Appendix A: Application of the Loading Simulation Program C++ (LSPC) to the Mahoning River Watershed, Ohio

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A1.0 Introduction

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream response for TMDL development in the Mahoning River watershed.

A2.0 Modeling Framework Selection

Selection of the appropriate approach or modeling technique required consideration of the following:

- Expression of water quality criteria
- Dominant processes
- Source Integration
- Scale of analysis
- Efficient TMDL scenario evaluation

The relevant criteria for pathogens were presented in Section 2 of the TMDL report. Numeric criteria, such as those applicable here, require evaluation of magnitude, frequency, and duration. Thresholds of a numeric measure are often evaluated for frequency of exceedance (e.g., not to exceed more than once every 3 years on average). Acute standards typically require evaluation over short time periods and violations may occur under variable flow conditions. Chronic criteria require the evaluation of the response over a monthly averaging period. The fecal coliform criteria are presented as either a geometric mean using a minimum of 5 samples over a 30 day period or an instantaneous maximum standard. The approach or modeling technique must permit representation of in-stream concentrations under a variety of flow conditions in order to evaluate critical periods for comparison to chronic and acute criteria.

The appropriate approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Mahoning River watershed, primary sources contributing to pathogen impairments include an array of nonpoint or diffuse sources as well as discrete direct inputs to the stream including permitted point source discharges, combined sewer overflow or animal direct deposition to the streams. Loading processes for nonpoint sources or land-based activities are typically rainfall-driven and thus relate to surface runoff and subsurface discharge to a stream.

Key in-stream factors that must be considered include routing of flow, dilution, transport, and fate (decay or transformation) of pathogens. In the stream systems of the Mahoning River watershed, the primary physical driving process affecting the transport of pathogens is the pathogen die-off.

Scale of analysis and waterbody type must also be considered in the selection of the overall approach. The approach should have the capability to evaluate watersheds at multiple scales, and be able to adequately represent the spatial distribution of sources and the delivery processes whereby pathogens are delivered throughout the stream network.

Based on the considerations described above, analysis of the monitoring data, review of the literature, characterization of the pathogen sources, the need to represent source controls to individual sources, and previous modeling experience, the Loading Simulation Program C++ (LSPC) was selected to represent the source-response linkage in the Mahoning River watershed. LSPC, the primary watershed modeling system for the recently released EPA TMDL Toolbox, is currently maintained by the EPA Office of Research and Development in Athens, GA (http://www.epa.gov/athens/wwqtsc).

A2.1 Loading Simulation Program C++ (LSPC) Overview

LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. LSPC is derived from the Mining Data Analysis System (MDAS), which was developed by EPA Region 3 and has been widely used for mining applications and TMDLs. A key data management feature of this system is that it uses a Microsoft Access database to manage model data and weather text files for driving the simulation. The system also contains a module to assist in TMDL calculation and source allocations. For each model run, it automatically generates comprehensive text-file output by subwatershed for all land-layers, reaches, and simulated modules, which can be expressed on hourly or daily intervals. Output from LSPC has been linked to other model applications such as EFDC, WASP, and CE-QUAL-W2. LSPC has no inherent limitations in terms of modeling size or model operations. The Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel.

LSPC was designed to facilitate data management for large-scale or complex watershed modeling applications. The model has been successfully used to model watershed systems composed of over 1,000 subwatersheds at a National Hydrography Dataset (NHD) stream-segment scale. The system is also tailored for source representation and TMDL calculation. The LSPC GIS interface, which is compatible with ArcView shape files, acts as the control center for launching watershed model scenarios. This stand-alone interface easily communicates with both shape files and an underlying Microsoft Access database, but does not directly rely on either of these main programs. Therefore, once a watershed application is created, it is easily transferable to users who may not have ArcView or MS Access installed on their computers.

This model is essentially a re-coded C++ version of selected HSPF modules. LSPC’s algorithms are identical to those in HSPF. Table 1 presents the modules from HSPF used in the LSPC dynamic watershed model. The user may refer to the Hydrologic Simulation Program FORTRAN User's Manual for a more detailed discussion of simulated processes and model parameters (Bicknell et al. 1996).

Table 1. HSPF modules available and supported in the LSPC watershed model

Simulation Type	HSPF Module	HSPF Module Description
Land Based Processes	PWATER	Water budget for pervious land
	IWATER	Water budget for impervious land
	SNOW	Incorporates snow fall and melt into water budget
	SEDMNT	Production and removal of sediment
	PWTGAS	Est. water temperature, dissolved gas concentrations
	IQUAL	Simple relationships with solids and water yield
	PQUAL	Simple relationships with sediment and water yield
In-stream Processes	HYDR ADCALC	Hydraulic behavior, pollutant transport
	CONS	Conservative constituents
	HTRCH	Heat exchange, water temperature
	SEDTRN	Behavior of inorganic sediment
	GQUAL	Generalized quality constituent

A2.2 Meteorological Data Processing

Weather conditions are the driving force for watershed hydrology processes. For the simulation options selected for the Mahoning River watershed model, the required parameters include hourly precipitation and hourly potential evapotranspiration. Precipitation is gage monitored, while potential evapotranspiration is empirically computed using temperature and gage latitude. Table 2 below summarizes the weather data that was collected for the Mahoning River watershed model. The source for this data is the National Climatic Data Center (NCDC).

Table 2. NCDC meteorological datasets compiled for Mahoning River watershed model

StationID	Timestep	Data Type	Station Name	Start Date	End Date	Elevation (ft)	Percent Complete
OH0107	Hourly	Precipitation	ALLIANCE 3 NNW	8/12/1948	12/31/2002	1055.0	87.7%
OH0639	Hourly	Precipitation	BERLIN LAKE	8/12/1948	12/31/2002	1040.0	92.3%
OH6949	Hourly	Precipitation	RAVENNA 2 S	8/11/1948	12/31/2002	1107.0	86.9%
OH9406	Hourly	Precipitation	YOUNGSTOWN WSO AP	8/8/1948	12/31/2002	1180.0	99.9%
PA6233	Hourly	Precipitation	NEW CASTLE 1 N	5/1/1948	12/4/2002	825.0	83.3%
333780	Daily	Precipitation	HIRAM	1/1/1900	12/31/2002	1230.0	98.8%
335505	Daily	Precipitation	MOSQUITO CREEK LAKE	1/1/1948	12/31/2002	910.0	98.8%
338769	Daily	Precipitation	WARREN 3 S	1/1/1936	12/31/2002	900.0	100.0%
OH0058	Hourly	Dewpoint Temp	AKRON CANTON WSO AP	1/1/1980	12/31/2002	1208.0	100.0%
OH9406	Hourly	Dewpoint Temp	YOUNGSTOWN WSO AP	1/1/1980	12/31/2002	1180.0	99.9%
OH0058	Hourly	Dry-Bulb Temperature	AKRON CANTON WSO AP	1/1/1980	12/31/2002	1208.0	100.0%
OH9406	Hourly	Dry-Bulb Temperature	YOUNGSTOWN WSO AP	1/1/1980	12/31/2002	1180.0	99.9%
OH0058	Hourly	Cloud Cover	AKRON CANTON WSO AP	1/1/1980	12/31/2002	1208.0	100.0%
OH9406	Hourly	Cloud Cover	YOUNGSTOWN WSO AP	1/1/1980	12/31/2002	1180.0	100.0%
OH0058	Hourly	Windspeed & Direction	AKRON CANTON WSO AP	1/1/1980	12/31/2002	1208.0	100.0%
OH9406	Hourly	Windspeed & Direction	YOUNGSTOWN WSO AP	1/1/1980	12/31/2002	1180.0	99.9%
OH0058	Hourly	Cloud Adjusted Solar Radiation	AKRON CANTON WSO AP	1/1/1980	12/31/2002	1208.0	100.0%
OH9406	Hourly	Cloud Adjusted Solar Radiation	YOUNGSTOWN WSO AP	1/1/1980	12/31/2002	1180.0	100.0%

These NCDC monitoring gages are located either directly in the Mahoning River watershed or adjacent watersheds. Figure 1 shows the weather monitoring stations relative to the Mahoning River watershed. Daily minimum and maximum temperature between 1980 and 2002 were used to compute the potential evapotranspiration time series. This process is described in greater detail in Section A.2.3.

Of the eight precipitation gages, daily data were found at three gages. The normal-ratio method (Dunn and Leopold, 1978) was used to disaggregate the daily rainfall to hourly based on hourly rainfall distributions at the nearby gages. First, a composite hourly distribution was determined as a weighted average hourly time series of the nearby surrounding gages. Second, the daily values were distributed to the resulting hourly time series, keeping the original rainfall volume intact. Also, using the same methodology, missing or deleted intervals in the data were simultaneously patched using the normal-weighted hourly distributions at the nearby gages. This entire process is described in greater detail in Section A.2.4.

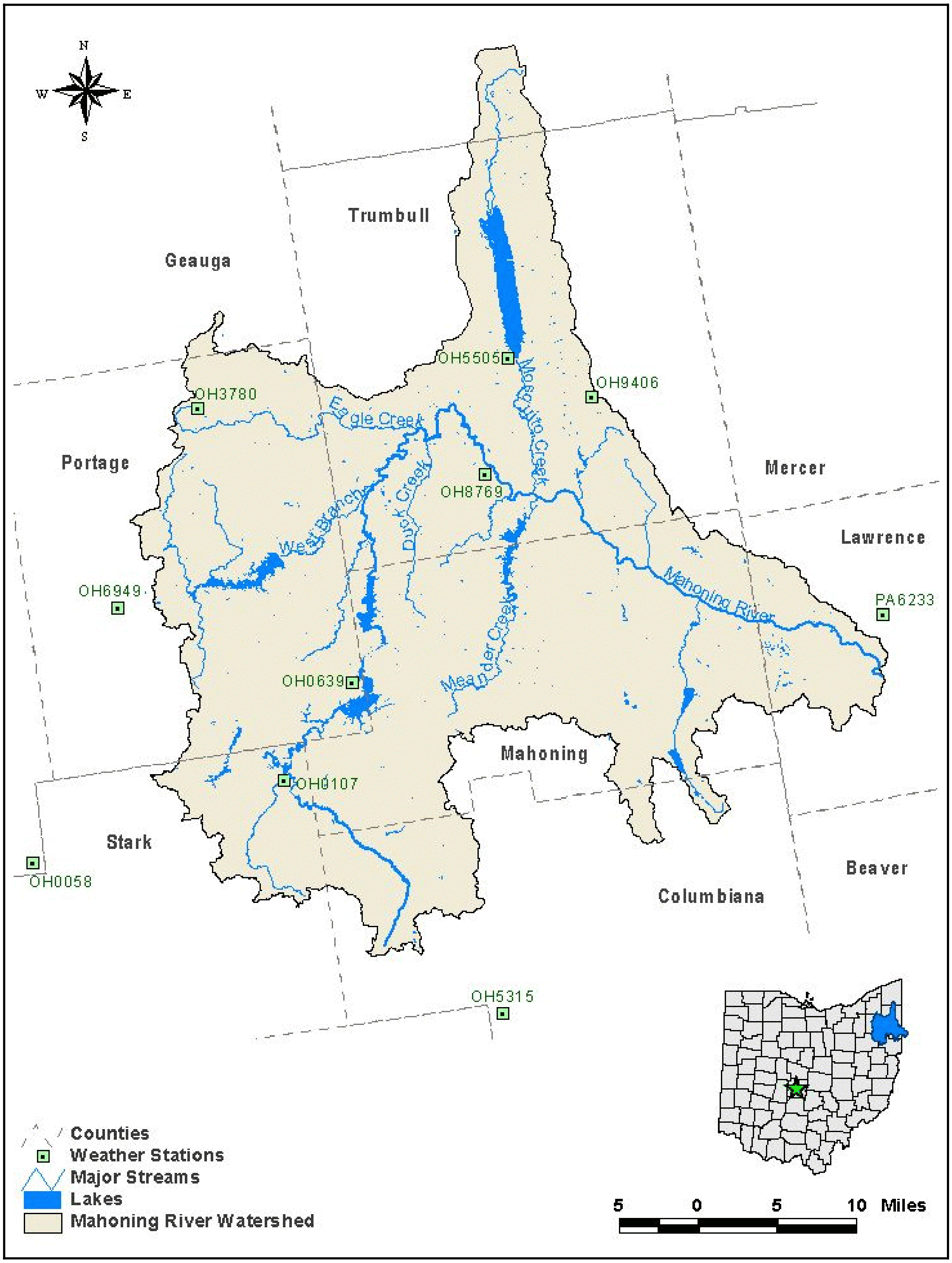

Figure 1. Weather stations near the Mahoning River watershed.

A2.3 Computing Potential Evapotranspiration

Daily minimum and maximum temperatures between 1980 and 2002 at OH0058 and OH9406 gages were used to compute the potential evapotranspiration time series. The Hamon method (1961) was used to compute evapotranspiration. The Hamon formula states that:

$$PET = CTS \times DYL \times VDSAT \qquad \text{Eqn 1}$$

where

PET	daily potential evapotranspiration (in)
CTS	monthly variable coefficient (a value of 0.0055 is suggested)
DYL	possible hours of sunshine, in units of 12 hours, computed as a function of latitude and time of year
VDSAT	saturated water vapor density (absolute humidity) at the daily mean air temperature (g/cm3)

The formula to compute saturated water vapor density (*VDSAT*) states that:

$$VDSAT = \frac{216.7 \times VPSAT}{TAVC + 273.3} \qquad \text{Eqn 2}$$

where

VPSAT	saturated vapor pressure at the air temperature
TAVC	mean daily temperature computed from daily min and max (Deg C)

The formula for saturation vapor pressure (*VPSAT*) states that:

$$VPSAT = 6.108 \times \exp\left(\frac{17.26939 \times TAVC}{TAVC + 273.3}\right) \qquad \text{Eqn 3}$$

Finally, the daily *PET* values were disaggregated to hourly time series values using a standard sine wave equation, over the daylight hours (*DYL*), which reaches its peak at noon of each day. The minimum and maximum temperature values monitored at the NCDC Youngstown and Akron gages (ID: OH0058 and OH9406), were used to compute potential evapotranspiration.

A2.4 Patching and Disaggregating Rainfall Data

Unless the percent coverage is 100%, meaning that the gage is always in operation and is accurately recording readings throughout the specified available time period, precipitation gages may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall gage malfunctions or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown.

