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SITE: GE - Housatonic
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Campbell, Scott (MNH)

From: Campbell, Scott (MNH)
Sent: Wednesday, April 07, 2004 4:05 PM
To: Kevin Mooney (Kevin.Mooney@corporate.ge.com)
Subject: DCN: GE-040704-ACDG Draft Watershed Model Calibration Report

Hello Kevin,

As requested by Susan Svirsky of EPA, please find the Draft Watershed Model Calibration Report for GE review. Due to the large size of the document, I was unable to convert the entire file into a single PDF file. The document has been formatted into four separate files to reduce the overall size. In addition, I have included the Table of Contents in Microsoft Word format as the PDF software was unable to preserve the document links once the main document was divided into separate files.

Please do not hesitate to contact me with any questions in regard to this submittal.

Scott

Appendix A
ershed Model.z

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Appendix A

Watershed Model Calibration Report

ATTACHMENTS

FIGURES

TABLES

A.1 INTRODUCTION

This report documents the application and calibration of the U. S. EPA Hydrological Simulation Program–FORTRAN (HSPF) (Bicknell et al., 2001) watershed model to the Housatonic River above Great Barrington, MA. This effort was performed, under contract to Weston Solutions, Inc., in support of the human health and ecological risk assessment being conducted by EPA for PCB contamination of the Housatonic River from GE facilities in Pittsfield, MA. The Housatonic Watershed Model developed in this effort provides the flow inflows and boundary conditions for the EFDC model, and water temperature conditions for use in the FCM. The intent of this report is to document: (1) the data available to support the model application, (2) the model setup and application to the Housatonic River Watershed, (3) the procedures and results of the model calibration.

Figure A.1-1 shows the Housatonic River watershed upstream of the U.S. Geological Survey (USGS) gaging station (ID # 01197500) at Great Barrington, MA, an area of 282 square miles; this area is referred to as the 'hydrologic study area', or HSA, and defines the entire watershed area to which the HSPF model is being applied. Figure A.1-1 also shows the mainstem of the Housatonic River, the major tributaries, subbasin drainage areas (referred to as model segments), and the Primary Study Area (PSA) represented by the 10-year floodplain (shaded area) between the confluence of the East and West Branch, and Woods Pond. An expanded view of the area between Dalton and Woods Pond, including the PSA, is shown in Figure A.1-2. (Note that the model segment numbers have been changed from those initially assigned in the MFD and QAPP.)

Following this introduction, Section 2 of this report describes the watershed model data needs and the available database to support the application to the Housatonic Watershed. Section 3 describes the watershed and channel characterization data used to segment the watershed area into individual subbasins and channel reaches, along with the data used to parameterize these model components for their physical characteristics and their spatial distribution throughout the watershed. In Section 4, we provide an overview of the HSPF hydrology calibration procedures, and then present the full range of model-data comparisons, both qualitative and quantitative, used to guide and assess the hydrology calibration. For those reviewers who are primarily interested in the ‘bottom line’, the conclusions and recommendations for the hydrology calibration can be found at the end of the section (i.e., Section 4.3). Section 5 discusses the sediment and water temperature calibration and presents the corresponding model results.

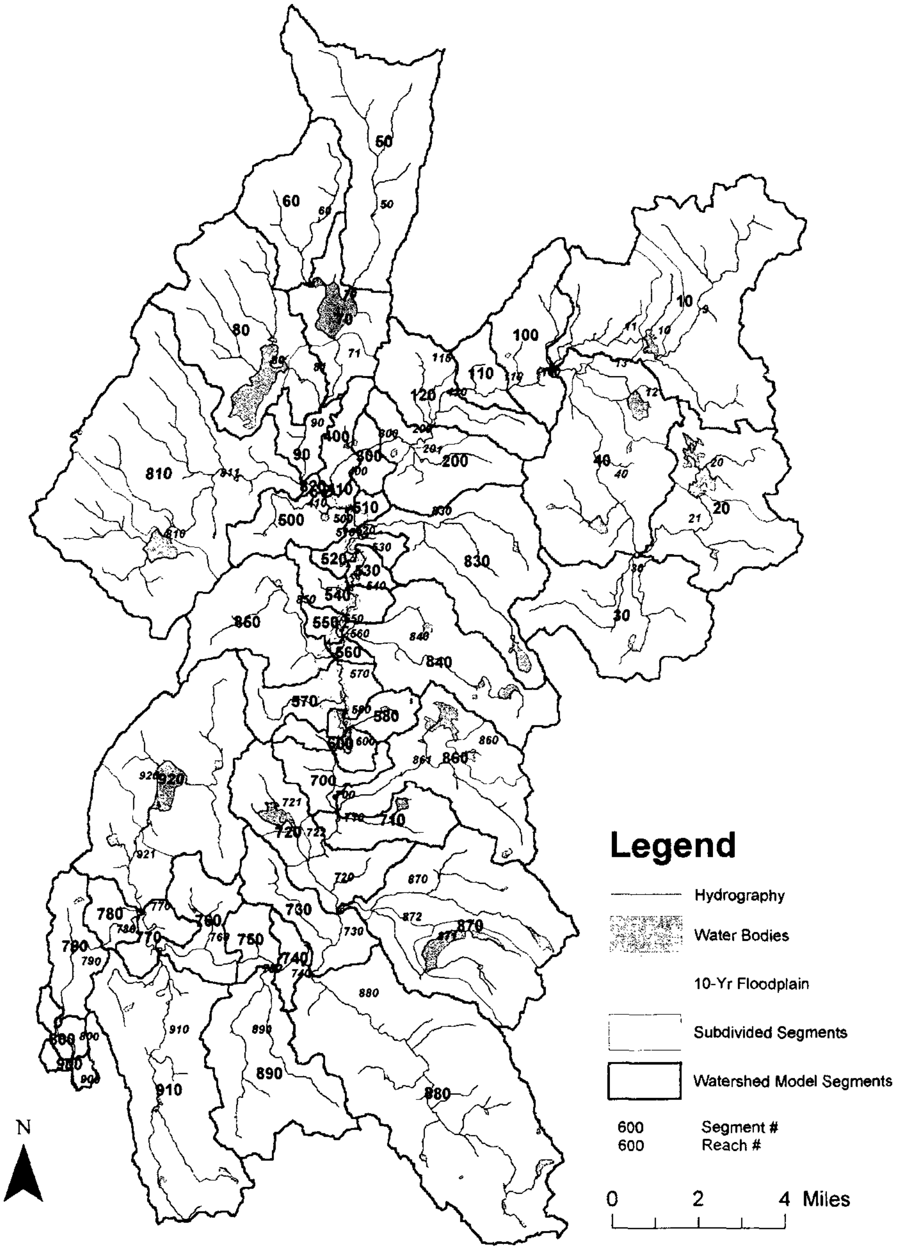

Figure A.1- 1 Housatonic River Watershed Segmentation

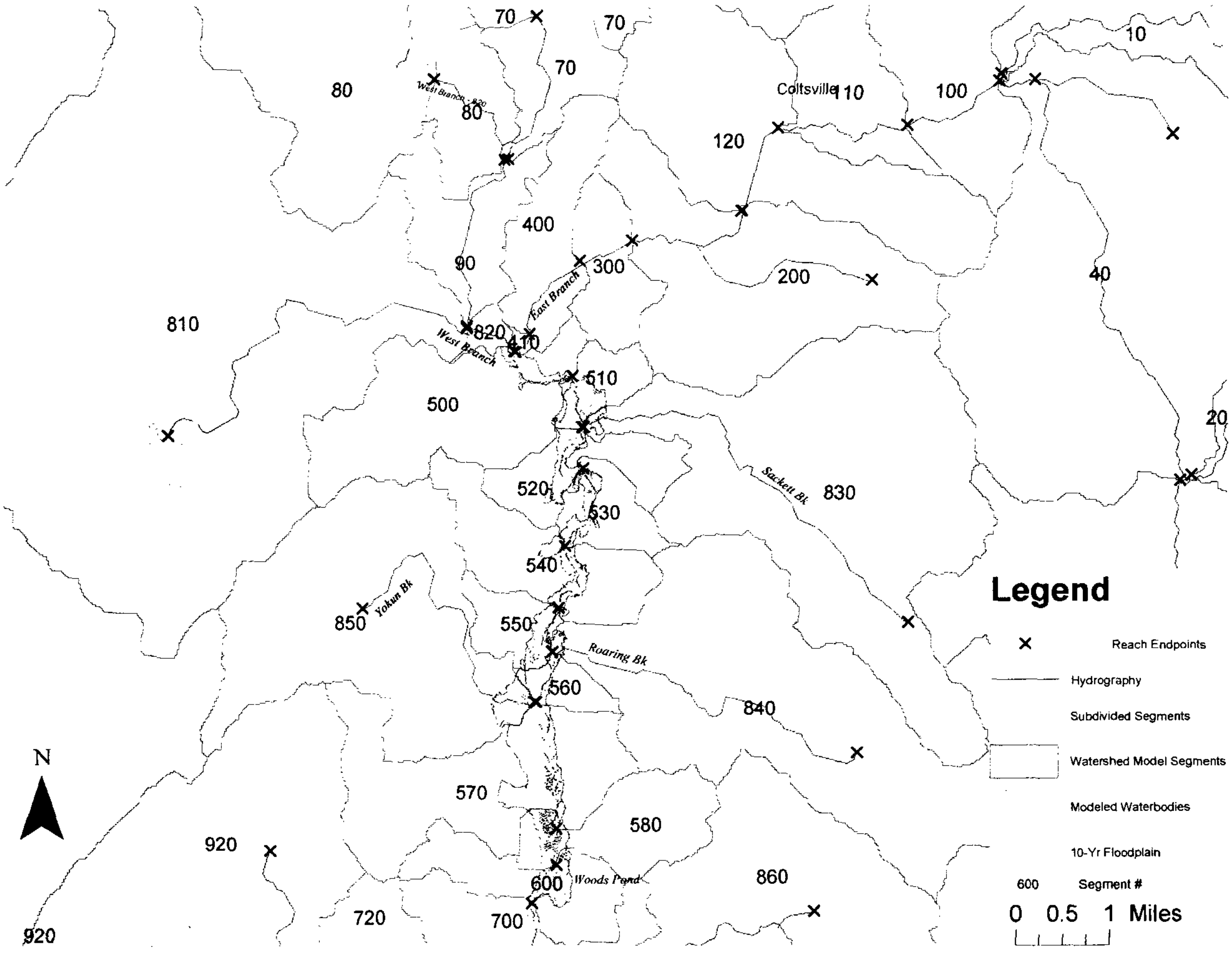

Figure A.1-2 Watershed Model Segmentation within the Primary Study Area

A.2 DATABASE DEVELOPMENT FOR WATERSHED MODELING

A.2.1 OVERVIEW OF WATERSHED MODEL DATA NEEDS

Data requirements for HSPF are extensive, in both spatial and temporal detail, especially for a watershed of the size and complexity of the Housatonic. Table A.2-1 lists the typical data requirements for an HSPF application. These data can be categorized as either input/execution data, watershed/channel characterization data, or calibration/validation data. Database development was a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when needed data were not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained. Fortunately, for this study a rich database exists to support the application. Historical data collected by GE, EPA, USGS, and various state agencies, supplemented with ongoing data collection efforts of these same groups, provides a sound basis for the watershed modeling effort.

A.2.1.1 Input/Execution data (Items 1, 4, and 5 in Table A.2.1)

Precipitation is the primary driving force in any watershed modeling effort, followed in importance by evaporation and air temperature; the remaining meteorological data (listed in Table A.2-1) are required when modeling snow accumulation and melt processes using an energy balance approach. The meteorological data obtained and used for the Housatonic model are discussed in Section 2.2. Diversions, withdrawals, and point sources can noticeably impact the water balance and therefore must be investigated and included in the model when determined to be significant. Section 2.3.3 discusses the known diversions, withdrawals, and point sources within the basin.

A.2.1.2 Watershed/Channel Characterization data (Items 2, 3, and 5 in Table A.2.1)

Information describing the characteristics of the watershed, including topography, drainage patterns, land use distribution, meteorological variability, and soils conditions are required for 'segmenting' the watershed into individual land segments that demonstrate a similar hydrologic and water quality response. In an analogous fashion, information describing the channel and floodplain morphology allows for the segmentation of the stream channel into discrete sections with similar hydraulic behavior. Location of dams/reservoirs, point source discharges, gages/data collectors, and diversions provides information to develop a channel segmentation that supports modeling localized conditions within the watershed. Section 3 discusses the segmentation and characterization of the watershed and channel reaches.

