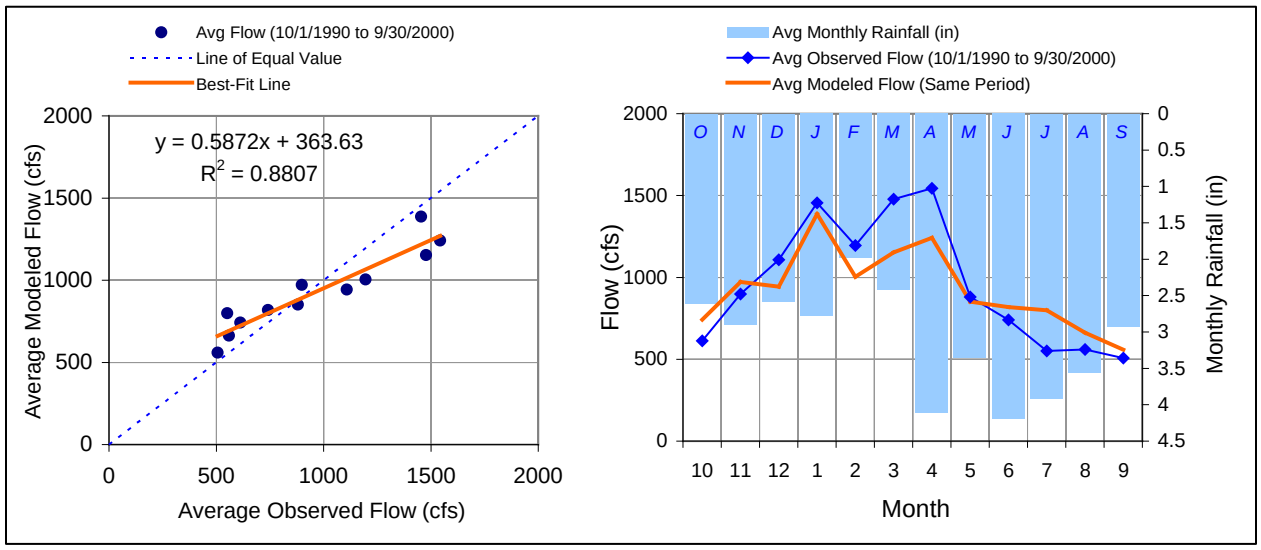

Figure 5. Seasonal regression and temporal aggregate at USGS 04208000 Cuyahoga River at Independence, OH – calibration period.

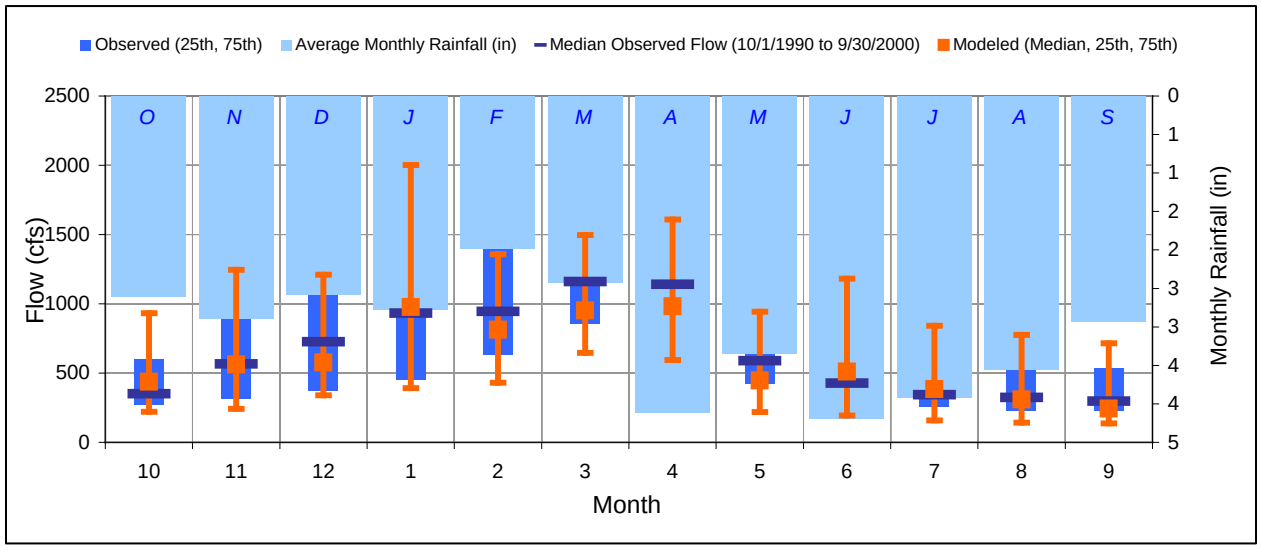

Figure 6. Seasonal medians and ranges at USGS 04208000 Cuyahoga River at Independence, OH – calibration period.