To disaggregate the daily rainfall totals to hourly, each day that rainfall is recorded is treated as an accumulated interval over that 24-hour period. The normal-ratio method (Dunn & Leopold, 1978) was used to repair accumulated, missing, and deleted data intervals based on hourly rainfall patterns at nearby stations where unimpaired data is measured. The normal-ratio method estimates a missing rainfall value using a weighted average from surrounding stations with similar rainfall patterns according to the relationship:

Eqn 4

$$P_A = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{N_A}{N_i} P_i\right)$$

where P_A is the impaired precipitation value at station *A*, n is the number of surrounding stations with unimpaired data at the same specific point in time, N_A is the long term average precipitation at station *A*, N_i is the long term average precipitation at nearby station *i*, and P_i is the observed precipitation at nearby station *i*. For each impaired data record at station *A*, *n* consists of only the surrounding stations with unimpaired data; therefore, for each record, *n* varies from one to the maximum number of surrounding stations. When no precipitation is available at the surrounding stations, zero precipitation is assumed at station *A*. The US Weather Bureau has a long established practice of using the long-term average rainfall as the precipitation normal. Since the normal ratio considers the long-term average rainfall as the weighting factor, this method is adaptable to regions where there is large orthographic variation in precipitation; therefore, elevation differences will not bias the predictive capability of the method. The figures below show 20 water year annual rainfall totals at the various stations by water year (Figures 2 through 5).

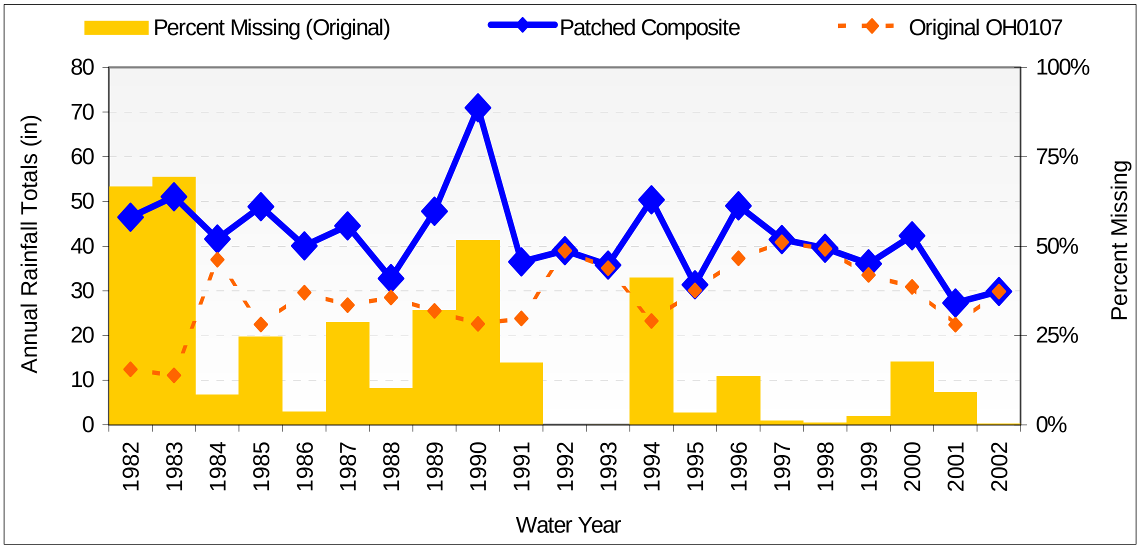

Figure 2. Rainfall at weather station OH0107.

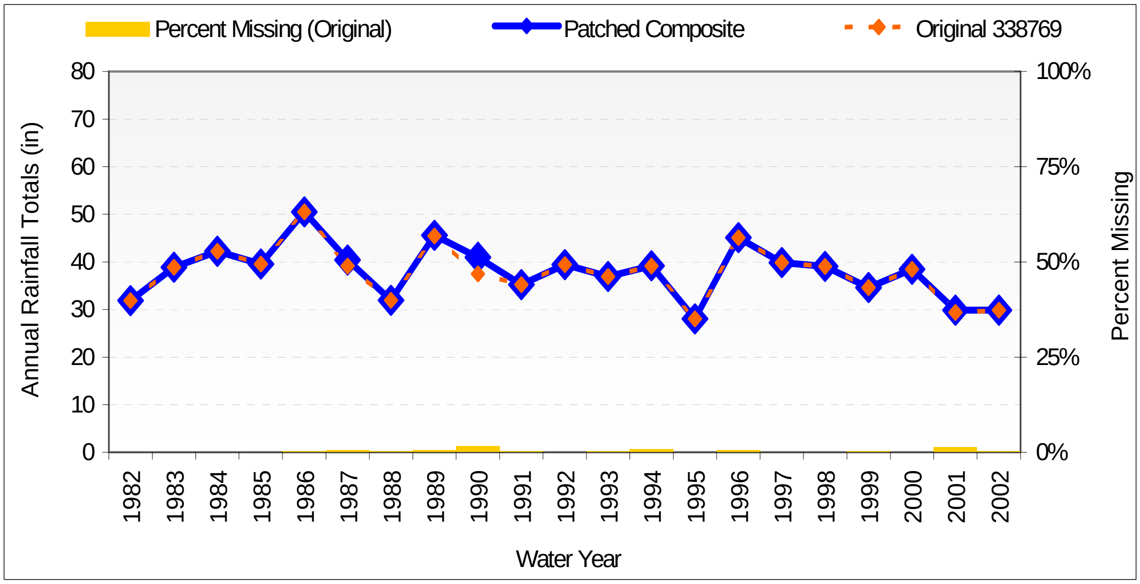

Figure 3. Rainfall at weather station 338769.

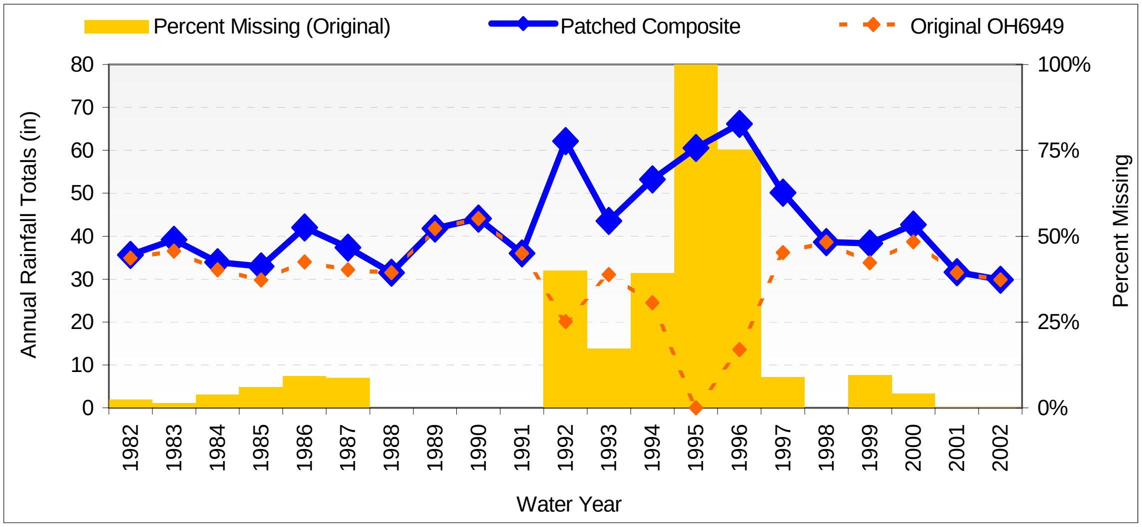

Figure 4. Rainfall at weather station OH6949.

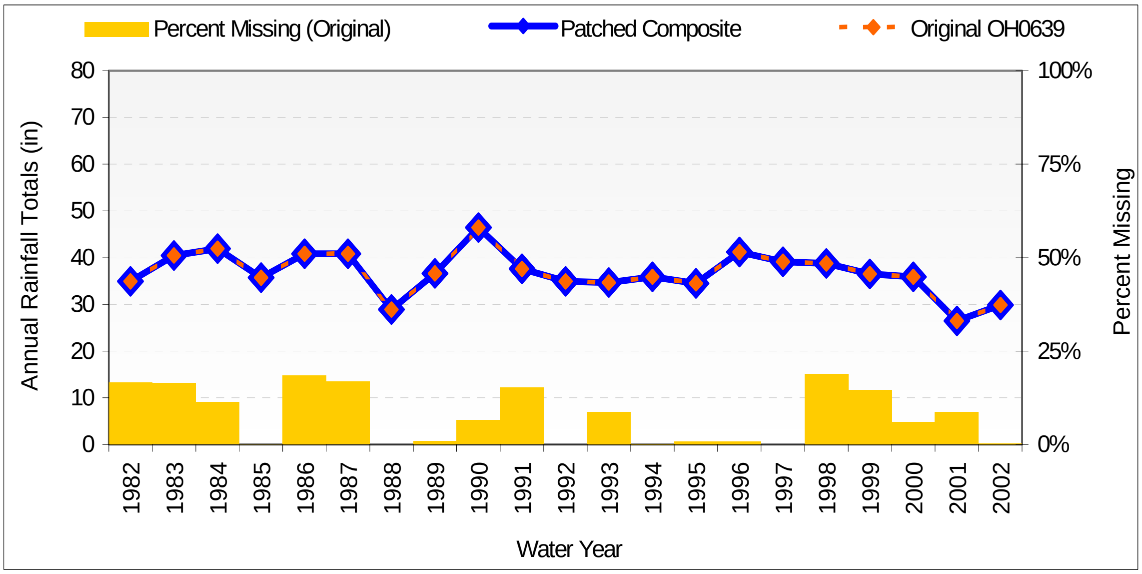

Figure 5. Rainfall at weather station OH0639.

A3.0 Model Setup

LSPC was configured for the Mahoning River watershed to simulate the watershed as a series of hydrologically connected subwatersheds. Configuration of the model involved subdivision of the Mahoning River watershed into modeling units and continuous simulation of flow and water quality for these units using meteorological, land use, point source loading, and stream data. The watershed was subdivided into fifty-eight subwatersheds to adequately represent the spatial variation in pathogen sources, watershed characteristics, hydrology, and the location of water quality monitoring and streamflow gaging stations. Perennial and intermittent streams in the Mahoning River watershed were digitized based on the location of “blue-line” streams as shown on the USGS 7.5 minute topographic maps of the area. The delineation of subwatersheds was based primarily on a topographic analysis of the watershed. Subwatersheds and primary streams are shown in Figure 6. Locations of the monitoring stations are shown in Figure 7. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

A continuous simulation period of twenty-two years (1980 to 2002) was used in the hydrologic simulation analysis. An important factor driving model simulation is precipitation data. The pattern and intensity of rainfall affect the build-up and wash-off of fecal coliform bacteria from the land into the streams, as well as the dilution potential of the stream.

Modeled land uses contributing to bacteria loads include pasture, cropland, urban pervious lands, urban impervious lands, and forest (including barren and wetlands). Other sources, such as septic systems and livestock in streams were modeled as direct sources in the model. Development of initial loading rates for land uses and direct sources are described in Section A4.0.

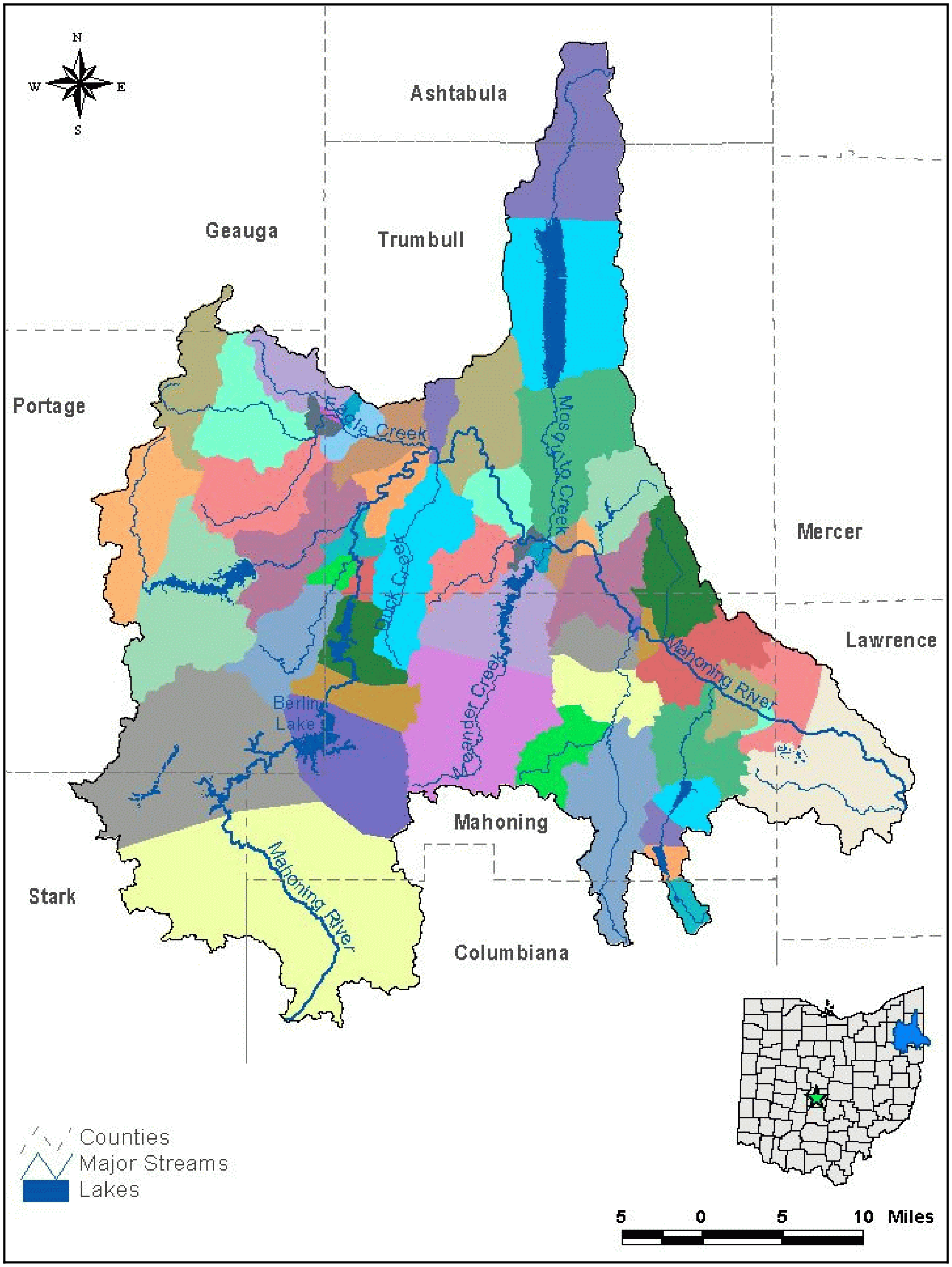

Figure 6. Modeling watersheds.