Table A.2-1 Data Requirements For Typical HSPF Applications

1.	**Precipitation and meteorologic data (for simulation period)**
a.	Hourly Precipitation
b.	Daily pan evaporation
c.	Daily maximum and minimum air temperature
d.	Total daily wind movement
e.	Total daily solar radiation
f.	Daily dewpoint temperature
g.	Average daily cloud cover
2.	**Watershed land use/land cover characteristics**
a.	Topographic map/data of watershed and subwatersheds
b.	Land use/cropping delineation and acreages
c.	Soils delineation and characteristics
3.	**Hydrography and channel characterization**
a.	Channel lengths and slopes
b.	Channel cross sections and geometry
c.	Channel bed composition
d.	Diversions, point sources, channelization segments, etc.
e.	Tributary area (and land use distribution) for each channel reach
4.	**Monitoring program observations**
a.	Flow rates during all monitored storm events
b.	Flow volume/rate totals for storm/daily, monthly, annual
c.	Sediment concentrations and mass losses in runoff
d.	Chemical concentrations and mass losses in runoff
e.	Soil concentrations of chemical/nutrient forms, if available
f.	Estimated /actual chemical concentrations in precipitation
g.	Particle size distributions (sand, silt, clay fractions) of soils and eroded sediments
5.	**Other useful information**
a.	Technical reports that describe/quantify the basin's water balance components and the factors that influence it (e.g., diversions, withdrawals, point sources)
b.	Technical reports or articles that analyze and/or summarize the monitoring data
c.	Soils characterization information for estimating model parameters

A.2.1.3 Calibration/Validation data (Items 4 and 5 in Table A.2.1)

The calibration and subsequent validation of a watershed model requires observed values of the model state variables, which for this study includes flow, sediment, and water temperature, over a wide range of environmental and climatic conditions. The hydrology calibration relied on continuous flow data, available from the USGS, at the Coltsville and Great Barrington stations as well as storm-event data collected at multiple sites in 1999-2000. Sediment and water temperature data were also available at most of the same sites, but for shorter periods and time spans. These data were compared with model predictions, and model parameters were adjusted to improve agreement during the calibration step. The hydrologic data are discussed in greater detail in Section 2.3, and the water quality data are discussed in Section 2.4.

A.2.2 METEOROLOGIC DATA

A.2.2.1 Precipitation Data

Figure A.2-1 displays the locations of available precipitation data within and neighboring the Housatonic River watershed; Appendix A lists all the stations, their period of record, and procedures for developing the final model input. Long-term hourly precipitation data required to drive the watershed modeling effort are limited to the National Weather Service (NWS) stations at Lanesboro, MA, in the northern portion of the watershed, at Littleville Lake, MA (about 20 miles east), and at Copake, NY (about 20 miles southwest); hourly data collection at all of these NWS stations was discontinued in 1995 or 1996. In addition, since 1994 GE has collected 15-minute and hourly data at its Pittsfield facility and Pittsfield Airport has collected hourly data since 1999.

There are a number of currently active NWS stations with long-term daily precipitation data surrounding the watershed, e.g. Plainfield, Great Barrington Airport, and West Otis. Periods of missing data are typical of all meteorologic data; the additional stations listed in Appendix A were used to supplement those mentioned above and fill in any missing periods. Missing data were filled from the nearest station with the same observation interval, and adjustments were made based on the ratio of their long-term average annual totals. Accumulated totals were distributed to days in the accumulation period based on the nearby station with the closest total rainfall in the accumulation period. The standard practice in watershed modeling is to use the available hourly data to distribute (or disaggregate) the daily records to derive estimated hourly records (and distribution during the day) at these stations. Thus, the hourly data at Lanesboro, the GE facility, and Pittsfield Airport, supplemented by the Littleville Lake and Copake stations (as needed), were used to distribute these daily records into hourly values. This process was performed using the procedures in the EPA interactive program, WDMUtil, (Hummel, 2001).

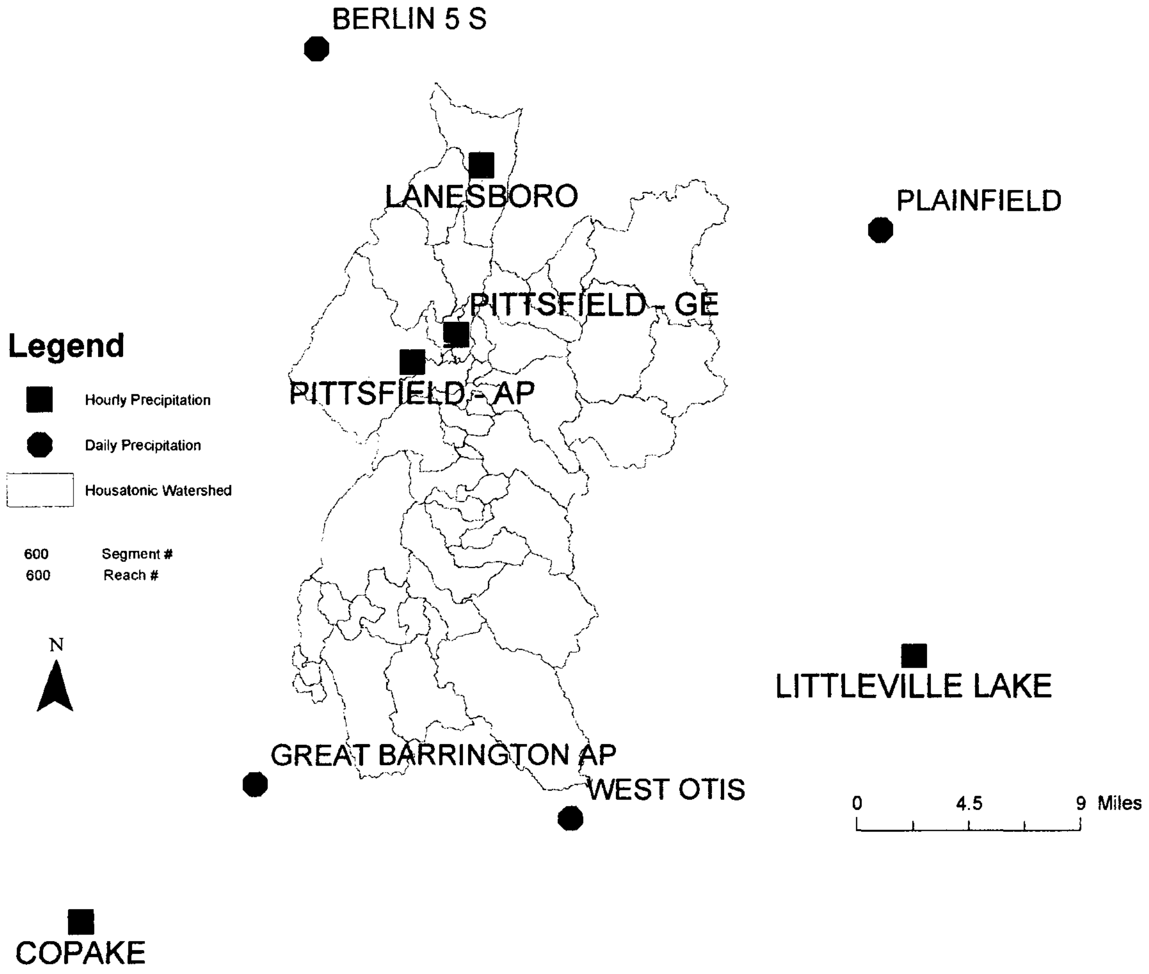

Figure A.2-1 Precipitation and Meteorological Gages

Ultimately, the six gages listed Table A.2-2 were used for hourly input in model simulations. The Lanesboro and nearby GE dataset were initially combined to develop a composite station with an hourly time series covering the 01/01/1979 - 12/31/2000 time period due to the Lanesboro station being discontinued in 1995. Upon reviewing the precipitation data and the station history of the GE site, the following observations were noted:

1. the annual totals after 1999 were consistently lower than surrounding gages;
2. the data contained no indicator of when missing or accumulated values were recorded, a standard practice in precipitation data recording;
3. the data contained multiple instances of the same time interval, often with different values;
4. the gage was hit by lightning on June 28th of 1999 and was not fully repaired until October 6th of 1999;
5. the data occasionally contained unreasonable values

Based on this analysis, the GE precipitation data were ultimately replaced with data from Pittsfield Airport, the only other hourly gage in the area, for years where data were available and errors in the GE data were apparent, i.e., 1999-2000 (AQUA TERRA Consultants, 2002a).

The six precipitation gages and four segment groupings, to which the rainfall is applied, are displayed in Figure A.2-2; the watershed segmentation process is discussed in detail in Section 3.0.

Table A.2-2 Precipitation Stations Used in the Watershed Model

Station Name	**Observation Interval**	**Start Date**	**End Date**	**Source**
GE at Pittsfield	15-Minute	01/01/94	12/31/00	GE
Lanesboro	Hourly	01/01/70	02/29/95	NCDC
Pittsfield Airport	Hourly	01/20/99	12/31/00	NRCC
Plainfield	Daily	06/01/48	12/31/00	NCDC
West Otis	Daily	01/01/48	12/31/00	NCDC
Great Barrington Airport	Daily	12/01/73	12/31/00	NCDC

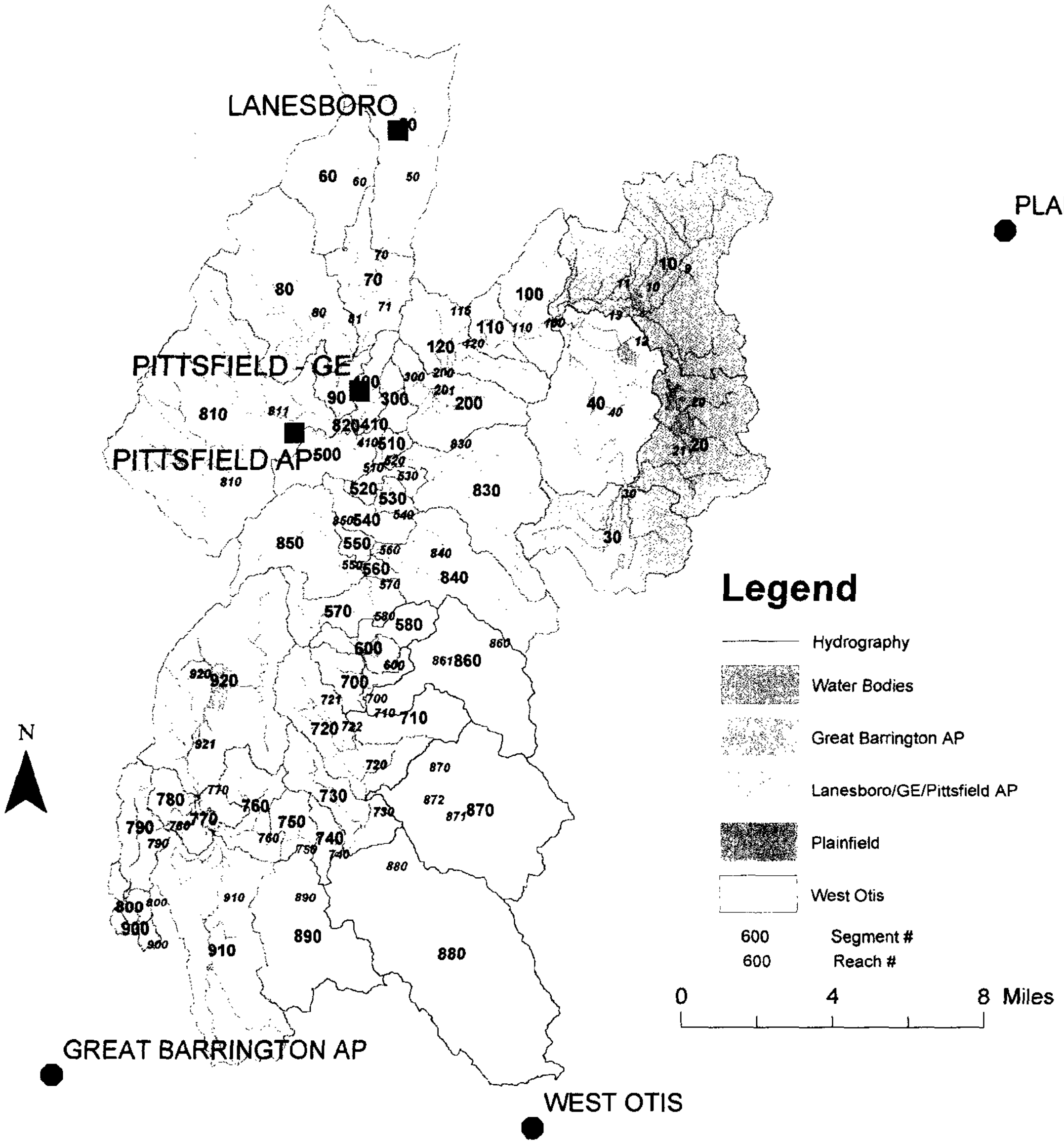

Figure A.2-2 Precipitation Gages and Segment Groupings

Previous modeling studies done in the Housatonic Watershed reported that orographic influences on precipitation were significant, and isolated thunderstorms accounted for up to one-third of the mean annual precipitation (Hydrocomp, 1994). In reviewing the observed long-term rainfall averages for the gages within and surrounding the Housatonic Watershed, it is clear that the upper elevations receive distinctly different rainfall totals than the valley floor. In order to account for these variations a 2 km resolution grid of precipitation estimates for the watershed was obtained, derived from the Oregon State University software system called 'Parameter-elevation Regressions on Independent Slopes Model' (PRISM). PRISM is an expert system that uses point data (i.e., gage long-term average annual totals) and a digital elevation model (DEM) to generate gridded estimates of climate parameters, including precipitation. PRISM incorporates a conceptual framework that allows the spatial scale and pattern of orographic precipitation to be quantified and generalized (PRISM website http://www.ocs.orst.edu/prism/). Overlaying the segment coverage (discussed in subsequent Section 3.2.2) allowed for the long term annual averages to be calculated on a segment-by-segment basis (see Figure A.2-3).