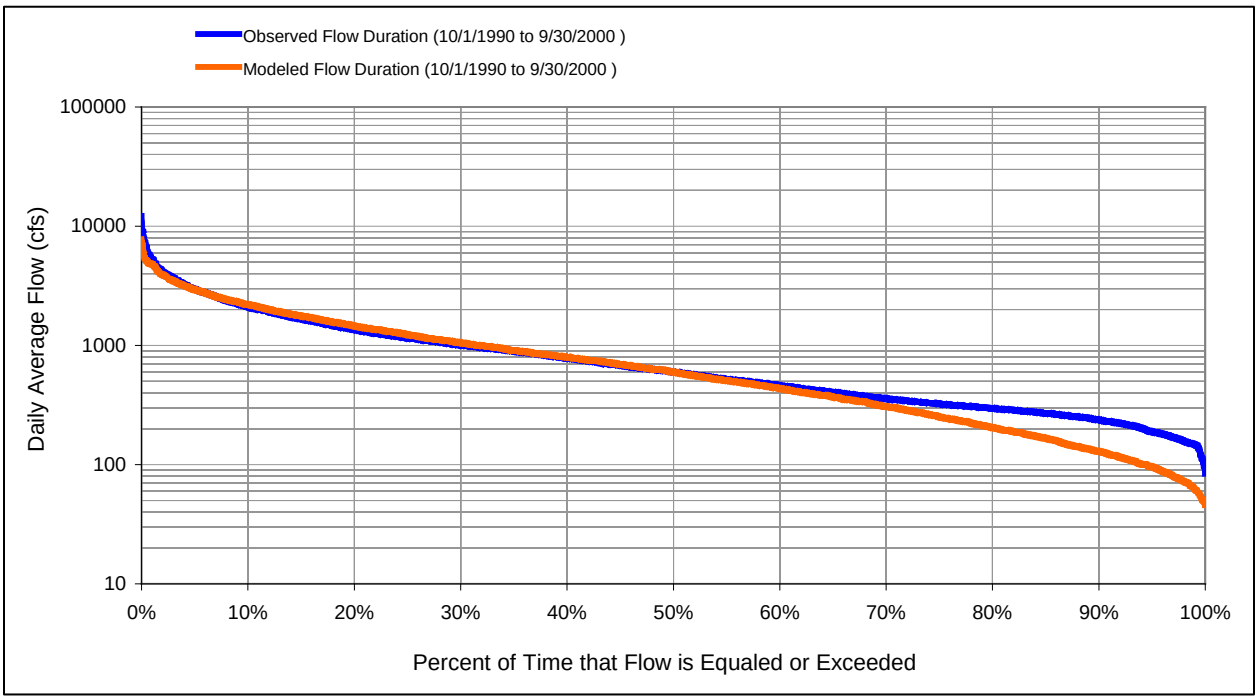

Figure 7. Flow exceedance at USGS 04208000 Cuyahoga River at Independence, OH – calibration period.

Table 6. Summary statistics at USGS 04208000 Cuyahoga River at Independence, OH – calibration period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 77 10-Year Analysis Period: 10/1/1990 - 9/30/2000 Flow volumes are (inches/year) for upstream drainage area		USGS 04208000 Cuyahoga River at Independence OH Hydrologic Unit Code: 4110002 Latitude: 41.39533087 Longitude: -81.6298478 Drainage Area (sq-mi): 707	
Total Simulated In-stream Flow:	**17.82**	Total Observed In-stream Flow:	**18.43**
Total of simulated highest 10% flows:	**6.24**	Total of Observed highest 10% flows:	**6.64**
Total of Simulated lowest 50% flows:	**2.68**	Total of Observed Lowest 50% flows:	**3.29**
Simulated Summer Flow Volume (months 7-9):	**3.27**	Observed Summer Flow Volume (7-9):	**2.61**
Simulated Fall Flow Volume (months 10-12):	**4.28**	Observed Fall Flow Volume (10-12):	**4.22**
Simulated Winter Flow Volume (months 1-3):	**5.64**	Observed Winter Flow Volume (1-3):	**6.56**
Simulated Spring Flow Volume (months 4-6):	**4.64**	Observed Spring Flow Volume (4-6):	**5.04**
Total Simulated Storm Volume:	**6.32**	Total Observed Storm Volume:	**7.04**
Simulated Summer Storm Volume (7-9):	**1.40**	Observed Summer Storm Volume (7-9):	**1.09**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-3.32	10	
Error in 50% lowest flows:	**-18.67**	**10**	
Error in 10% highest flows:	-6.08	15	
Seasonal volume error - Summer:	25.11	30	
Seasonal volume error - Fall:	1.39	30	
Seasonal volume error - Winter:	-14.11	30	
Seasonal volume error - Spring:	-7.94	30	
Error in storm volumes:	-10.20	20	
Error in summer storm volumes:	28.01	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.610	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.442	as E or E' approaches 1.0	
Monthly NSE	0.843		