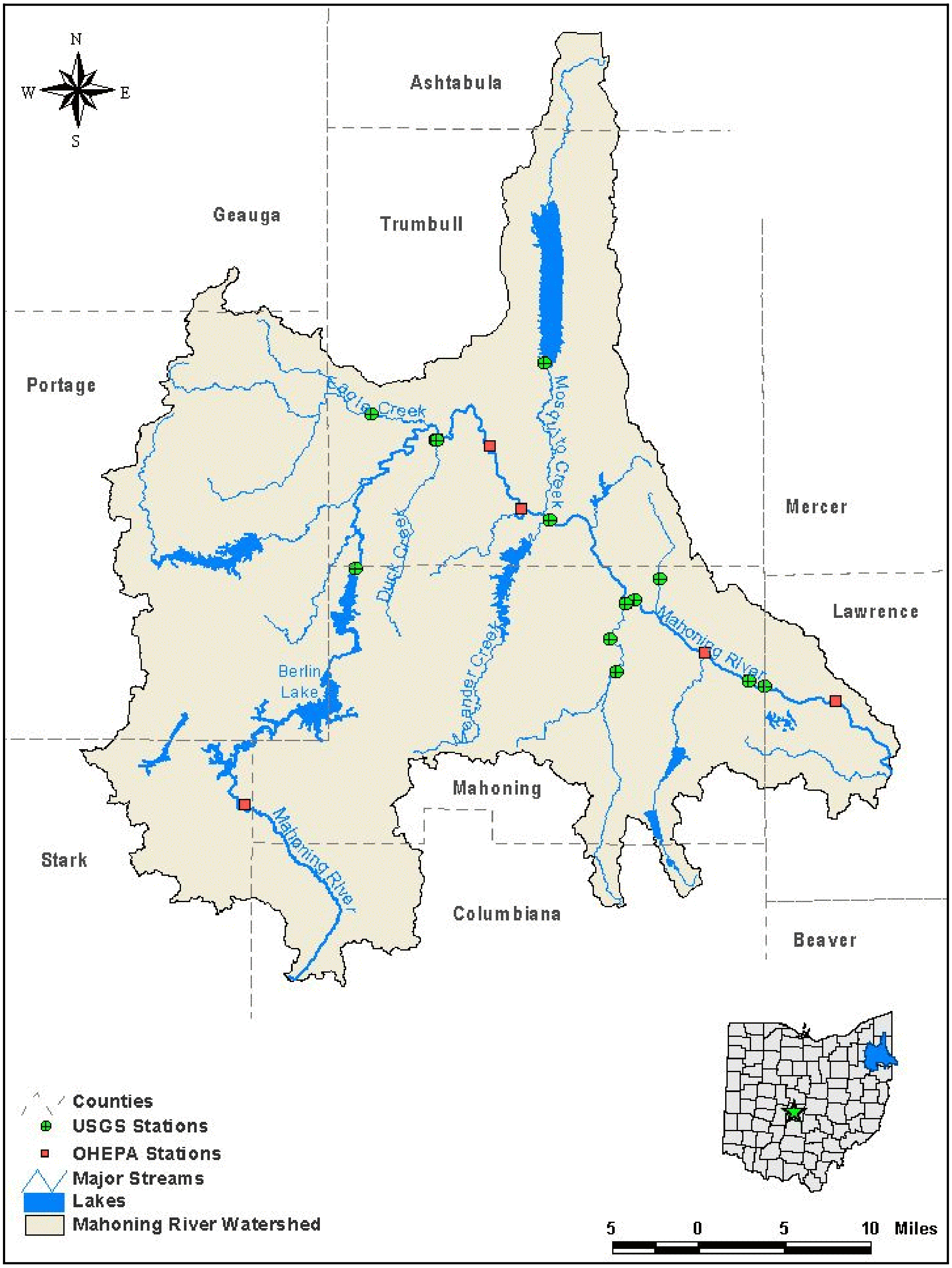

Figure 7. Monitoring stations.

A4.0 Source Representation

Both point and nonpoint sources were represented in the model for the Mahoning River. In general, the point sources were added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources were represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as deposited directly to the stream (e.g. animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream.

A4.1 Failing Septic Systems

Septic systems provide the potential to deliver bacteria loads to surface waters due to system failures caused by improper maintenance and/or malfunctions. The number of septic systems in each subwatershed was determined using U.S. Census Year 2000 and 1990 block group data for Ashtabula, Columbiana, Geauga, Lawrence, Mahoning, Portage, Stark and Trumbull Counties. The number of failing septic systems was estimated using a failure rate of 20 percent based on discussions with the Trumbull County Health Department and a review of failure rates used in other TMDL watersheds with a significant urban population. In some cases, human waste is directly deposited into surface waters from houses without septic systems. The population served by straight pipes was assumed to be 1 percent of the total septic/other disposal means population in the watershed. Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal bacteria to surface waters.

A4.2 Livestock

Pathogens produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Pathogens deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed.

Animal population estimates for the Mahoning River watershed were based on the 1997 Ohio Agricultural Census data for each county. Pathogen loads directed through each pathway were calculated by multiplying the bacteria density with the amount of waste expected through that pathway.

The population of each livestock species was distributed among subwatersheds based on the total area of pasture in each subwatershed . The total population reported for cattle and calves was used to determine the total number of beef and dairy cattle in each subwatershed.

Grazing animals also contribute bacteria to the land surface, which is available for washoff to surface waters during storm events. Beef and dairy cattle were the most abundant grazing animals in the watershed. Cattle, sheep, and horses were distributed throughout pasture and hayland areas in each subwatershed. Bacteria accumulation rates (#/acre/day) for each of these livestock species were calculated using subwatershed population estimates and the bacteria production rate established for each species.

A4.3 Wildlife

The population of each wildlife species was estimated using the population density per square mile of habitat and the total area of suitable habitat in each subwatershed. As with grazing livestock, wildlife deposit manure on the land and directly to surface waters. The habitat and percentage of time each species typically spends in streams was used to determine the proportion of bacteria that was deposited on land versus directly to surface waters. Loads applied to the land (in each subwatershed) were distributed according to the total area of each land use type within the established habitat area of each species.

A4.4 Combined Sewer Overflows

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows, called combined sewer overflows (CSOs), can contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. Because they are associated with wet weather events, CSOs typically discharge for short periods of time at random intervals.

Several communities in the Mahoning River watershed have combined sewer systems that are potential sources of bacteria. Information on the location and characteristics of the Youngstown CSOs were provided by the city and were also summarized in a USGS report (USGS, 2002). The CSO loads of bacteria for each subbasin were estimated based on the residential and commercial impervious area. It was assumed that 20 percent of the runoff generated on impervious land enters a combined sewer while 80 percent enters receiving water via other pathways. Overflows were assumed to occur when rainfall was greater than 0.l inches. Furthermore, it was assumed that 60 percent of the overflow occurs during the first day after a rainfall, 30 percent occurs during the second day after the rainfall, and 10 percent occurs during the third day (USGS, 2002). The calculated annual overflow rates for the city of Youngstown using this approach matched the observed annual overflow rates at Lowellville for 1999 with a reasonable error range (estimated 1461 million gallons per year; observed 1400 million gallons per year). After the overflow rate was obtained, the load was computed for each subbasin by multiplying the daily overflow rate by a fecal coliform concentration of 350,000 cfu/100ml (USGS, 2002). (Although USGS reported *E. coli* (and not fecal coliform) counts for CSOs, it was assumed that the large majority of fecal coliforms were *E. coli*.

Paired fecal coliform and *E. coli* data collected by OEPA indicate that *E. coli* counts are typically 70 to 80 percent of fecal coliform counts).

A4.5 Point Sources

Treated municipal sewage is a point source of bacterial contamination. As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Numerous such facilities are located in the Mahoning River watershed and discharge monitoring data were used to develop time variable loads for these facilities. Those included in the model are listed in Table 3.

Table 3. List of NPDES facilities in the Mahoning River watershed.

NPDES Permit Number	Location Name	Major Facility	NPDES Permit Number	Location Name	Major Facility
OH0023868	ALLIANCE REGIONAL STP	Yes	OH0083909	KMART DISTRIBUTION CENTER	No
OH0024325	CAMPBELL WWTP	Yes	OH0044881	LAKEVIEW MHP	No
OH0025364	GIRARD STP	Yes	OH0128872	LEAVITT ROAD ELEMENTARY SCHOOL	No
OH0037249	MAHONING CO BOARDMAN WWTP	Yes	OH0026204	LOWELLVILLE STP	No
OH0045721	MAHONING CO MEANDER CREEK WWTP	Yes	OH0043851	MAHONING CO LAKE MILTON WWTP	No
OH0026743	NILES WWTP	Yes	OH0046078	MAHONING CO PALMYRA RD	No
OH0011533	ORION MIDWEST NILES PLANT	Yes	OH0045641	MAPLE DEL MANOR MHP	No
OH0027600	STRUTHERS WWTP	Yes	OH0128571	MAPLEWOOD HIGH SCHOOL	No
OH0011363	THOMAS STEEL STRIP CORP.	Yes	OH0126250	MAPLEWOOD N ELEM SCHOOL	No
OH0043401	TRUMBULL CO MOSQUITO CREEK WWT	Yes	OH0128490	MARATHON ALRI TRUCK PLAZA	No
OH0027987	WARREN WWTP	Yes	OH0045675	MARLINGTON LOCAL SCHOOLS	No
OH0028223	YOUNGSTOWN WWTP	Yes	OH0129089	MATHEWS HIGH SCHOOL	No
OH0011878	ALLIANCE MIDWEST TUBULAR PRODU	No	OH0126225	NEMENZ FOOD MART	No

NPDES Permit Number	Location Name	Major Facility	NPDES Permit Number	Location Name	Major Facility
OH0107484	ARHAVEN ESTATES	No	OH0125792	NEMENZ LIL SHOPPER	No
OH0129062	BAKER ELEMENTARY SCHOOL	No	OH0022110	NEWTON FALLS STP	No
OH0128945	BAZETTA CHRISTIAN CHURCH	No	OH0126004	OBLATE SISTERS OF THE-SACRED H	No
OH0128937	BAZETTA ELEMENTARY SCHOOL	No	OH0037893	ODNR WEST BRANCH BEACH AREA	No
OH0024091	BELOIT WWTP	No	OH0107522	PLEASANT PARK MOBILE COURT	No
OH0107433	BLUE WATER MANOR	No	OH0044300	PM ESTATES	No
OH0129755	BP OIL STATION NO. 0592905	No	OH0117587	PONDEROSA PARK RESORTS INC	No
OH0107506	BRENTWOOD MANOR MHP	No	OH0038792	PORTAGE CO ATWATER WWTP	No
OH0129241	BUCKEYE PACKAGING COMPANY	No	OH0038539	PORTAGE CO WEST BRANCH MHP	No
OH0129682	BUDGET LODGE	No	OH0038547	PORTAGE CO WESTERN RESERVE WWT	No
OH0131326	CERTIFIED GAS STATION 410	No	OH0126365	RENT A HOME	No
OH0091901	CIRCLE RESTAURANT INC	No	OH0131474	RIDGE RANCH CAMPGROUND	No
OH0021776	COLUMBIANA WWTP	No	OH0010863	RMI TITANIUM CO NILES PLANT	No
OH0128708	COUNTRY ACRES CAMPGROUND	No	OH0128805	RODEWAY INN	No
OH0129178	CSR HYDRO CONDUIT	No	OH0087921	SCHAEFER EQUIPMENT INC	No
OH0129071	CURRIE ELEMENTARY SCHOOL	No	OH0020443	SEBRING WWTP	No
OH0129658	DAMASCUS WASTEWATER TREATMENT	No	OH0117561	SHORT STOP TRUCK PLAZA	No
OH0011193	DENMAN TIRE CORP	No	OH0038571	SOUTHEAST HIGH SCHOOL	No
OH0129038	DG AND ASSOCIATES INC.	No	OH0044113	STARK COUNTY	No
OH0123757	FAIR ACRES LTD	No	OH0092461	STONEYBROOK VILLAGE MHP	No

NPDES Permit Number	Location Name	Major Facility	NPDES Permit Number	Location Name	Major Facility
OH0128287	FONDERLAC INC	No	OH0128856	TRACK'S INN	No
OH0128732	GARDENBROOK PARTY CENTER	No	OH0092550	TRUMBULL CO BAZETTA NO 1	No
OH0025330	GARRETTSVILLE WWTP	No	OH0091634	TRUMBULL CO MECCA NO 1 WWTP	No
OH0064301	GCO LTD	No	OH0097993	TRUMBULL CO VIENNA NO 1 WWTP	No
OH0091740	HAMLET MHP	No	OH0023671	US CORP OF ENGINEERS MILL CREE	No
OH0025801	HIRAM STP	No	OH0128953	VALLEY MHP	No
OH0123676	HOMESTEAD MANOR MOBILE HOME	No	OH0102822	WESTWOOD HOMES INC	No
OH0107450	IMPERIAL MHP WWTP	No	OH0045462	WINDHAM WWTP	No
OH0123854	JOLLY TIME MHP	No	OH0117625	YANKEE KITCHEN RESTAURANT	No

A5.0 Stream Characteristics

Watershed segmentation refers to the subdivision of all watersheds in the Mahoning River watershed into smaller, discrete subwatersheds for modeling and analysis. This subdivision was primarily based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries. The Mahoning River watershed was divided into 58 subwatersheds for model configuration and watershed delineation. The watershed and respective subwatershed delineations are presented in Figure 6.

Each delineated subwatershed was represented with a single stream assumed to be completely mixed, one-dimensional segments with a trapezoidal cross-section. The National Hydrography Dataset (NHD) stream reach network for USGS hydrologic unit 05030103 was used to determine the representative stream reach for each subwatershed. Once the representative reach was identified, slopes were calculated based on DEM data and stream lengths measured from the original NHD stream coverage. In addition to stream slope and length, mean depths and channel widths are required to route flow and pollutants through the hydrologically connected subwatersheds. Mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream dimensions. An estimated Manning's roughness coefficient of 0.2 was also applied to each representative stream reach.