The average precipitation totals (inches per year) for the segments, based on the PRISM model, range from 42.7 inches (1085 mm) in the valley floor near Pittsfield to 53.4 inches (1356 mm) near Plainfield with an overall watershed average of 46.5 inches (1181 mm). Using the GIS coverages it was possible to compare the PRISM's mean annual segment precipitation total and the long-term station average for the station assigned to each model segment. This provided a reasonable method to assist in assigning weighting factors (called MFACTS), or multipliers, to each precipitation gage on a segment-by-segment basis. The MFACTS used for model simulations are shown in Table A.2-3.

As previously mentioned, the Lanesboro and nearby GE datasets were combined to develop a single hourly timeseries covering the time period of 1970-2000. Combining the Lanesboro gage with the GE gage, which lies in a rain shadow and consistently receives less precipitation, can present calibration problems due to the rainfall differences between the two sites; calibration must be based on a consistent precipitation record and spatial distribution throughout the entire calibration period. To ensure this consistency in the input precipitation data record, a multiplication factor of 0.90 was applied to the Lanesboro gage prior to combining with the GE data. This factor was based on a limited number of years of overlap between the two gages, and the ratio of the PRISM model's values for the corresponding model segments. The Pittsfield Airport station is less than 2.5 miles away from the GE station and at a comparable elevation. A multiplication factor was not used when combining the timeseries for these two stations for the time period of 1999-2000, as their annual rainfall totals are expected to be similar.

Table A.2-3 MFACTS for Watershed Segments

Segment	Mean PRISM Precipitation (in.)	Precip. Gage	Observed Long-term Average (in.)	MFACT
10	52.51	Plainfield	48.01	1.09
20	53.44	Plainfield	48.01	1.11
30	50.76	Plainfield	48.01	1.06
40	49.83	Lanesboro/GE/PittsAP	44.95	1.11
100	49.23	Lanesboro/GE/PittsAP	44.95	1.10
110	47.12	Lanesboro/GE/PittsAP	44.95	1.05
120	44.18	Lanesboro/GE/PittsAP	44.95	0.98
200	43.79	Lanesboro/GE/PittsAP	44.95	0.97
300	42.70	Lanesboro/GE/PittsAP	44.95	0.95
400	43.00	Lanesboro/GE/PittsAP	44.95	0.96
410	43.20	Lanesboro/GE/PittsAP	44.95	0.96
50	46.42	Lanesboro/GE/PittsAP	44.95	1.03
60	48.84	Lanesboro/GE/PittsAP	44.95	1.09
70	43.56	Lanesboro/GE/PittsAP	44.95	0.97
80	45.15	Lanesboro/GE/PittsAP	44.95	1.00
90	43.20	Lanesboro/GE/PittsAP	44.95	0.96
810	47.16	Lanesboro/GE/PittsAP	44.95	1.05
820	43.20	Lanesboro/GE/PittsAP	44.95	0.96
500	44.28	Lanesboro/GE/PittsAP	44.95	0.99
510	43.49	Lanesboro/GE/PittsAP	44.95	0.97
830	48.60	Lanesboro/GE/PittsAP	44.95	1.08
520	45.76	Lanesboro/GE/PittsAP	44.95	1.02
530	46.32	Lanesboro/GE/PittsAP	44.95	1.03
540	45.54	Lanesboro/GE/PittsAP	44.95	1.01
550	45.03	Lanesboro/GE/PittsAP	44.95	1.00
840	49.56	Lanesboro/GE/PittsAP	44.95	1.10
560	48.60	Lanesboro/GE/PittsAP	44.95	1.08
850	45.82	Lanesboro/GE/PittsAP	44.95	1.02
570	47.03	GBAP	46.31	1.02
580	49.84	West Otis	44.91	1.11
600	47.76	GBAP	46.31	1.03
700	46.80	GBAP	46.31	1.01
860	50.77	West Otis	44.91	1.13
710	49.18	West Otis	44.91	1.09
720	46.60	GBAP	46.31	1.01
870	49.09	West Otis	44.91	1.09
730	45.51	GBAP	46.31	0.98
880	46.08	West Otis	44.91	1.03
740	44.48	GBAP	46.31	0.96
890	50.20	West Otis	44.91	1.12
750	44.47	GBAP	46.31	0.96
760	44.77	GBAP	46.31	0.97
910	45.56	GBAP	46.31	0.98
770	44.49	GBAP	46.31	0.96
920	46.41	GBAP	46.31	1.00
780	44.72	GBAP	46.31	0.97
790	45.11	GBAP	46.31	0.97
800	44.79	GBAP	46.31	0.97
900	44.72	GBAP	46.31	0.97
Min	42.70		44.91	0.95
Max	53.44		48.01	1.13
Average	46.50		45.55	1.02

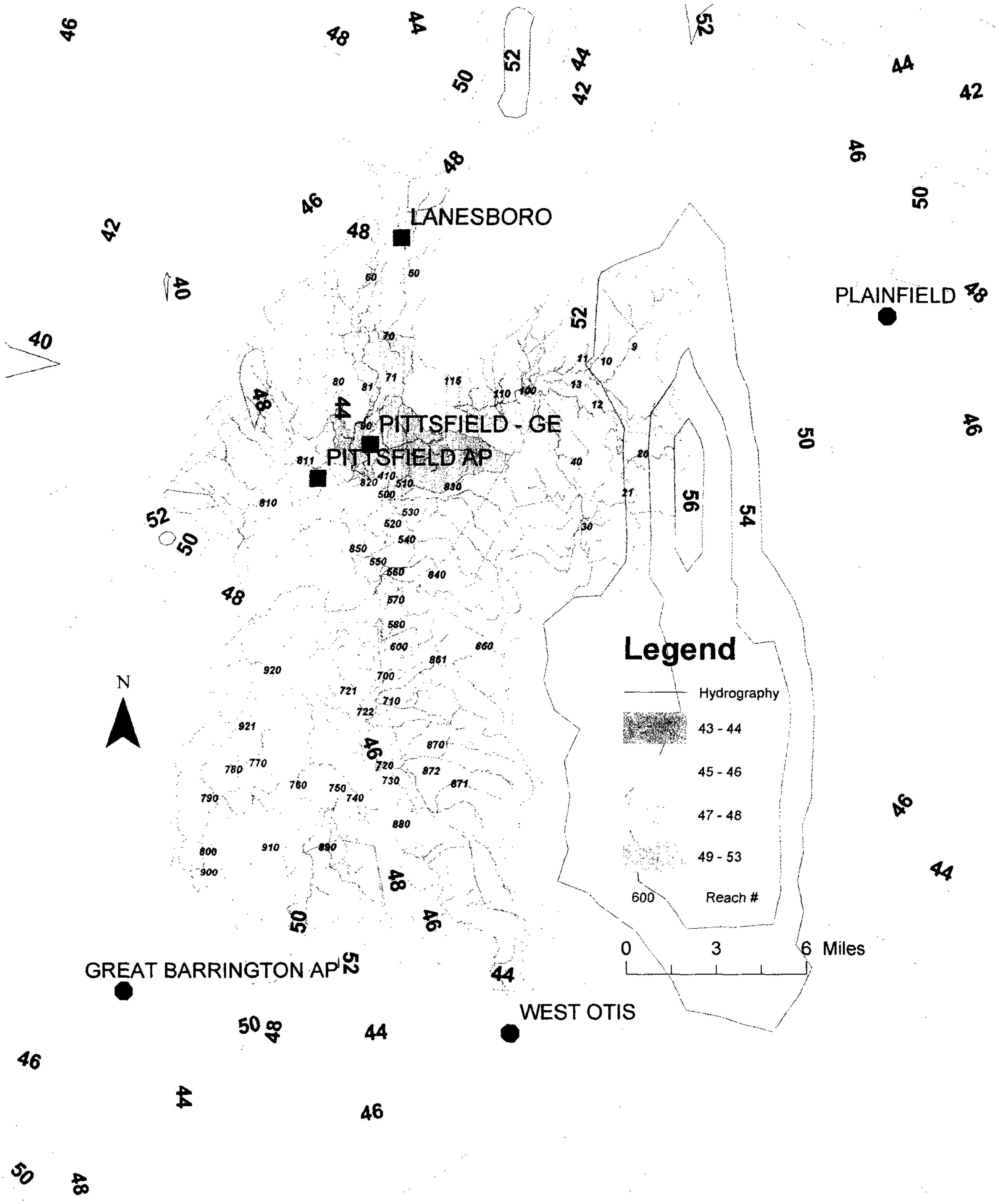

Figure A.2-3 Long-Term Average Annual Segment Precipitation (in) - PRISM Model

A.2.2.2 Evaporation Data

Pan evaporation data are used in watershed modeling to estimate total potential evapotranspiration (PET), which includes both direct evaporation and plant transpiration processes. Typically a "pan coefficient" is applied to the observed pan evaporation data, either on an annual or monthly basis, to estimate PET; pan coefficients have been tabulated and mapped for the conterminous U.S. by the National Weather Service (NWS, 1982a; 1982b). For the Housatonic River watershed, the closest pan evaporation data are recorded at the Albany and Hartford airports, which are approximately 30 miles northwest and southeast, respectively, from the watershed. Pan evaporation does not demonstrate much spatial variability, and it is common practice to use pan evaporation data from such distances for watershed modeling. The data were obtained from the Northeast Regional Climate Center (NRCC, Cornell University, Ithaca, NY). Missing data were filled from the nearest station(s) that had data for the missing time periods, prior to disaggregating the data to an hourly time step, using WDMUtil. Neither of the stations was determined to be more representative than the other and therefore the stations were averaged to develop a single evaporation timeseries for input in model simulations. A pan factor of 0.73 was then applied to estimate PET as prescribed by historical data on pan coefficients and PET values (see *NOAA Technical Report NWS 33, NEWS, 1982a; 1982b).*

Table A.2-4 Evaporation Stations Used in the Watershed Model

Station Name	Observation Interval	Start Date	End Date	Source
Hartford Bradley Airport	Daily	01/01/76	12/31/00	NRCC
Albany County Airport	Daily	01/01/68	12/31/00	NRCC

A.2.2.3 Other Meteorologic Data

HSPF requires additional climatic inputs for modeling snow accumulation and melt processes when using an energy balance approach. The required time series include air temperature, cloud cover, dewpoint temperature, wind speed, and solar radiation. Since these environmental conditions are either less variable than rainfall, or the overall model results are less sensitive to their values, less spatial resolution is warranted. Also, except for air temperature, there are fewer sites where continuous data are available for these meteorological variables.

A.2.2.3.1 Air Temperature

The Housatonic watershed model utilizes air temperature data from four stations: Berlin 5S, Lanesboro, Great Barrington Airport, and West Otis. Refer to Table A.2-5 for additional information describing the station specific data. Missing data were filled from the nearest station with the same observation interval. Once filled, the daily max-min air temperatures were converted to hourly values based on a smooth variation with the daily minimum at 6 AM and the daily maximum at 4 PM. This process was performed using WDMUtil. The Lanesboro and nearby Berlin 5S dataset were combined to develop an hourly time series covering the 01/01/1979 - 12/31/1999 time period. The Berlin 5S station went offline in 2000. The timeseries was further extended through 2000 using data collected at the GE station.

In addition, air temperature values are adjusted within the model as a function of the elevation difference between the gage site and the model segment, based on meteorological conditions i.e., separate 'lapse' rates (i.e., change in temperature per foot of elevation change) are used for wet and dry conditions.

A.2.2.3.2 Cloud Cover and Dewpoint Temperature

The Housatonic watershed model utilizes hourly data for cloud cover and dewpoint temperature from Hartford Bradley and Albany County Airports. WDMUtil was used to correct and fill-in missing periods of data. Refer to Table A.2-5 for additional information describing the station specific data.