Hydrology Validation

Hydrology validation for Cuyahoga River at Independence was performed for the period 10/1/1980 through 9/30/1990. The validation achieves a moderately high coefficient of model fit efficiency, but is below on total flow, 50 percent lowest flow and 10 percent highest flow volumes. Validation results for the Cuyahoga River are summarized in Figure 8, Figure 9, Figure 10, Figure 11 and Table 7.

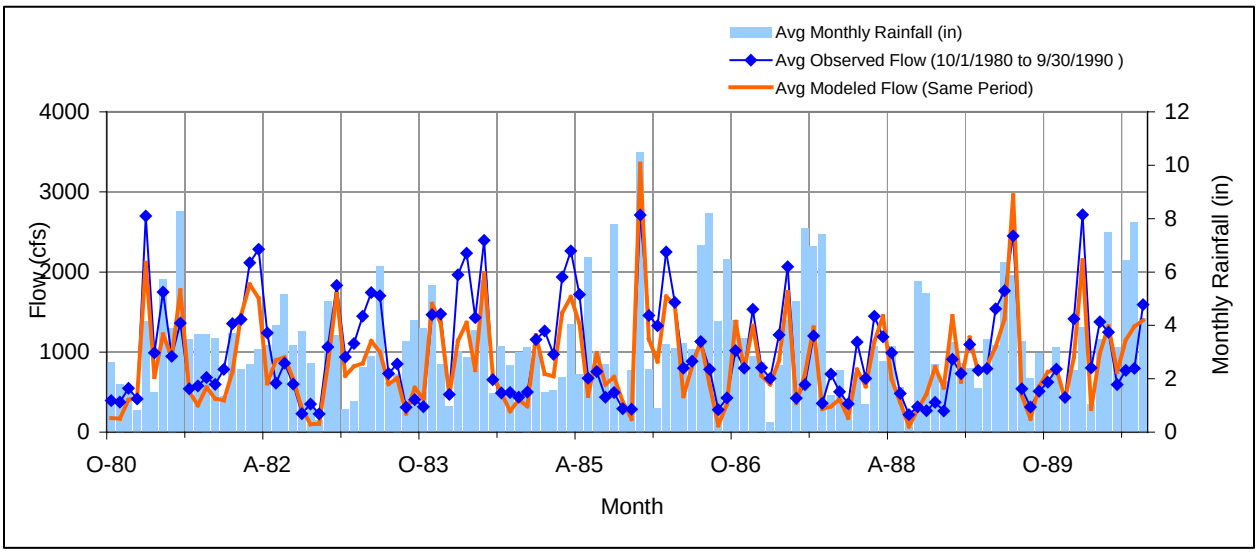

Figure 8. Mean monthly flow at USGS 04208000 Cuyahoga River at Independence, OH – validation period.