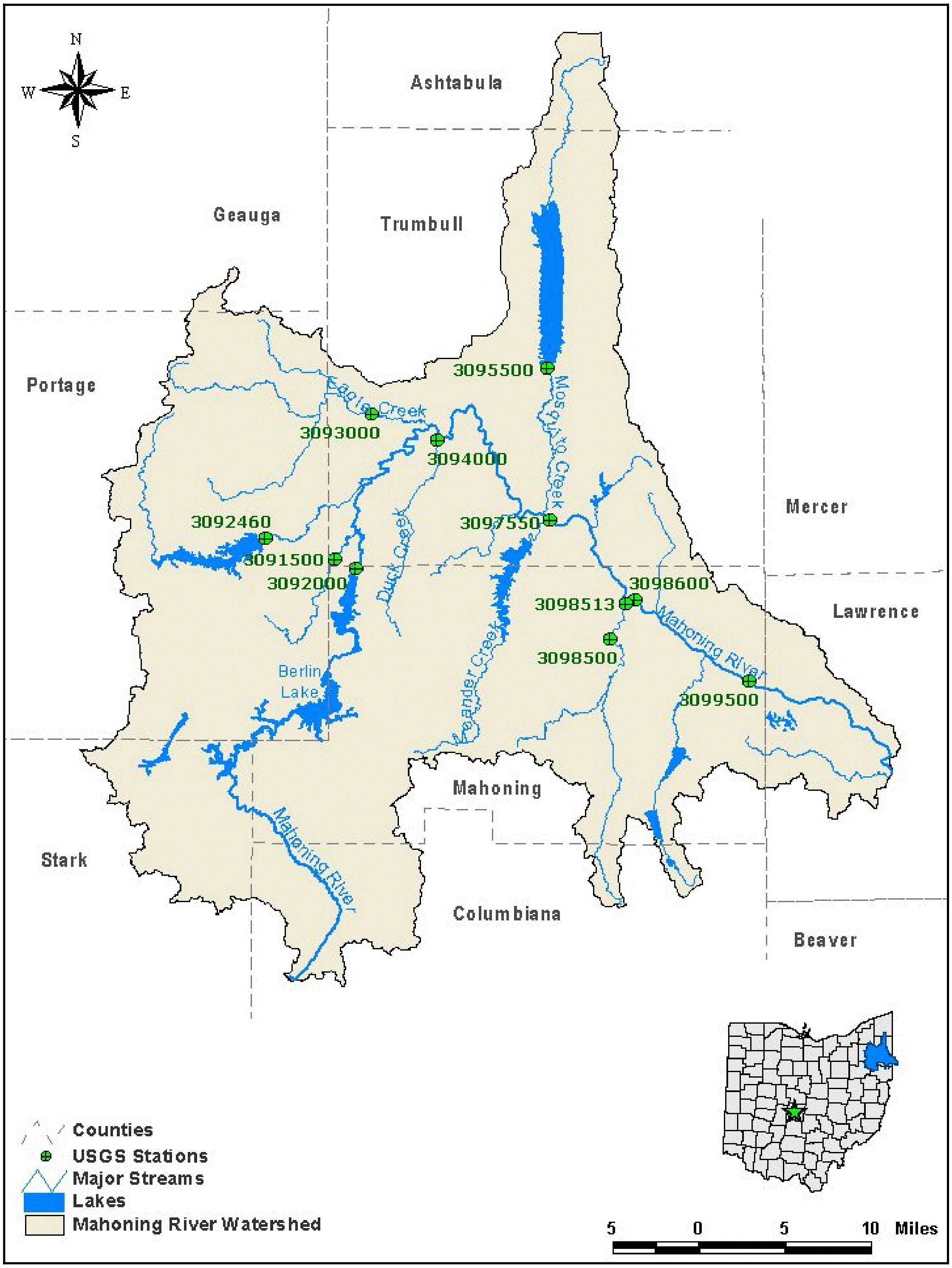

Figure 8. USGS flow gages used in the Mahoning River modeling.

To represent the larger reservoirs in the watershed model, the length, width, maximum depth, infiltration rate, and spillway height and width were obtained for each reservoir where data were available. The reservoirs were assumed to impound all upstream flow until the water depth exceeded the spillway height, causing overflow and thus contributing to downstream flow and pollutant loading.

A6.0 Selection of a Representative Modeling Period

The selection of a representative modeling period was based on the availability of stream flow and water quality data collected in the Mahoning River watershed that cover varying wet and dry time periods. Annual rainfall totals from the weather stations located within the watershed were ranked. The time period represents varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area. This was an important consideration because during dry weather and low flow, constant direct discharges dominate the impact on in-stream concentrations; however, during wet weather and high flow periods, surface runoff delivers nonpoint source fecal coliform to the stream, affecting the in-stream conditions more than constant discharges.

A7.0 Model Calibration Process

Hydrology and water quality calibration were performed in sequence, since water quality modeling is dependent on an accurate hydrology simulation.

A7.1 Hydrology Calibration

Hydrology was the first model component calibrated. The hydrology calibration involved a comparison of model results to in stream flow observations at the USGS flow monitoring stations. Figure 8 shows the locations of the flow monitoring stations. The Mahoning River watershed includes as many as 15 reservoirs and lakes. Five of the reservoirs were modeled as simple reservoirs and conceptually dimensioned to maintain near average pool volume.

The model was calibrated using daily stream flow observations at USGS gages for three selected years during the 1990s. Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period.
2. Representation of low-flow, average-flow, and high-flow water years.
3. Consistency of selected period with key model inputs (i.e., land use coverage)
4. Correlation between observed data and initial modeling results

Based on a review of these four selection criteria, water years 1988, 1989, and 1990 were chosen as model calibration years. These three water years represented a high-flow (1990), average-flow (1989), and low-flow (1988) water years, when compared with other water years within the 20-year simulation period. Also, since the MRLC land use coverage used in the model was actually developed during the mid 1990s, the selected calibration periods are consistent with this key model input. The model was validated for long-term and seasonal representation of hydrologic trends using the period 1991 to 2002, depending on available data.

The model calibration was performed using the guidance of error statistics criteria specified in HSPEXP, temporal comparisons and comparisons of seasonal, high flows, and low flows. Calibration involved adjustment of infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. The model was validated for 20 years using composite results for two independent ten-year periods in an effort to ensure systematic hydrologic consistency. Hydrologic calibration was based on quantitative comparisons between modeled streamflow and observed streamflow upstream of the USGS gages (Table 4) on the Mahoning River.

Table 4. USGS flow gages used in the Mahoning River modeling.

Station	Location	Period of Record
USGS 3099500	Mahoning River at Lowellville OH	1953-1991
USGS 3098513	Mill Ck at Price Rd, Youngstown OH	1999-2000
USGS 3098500	Mill Ck at Youngstown OH	1943-2000
USGS 3098600	Mahoning River below West Ave, Youngstown OH	1987-2002
USGS 3097550	Mahoning River at Ohio Edison Plt at Niles OH	1987-2002
USGS 3091500	Mahoning River at Pricetown, OH	1929-2002
USGS 3092000	Kale Creek near Pricetown, OH	1941-1993
USGS 3092460	West Br,. Mahoning River at Wayland, OH	1968-1991
USGS 3093000	Eagle Creek at Phalanx Station	1926-2002
USGS 3094000	Mahoning River at Leavittsburg, OH	1940-2002
USGS 3095500	Mosquito Creek below Mosquito Creek Dam near Cortland OH	1926-1991

Representative results are presented below for the Eagle Creek and Mahoning River at Lowellville USGS gages:

- Figures 9 through 14 show the calibration and validation results for the Eagle Creek watershed. The importance of this location is that it's unregulated, showing that the watershed hydrology is captured.
- Figures 15 to 20 show the calibration and validation results for the Mahoning River at the most downstream USGS gage (at Lowellville). The validation period for this gage is 1980 to 1987 because no data are available after 1991. The poorer calibration at the downstream portion of the watershed is due to the many reservoirs within the watershed with controlled releases that are difficult to capture with the model.

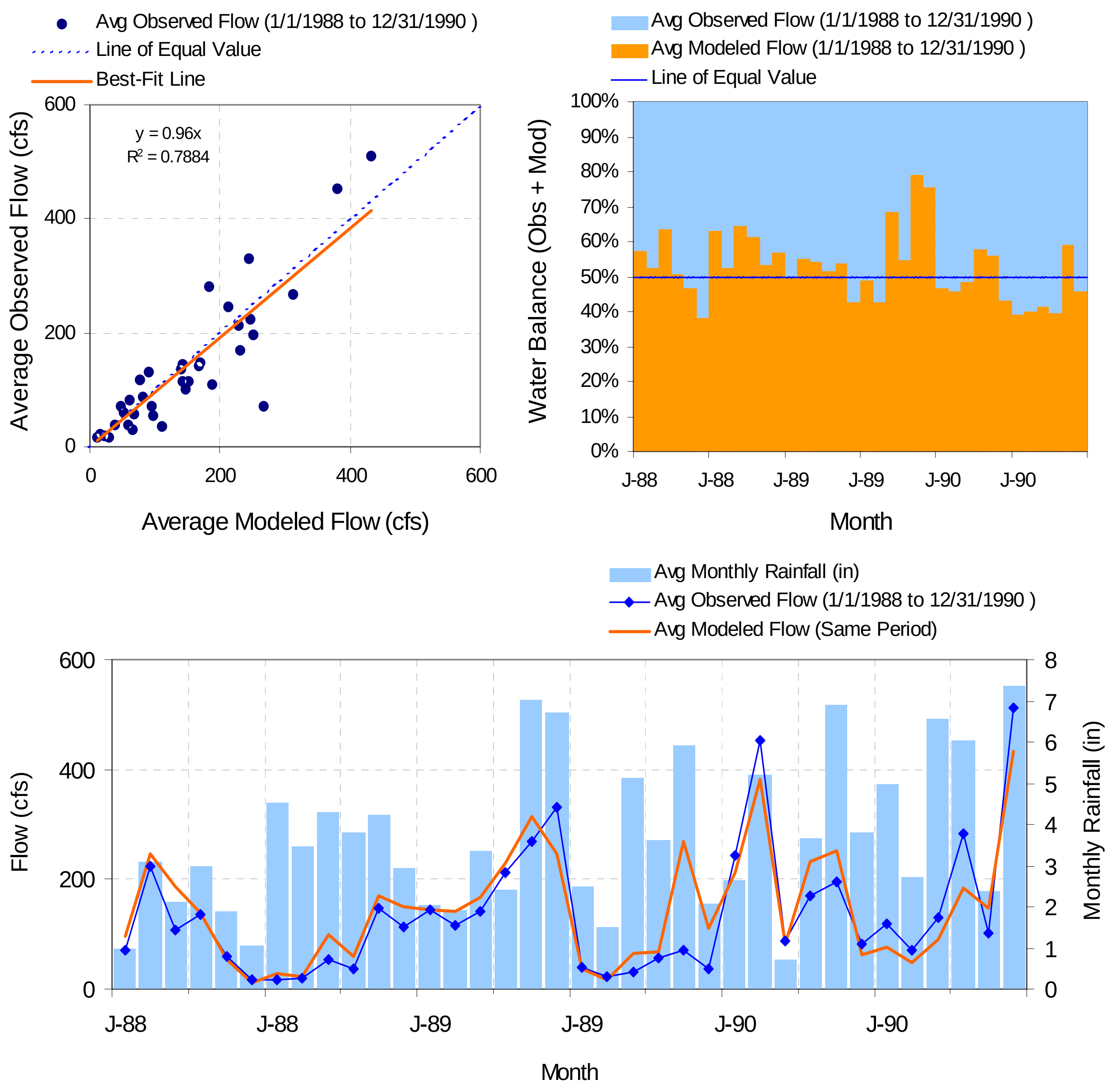

Figure 9. Time series hydrologic calibration results (1988 to 1990) for the Eagle Creek subwatershed (USGS gage 3093000).

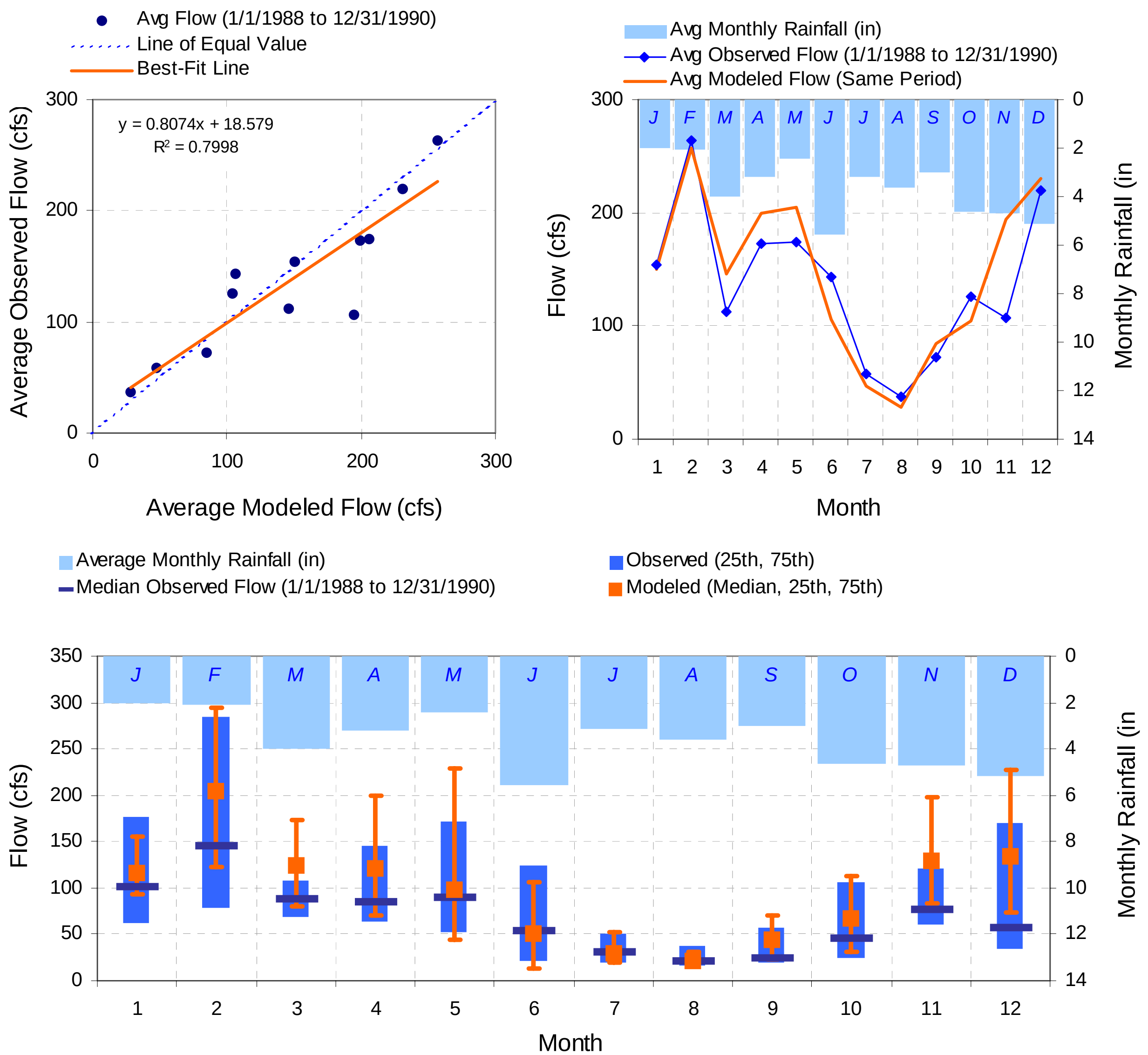

Figure 10. Composite (average monthly) hydrologic calibration results (1988 to 1990) for the Eagle Creek subwatershed (USGS gage 3093000).