A.2.2.3.3 Wind Speed and Solar Radiation

Wind speed and solar radiation data were available from three stations: GE, Hartford Bradley Airport, and Albany County Airport. WDMUtil was used to aggregate 15-minute data to hourly, correct and fill-in missing periods of data, and dis-aggregate daily data to hourly. Wind speed and solar radiation data from the three stations were combined to develop representative hourly data sets for each variable for use in model simulations. The average of the wind speeds recorded at Hartford Bradley and Albany County Airports provided input for the time period prior to the GE station coming online (i.e., prior to 1994). In a similar fashion, the average solar radiation recorded at Hartford Bradley and Albany County Airports provided input for the time period prior to 1994; however, problems with the solar radiation data recorded by the GE station after 1999 required the average solar radiation recorded at the airports to be used again for the 1999-2000 time period (AQUA TERRA Consultants, 2002a). Table A.2-5 includes additional information describing the station specific data.

Table A.2-5 Other Meteorological Data Used in the Watershed Model

Data Type	**Station Name**	**Observational Interval**	**Start Date**	**End Date**	**Source**
Air Temperature					
	GE at Pittsfield	15-minute	01/01/94	12/31/00	GE
	Berlin 5S	Daily	01/01/73	12/31/99	NRCC
	Lanesboro	Daily	01/01/70	12/31/95	NCDC
	Great Barrington Airport	Daily	01/01/73	12/31/00	NCDC
	West Otis	Daily	01/01/73	12/31/00	NRCC
Cloud Cover					
	Hartford Bradley Airport	Hourly	01/01/49	12/31/00	NCDC
	Albany County Airport	Hourly	01/01/45	12/31/00	NCDC
Wind Speed					
	GE at Pittsfield	15-minute	01/01/94	12/31/00	GE
	Hartford Bradley Airport	Hourly	01/01/49	12/31/00	NCDC
	Albany County Airport	Hourly	01/01/45	12/31/00	NCDC
Solar Radiation					
	GE at Pittsfield	15-minute	01/01/94	12/31/00	GE
	Hartford Bradley Airport	Hourly	01/01/76	12/31/00	NRCC
	Albany County Airport	Hourly	01/01/68	12/31/00	NRCC

A.2.3 FLOW AND SNOW DATA

The HSPF watershed model calibration relied on available flow data at the USGS Coltsville and Great Barrington gages, supplemented with stormwater monitoring data collection performed by Weston Solutions, Inc., as part of the SIWP, and by GE. For snow observations, data were obtained from NCDC for eleven stations located in and around the watershed. Model comparisons were primarily made with snow depth measurements collected at Berlin 5S, Lanesboro, Dalton, New Lenox, and Great Barrington. These stations provided the necessary period of record that coincided with the simulation time period and spatial coverage to calibrate the model. The remaining stations had shorter periods of record or were located greater distances outside the watershed.

A.2.3.1 Available Continuous Flow Data

The available continuous flow data consists of long-term daily data and hourly data at Coltsville (station ID # 01197000) and Great Barrington (station ID # 01197500); the hourly data were acquired for water year 1988 through 2000, while the daily records extend back to 1936 and 1913, at Coltsville and Great Barrington, respectively. The USGS states that: the records for Coltsville are of 'good' quality and the flow is regulated by powerplants since 1949 and by Cleveland Brook Reservoir which is used for municipal water supply; the records for Great Barrington are of 'good' quality and the low flows are regulated by dams that use water for hydroelectric and paper mills processes and high flows are slightly affected by a retarding reservoir since 1973 (Socolow et al., 2000).

Table A.2-6 USGS Continuous Flow Data

Location	Description	Start Date	End Date
Coltsville			
	Hourly Flow	10/01/87	12/31/00
	Daily Flow	03/08/36	12/31/00
Great Barrington			
	Hourly Flow	10/01/87	12/31/00
	Daily Flow	05/17/13	12/31/00

A.2.3.2 Storm Event Data

The stormwater monitoring data collection was performed from 1999 through 2000 for eleven selected storm events at nine mainstem and tributary sites. The hydraulic parameters measured during these storm events consisted of a single staff height and velocity measurements at various locations across the channel cross-section. The parameters were recorded at frequent intervals throughout the respective storm events.

Table A.2-7 Storm Events in 1999-2000

Storm Event	Dates	Storm Event	Dates
1	May 19–21, 1999	7	Aug 14–16, 1999
2	June 14–15, 1999	8	Aug 26, 1999
3	June 17-18, 1999	9	Sept 15-19, 1999
4	June 29-30, 1999	10	Sept 30, 1999
5	July 2, 1999	11	June 6-10, 2000
6	July 6-8, 1999		

In order to convert the staff gauge readings to flow, rating curves were developed at the primary sampling sites (Pomeroy Ave. Bridge, New Lenox St., and Woods Pond Footbridge) based on a series of simultaneous flow measurements and staff gauge readings that were recorded during 2000 and 2001. Table A.2-8 lists all the storm event sampling sites; however, the available monitoring data needed to develop accurate rating curves were limited to the 3 primary sites noted above.

Table A.2-8 Storm Event Sampling Locations

Location ID	Location	Reach Description
ST000002	Hubbard St. Bridge	Reach 1,2 - East Branch Housatonic River - Upstream of Newell Street
ST000003	Unkamet Brook	Reach 1,2 - East Branch Housatonic River - Upstream of Newell Street
ST000004	Pomeroy Ave. Bridge	Reach 4 - East Branch Housatonic River - Lyman to Confluence with West Branch
ST000005	West Branch Confluence	Housatonic River - West Branch Confluence
ST000006	Sackett Brook	Reach 5 - Housatonic River - Confluence to Woods Pond
ST000007	New Lenox St.	Reach 5 - Housatonic River - Confluence to Woods Pond
ST000008	Roaring Brook	Reach 5 - Housatonic River - Confluence to Woods Pond
ST000009	Woods Pond Footbridge	Reach 6 - Woods Pond

A.2.3.3 Snow Data

The primary goal of the snow simulation was to adequately represent the total volume and relative timing of snowmelt to produce reasonable soil moisture conditions in the spring and early summer so that subsequent rainfall events were accurately simulated. A tremendous variation in observed snow depth values can occur in a watershed, as a function of elevation, exposure, topography, etc. Thus a single observation point or location will not always be representative of the watershed average. For the Housatonic, snow depth data were obtained from NCDC for eleven stations located within and in proximity to the watershed. These stations along with their respective periods of record are listed in Table A.2-9. Model comparisons were primarily made with the first five stations listed in the Table A.2-9, with the remaining stations providing supplemental data to explain the temporal and spatial variation of snow melt and accumulation within the region.

Table A.2-9 Snow Depth Data

Station Name	Start Date	End Date
Berlin 5S	1959/01/01	2000/12/31
Lanesboro	1970/01/01	1995/03/31
Dalton	1996/09/01	2000/12/31
New Lenox	1996/08/01	2000/12/31
Great Barrington	1975/01/01	2000/12/31
Hartford Bradley Airport	1949/01/01	2000/12/31
Albany County Airport	1938/06/01	2000/12/31
Worcester	1949/01/01	2000/12/31
Plainfield	2000/01/01	1995/10/31
West Otis	2000/01/01	2000/12/31
Pittsfield Airport	1925/01/01	1970/07/31

A.2.3.4 Diversions, Withdrawals, and Point Sources

Various agencies were contacted and documents obtained in an effort to determine if significant diversions, withdrawals, and/or point sources existed within the watershed that would affect calibration efforts at one or more of the gages. The Coltsville gage was determined to be impacted by diversion of Windsor Brook, a large third order stream in the Northeastern portion of the watershed above the Coltsville gage. The total flow of the brook is diverted into Cleveland Reservoir and subsequently withdrawn from the system for water supply for the City of Pittsfield. According to the *Housatonic River Basin 1997/1998 Water Quality Assessment Report (Kennedy et al., 2000),* Cleveland Reservoir has a safe yield of 9.4 MGD (14.5 cfs) and an average yield of approximately 8.0 MGD (12.4 cfs). The majority of this water is later processed by the Pittsfield Wastewater Treatment Plant (WTP) and returned downstream of the Coltsville gage. According to records from the City of Pittsfield, the average effluent flow from the Pittsfield WTP during the calibration and validation period was 11.5 MGD (17.8 cfs).

Within the model, the flow of Windsor Brook is sent directly to Cleveland Reservoir and then withdrawn from the reservoir at a constant 8 MGD. The Pittsfield WTP is simulated as a constant point discharge of 11.5 MGD into its respective outfall reach. No additional diversions, withdrawals, or point sources were determined to be significant enough or have enough data to quantify and include in the model. The difference in simulated withdrawals and the Pittsfield WTP discharge is 3.5 MGD (5.4 cfs). This difference likely reflects the numerous smaller withdrawals occurring within the region serviced by the Pittsfield WTP. A 3.5 MGD withdrawal represents approximately 1.29" and 0.26" per year of runoff from the drainage areas above Coltsville and Great Barrington, respectively. If the 3.5 MGD were withdrawn from entirely above the Coltsville gage, this would account for approximately 5% of the average annual water balance above Coltsville. At the Great Barrington gage this withdrawal accounts for approximately 1% of the water balance. It is unlikely that all 3.5 MGD is withdrawn above the Coltsville gage. Therefore, the error in excluding this 3.5 MGD is small and deemed to be acceptable in achieving model objectives.

A.2.4 SEDIMENT AND WATER TEMPERATURE DATA

A.2.4.1 Sediment Calibration Data

Model calibration for sediment focuses on sites with observed data, supported by review of model behavior and simulations in all parts of the watershed to insure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. However, other types of comparisons are also possible, such as load estimates and sediment rating curves. For the Housatonic, data or estimates for each of these types of comparisons were available at selected sites within the watershed. The following table summarizes the data used for model calibration.

Table A.2-10 Sediment Data and Load Estimates

	Location	Data Available	Time period
TSS Concentrations	Storm and Surface Water Sites	High frequency and monthly TSS concentrations were collected at stations tributary to and within the PSA during storm events and baseflow conditions. Refer to Table A.2-8 for the locations of the storm event sites.	Data were collected at storm event sites for eleven storms occurring from 5/19/1999 to 6/10/2000. The majority of the data at the surface water sites were collected from 1998 through 2000 at a monthly interval
	Great Barrington	High frequency TSS concentrations were collected by the USGS in cooperation with the Massachusetts Department of Environmental Management, Division of Resource Conservation, Office of Water	From April 1994 through March 1996
Load Estimates	Flux Analysis Sites	The stormwater monitoring data included flow rates and water column measurements of TSS. These data, along with all available historical data at these sites, were used by HydroQual to develop estimates of TSS mass flux entering and passing through various points in the PSA (i.e., at the East and West Branches, Holmes Road, and Woods Pond) (Attachment B.3)	Annual loads were estimated for the years of 1988-2001
	Mainstem and tributary sites	Additional loading estimates were developed by BBL and QEA (2003) for numerous tributary and mainstem sites within the watershed. These sites typically overlapped with the flux analysis sites; however, estimates were also made at Unkamet Bk, Roaring Bk., Sackett Bk. , and Woods Pond Headwaters.	Average Annual loads were estimated using available data
	Great Barrington	Using high frequency TSS concentration data and concurrent instantaneous flows, the USGS developed annual load estimates	From April 1994 through March 1996

The data and load estimates listed in Table A.2-10 were used to generate additional information, such as which reaches were erosional versus depositional, and to develop sediment rating curves at select sites to compare with model results.

A.2.4.2 Water Temperature Calibration Data

Data were available at numerous sites to make model-data comparisons for water temperature simulations. The data used during the calibration effort included high-frequency samples collected by the USGS at Great Barrington from 4/1994 to 4/1996, high-frequency samples collected by WESTON at numerous sites during the time period of 5/2000 to 9/2000, and monthly samples collected by the USGS at Coltsville from 1/1990 to 5/1993. The WESTON sampling sites included the East Branch above the confluence, the West Branch above the confluence, the mainstem at Holmes Road (~ one mile below the confluence), and Woods Pond at the footbridge.

A.3 SEGMENTATION AND CHARACTERIZATION OF THE HOUSATONIC WATERSHED ABOVE GREAT BARRINGTON

A.3.1 HSPF HOUSATONIC WATERSHED DOMAIN

The physical domain of the HSPF model for this study is the entire watershed that drains to the USGS gage at Great Barrington, MA, an area of approximately 282 square miles. This downstream boundary was selected because of the long-term flow record available (more than 80 years) for model application.

A.3.2 WATERSHED SEGMENTATION AND CHARACTERIZATION

Whenever HSPF, or any watershed model, is applied to an area of this size, the entire study area must undergo a process referred to as "segmentation." The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, which are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation then provides the basis for assigning similar or identical parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area. The initial watershed and channel segmentation of the Housatonic River watershed are discussed separately below. The final segmentation is shown in Figure A.3-1.

Watershed segmentation is based on individual characteristics of the watershed, including topography, drainage patterns, land use distribution, meteorologic variability, and soil conditions. The process is essentially an iterative procedure of overlaying these data layers and identifying portions of the watershed with similar groupings of these characteristics. Over the past decade, the advent of geographic information systems (GIS) and associated software tools, combined with advances in computing power, has produced automated capabilities that can efficiently perform the data-overlay process.