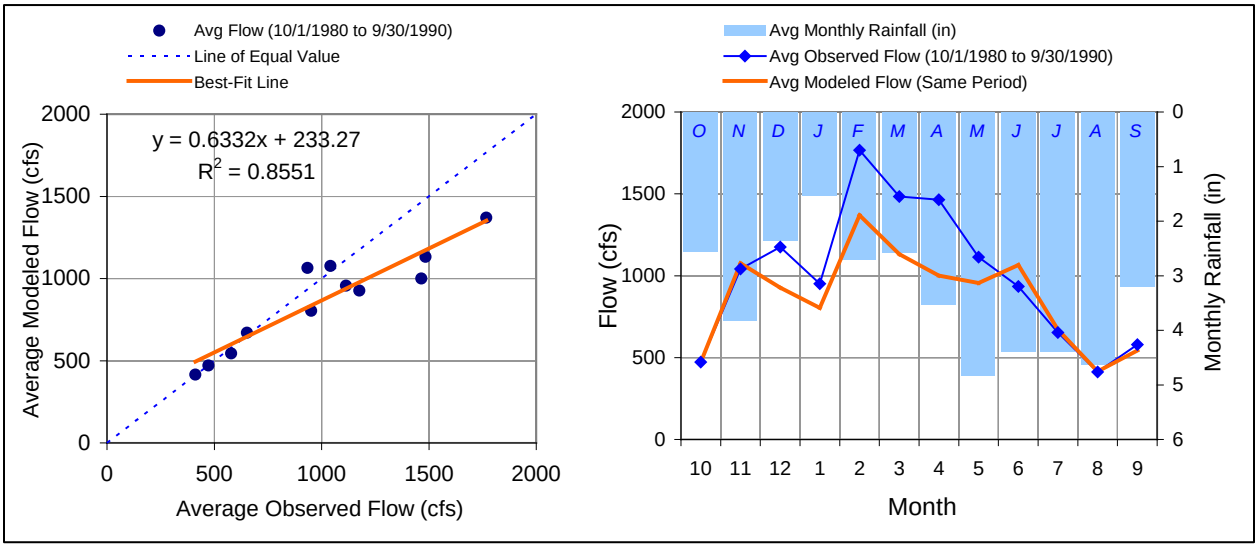

Figure 9. Seasonal regression and temporal aggregate at USGS 04208000 Cuyahoga River at Independence, OH – validation period.

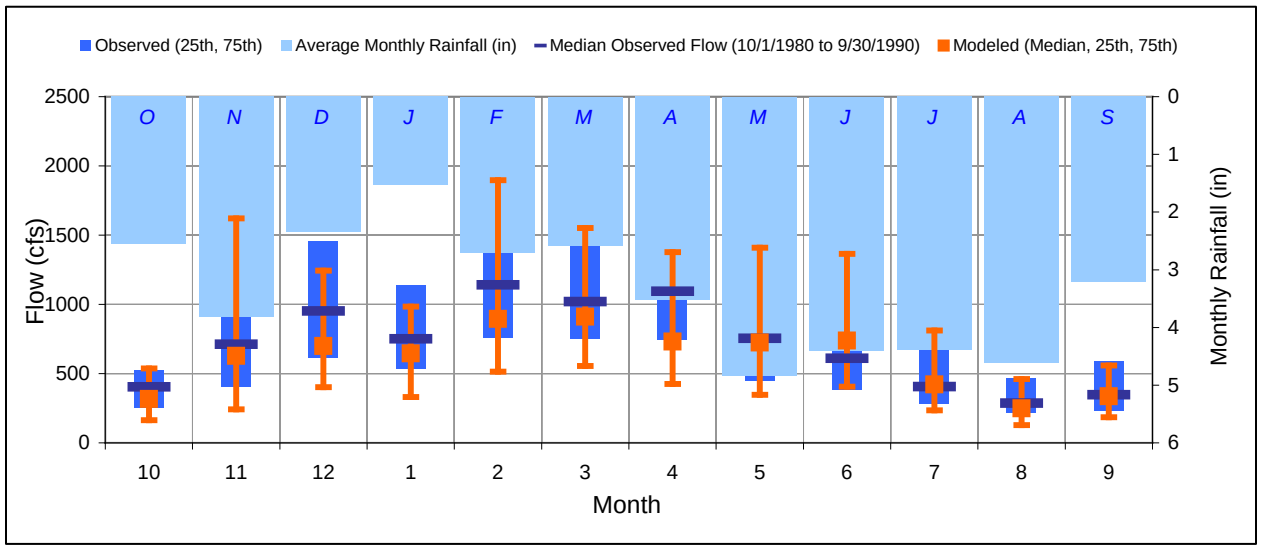

Figure 10. Seasonal medians and ranges at USGS 04208000 Cuyahoga River at Independence, OH – validation period.