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 46 3-Year Analysis Period: 1/1/1988 - 12/31/1990 Flow volumes are (inches/year) for upstream drainage area		USGS 03093000 Eagle Creek at Phalanx Station OH Trumbull County, Ohio Hydrologic Unit Code 05030103 Latitude 41°15'40", Longitude 80°57'16" NAD27 Drainage area 97.60 square miles	
Total Simulated In-stream Flow:	**20.24**	Total Observed In-stream Flow:	**18.91**
Total of simulated highest 10% flows:	**8.76**	Total of Observed highest 10% flows:	**9.40**
Total of Simulated lowest 50% flows:	**2.94**	Total of Observed Lowest 50% flows:	**2.45**
Simulated Summer Flow Volume (months 7-9):	**1.87**	Observed Summer Flow Volume (7-9):	**1.95**
Simulated Fall Flow Volume (months 10-12):	**6.18**	Observed Fall Flow Volume (10-12):	**5.30**
Simulated Winter Flow Volume (months 1-3):	**6.27**	Observed Winter Flow Volume (1-3):	**5.99**
Simulated Spring Flow Volume (months 4-6):	**5.92**	Observed Spring Flow Volume (4-6):	**5.67**
Total Simulated Storm Volume:	**9.98**	Total Observed Storm Volume:	**10.78**
Simulated Summer Storm Volume (7-9):	**0.96**	Observed Summer Storm Volume (7-9):	**1.05**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	6.58	10		
Error in 50% lowest flows:	**16.59**	**10**		
Error in 10% highest flows:	-7.29	15		
Seasonal volume error - Summer:	-4.24	30		
Seasonal volume error - Fall:	14.23	30		
Seasonal volume error - Winter:	4.53	30		
Seasonal volume error - Spring:	4.18	30		
Error in storm volumes:	-7.93	20		
Error in summer storm volumes:	-9.25	50		

Figure 11. Error statistics for hydrologic calibration results (1988 to 1990) for the Eagle Creek subwatershed (USGS gage 3093000).

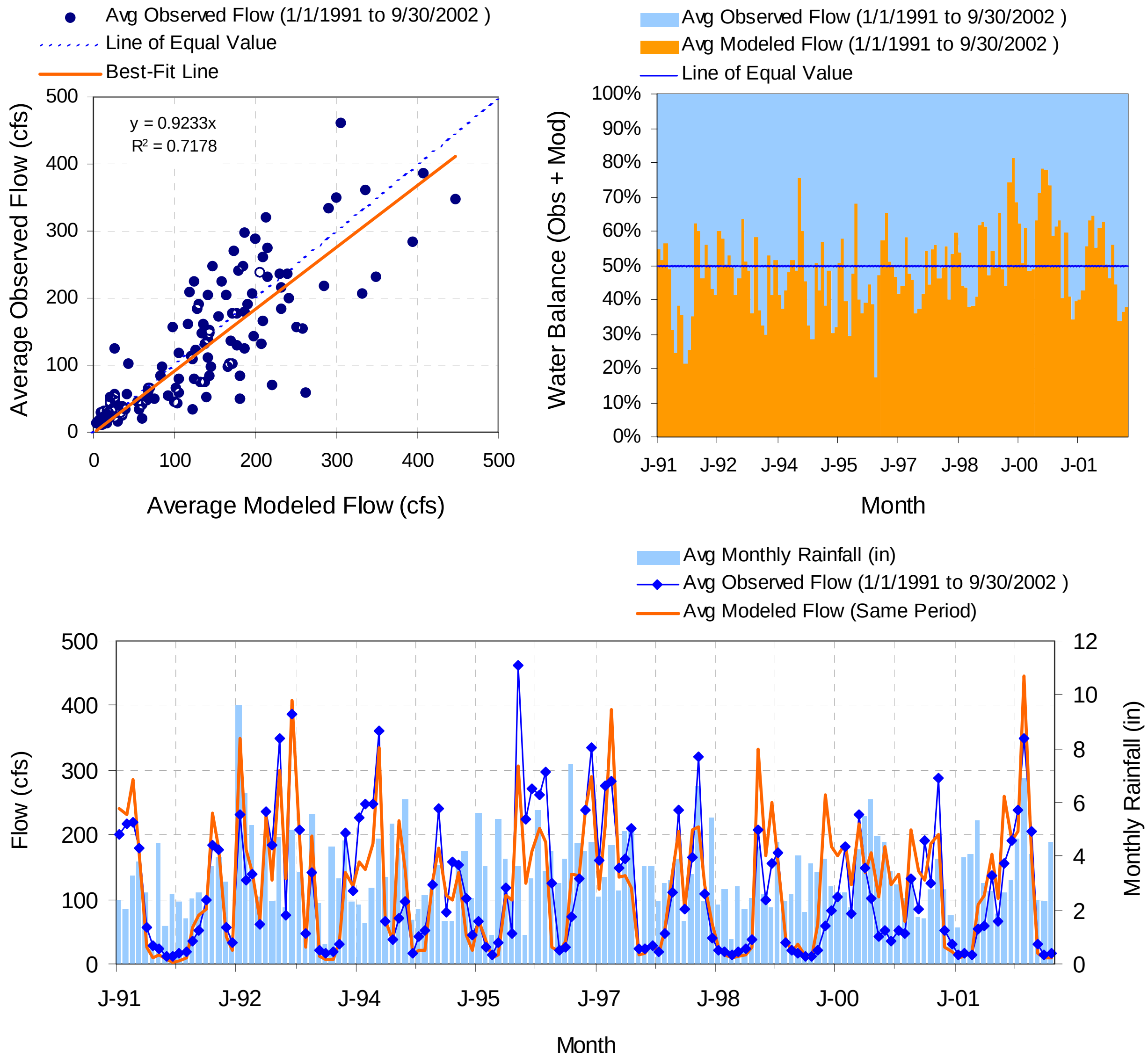

Figure 12. Time series hydrologic validation results (1991 to 2002) for the Eagle Creek subwatershed (USGS gage 3093000).

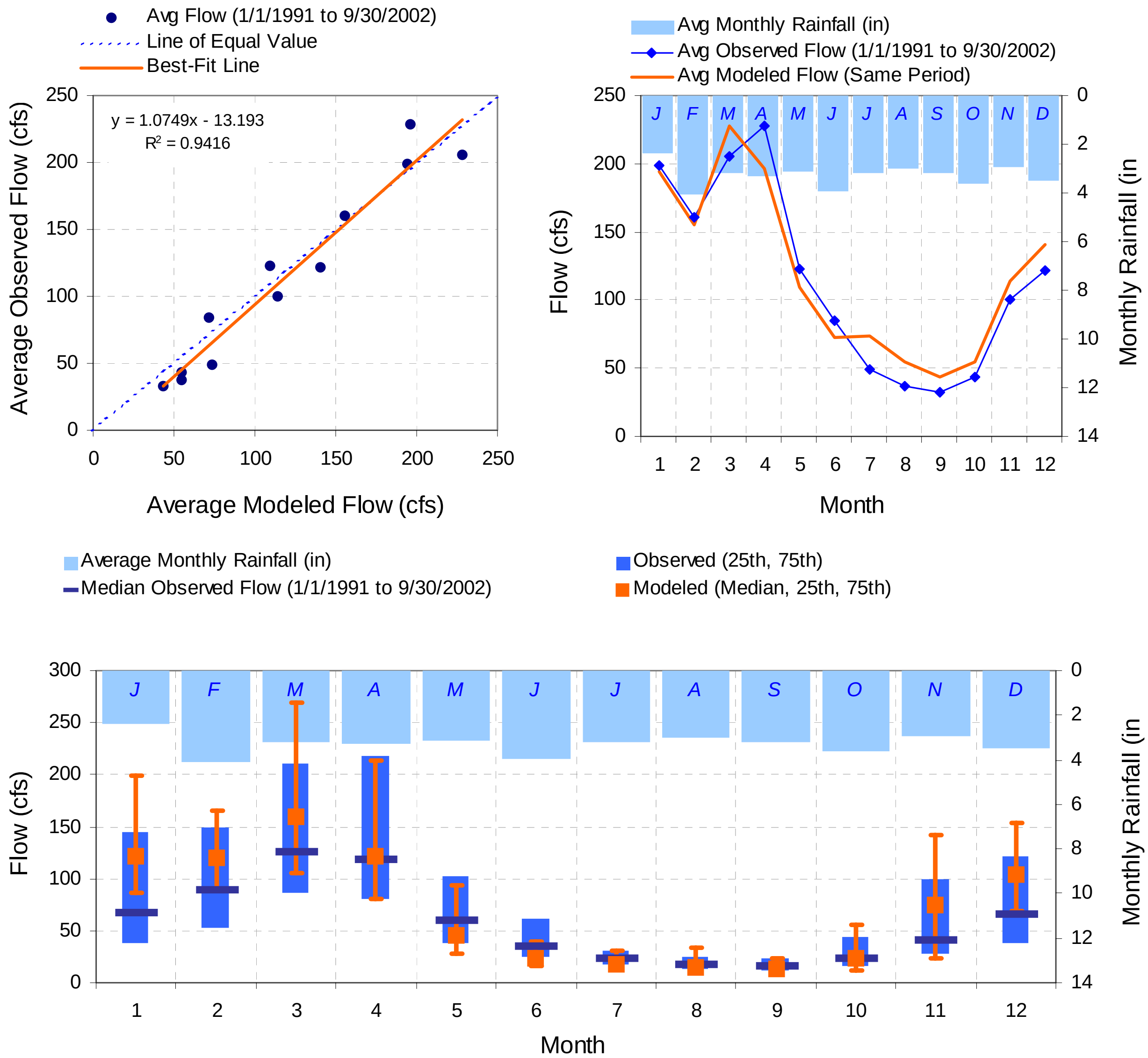

Figure 13. Composite (average monthly) hydrologic validation results (1990 to 2002) for the Eagle Creek subwatershed (USGS gage 3093000).

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 46 11.75-Year Analysis Period: 1/1/1991 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		USGS 03093000 Eagle Creek at Phalanx Station OH Trumbull County, Ohio Hydrologic Unit Code 05030103 Latitude 41°15'40", Longitude 80°57'16" NAD27 Drainage area 97.60 square miles		
Total Simulated In-stream Flow:	**16.68**	Total Observed In-stream Flow:		**16.10**
Total of simulated highest 10% flows:	**7.82**	Total of Observed highest 10% flows:		**8.65**
Total of Simulated lowest 50% flows:	**1.72**	Total of Observed Lowest 50% flows:		**1.73**
Simulated Summer Flow Volume (months 7-9):	**2.05**	Observed Summer Flow Volume (7-9):		**1.42**
Simulated Fall Flow Volume (months 10-12):	**3.38**	Observed Fall Flow Volume (10-12):		**2.89**
Simulated Winter Flow Volume (months 1-3):	**6.80**	Observed Winter Flow Volume (1-3):		**6.65**
Simulated Spring Flow Volume (months 4-6):	**4.46**	Observed Spring Flow Volume (4-6):		**5.14**
Total Simulated Storm Volume:	**8.24**	Total Observed Storm Volume:		**9.15**
Simulated Summer Storm Volume (7-9):	**1.26**	Observed Summer Storm Volume (7-9):		**0.72**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	3.50	10		
Error in 50% lowest flows:	-0.77	10		
Error in 10% highest flows:	-10.63	15		
Seasonal volume error - Summer:	**30.75**	**30**		
Seasonal volume error - Fall:	14.28	30		
Seasonal volume error - Winter:	2.21	30		
Seasonal volume error - Spring:	-15.23	30		
Error in storm volumes:	-10.98	20		
Error in summer storm volumes:	42.68	50		

Figure 14. Error statistics for hydrologic validation results (1990 to 2002) for the Eagle Creek subwatershed (USGS gage 3093000).

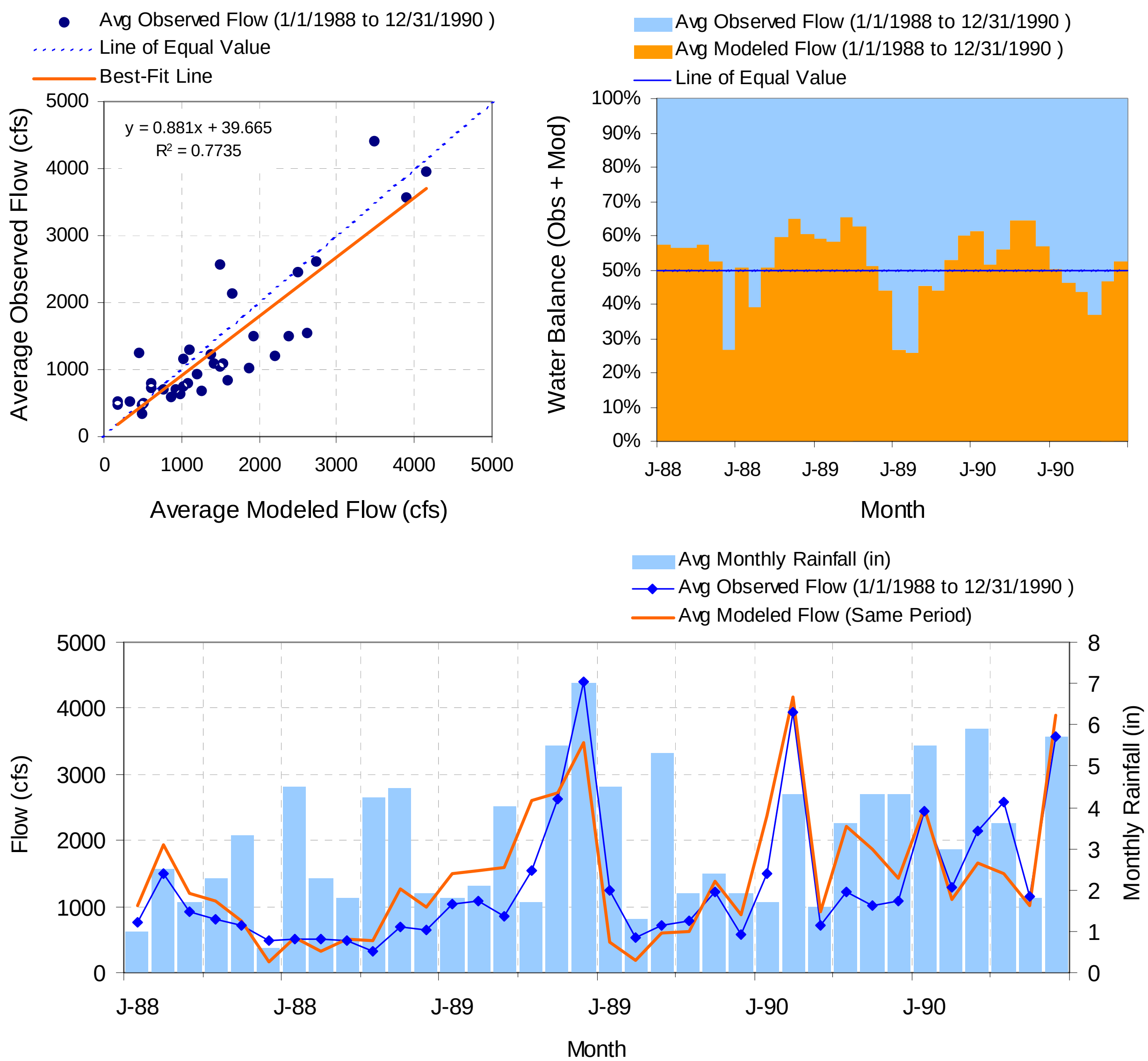

Figure 15. Time series hydrologic calibration results (1988 to 1990) for the entire Mahoning River watershed (USGS gage 3099500).