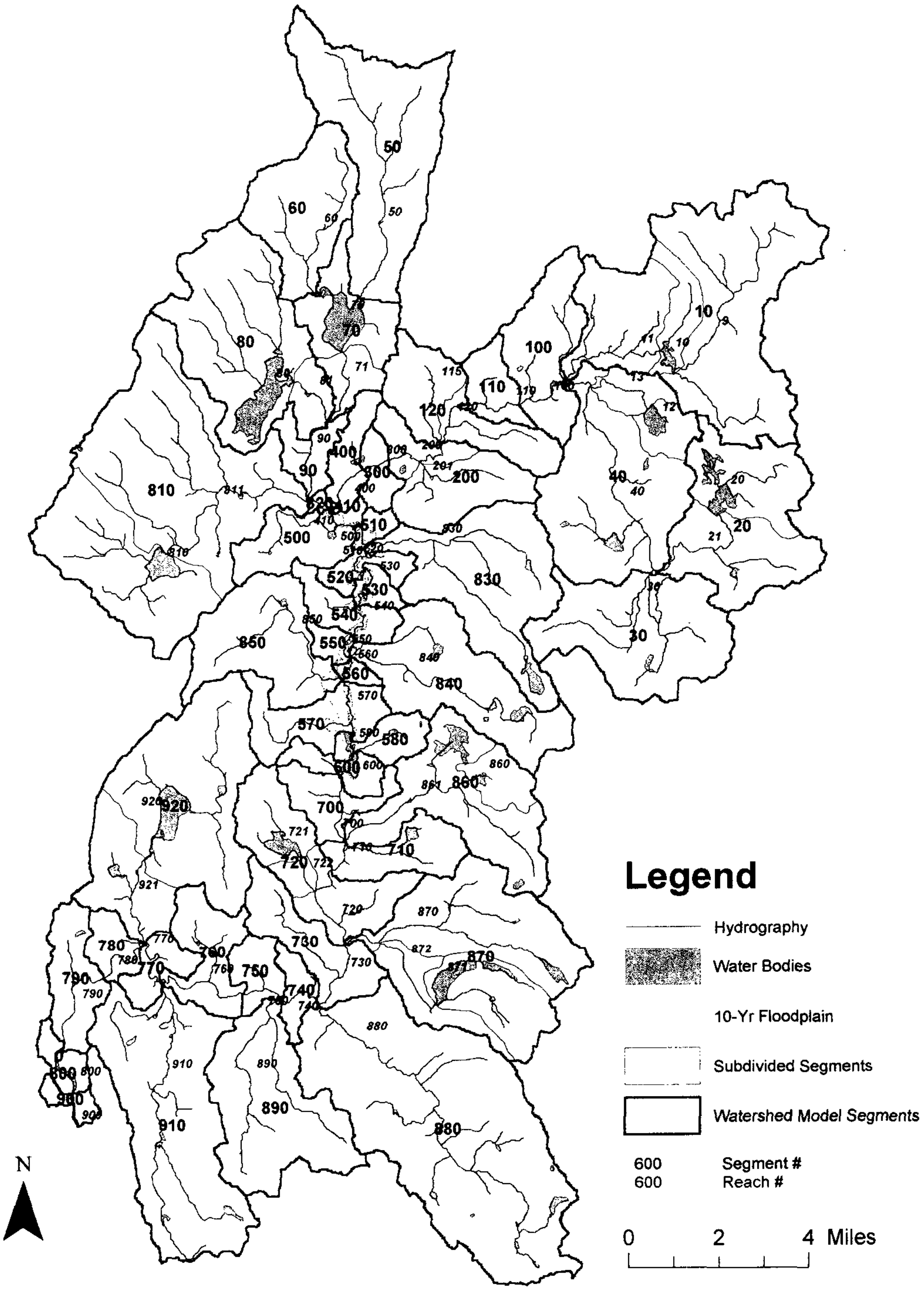

Figure A.3-1 Housatonic Watershed Segmentation above Great Barrington

A.3.2.1 Data and GIS Coverages

Fortunately, for this project a wealth of data and GIS coverages are available to spatially characterize the watershed. The data are available from a variety of sources including the USGS, EPA, MassGIS, and data collected specifically for this project that have been made available on the Weston Solutions virtual project network (VPN). The table below summarizes the data and GIS coverages that were obtained and found to be most beneficial in performing the segmentation and characterization of the watershed and reach network. Numerous additional GIS coverages and information were obtained and generated based on these original coverages and data. Where appropriate, these GIS coverages and information are discussed in subsequent sections.

Table A.3-1 Data and GIS Coverages used for Segmentation and Characterization of the Watershed and Reach Network

Data / GIS Coverage	Source	Comment
Digital Elevation Model (DEM)	USGS	Required 12 individual 30 meter resolution DEMs to be mosaiced together
Site Specific DEM for the PSA	Dynamic Solutions, LLC	High Resolution DEM of the PSA developed from topography established by GE and channel bed topography provided by cross-sectional data collected by WESTON
Land Use	MassGIS	Interpolated from 1:25,000 aerial photography taken in 1985; 21 land use categories
Soils	MassGIS	Developed from 1:25,000 published soils surveys; SSURGO certified
Hydrography	EPA, MassGIS, VPN	Reach File 3 available from EPA; More detailed hydrography available from MassGIS and VPN
Stream Gages	VPN	Locations of Storm Event, Synoptic, and USGS gages
Dam Locations	VPN	Locations of dams along the Housatonic River
Cross-sections	VPN	Spreadsheet containing (x,y,z) data collected and processed by WESTON personnel during the fall of 1999 for reaches 5,6, and specified tributaries
Woods and Rising Pond Bathymetry	VPN	Spreadsheet containing data collected and processed by CR ENVIRONMENTAL during the winter of 1998/1999; Bathymetric elevation field calculated by WESTON
Orthophotos	MassGIS, VPN	Black and white TIFF files available for entire watershed from MassGIS; Color MrSid file available for PSA from VPN

A.3.2.2 Subbasin Delineation

For the Housatonic River watershed, the topographic and drainage pattern analysis for subbasin delineation was performed using the tool AVSWAT (Neitsch et al., 2001), which produces map layers of subbasins and river segments using an elevation grid, derived from a digital elevation model (DEM), as input. For this application a 30-meter DEM was developed (see Figure A.3-2) by mosaicing (i.e., edge-matching) 12 individual DEMs acquired from the USGS, filling in the artificial depressions (pits), and "burning in" reach file 3 (RF3) river segments to ensure the alignment of subbasin outlets and rivers/streams. This burning-in process consists of raising the elevation of all DEM cells but those that coincide with the RF3 by a constant value (e.g., 5000). By doing this, water is forced to remain in the streams once it gets there; however, the overland flow paths remain unchanged. AVSWAT can automatically define subbasins based on a user-specified threshold number of grid cells (i.e., number of cells above a particular outlet), but also allows the user to specify locations of desired subbasin outlets. For segmenting the Housatonic River Watershed, subbasin outlets were specified at predetermined locations. This process resulted in 49 separate subbasins within the Housatonic River watershed down to Great Barrington (as shown in Figure A.3-1). These subbasins range in size from 0.4 to 23.8 mi^2. The guidelines followed in producing the segmentation are outlined below:

1. Two of the model segments were defined with outlets at the USGS gaging stations at Coltsville and Great Barrington to facilitate hydrologic calibration to the available flow data at these sites. Additional outlets were defined at synoptic and storm event stations, operated by Weston, along the Housatonic River to further allow refinement of the calibration.

2. Outlets were defined for most of the major tributary-to-tributary junctions and all of the major tributary-to-mainstem junctions.

3. The segment division between Dalton and Woods Pond was designed to correspond, at scale equal to or finer than, the river segments defined in the Supplemental Investigation Work Plan (WESTON, 2000a); thus, WESTON river Reach 1 corresponds to HSPF reaches in the 100s, WESTON Reach 2 corresponds to HSPF reaches in the 200s, etc. Model land segments (i.e., drainage areas to each reach) were assigned an identical segment number as the respective reach to which they drained. Some segments were further divided to define and separate the drainage areas for tributaries and the mainstem, e.g. segment 120 includes both the drainage area for Unkamet Brook, reach 115, and the direct drainage into reach 120 of the mainstem.

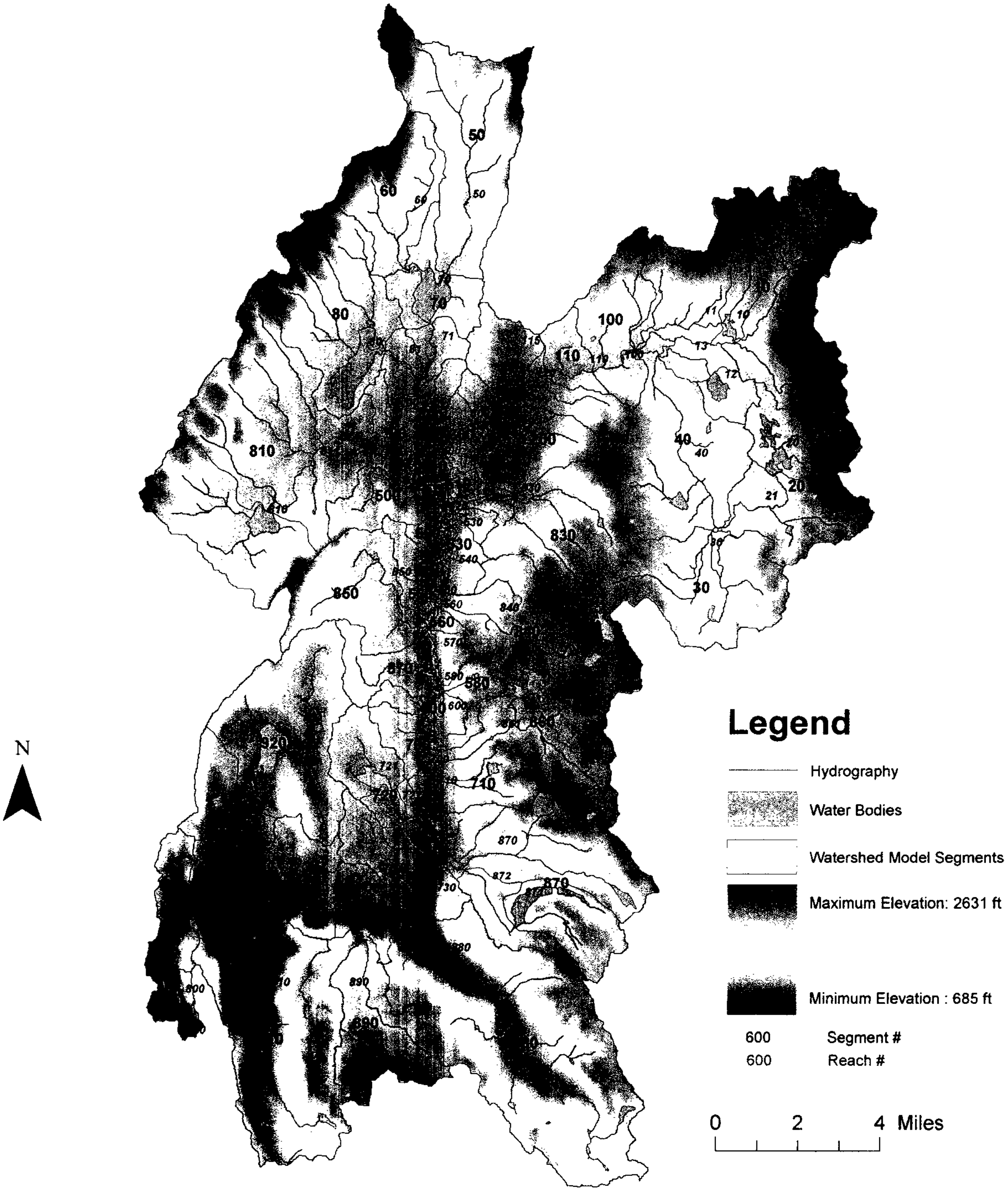

Figure A.3-2 Housatonic Watershed 30 meter DEM

4. In addition to the Woods Pond Dam, outlets were defined for four other dams along the mainstem (Columbia Mill, Willow Mill, Glendale, and Rising Paper Company) and 10 major waterbodies (see Figure A.3-2), in order to account for the hydraulic properties and impacts of the dams, spillways, and waterbody storage volumes.