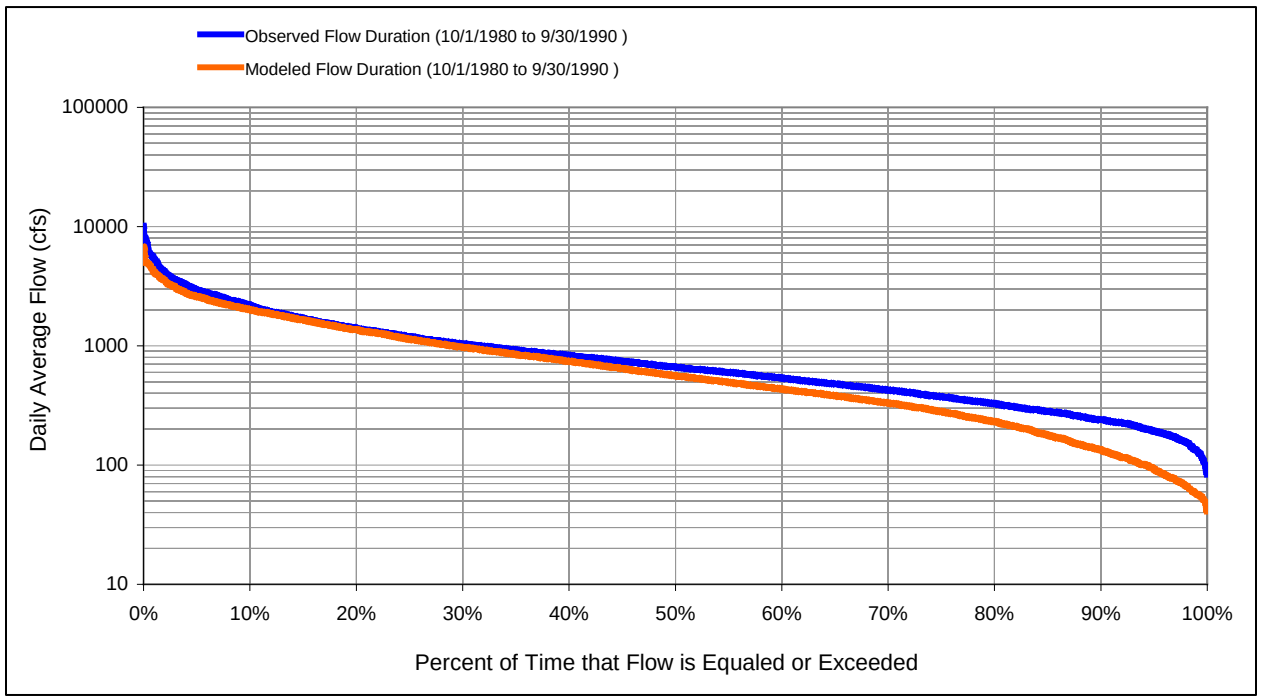

Figure 11. Flow exceedance at USGS 04208000 Cuyahoga River at Independence, OH – validation period.

Table 7. Summary statistics at USGS 04208000 Cuyahoga River at Independence, OH – validation period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 77 10-Year Analysis Period: 10/1/1980 - 9/30/1990 Flow volumes are (inches/year) for upstream drainage area		USGS 04208000 Cuyahoga River at Independence OH Hydrologic Unit Code: 4110002 Latitude: 41.39533087 Longitude: -81.6298478 Drainage Area (sq-mi): 707	
Total Simulated In-stream Flow:	**16.61**	Total Observed In-stream Flow:	**19.18**
Total of simulated highest 10% flows:	**5.59**	Total of Observed highest 10% flows:	**6.65**
Total of Simulated lowest 50% flows:	**2.75**	Total of Observed Lowest 50% flows:	**3.70**
Simulated Summer Flow Volume (months 7-9):	**2.63**	Observed Summer Flow Volume (7-9):	**2.65**
Simulated Fall Flow Volume (months 10-12):	**3.98**	Observed Fall Flow Volume (10-12):	**4.33**
Simulated Winter Flow Volume (months 1-3):	**5.19**	Observed Winter Flow Volume (1-3):	**6.59**
Simulated Spring Flow Volume (months 4-6):	**4.82**	Observed Spring Flow Volume (4-6):	**5.60**
Total Simulated Storm Volume:	**5.64**	Total Observed Storm Volume:	**6.90**
Simulated Summer Storm Volume (7-9):	**1.08**	Observed Summer Storm Volume (7-9):	**1.11**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	**-13.38**	**10**	
Error in 50% lowest flows:	**-25.70**	**10**	
Error in 10% highest flows:	**-15.93**	**15**	
Seasonal volume error - Summer:	-0.83	30	
Seasonal volume error - Fall:	-8.18	30	
Seasonal volume error - Winter:	-21.31	30	
Seasonal volume error - Spring:	-14.01	30	
Error in storm volumes:	-18.14	20	
Error in summer storm volumes:	-2.36	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.622	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.441	as E or E' approaches 1.0	
Monthly NSE	0.860		

Hydrology Results for Larger Watershed

As described above, parameters determined for the gage at Cuyahoga River at Independence were initially transferred to other gages in the watershed. However, changes to subbasin level parameter were required to fit the model to the observed flows. In all, calibration and validation was pursued at a total of seven gages throughout the watershed. Results of the calibration and validation exercise are summarized in Table 8 and Table 9, respectively. Calibration and validation results were acceptable at most gages.