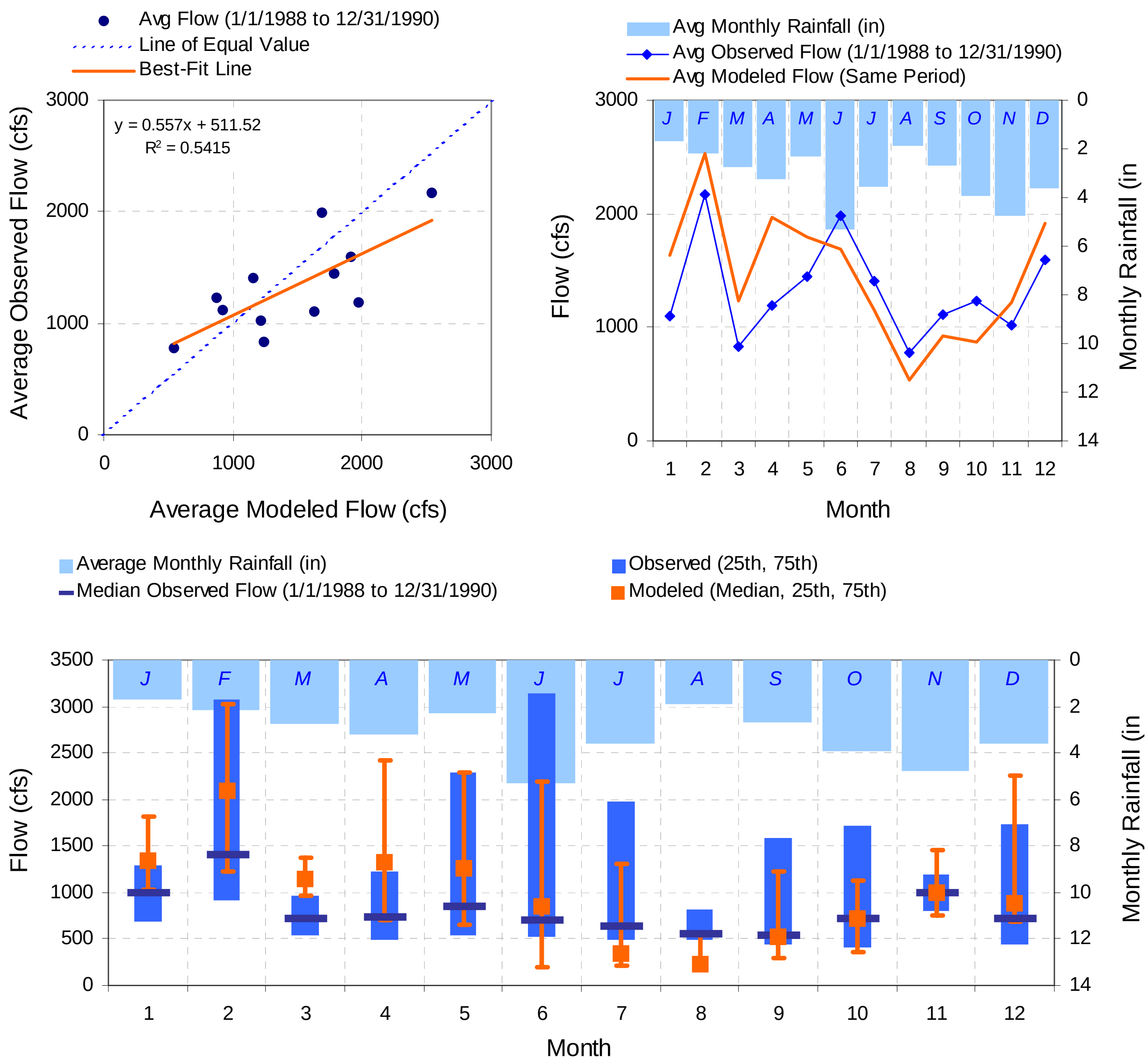

Figure 16. Composite (average monthly) hydrologic calibration results (1988 to 1990) for the entire Mahoning River watershed (USGS gage 3099500).

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 2 3-Year Analysis Period: 1/1/1988 - 12/31/1990 Flow volumes are (inches/year) for upstream drainage area		USGS 03099500 Mahoning River at Lowellville OH Mahoning County, Ohio Hydrologic Unit Code 05030103 Latitude 41°02'12", Longitude 80°32'11" NAD27 Drainage area 1,073.00 square miles	
Total Simulated In-stream Flow:	**18.34**	Total Observed In-stream Flow:	**16.67**
Total of simulated highest 10% flows:	**6.73**	Total of Observed highest 10% flows:	**5.92**
Total of Simulated lowest 50% flows:	**3.24**	Total of Observed Lowest 50% flows:	**3.35**
Simulated Summer Flow Volume (months 7-9):	**2.78**	Observed Summer Flow Volume (7-9):	**3.50**
Simulated Fall Flow Volume (months 10-12):	**4.26**	Observed Fall Flow Volume (10-12):	**4.10**
Simulated Winter Flow Volume (months 1-3):	**5.57**	Observed Winter Flow Volume (1-3):	**4.20**
Simulated Spring Flow Volume (months 4-6):	**5.73**	Observed Spring Flow Volume (4-6):	**4.86**
Total Simulated Storm Volume:	**9.04**	Total Observed Storm Volume:	**6.87**
Simulated Summer Storm Volume (7-9):	**1.57**	Observed Summer Storm Volume (7-9):	**1.36**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	9.13	10		
Error in 50% lowest flows:	-3.17	10		
Error in 10% highest flows:	12.07	15		
Seasonal volume error - Summer:	-26.02	30		
Seasonal volume error - Fall:	3.71	30		
Seasonal volume error - Winter:	24.60	30		
Seasonal volume error - Spring:	15.14	30		
Error in storm volumes:	**23.94**	**20**		
Error in summer storm volumes:	12.84	50		

Figure 17. Error statistics for hydrologic calibration results (1988 to 1990) for the entire Mahoning River watershed (USGS gage 3099500).

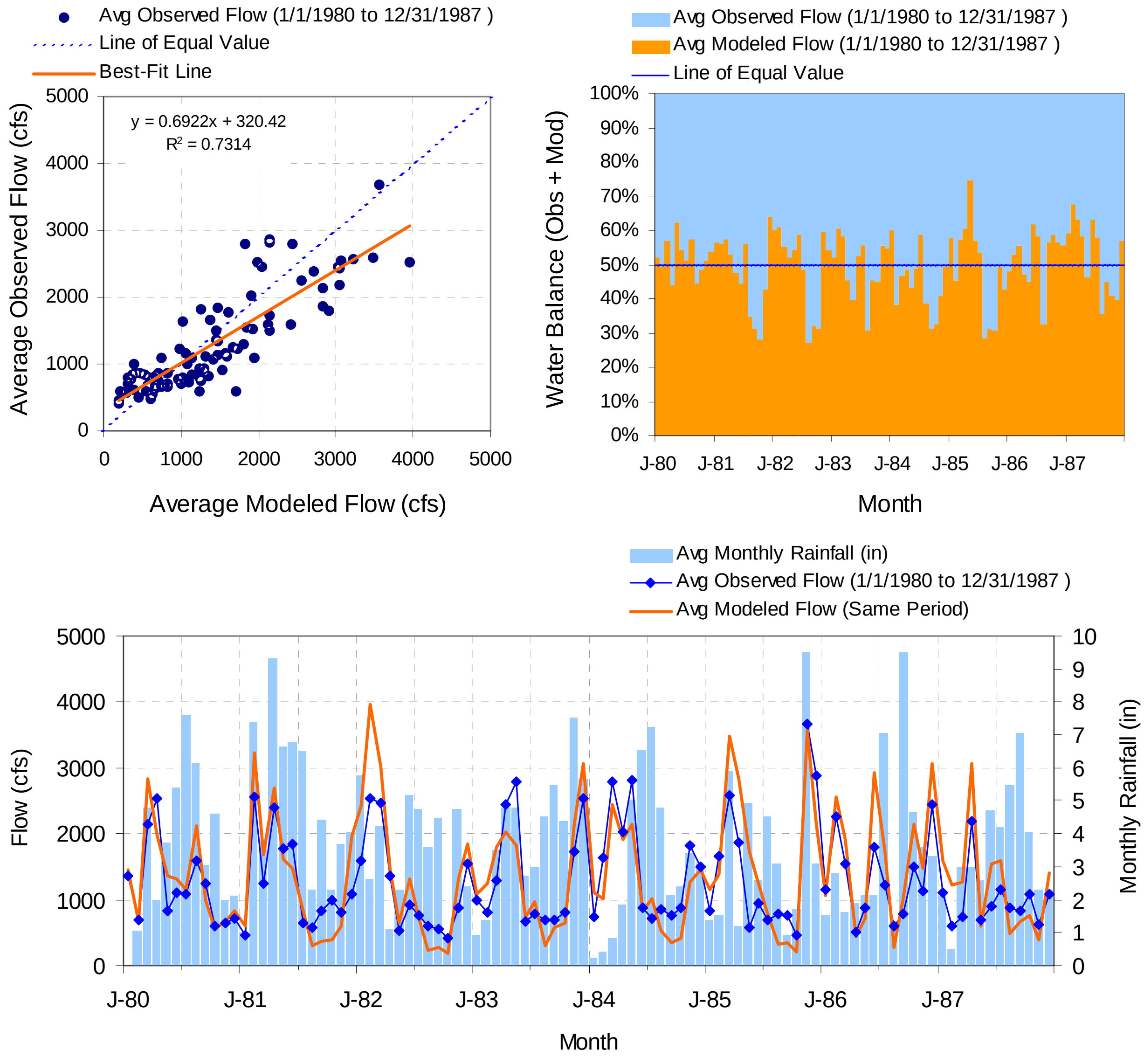

Figure 18. Time series hydrologic validation results (1980 to 1987) for the entire Mahoning River watershed (USGS gage 3099500).

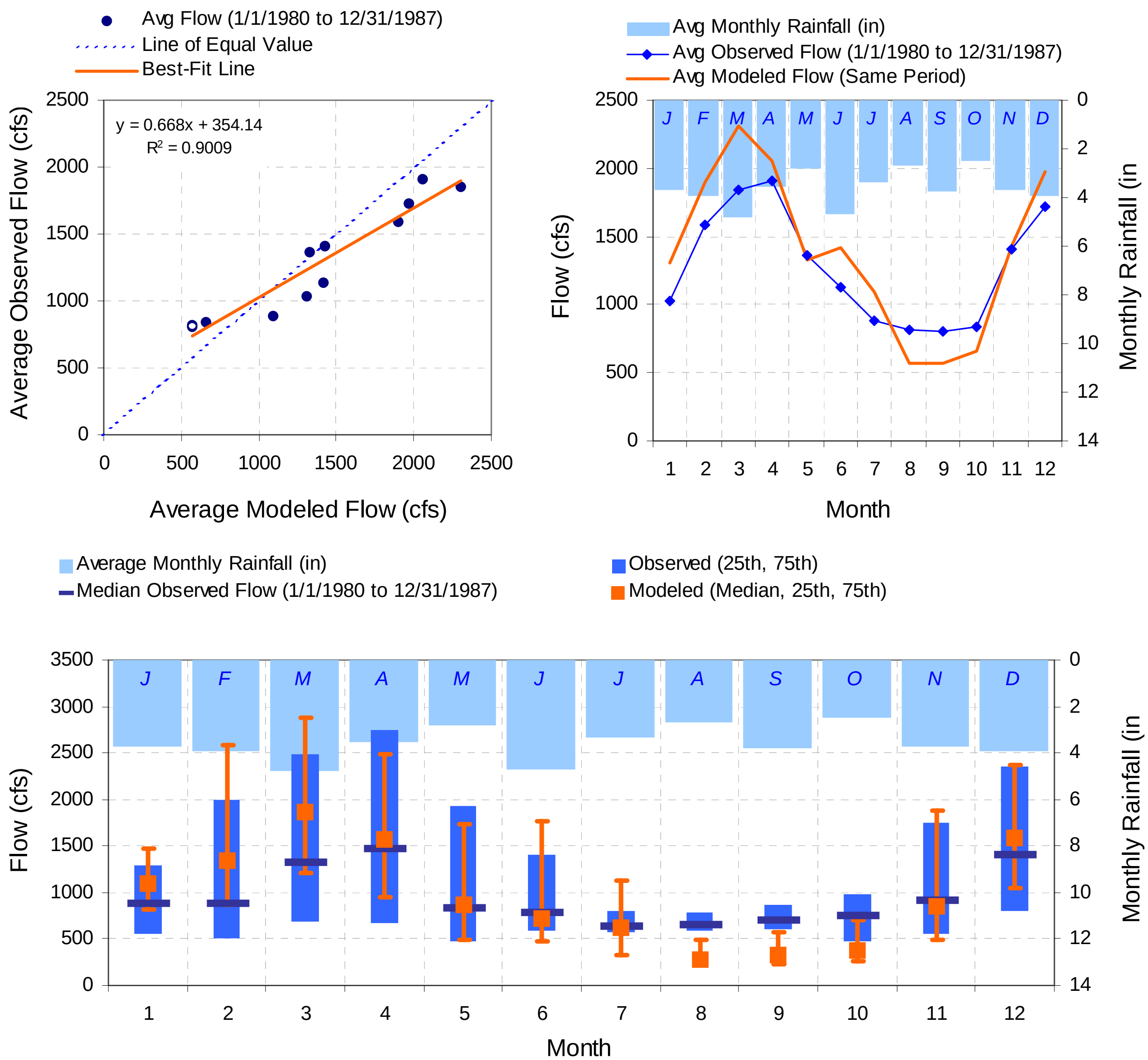

Figure 19. Composite (average monthly) hydrologic validation results (1980 to 1987) for the entire Mahoning River watershed (USGS gage 3099500).