A.3.2.3 Land Use, Slope, and Elevation

Once the segmentation was completed, the land use within the segments was characterized. The subbasins were overlaid with the land use data to determine the areas of each land use category contributing to the respective river segments. The analysis was performed using a land use data layer available from MassGIS (http://www.state.ma.us/mgis/), maintained by the Massachusetts Executive Office of Environmental Affairs (EOEA), that was interpreted from aerial photography taken in 1985. The resolution of the data layer is 1:25,000 with 21 unique land use classifications. The land use classifications were aggregated into logical groupings, based on land surface conditions, to develop five model land use categories and distributions within each model segment. The five modeled land uses are comprised of four pervious categories - forest, agriculture, urban pervious, wetlands - and urban impervious. Table A.3-2 displays the correspondence between the model land use and MassGis land use categories and the percentage of each of the MassGis categories within the HSA. Figure A.3-3 shows the resulting land use for the Housatonic Watershed for the aggregated model land use categories. The MassGis categories determined to have an impervious component (e.g., commercial, residential) were divided into pervious and impervious areas based on estimated percent 'effective' imperviousness (EIA) for each category. The term effective implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., open channel, river) and the resulting overland flow will not run onto pervious areas and therefore will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody.

Table A.3-2 Correspondence between MassGis and Model Land Use Categories

MassGis Category	Percent of HSA	Model Category	EIA	Definition
Cropland	5.6%	Agriculture	--	Intensive agriculture
Pasture	2.7%	Agriculture	--	Extensive agriculture
Open Land	2.7%	Agriculture	--	Abandoned agriculture; power lines; areas of no vegetation
Forest	70.3%	Forest	--	Forest
Woody Perennial	0.1%	Forest	--	Orchard; nursery; cranberry bog
Mining	0.5%	Urban	3.0%	Sand; gravel & rock
Participation Recreation	1.0%	Urban	--	Golf; tennis; playgrounds; skiing
Spectator Recreation	0.1%	Urban	15.0%	Stadiums; racetracks; fairgrounds; drive-ins
Water Based Recreation	0.0%	Urban	--	Beaches; marinas; swimming pools
Multi-Family Residential	0.1%	Urban	12.0%	Multi-family
High Density Residential	2.7%	Urban	15.0%	Smaller than 1/4 acre lots
Medium Density Residential	2.0%	Urban	8.0%	1/4 - 1/2 acre lots
Low Density Residential	3.8%	Urban	5.0%	Larger than 1/2 acre lots
Commercial	0.8%	Urban	30.0%	General urban; shopping center
Industrial	0.5%	Urban	25.0%	Light & heavy industrial
Urban Open	0.9%	Urban	--	Parks; cemeteries; public & institutional greenspace; also vacant undeveloped
Transportation	0.4%	Urban	30.0%	Airports; docks; divided highway; freight; storage railroads
Waste Disposal	0.2%	Urban	--	Landfills; sewage lagoons
Non-Forested Wetland	3.1%	Wetland	--	Nonforested freshwater wetland
Salt Water Wetland	0.0%	Wetland	--	Salt marsh
Water	2.4%	Wetland	--	Fresh water; coastal embayment

The final model land use distributions for each model reach are shown in Table A.3-3. The overall land use distribution for the entire watershed area above Great Barrington is as follows:

Forest	70 %
Agriculture	10 %
Urban Pervious	13 %
Wetland	6 %
Urban Impervious	1%

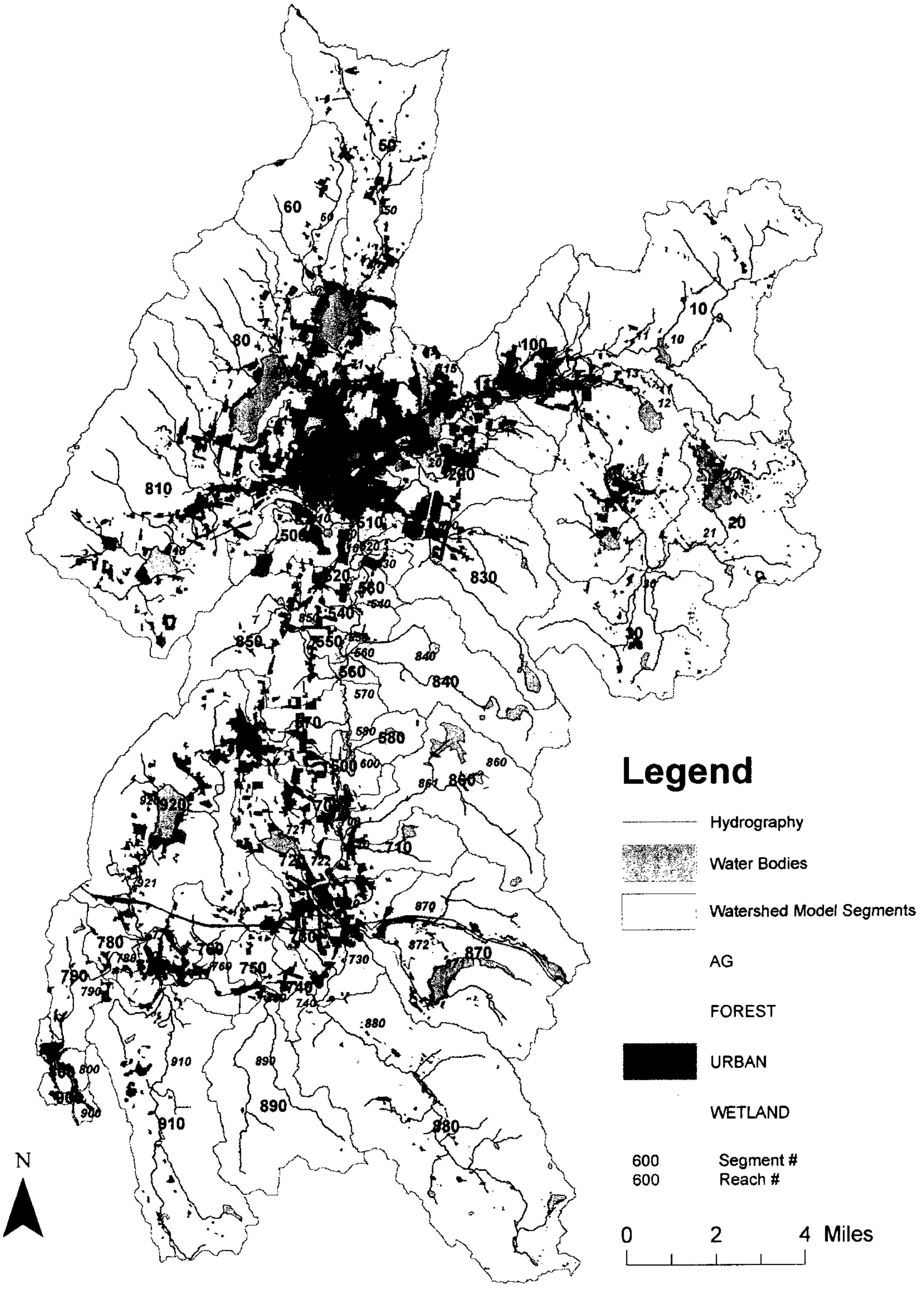

Figure A.3-3 Housatonic Watershed Model Land Use

Table A.3-3 Model Land Use Distributions for each Model Reach

		PERVIOUS								IMPERVIOUS		
REACH	SEGMENT	FOREST		AG		URBAN PERVIOUS		WETLAND		URBAN IMPERVIOUS		TOTAL
		acres	%	acres	%	acres	%	acres	%	acres	%	acres
9	10	6991.78	87.0%	660.30	8.2%	192.55	2.4%	175.25	2.2%	12.28	0.2%	8032.16
10	10	985.23	88.1%	29.13	2.6%	28.40	0.4%	73.61	0.9%	1.41	0.1%	1117.78
11	10	2346.31	80.6%	415.22	14.3%	119.23	1.5%	15.35	0.2%	13.54	0.5%	2909.65
20	20	2039.84	72.0%	97.41	3.4%	382.52	4.8%	294.23	3.7%	20.91	0.7%	2834.92
21	20	2734.40	83.3%	273.77	8.3%	147.82	1.8%	116.98	1.5%	8.31	0.3%	3281.27
30	30	4687.95	80.5%	412.11	7.1%	246.09	4.2%	463.48	8.0%	12.11	0.2%	5821.74
40	40	4757.56	72.6%	470.15	7.2%	988.85	15.1%	282.22	4.3%	58.21	0.9%	6556.99
12	40	629.39	72.9%	43.59	5.0%	19.65	2.3%	169.69	19.7%	1.03	0.1%	863.35
13	40	605.59	72.8%	38.92	4.7%	173.85	20.9%	7.34	0.9%	6.51	0.8%	832.22
100	100	2256.24	71.8%	165.91	5.3%	602.71	19.2%	29.36	0.9%	89.62	2.9%	3143.83
110	110	769.06	66.1%	47.15	4.1%	297.87	25.6%	8.67	0.7%	41.07	3.5%	1163.81
115	120	594.47	33.6%	198.82	11.2%	677.54	38.2%	184.15	10.4%	116.64	6.6%	1771.63
120	120	884.04	57.2%	142.78	9.2%	367.93	23.8%	62.94	4.1%	87.76	5.7%	1545.45
200	200	94.52	9.3%	84.73	8.4%	609.24	60.2%	116.76	11.5%	107.55	10.6%	1012.81
201	200	1309.49	55.5%	271.77	11.5%	613.20	26.0%	78.95	3.3%	85.58	3.6%	2358.99
300	300	44.92	6.1%	52.71	7.2%	516.04	70.4%	15.57	2.1%	103.34	14.1%	732.58
400	400	128.55	11.8%	85.62	7.9%	718.24	66.1%	26.24	2.4%	127.54	11.7%	1086.20
410	410	11.79	42.1%	2.89	10.3%	8.94	31.9%	3.11	11.1%	1.29	4.6%	28.02
50	50	4842.96	65.7%	1644.42	22.3%	718.22	9.7%	109.42	1.5%	54.84	0.7%	7369.86
60	60	3159.40	82.2%	382.75	10.0%	232.77	6.1%	56.49	1.5%	11.20	0.3%	3842.61
70	70	835.33	37.4%	163.91	7.3%	565.57	25.3%	602.70	27.0%	64.71	2.9%	2232.22
71	70	267.32	30.8%	110.31	12.7%	428.84	49.4%	9.12	1.0%	53.32	6.1%	868.91
80	80	4459.77	67.2%	777.28	11.7%	676.21	10.2%	684.32	10.3%	39.25	0.6%	6636.83
81	80	172.80	21.8%	32.92	4.1%	500.05	63.0%	23.57	3.0%	64.18	8.1%	793.52
90	90	130.77	12.1%	59.38	5.5%	730.16	67.8%	24.24	2.3%	132.30	12.3%	1076.86
810	810	3341.99	65.4%	736.59	14.4%	550.63	10.8%	443.24	8.7%	41.17	0.8%	5113.62
811	810	6023.45	62.9%	1582.15	16.5%	1485.78	15.5%	299.57	3.1%	184.21	1.9%	9575.17
820	820	12.01	9.5%	4.23	3.3%	77.77	61.6%	22.02	17.4%	10.30	8.2%	126.32
500	500	1097.54	51.9%	251.98	11.9%	608.08	28.8%	110.98	5.3%	44.88	2.1%	2113.46
510	510	132.77	35.6%	143.45	38.4%	73.58	19.7%	16.90	4.5%	6.48	1.7%	373.19
830	830	5155.88	84.6%	312.92	5.1%	381.10	6.3%	212.84	3.5%	29.00	0.5%	6091.73
520	520	292.01	37.8%	229.52	29.7%	199.35	25.8%	35.58	4.6%	15.49	2.0%	771.95
530	530	296.24	58.9%	115.43	22.9%	66.73	13.3%	16.68	3.3%	8.22	1.6%	503.29
540	540	628.50	50.0%	305.35	24.3%	262.74	20.9%	37.81	3.0%	22.82	1.8%	1257.22
550	550	152.79	35.2%	102.75	23.7%	91.63	21.1%	81.18	18.7%	6.00	1.4%	434.35
840	840	4894.78	93.9%	48.93	0.9%	9.94	0.2%	256.87	4.9%	0.29	0.0%	5210.81
560	560	233.07	88.6%	0.00	0.0%	9.08	3.5%	20.46	7.8%	0.48	0.2%	263.10
850	850	3062.43	74.5%	297.35	7.2%	432.90	10.5%	258.43	6.3%	58.38	1.4%	4109.49
570	570	1457.38	63.0%	182.81	7.9%	448.10	19.4%	171.25	7.4%	54.30	2.3%	2313.84
580	580	822.65	82.1%	50.26	5.0%	8.34	0.8%	117.87	11.8%	2.34	0.2%	1001.46
600	600	539.32	58.4%	76.95	8.3%	214.39	23.2%	79.40	8.6%	14.01	1.5%	924.07
700	700	663.86	45.6%	185.93	12.8%	548.94	37.7%	23.80	1.6%	34.41	2.4%	1456.94
860	860	813.09	82.5%	10.90	1.1%	7.12	0.7%	154.12	15.6%	0.00	0.0%	985.23
861	860	4033.43	87.3%	135.89	2.9%	115.41	2.5%	326.04	7.1%	7.13	0.2%	4617.89
710	710	1387.55	73.3%	239.97	12.7%	184.51	9.7%	62.05	3.3%	19.43	1.0%	1893.51
721	720	781.07	44.1%	355.17	20.0%	428.04	24.1%	187.70	10.6%	20.98	1.2%	1772.96
722	720	106.53	26.3%	115.20	28.4%	170.68	42.1%	0.44	0.1%	12.58	3.1%	405.43
720	720	787.29	41.8%	229.74	12.2%	730.66	38.8%	41.37	2.2%	94.66	5.0%	1883.72
870	870	4153.97	83.9%	129.21	2.6%	415.96	8.4%	182.59	3.7%	69.31	1.4%	4951.05
871	870	2001.81	78.1%	23.80	0.9%	102.99	4.0%	428.56	16.7%	5.98	0.2%	2563.15
872	870	1271.23	88.7%	7.78	0.5%	135.10	9.4%	12.01	0.8%	7.68	0.5%	1433.81
730	730	1180.72	46.1%	718.57	28.1%	519.26	20.3%	63.38	2.5%	79.66	3.1%	2561.59
880	880	11870.32	82.3%	1604.39	11.1%	324.20	2.2%	597.59	4.1%	18.29	0.1%	14414.79
740	740	386.53	49.5%	254.87	32.6%	89.36	11.4%	25.80	3.3%	24.51	3.1%	781.07
890	890	5488.14	97.0%	27.13	0.5%	28.36	0.5%	110.75	2.0%	1.66	0.0%	5656.05
750	750	537.98	52.3%	256.65	24.9%	187.05	18.2%	30.02	2.9%	17.78	1.7%	1029.48
760	760	1228.09	55.1%	405.88	18.2%	336.86	15.1%	207.94	9.3%	48.55	2.2%	2227.33
910	910	6695.99	79.1%	823.77	9.7%	356.69	4.2%	572.01	6.8%	15.83	0.2%	8464.28
770	770	363.40	35.6%	183.26	18.0%	403.72	39.5%	54.04	5.3%	16.40	1.6%	1020.81
920	920	4374.37	61.1%	929.85	13.0%	1113.91	15.6%	686.32	9.6%	57.25	0.8%	7161.69
921	920	1618.18	65.1%	353.84	14.2%	315.39	12.7%	148.56	6.0%	48.23	1.9%	2484.20
780	780	631.17	65.9%	132.33	13.8%	116.50	12.2%	71.17	7.4%	6.04	0.6%	957.21
790	790	1684.23	83.3%	145.45	7.2%	122.44	6.1%	62.27	3.1%	7.67	0.4%	2022.05
800	800	393.20	59.0%	28.91	4.3%	177.78	26.7%	43.15	6.5%	23.49	3.5%	666.53
900	900	229.52	54.2%	81.62	19.3%	90.95	21.5%	12.68	3.0%	8.68	2.1%	423.45
	Total	126,563.93	70.3%	18,484.69	10.3%	22,504.55	12.5%	9,919.22	5.5%	2,459.07	1.4%	179,931.47