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

Station	USGS 04186500	USGS 04193500	USGS 04198000	USGS 04199000	USGS 04200500	USGS 04206000
Error in total volume:	5.12	2.84	-4.64	-0.99	4.21	3.58
Error in 50% lowest flows:	6.38	56.11	-22.60	0.52	-1.16	6.29
Error in 10% highest flows:	-13.25	-17.02	-15.38	-14.74	-13.91	0.47
Seasonal volume error - Summer:	1.15	32.48	7.14	47.98	61.88	34.36
Seasonal volume error - Fall:	2.86	11.98	-4.26	-27.69	-9.71	10.28
Seasonal volume error - Winter:	0.49	-5.40	-10.53	-12.37	2.40	-8.25
Seasonal volume error - Spring:	14.92	-3.26	-1.41	11.29	-2.52	-0.57
Error in storm volumes:	-14.61	-13.55	-9.60	-14.98	-9.93	4.12
Error in summer storm volumes:	-22.24	7.55	2.62	27.73	47.01	30.36
Nash-Sutcliffe Coefficient of Efficiency, E:	0.44	0.65	0.51	0.29	0.35	0.69
Baseline adjusted coefficient (Garrick), E':	0.40	0.54	0.46	0.31	0.34	0.49

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

Station	USGS 04186500	USGS 04193500	USGS 04198000	USGS 04199000*	USGS 04200500	USGS 04206000
Error in total volume:	-1.78	1.97	1.22	ND	-2.34	6.41
Error in 50% lowest flows:	-35.07	26.39	-28.85	ND	-26.57	4.79
Error in 10% highest flows:	-11.70	-11.39	-11.72	ND	-17.25	0.84
Seasonal volume error - Summer:	-1.85	41.13	23.91	ND	59.12	33.99
Seasonal volume error - Fall:	5.85	1.71	10.39	ND	-2.63	12.35
Seasonal volume error - Winter:	-10.23	-7.70	-18.67	ND	-13.18	-2.88
Seasonal volume error - Spring:	3.98	3.07	13.05	ND	-1.16	1.39
Error in storm volumes:	-18.28	-8.68	-3.71	ND	-12.42	10.14
Error in summer storm volumes:	-14.19	19.02	21.09	ND	43.95	37.97
Nash-Sutcliffe Coefficient of Efficiency, E:	0.30	0.71	0.43	ND	0.42	0.60
Baseline adjusted coefficient (Garrick), E':	0.38	0.56	0.45	ND	0.38	0.43

*No data (ND) were available for the validation period at USGS station 04199000.

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done on the Cuyahoga River at Independence (USGS 04208000), using 1990-2000 for calibration and 1980-1990 for validation. As with hydrology, water quality calibration was performed on the later period as this better reflects the land use included in the model.

Calibration adjustments for sediment focused on the following parameters:

- SPCON (linear parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)

- SPEXP (exponential parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- CH_COV (channel cover factor)
- CH_EROD (channel erodibility factor)
- USLE_P (USLE support practice factor)

Simulated and estimated sediment loads at the Cuyahoga River station for both the calibration and validation periods are shown in Figure 12 and statistics for the two periods are provided separately in Table 10. The key statistic in Table 10 is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. Table 10 also shows the relative average absolute error, which is the average of the relative magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows better agreement.