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 2 8-Year Analysis Period: 1/1/1980 - 12/31/1987 Flow volumes are (inches/year) for upstream drainage area		USGS 03099500 Mahoning River at Lowellville OH Mahoning County, Ohio Hydrologic Unit Code 05030103 Latitude 41°02'12", Longitude 80°32'11" NAD27 Drainage area 1,073.00 square miles	
Total Simulated In-stream Flow:	**17.48**	Total Observed In-stream Flow:	**16.16**
Total of simulated highest 10% flows:	**6.17**	Total of Observed highest 10% flows:	**5.21**
Total of Simulated lowest 50% flows:	**2.94**	Total of Observed Lowest 50% flows:	**3.66**
Simulated Summer Flow Volume (months 7-9):	**2.38**	Observed Summer Flow Volume (7-9):	**2.67**
Simulated Fall Flow Volume (months 10-12):	**4.31**	Observed Fall Flow Volume (10-12):	**4.22**
Simulated Winter Flow Volume (months 1-3):	**5.75**	Observed Winter Flow Volume (1-3):	**4.65**
Simulated Spring Flow Volume (months 4-6):	**5.04**	Observed Spring Flow Volume (4-6):	**4.62**
Total Simulated Storm Volume:	**8.14**	Total Observed Storm Volume:	**6.37**
Simulated Summer Storm Volume (7-9):	**1.32**	Observed Summer Storm Volume (7-9):	**0.76**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	7.56	10		
Error in 50% lowest flows:	**-24.62**	**10**		
Error in 10% highest flows:	**15.55**	**15**		
Seasonal volume error - Summer:	-11.92	30		
Seasonal volume error - Fall:	2.17	30		
Seasonal volume error - Winter:	19.15	30		
Seasonal volume error - Spring:	8.18	30		
Error in storm volumes:	**21.73**	**20**		
Error in summer storm volumes:	41.94	50		

Figure 20. Error statistics for hydrologic validation results (1980 to 1987) for the entire Mahoning River watershed (USGS gage 3099500).

A7.2 Water Quality Calibration

Following hydrology calibration, the water quality was calibrated by comparing modeled versus observed in-stream fecal coliform bacteria concentrations. The water quality calibration consisted of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting water quality parameters within a reasonable range. The water quality parameters that were adjusted to obtain a calibrated model were the build-up and washoff of fecal coliform bacteria from the land uses and the direct load estimates such as cattle in the streams and failing septic systems.

The approach taken to calibrate water quality focused on matching trends identified during the water quality analysis. Daily average in-stream fecal coliform bacteria concentrations from the model were compared directly to observed data. The objective was to best simulate concentrations during low flow, mean flow, and storm peaks at representative water quality monitoring stations.

The time period of the model water quality calibration was from 10/1/1994 through 9/31/1996. The validation period was 10/1/2000 to 9/31/2002. This time period was selected based on the time period associated with the landuse cover, falls within the hydrology calibration and validation periods, and relevance of the observed data to the current conditions in the watershed.

Fecal coliform accumulation and surface loading parameters for land uses were calculated based on contributions from various sources, as discussed in Section A4. After incorporating these model parameters and inputs, as well as contributions from livestock and wildlife point sources, CSOs, septic systems, and background concentrations in the streams, modeled in-stream fecal coliform bacteria concentrations were compared to observed data. The modeled concentrations closely correspond to the observed fecal coliform values, as shown in Figures 21 through 27. The relative pattern of observed concentration levels is maintained in the modeled concentrations and the model is determined to be appropriate for use in TMDL development.

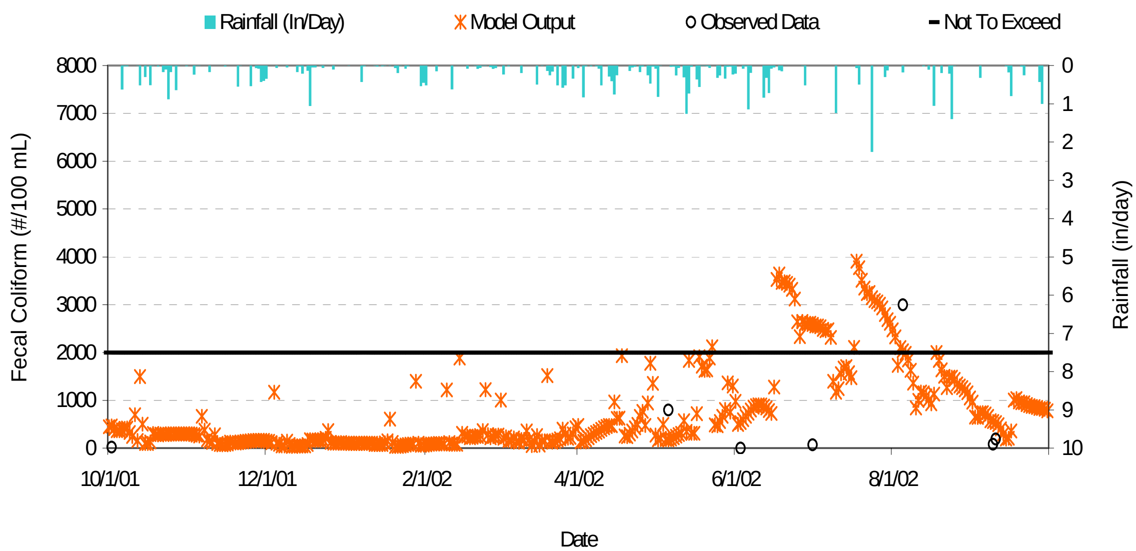

Figure 21. Fecal coliform water quality calibration subwatershed 27, sampling location OH0027987 (Warren STP).

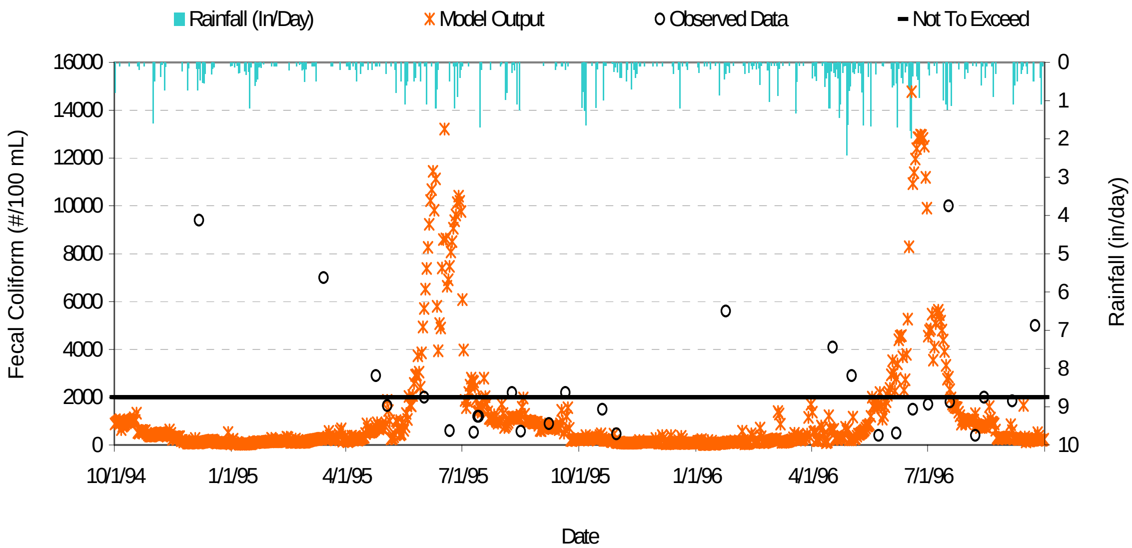

Figure 22. Fecal coliform water quality validation subwatershed 27, sampling location OH0027987 (Warren STP).

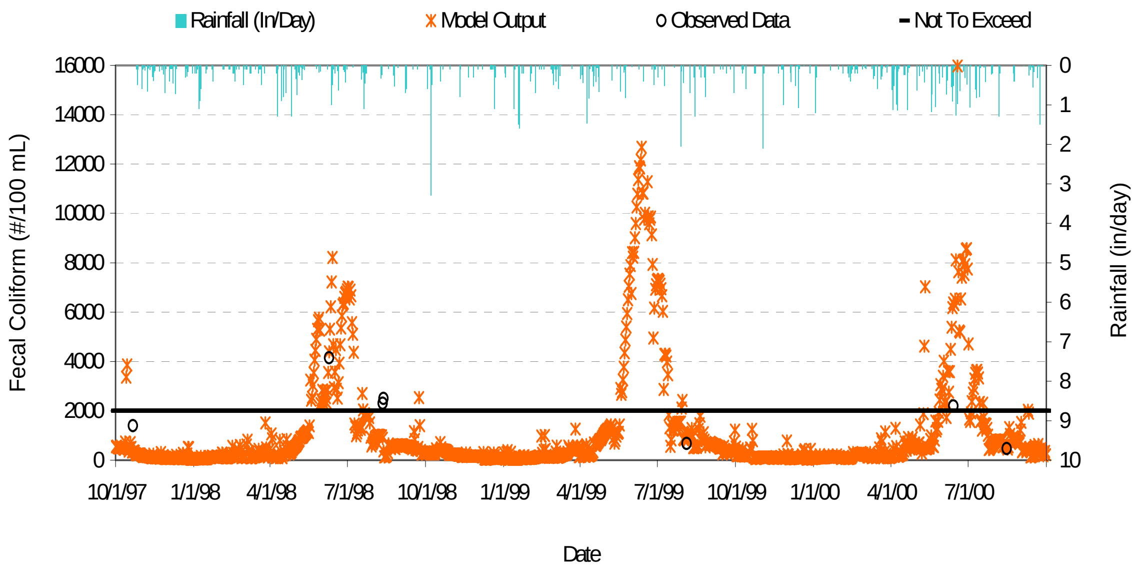

Figure 23. Fecal coliform water quality calibration subwatershed 2, sampling location 3815050319000 (Lowellville).

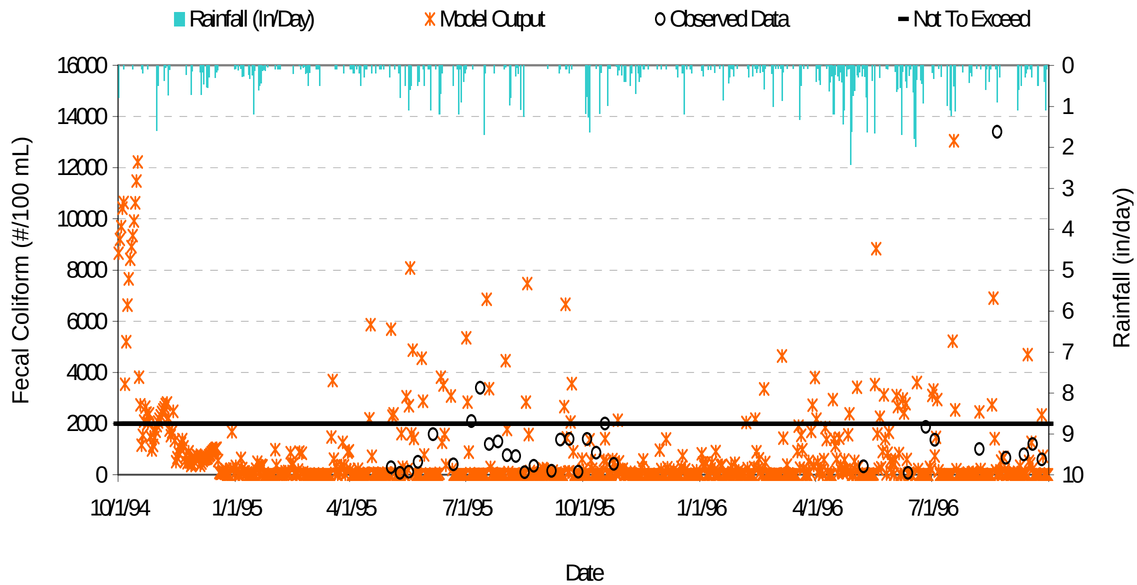

Figure 24. Fecal coliform water quality validation subwatershed 2, sampling location 3815050319000 (Lowellville).

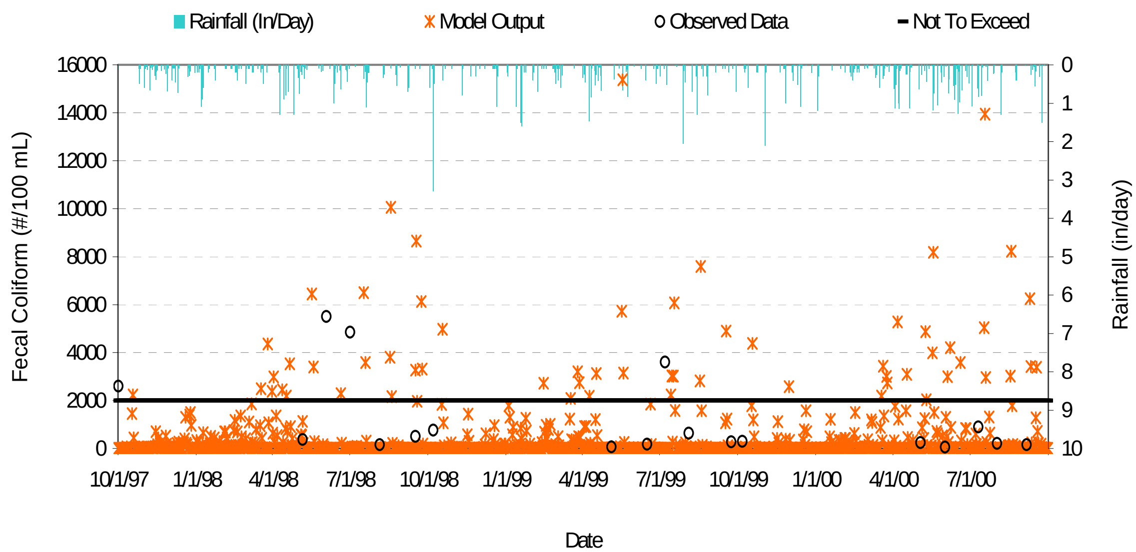

Figure 25. Fecal coliform water quality calibration subwatershed 16, sampling location OH0037249 (Boardman WWTP)

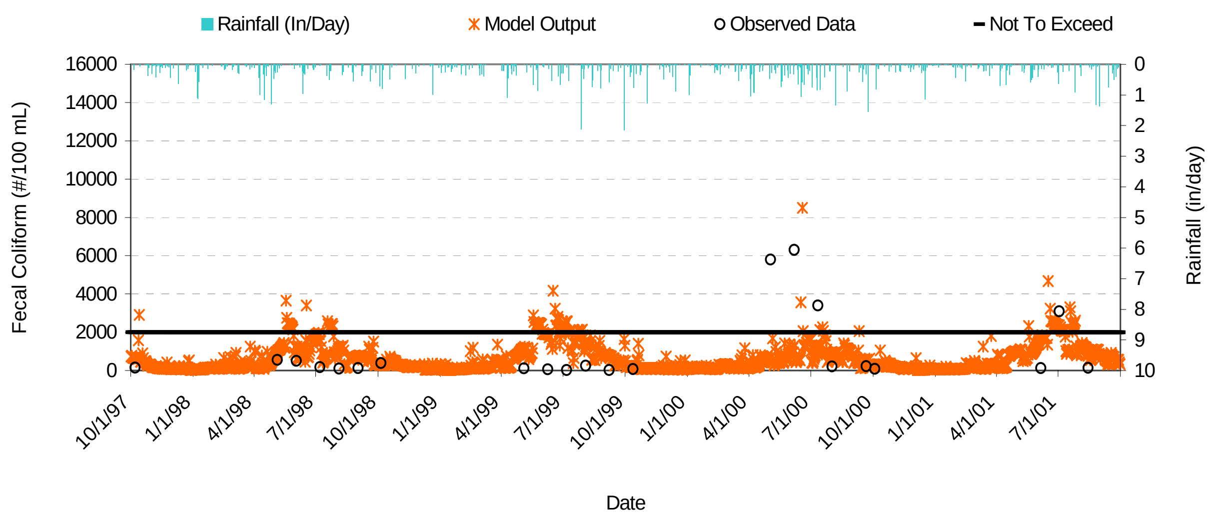

Figure 26. Fecal coliform water quality validation subwatershed 16, sampling location OH0037249 (Boardman WWTP).