The slope of the assumed overland flowpath and average elevation, when snow is being simulated, are important hydrologic parameters within HSPF that can be readily calculated using a GIS. Slope is used when calculating the surface runoff in HSPF, using the Chezy-Manning equation and an empirical equation relating outflow depth to detention storage. When simulating snow processes, HSPF uses the mean elevation to (1) estimate atmospheric pressure variations with elevation, (2) compute the convective heat flux from the atmosphere to the snow pack, and (3) correct, or adjust, the air temperature based on the elevation difference between the gage and the associated land segment using lapse rates (i.e., temperature gradients with elevation).

Using the DEM and tools available within the GIS, a slope coverage was created with the same resolution and extent of the DEM. The model land use was then overlaid with the slope coverage and DEM; each contiguous model land use polygon was then assigned an average slope and elevation. An average slope and elevation was then determined for each model land use within each of the 49 segments. Tables A.3-4 and A.3-5 display the model land use specific slopes and elevations, respectively.

A.3.3 CHANNEL SEGMENTATION AND CHARACTERIZATION

As previously mentioned, segmentation of the watershed was performed using the AVSWAT tool and specifying subbasin outlets along the channel at locations of importance (e.g., gage/data recorders, channel junctions, point sources). In this approach, a single HSPF stream or channel reach was initially included within each segment. In some watershed segments with long channel reaches or large reservoirs, multiple HSPF reaches were included to better model the hydraulic characteristics within the segment. In such cases a new watershed segment was not created. Instead, the contributing drainage area to each new channel reach was calculated, and these new areas were then assigned to each reach or reservoir within the model segment.

Table A.3-4 Land Use Specific Slopes (fraction) for Watershed Segments

	PERVIOUS				*IMPERVIOUS*	
SEGMENT	**FOREST**	**AG**	**URBAN PERVIOUS**	**WETLAND**	**URBAN IMPERVIOUS**	**AVERAGE**
10	0.0915	0.0658	0.0665	0.0315	0.0665	0.0644
20	0.0905	0.0594	0.0605	0.0178	0.0605	0.0577
30	0.0905	0.0774	0.0785	0.0168	0.0785	0.0683
40	0.0945	0.0674	0.0637	0.0149	0.0637	0.0609
100	0.1303	0.0609	0.0558	0.0272	0.0558	0.0660
110	0.1193	0.0750	0.0507	0.0448	0.0507	0.0681
120	0.1289	0.0800	0.0451	0.0178	0.0451	0.0634
200	0.1045	0.0367	0.0352	0.0121	0.0352	0.0447
300	0.0240	0.0112	0.0258	0.0048	0.0258	0.0183
400	0.0577	0.0471	0.0352	0.0103	0.0352	0.0371
410	0.0180	0.0000	0.0527	0.0077	0.0527	0.0262
50	0.1738	0.0914	0.0857	0.0208	0.0857	0.0915
60	0.1764	0.0911	0.0804	0.0362	0.0804	0.0929
70	0.0917	0.0690	0.0625	0.0137	0.0625	0.0599
80	0.1657	0.0630	0.0503	0.0094	0.0503	0.0677
90	0.0482	0.0563	0.0400	0.0026	0.0400	0.0375
810	0.1530	0.0593	0.0593	0.0132	0.0593	0.0688
820	0.0277	0.0111	0.0473	0.0051	0.0473	0.0277
500	0.1267	0.0629	0.0676	0.0078	0.0676	0.0665
510	0.0222	0.0401	0.0361	0.0140	0.0361	0.0297
830	0.1293	0.0701	0.0711	0.0298	0.0711	0.0743
520	0.1199	0.0618	0.0578	0.0115	0.0578	0.0617
530	0.1636	0.0698	0.0765	0.0269	0.0765	0.0826
540	0.1152	0.0411	0.0585	0.0123	0.0585	0.0571
550	0.0329	0.0339	0.0603	0.0004	0.0603	0.0376
840	0.1168	0.0355	0.0591	0.0252	0.0591	0.0591
560	0.1857	NA	0.1164	0.0114	0.1164	0.1075
850	0.1455	0.0851	0.0798	0.0190	0.0798	0.0818
570	0.1523	0.0707	0.0758	0.0554	0.0758	0.0860
580	0.1591	0.0865	0.0573	0.0267	0.0573	0.0774
600	0.1783	0.0749	0.0629	0.0335	0.0629	0.0825
700	0.0961	0.0733	0.0684	0.1243	0.0684	0.0861
860	0.1260	0.1061	0.0706	0.0273	0.0706	0.0801
710	0.1613	0.1224	0.0807	0.0438	0.0807	0.0978
720	0.1137	0.0669	0.0799	0.0164	0.0799	0.0714
870	0.1666	0.1252	0.1221	0.0355	0.1221	0.1143
730	0.1110	0.0599	0.0605	0.0477	0.0605	0.0679
880	0.1593	0.0778	0.1021	0.0276	0.1021	0.0938
740	0.1264	0.0459	0.0683	0.0185	0.0683	0.0655
890	0.1366	0.0967	0.0512	0.0553	0.0512	0.0782
750	0.1100	0.0666	0.0645	0.0350	0.0645	0.0681
760	0.1737	0.0534	0.0566	0.0264	0.0566	0.0733
910	0.1642	0.0948	0.0727	0.0276	0.0727	0.0864
770	0.0647	0.0510	0.0501	0.0181	0.0501	0.0468
920	0.1515	0.0723	0.0748	0.0200	0.0748	0.0787
780	0.1082	0.0595	0.0749	0.0648	0.0749	0.0765
790	0.1739	0.1193	0.1040	0.1377	0.1040	0.1278
800	0.2370	0.1868	0.0909	0.0848	0.0909	0.1381
900	0.1187	0.0394	0.0590	0.0429	0.0590	0.0638
Average	0.1211	0.0682	0.0658	0.0293	0.0658	0.0700
Min	0.0180	0.0000	0.0258	0.0004	0.0258	0.0183
Max	0.2370	0.1868	0.1221	0.1377	0.1221	0.1381

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Table A.3-5 Land Use Specific Elevations (ft) for Watershed Segments

	PERVIOUS				*IMPERVIOUS*	
SEGMENT	**FOREST**	**AG**	**URBAN PERVIOUS**	**WETLAND**	**URBAN IMPERVIOUS**	**AVERAGE**
10	1,847	1,690	1,682	1,731	1,682	1,727
20	1,775	1,590	1,680	1,573	1,680	1,660
30	1,652	1,571	1,566	1,443	1,566	1,559
40	1,574	1,487	1,396	1,463	1,396	1,463
100	1,576	1,249	1,168	1,263	1,168	1,285
110	1,207	1,100	1,103	1,025	1,103	1,108
120	1,371	1,176	1,074	997	1,074	1,139
200	1,356	1,051	1,043	992	1,043	1,097
300	994	1,000	1,022	995	1,022	1,006
400	1,135	1,165	1,034	985	1,034	1,071
410	974	973	989	968	989	978
50	1,628	1,316	1,269	1,140	1,269	1,325
60	1,616	1,355	1,325	1,229	1,325	1,370
70	1,214	1,188	1,137	1,105	1,137	1,156
80	1,562	1,173	1,102	1,098	1,102	1,207
90	1,102	1,082	1,036	1,011	1,036	1,053
810	1,450	1,157	1,131	1,129	1,131	1,200
820	976	975	991	973	991	981
500	1,148	1,093	1,057	1,040	1,057	1,079
510	983	1,007	1,021	973	1,021	1,001
830	1,657	1,112	1,113	1,588	1,113	1,317
520	1,183	1,040	1,035	974	1,035	1,053
530	1,266	1,031	999	971	999	1,053
540	1,168	1,014	1,053	990	1,053	1,055
550	1,004	997	1,036	965	1,036	1,008
840	1,784	1,279	1,700	1,823	1,700	1,657
560	1,276	NA	1,074	966	1,074	1,097
850	1,337	1,196	1,176	1,130	1,176	1,203
570	1,267	1,103	1,197	972	1,197	1,147
580	1,656	998	968	1,183	968	1,155
600	1,250	1,074	1,103	952	1,103	1,096
700	1,254	1,061	1,064	975	1,064	1,084
860	1,801	1,134	1,245	1,801	1,245	1,445
710	1,634	1,100	1,023	1,411	1,023	1,238
720	1,139	1,050	1,016	969	1,016	1,038
870	1,623	1,356	1,313	1,509	1,313	1,423
730	1,114	970	949	880	949	973
880	1,462	994	1,094	1,133	1,094	1,155
740	1,085	906	925	847	925	937
890	1,703	1,436	1,210	1,684	1,210	1,449
750	1,002	968	922	853	922	933
760	1,073	1,006	939	969	939	985
910	1,219	976	926	901	926	990
770	872	875	876	825	876	865
920	1,150	1,040	1,050	944	1,050	1,047
780	917	877	879	834	879	877
790	1,007	872	859	848	859	889
800	957	811	773	716	773	806
900	819	730	752	703	752	751
Average	1,302	1,113	1,104	1,111	1,104	1,147
Min	819	730	752	703	752	751
Max	1,847	1,690	1,700	1,823	1,700	1,727

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A.3.3.1 Reach Network

The final reach network consists of 65 river, pond, and reservoir segments. The river segments make up 49 of these segments and range in length from 0.40 to 8.84 miles. Longer segments were used for the tributary reaches where cross-section data were sparse and model objectives did not warrant a finer scale. Shorter reaches were used along the mainstem and throughout the PSA where more than adequate geometry data were available and numerous synoptic and storm event calibration sites dictated the need for reach outlets. The longest reach along the mainstem and within the PSA of the mainstem measures 2.99 and 1.89 miles, respectively. Obviously, numerous smaller order streams are not explicitly represented in the reach network. The residence time in the smaller order streams is typically so short that excluding them in the model's reach network has a negligible effect on the mainstem flow rates and hydrographs.