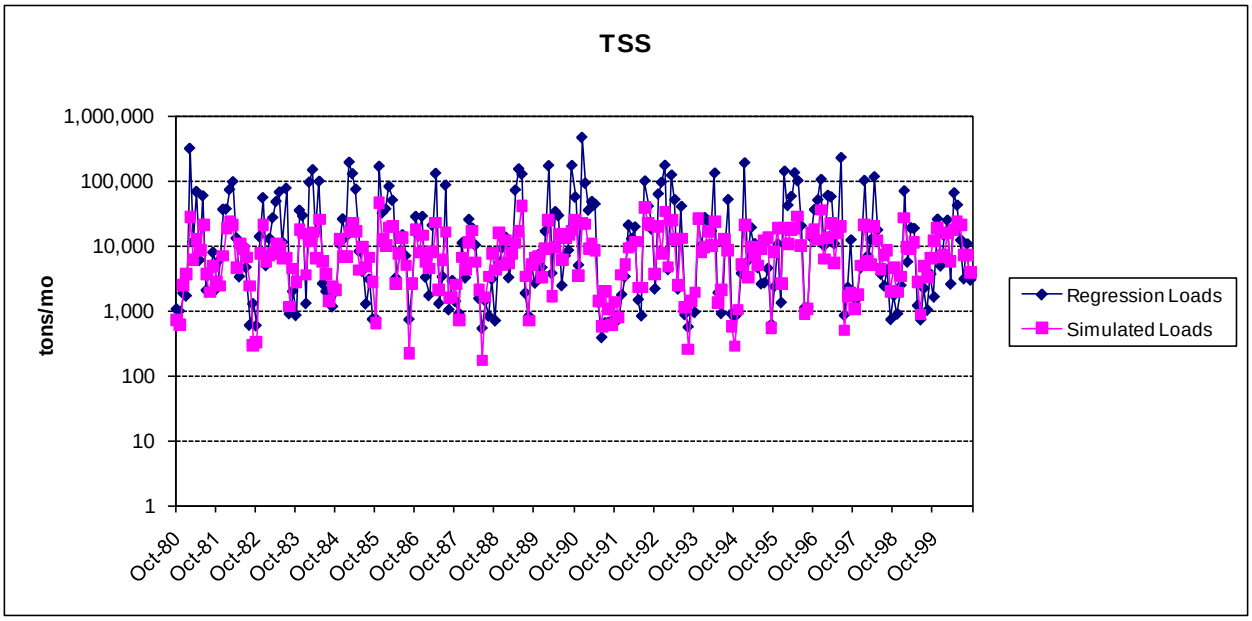

Figure 12. Fit for monthly Load of TSS at USGS 04208000 Cuyahoga River at Independence, OH.

Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 04208000 Cuyahoga River at Independence, OH

Statistic	Calibration period (1990-2000)	Validation period (1980-1990)
Relative Percent Error	67.9.9%	69.8%
Relative Average Absolute Error	74.5%	75.8%
Relative Median Absolute Error	11.9%	12.2%

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

- RHOQ (algal respiration rate at 20° C)
- PHOSKD (phosphorus soil partitioning coefficient)
- PSP (phosphorus availability index)
- RS1 (Local algal settlement rate in the reach at 20° C)

- AL1 (Fraction of algal biomass that is nitrogen)
- AL2 (Fraction of algal biomass that is phosphorus)
- MUMAX (Rate of oxygen uptake per unit NO_2-N oxidation at 20° C)
- RHOQ (Algal respiration rate at 20° C)
- RS2 (benthic source rate for dissolved P in the reach at 20° C)
- RS3 (Benthic source rate for NH_4-N in the reach at 20° C)
- RS5 (organic P settling rate in the reach at 20° C)
- BC4 (rate constant for mineralization of organic P to dissolved P in the reach at 20° C)
- RS4 (rate coefficient for organic N settling in the reach at 20° C)
- CH_ONCO (Channel organic nitrogen concentration)
- CH_OPCO (Channel organic phosphorus concentration)
- SDNCO (Denitrification threshold water content)
- CDN (Denitrification exponential rate constant)

Results for the phosphorus simulation are shown in Figure 13 and Table 11. Results for the nitrogen simulation are shown in Figure 14 and Table 12. The model fit is generally acceptable.

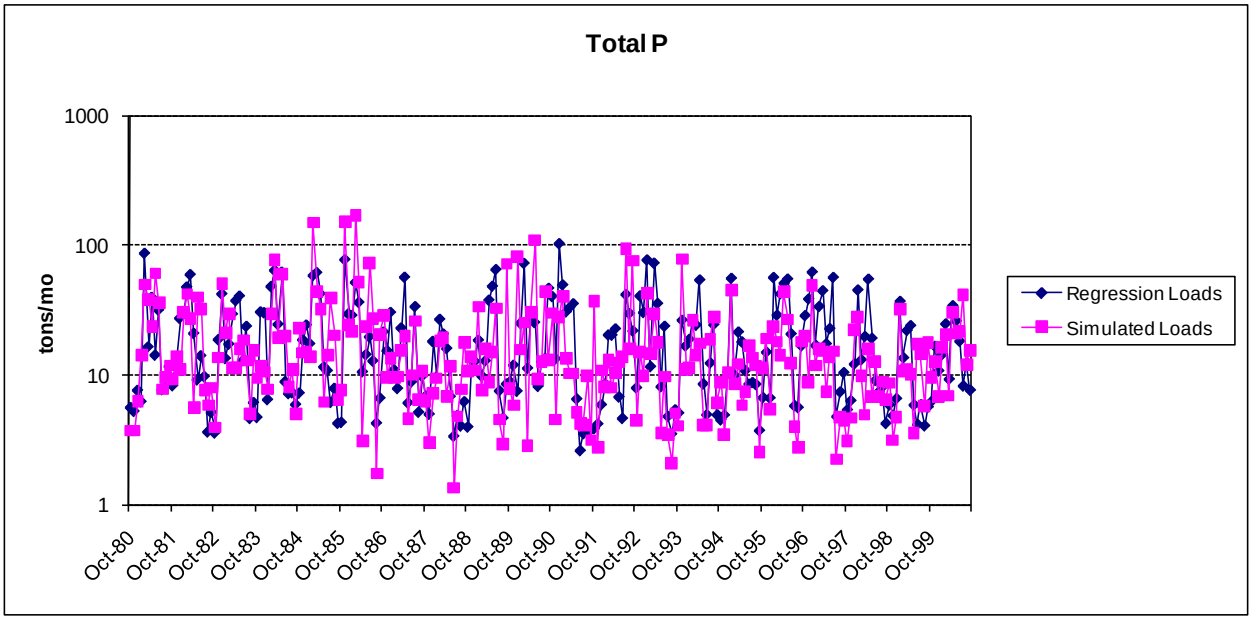

Figure 13. Fit for monthly load of total phosphorus at USGS 04208000 Cuyahoga River at Independence, OH.

Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 04208000 Cuyahoga River at Independence, OH

Statistic	Calibration period (1990-2000)	Validation period (1980-1990)
Relative Percent Error	23.9%	-12.5%
Average Absolute Error	54.2%	66.9%
Median Absolute Error	27.4%	33.2%

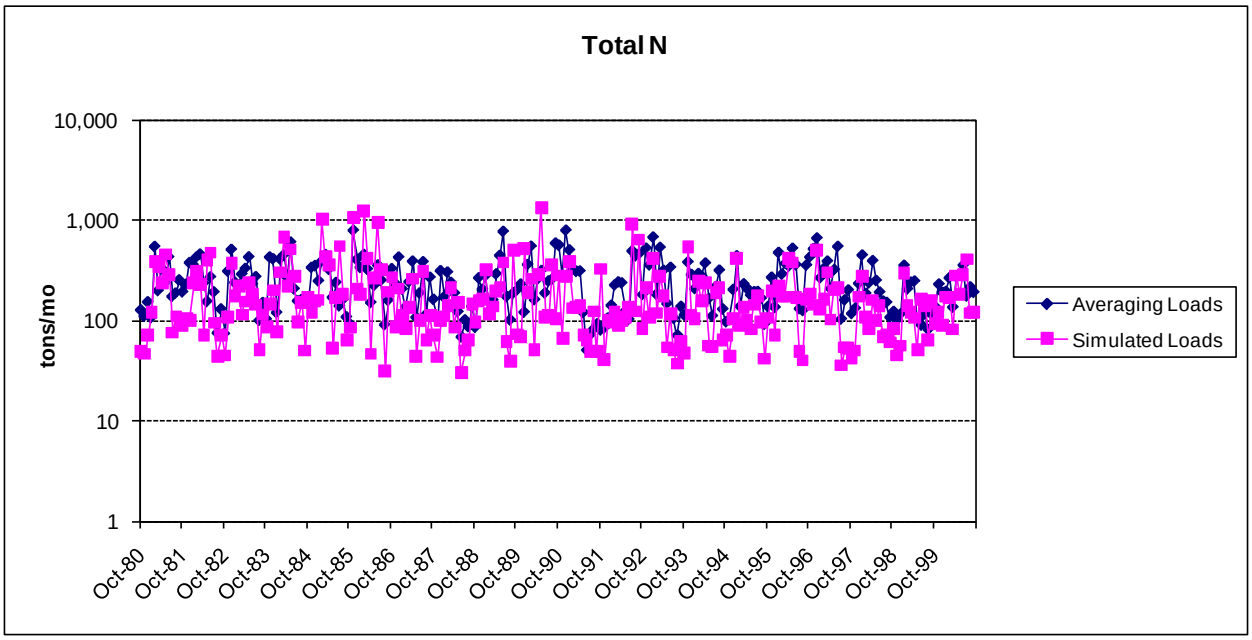

Figure 14. Fit for monthly load of total nitrogen at USGS 04208000 Cuyahoga River at Independence, OH.

Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 04208000 Cuyahoga River at Independence, OH

Statistic	Calibration period (1990-2000)	Validation period (1980-1990)
Relative Percent Error	35.8%	13.7%
Average Absolute Error	46.4%	53.6%
Median Absolute Error	37.4%	37.5%

Water Quality Results for Larger Watershed

As with hydrology, a spatial calibration approach was adopted. Cuyahoga River watershed SWAT model parameters for water quality were transferred to other portions of the watershed with necessary changes to subbasin level parameters. Summary statistics for the SWAT water quality calibration and validation at other stations in the watershed are provided in Table 13 and Table 14.

Table 13. Summary statistics for water quality at all stations – calibration period 1990-2000

Station	USGS 04193500	USGS 04198000
Relative Percent Error TSS Load	9.9%	17.0%
Relative Percent Error TP Load	33.5%	10.9%
Relative Percent Error TN Load	12.1%	16.8%

Table 14. Summary statistics for water quality at all stations – validation period 1980-1990

Station	USGS 04193500	USGS 04198000
Relative Percent Error TSS Load	11.2%	8.1%
Relative Percent Error TP Load	15.4%	-24.4%
Relative Percent Error TN Load	-5.0%	-19.6%

References

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