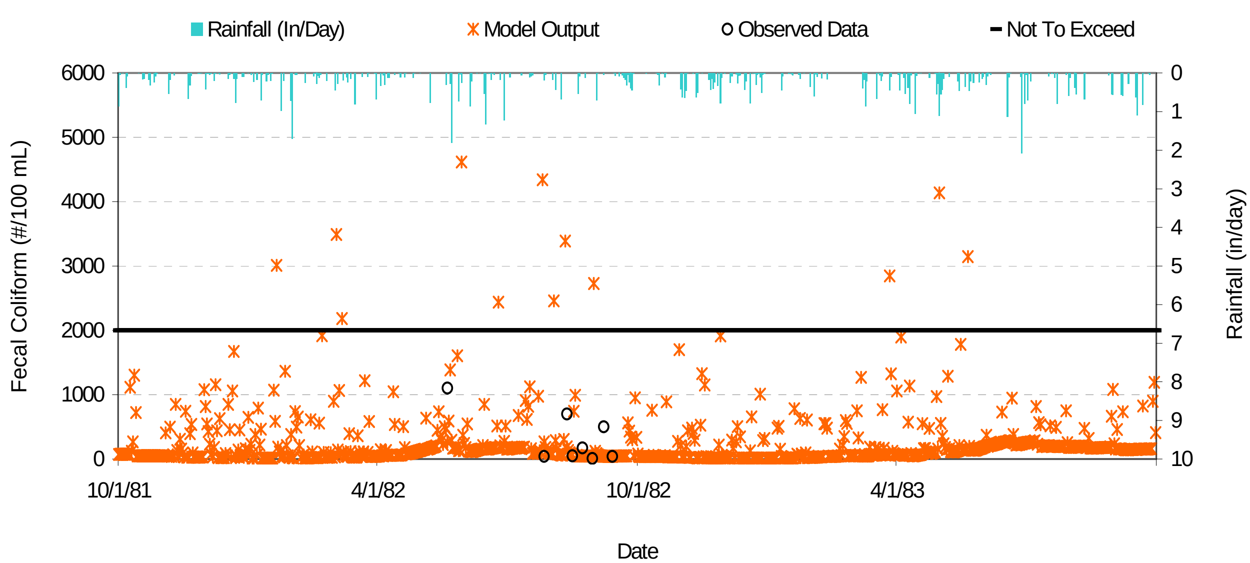

Figure 27. Fecal coliform water quality calibration subwatershed 11, sampling location OH0028223 (Youngstown WWTP).

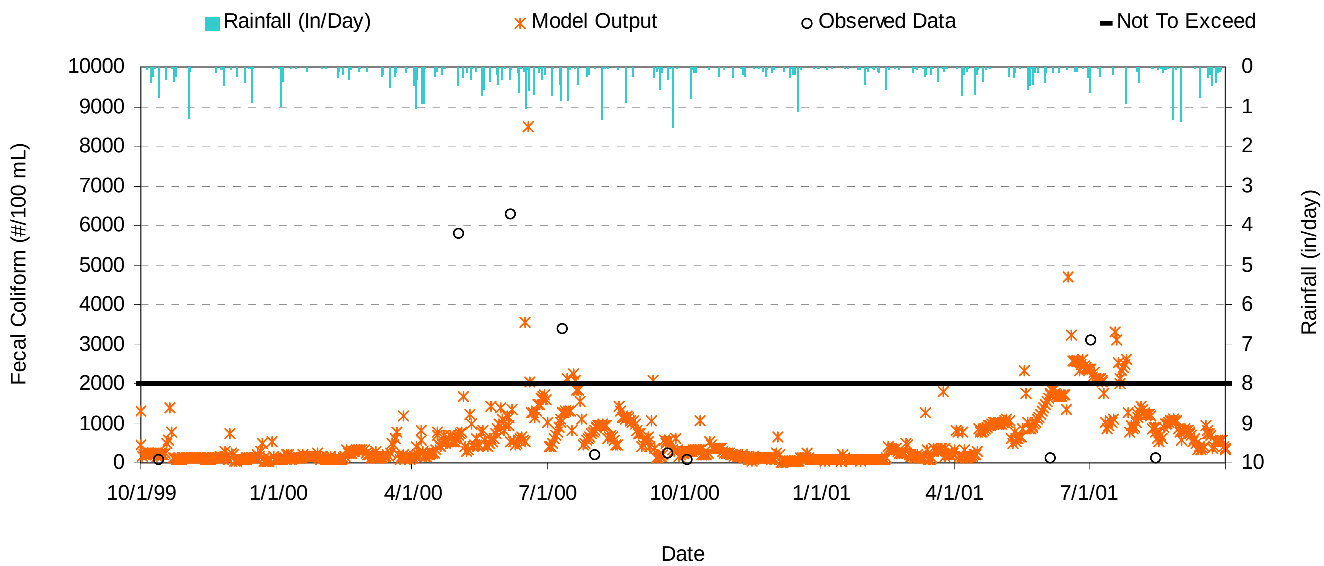

Figure 28. Fecal coliform water quality validation subwatershed 11, sampling location OH0028223 (Youngstown WWTP).

References

Dunne, T. and L.B. Leopold (1978). *Water in Environmental Planning*. W.H. Freeman and Co., San Francisco, CA.

USGS. 2002. *Water Quality of the Mahoning River and Selected Tributaries in Youngstown, Ohio*. U.S. Department of the Interior, U.S. Geological Survey Water-Resources Investigations Report 02–4122. In cooperation with the City of Youngstown.

Appendix A: Application of the Loading Simulation Program C++ (LSPC) to the Mahoning River Watershed, Ohio

Addendum
September 10, 2004

Source Representation

Both point and nonpoint sources were represented in the model for the Mahoning River watershed. In general, the point sources were added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources were represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (e.g., illicit onsite wastewater connections, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream.

Bacterial production rates for the various sources (i.e., failing septic systems, livestock, wildlife) were based on literature values summarized in EPA's Bacteria Indicator Tool (http://www.epa.gov/waterscience/ftp/basins/system/BASINS3/bit.htm)

Land-to-Water Bacterial Delivery Ratio

The LSPC model estimates nonpoint source loading based on the quantity of fecal coliform in storage on the land surface and the volume of overland flow during that time step. Fecal coliform is not washed from the land surface as a linear delivery ratio related to overland flow, since a limit of fecal coliform storage is set to represent in-situ decay on the land surface. Therefore, a relationship between overland flow and the quantity of fecal coliform transported to the receiving water is no longer linear once the stored quantity on the land surface is depleted. Bacteria accumulation rates (#/acre/day) considering the sources described in the Source Assessment section of the TMDL Report were calculated using subwatershed population estimates and the bacteria production rate established for each species as specified in EPA's Bacteria Indicator Tool spreadsheet. The Bacteria Indicator Tool thus estimates a landuse-specific accumulation rate for fecal coliform.

LSPC utilizes the Chezy-Manning equations in simulating overland flow. These equations require a value for average land surface slope over the overland flow plane, a length for the overland flow plane, and a Manning's roughness coefficient. For the Mahoning River TMDL, subwatershed-specific slope values were assigned for each of the subwatersheds based on digital elevation model (DEM) analyses, in order to address localized variations in land-waterbody travel times.

Failing Septic Systems

Septic systems provide the potential to deliver bacteria loads to surface waters due to system failures caused by improper maintenance and/or malfunctions. The number of septic systems in each subwatershed was determined using U.S. Census Year 2000 and 1990 block group data for Ashtabula, Columbiana, Geauga, Lawrence, Mahoning, Portage, Stark and Trumbull Counties as described in Section 4.1 of the July 12, 2004 version of Appendix A. The number of failing septic systems was estimated using a failure rate of 20 percent based on discussions with the Trumbull County Health Department and a review of failure rates used in other TMDL watersheds with a significant urban population. In some cases, human waste is directly deposited into surface waters from houses without septic systems (i.e., “straight pipe” systems). The population served by straight pipes was assumed to be 1% of the total septic/other disposal means population in the watershed. Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal bacteria to surface waters.

The estimated flow rates for failing septic systems in the Mahoning River watershed are shown in Table 1.

Table 1. Estimated flow rates for failing septic systems in the Mahoning River watershed.

County	Tot. # people on septics	Density people/septic	# failing septics	Tot. # people served	Septic flow (gal/day)	Septic flow (mL/hr)
Ashtabula	135	2.3	9	20	1,414	223,001
Columbiana	4503	2.4	278	675	47,277	7,455,949
Geauga	24	2.8	1	4	255	40,187
Lawrence	4680	2.4	294	702	49,144	7,750,370
Mahoning	36959	2.3	2,406	5,544	388,072	61,202,225
Portage	10671	2.5	633	1,601	112,046	17,670,636
Stark	7687	2.4	479	1,153	80,715	12,729,481
Trumbull	54250	2.4	3,438	8,138	569,630	89,835,327

Livestock

Pathogens produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Pathogens deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed and it was assumed that grazing stock have limited stream access due to the forested buffer present in a large part of the watershed.

Animal population estimates for the Mahoning River watershed were based on the 1997 Ohio Agricultural Census data for each of the eight counties within the watershed and are summarized in Table 2. Phone calls were placed to the local soil and water conservation districts to update the Census values, but comprehensive updates for each county were not readily available. Pathogen loads directed through each pathway were calculated by multiplying the bacteria density with the amount of waste expected through that pathway.

Animals included in the livestock pathogen calculation include cattle, swine, chicken, sheep and horses. The population of each livestock species was distributed among subwatersheds based on the total area of pasture in each subwatershed . The total population reported for cattle and calves was used to determine the total number of beef and dairy cattle in each subwatershed. Bacteria and manure production rates for the livestock were based on literature values summarized in EPA's Bateria Indicator Tool and are summarized in Tables 3 and 4.

Table 2. Number of cattle, by county, in the Mahoning River watershed (1997 Agricultural Census).

COUNTY	BEEF CATTLE	SWINE (HOGS)	DAIRY CATTLE	CHICKENS	HORSES	SHEEP
Ashtabula	393	70	260	4	1194	37
Columbiana	2960	1184	1860	17	1216	433
Geauga	79	25	53	8	2534	12
Lawrence	1423	568	739	70	1011	196
Mahoning	6507	2596	3379	320	1052	897
Portage	3388	1356	1455	37	1790	559
Stark	1799	990	971	25107	1704	145
Trumbull	3768	491	1614	197	1254	133

Table 3. Bacteria production rates for livestock animals (EPA Bacteria Indicator Tool).

Animal	FC (count/animal/day)
Dairy cow	1.01E+11
Beef cow	1.04E+11
Hog	1.08E+10
Sheep	1.20E+10
Horse	4.20E+08
Chicken	1.36E+08

Table 4. Manure production rates for livestock animals.

Animal	Total Manure prod	Typical Animal Mass	Manure prod per animal	Fecal Coliform	Fecal Coliform	Manure prod	Fecal Coliform
	(lb/day per 1,000 lb animal)	(lb)	(lb/day)	(count/day E10 per 1,000 lb animal)	(count/day)	(lb/yr)	(count/yr)
Dairy cow	86	1400	120	7.2	1.01E+11	43946	3.68E+13
Beef cow	58	800	46	13	1.04E+11	16936	3.80E+13
Hog	84	135	11	8	1.08E+10	4139	3.94E+12
Sheep	40	60	2	20	1.20E+10	876	4.38E+12
Horse	51	1000	51	0.042	4.20E+08	18615	1.53E+11
Chicken (Layer)	64	4	0	3.4	1.36E+08	93	4.96E+10

Wildlife

The population of each wildlife species was estimated using the population density per square mile of habitat and the total area of suitable habitat in each subwatershed. As with grazing livestock, wildlife deposit manure on the land and directly to surface waters. The habitat and percentage of time each species typically spends in streams was used to determine the proportion of bacteria that was deposited on land versus directly to surface waters. Loads applied to the land (in each subwatershed) were distributed according to the total area of each land use type within the established habitat area of each species. The animal densities and bacteria production rates for wildlife values used in the model are summarized in Tables 5 and 6.

Table 5. Animal densities used in the Mahoning River watershed modeling.

Animal	Cropland	Cropland	Pasture	Pasture	Forest	Forest	Built-up	Built-up
	#/mi^2	#/acre	#/mi^2	#/acre	#/mi^2	#/acre	#/mi^2	#/acre
Ducks	0.581	0.001	0.759	0.001	6.000	0.009	3.000	0.005
Geese	12.000	0.019	12.000	0.019	6.000	0.009	3.000	0.005
Deer	35.000	0.055	35.000	0.055	35.000	0.055	8.500	0.013
Beaver	0.014	0.000	0.019	0.000	0.089	0.000	0.089	0.000
Raccoons	7.000	0.011	7.000	0.011	15.000	0.023	5.000	0.008

Table 6. Bacteria production rates for wildlife.

Animal	FC (count/animal/day)
Goose	4.90E+10
Deer	5.00E+08
Beaver	2.50E+08
Raccoon	1.25E+08
Ducks	2.43E+09