A.3.3.2 Reach Geometry and Hydraulic Properties

Within the channel module (RCHRES) of HSPF, each stream reach is represented by a hydraulic function table, called an FTABLE, which defines the flow rate, surface area, and volume as a function of the water depth in the channel reach. In order to develop an FTABLE, the channel's geometric and hydraulic properties (e.g., Manning's n) must be first defined using observed data or estimated values. Once the geometry and hydraulic properties have been defined, it is necessary to develop the FTABLE as a function of the depth of water at the outlet, in order to simulate the hydraulic behavior of the reach. The method used in developing the FTABLE depends on the model objectives and available data, and can range from: 1) simply using a single cross-section at the outlet, applying Manning's equation to calculate cross-sectional outlet area and depth for a given flow rate, and then assuming the channel to be prismatic along its length and calculating the corresponding surface area and volume; or 2) entering the geometric and hydraulic properties into a more complex hydraulic model, such as HEC-RAS, and allowing the model to develop the relationships. All of the FTABLEs in the model, excluding the major ponds, reservoirs, and lakes, were initially developed using HEC-RAS, and then the PSA reach FTABLEs were refined based on the EFDC model grid.

The geometric data for the HEC-RAS model were provided by either: 1) a high resolution DEM of the PSA and channel bed developed from topography surveys; or 2) cross-sectional data (right and left bank coordinates, and X, Y, Z, data for individual measurements) available for Weston Reaches 5, 6, and specified tributaries. Topographic and cross-section data were available from surveys performed by GE in 1977, by Weston in 1998-1999, and the U.S. Army Corps of Engineers. For the PSA, the high resolution DEM provided a virtually unlimited number of cross-sections for each reach; using the functionality of the GIS allowed for the remaining geometric properties (e.g., channel length, slope) to be calculated. Converting the Weston cross-section data into a GIS shapefile provided a means to match up cross-sections and HSPF reaches, for those reaches outside of the PSA, and to calculate the remaining geometric properties not readily available in the original data.

Additional reach dependent hydraulic properties input into the HEC-RAS model included channel and floodplain roughness, spillway information, and rating curves. The channel and floodplain roughness are defined by assigning a unique Manning's n value for the right floodplain, channel, and left floodplain (as you look downstream) within HEC-RAS. Selecting a representative Manning's n involves both science and engineering judgment, and typically involves matching up photographs and descriptive data of the channel and floodplain in question with available literature values. The Manning's n values for the 49 reaches were assigned using photographs from field visits, high resolution orthophotos, and the land use coverage in conjunction with literature values presented in *Roughness Characteristics of Natural Channels (Barnes, 1967)* and *Hydraulic Design Handbook (Mays, 1999)*. The reach segments with outlets at Columbia Mill, Willow Mill, and Glendale Dams included both an upstream free flowing section and the region directly impounded behind the dam. Spillway information was entered into HEC-RAS for these segments in order to simulate their effect on the system (e.g., attenuation of peak flows) and develop reasonable FTABLEs. The spillway information was primarily provided by a report entitled *Report on Six Housatonic River Dams* (Harza Engineering, 1991). Rating curves, available from the USGS for the gages at Coltsville and Great Barrington, were input into the HEC-RAS model at the corresponding reaches. During the computations, the program then uses the water surface elevation from the rating curve instead of computing a value. As noted earlier, PSA FTABLES were subsequently replaced with the corresponding data developed from the EFDC model grid.

Table A.3-6 shows reach attribute data, including the segment in which the channel resides, Manning's n values assigned, reach length, elevation drop across its length, and slope.

Table A.3-6 HSPF Reach Characterization

Mainstem Mainstem PSA				Reach Endpoints	Manning's n (left and right are oriented as you look downstream)			Length	Δ Elevation	Slope
MFD Segment #	HSPF Segment #	Reach #	Reach name - Segment #	river miles	Left Floodplain	Channel	Right Floodplain	(miles)	(ft)	(ft/ft)
100	10	9	Windsor - 10		0.075	0.050	0.075	3.98	409.16	0.0195
100	10	10	Windsor Reservoir - 10		Weir Equation			0.50	0.00	0.0000
100	10	11	Wahconah - 10		0.060	0.045	0.060	3.56	365.15	0.0194
130	40	12	Cleveland Res. - 40		Weir Equation			0.75	0.00	0.0000
130	40	13	Cleveland Bk. - 40		0.060	0.050	0.060	1.88	291.00	0.0293
110	20	20	Ashmere Lake - 20		Weir Equation			1.50	0.00	0.0000
110	20	21	Bennett Bk - 20		0.075	0.045	0.075	4.12	157.49	0.0072
120	30	30	East Branch - 30		0.075	0.050	0.075	2.37	39.37	0.0031
130	40	40	East Branch - 40		0.065	0.050	0.065	5.53	312.17	0.0107
140	100	100	East Branch (Dalton/Center Pond) - 100		0.060	0.040	0.060	1.05	16.40	0.0030
1000	110	110	Housatonic (Coltsville) - 110	140.62	Rating Curve			1.47	108.28	0.0140
200	120	115	Unkamet Brook - 120		0.060	0.040	0.060	1.19	6.31	0.0010
1010	120	120	East Branch - 120	139.24	0.060	0.040	0.060	1.38	5.33	0.0007
2000	200	200	East Branch - 200	137.13	0.055	0.040	0.055	2.11	8.52	0.0008
2000	200	201	Brattle Bk - 200	137.13	0.055	0.040	0.055	2.82	328	0.0221
3000	300	300	East Branch - 300	136.47	0.055	0.040	0.055	0.66	3.11	0.0009
4000	400	400	East Branch (Pomeroy) - 400	135.40	0.060	0.045	0.060	1.07	6.04	0.0011
4000	410	410	East Branch Confluence - 410	135.00	0.060	0.045	0.065	0.40	1.42	0.0007
500	50	50	Town Brook - 50		0.075	0.050	0.075	6.61	288.72	0.0083
510	60	60	Secum Bk - 60		0.075	0.050	0.075	2.49	108.27	0.0082
510	70	70	Pontoosuc Res. - 70		Weir Equation			1.25	0.00	0.0000
520	70	71	West Branch - 70		0.065	0.045	0.065	2.02	59.80	0.0056
530	80	80	Onota Res. - 80		Weir Equation			0.75	0.00	0.0000
530	80	81	Daniels Bk - 80		0.075	0.045	0.075	3.39	193.57	0.0108
550	90	90	West Branch - 90		0.060	0.045	0.060	1.96	10.37	0.0010
540	810	810	Richmond Pond - 810		Weir Equation			0.60	0.00	0.0000
540	810	811	S. West Branch - 810		0.070	0.055	0.070	6.48	196.86	0.0058
550	820	820	West Branch Confluence - 820	135.00	0.065	0.045	0.065	0.88	4.66	0.0010
5000	500	500	Housatonic - 500	133.97	0.070	0.050	0.070	1.03	3.00	0.0006
5000	510	510	Housatonic - 510	133.50	0.065	0.050	0.065	0.47	3.30	0.0013
560	830	830	Sackett Bk - 830	133.50	0.065	0.045	0.065	3.74	308.41	0.0156
5010	520	520	Housatonic - 520	132.00	0.060	0.055	0.065	1.50	1.20	0.0002
5010	530	530	Housatonic - 530	130.20	0.065	0.055	0.060	1.80	4.00	0.0004
5010	540	540	Housatonic (Test Reach/New Lenox Rd) - 540	129.18	0.065	0.060	0.070	1.11	5.00	0.0008
5020	550	550	Housatonic - 550	128.10	0.070	0.060	0.070	1.08	1.00	0.0002
580	840	840	Roaring Bk - 840	128.10	0.075	0.040	0.075	1.86	492.44	0.0501
5020	560	560	Housatonic - 560	127.33	0.065	0.055	0.075	0.77	1.00	0.0002
570	850	850	Yokun Bk - 850	127.33	0.075	0.055	0.075	3.18	227.79	0.0136
5030	570	570	Housatonic - 570	125.44	0.065	0.060	0.065	1.89	1.00	0.0001
6000	580	580	Woods Pond Backwaters - 580	124.83	Weir Equation			0.61	0.00	0.0000
6000	600	600	Woods Pond - 600	124.40	Weir Equation			0.43	0.00	0.0000
7000	700	700	Housatonic - 700	123.06	0.065	0.040	0.060	1.34	52.49	0.0074
700	860	860	October Mtn. Res. - 860		Weir Equation			0.43	0.00	0.0000

Table A.3-6 HSPF Reach Characterization

Mainstem **Mainstem PSA**				**Reach Endpoints**	**Manning's n (left and right are *oriented as you look downstream*)**			**Length**	**Δ Elevation**	**Slope**
MFD Segment #	**HSPF Segment #**	**Reach #**	***Reach name - Segment #***	***river miles***	**Left Floodplain**	**Channel**	**Right Floodplain**	**(miles)**	**(ft)**	**(ft/ft)**
700	860	861	Washington Mtn. - 860	123.06	0.065	0.040	0.065	5.61	938.37	0.0317
7010	710	710	Housatonic (Columbia Mill Dam) - 710	122.23	0.060	0.040	0.060	0.83	11.97	0.0027
7010	720	720	Housatonic - 720	119.66	0.060	0.040	0.060	2.57	35.92	0.0026
7010	720	721	*Laurel Lk - 720*		Weir Equation			1.00	0.00	0.0000
7010	720	722	Laurel Bk - 720		0.065	0.040	0.065	0.86	98.00	0.0216
710	870	870	Greenwater Bk - 870	119.66	0.065	0.040	0.065	5.32	498.72	0.0178
710	*870*	*871*	*Goose Pond - 870*		Weir Equation			2.40	0.00	0.0000
710	870	872	Goose Pond Bk - 870	119.66	0.065	0.040	0.065	2.22	464.00	0.0396
7010	730	730	Housatonic - 730	117.88	0.060	0.045	0.060	1.78	8.91	0.0009
720	880	880	Hop Bk - 880	117.88	0.070	0.040	0.070	8.84	501.98	0.0108
7030	740	740	Housatonic - 740	116.68	0.060	0.045	0.060	1.20	5.55	0.0009
730	890	890	West Bk - 890	116.68	0.075	0.040	0.075	3.38	684.82	0.0384
7040	750	750	Housatonic (Willow Mill Dam) - 750	115.43	0.060	0.040	0.060	1.25	17.71	0.0027
7040	760	760	Housatonic - 760	112.87	0.070	0.040	0.070	2.56	47.25	0.0035
740	*910*	*910*	*Knokapot Bk - 910*	112.87	0.070	0.055	0.070	7.36	124.68	0.0032
7040	770	770	Housatonic - 770	110.86	0.060	0.040	0.060	2.01	33.47	0.0032
750	920	920	Stockbridge Bowl - 920		Weir Equation			1.90	0.00	0.0000
750	920	921	*Larrywaug Bk - 920*	110.86	*0.070*	*0.050*	*0.070*	*7.49*	*292.00*	*0.0074*
7050	780	780	Housatonic (Glendale Dam) - 780	109.00	0.070	0.040	0.070	1.86	44.39	0.0045
7050	790	790	Housatonic - 790	106.01	0.070	0.040	0.070	2.99	63.88	0.0040
8000	800	800	Rising Pond Dam - 800	105.16	Weir Equation			0.85	0.00	0.0000
9000	900	900	Housatonic (Great Barrington) - 900	104.52	Rating Curve			0.64	9.84	0.0029

A.3.3.3 Impoundments

As mentioned in the Reach Network section, 16 of the reach segments are not considered to be free flowing rivers as downstream dams and outlets control their outflows. Three of these segments are mixtures of a free flowing upstream river and a downstream impoundment formed at Columbia Mill, Willow Mill, and Glendale Dams. These three segments and FTABLE development were discussed in the previous section. Of the 13 impoundments remaining, three are located along the mainstem, formed by Woods Pond dam and its headwaters (as separate reaches), and Rising Pond dam, and 10 are larger impoundments tributary to the mainstem.

Detailed bathymetry data were available in a GIS format for Woods Pond and Rising Pond based on data collected during sub-bottom profiling (CR Environmental, Inc., 1998). The reach segments were confined to the region impounded by the dams and therefore made a level pool analysis possible. The depth, surface area, and volume relationships were developed by using functionality built into the GIS to: 1) create 3-dimensional models of the ponds; 2) incrementally fill-up the ponds to specified water surface elevations; and 3) calculate the corresponding surface areas and volumes. The flow (Q) was calculated as a function of head (H) above the spillway crest and spillway length (L) using a broad crested weir equation ($Q = 3.33 * H^{1.5} * L$).

The FTABLEs for the remaining impoundments were primarily based on data available from the National Inventory of Dams (NID) database (http://crunch.tec.army.mil/nid/webpages/nid.cfm). The NID provided the normal surface area and storage, the maximum surface area and storage, spillway and dam height, and the spillway length. Using this information and the previously described broad crested weir equation, it was possible to approximate a reasonable FTABLE.

A.3.4 FINAL WATERSHED AND CHANNEL SEGMENTATION

The final watershed and channel segmentation resulted in 49 watershed segments, ranging in size from 0.4 to 23.8 mi^2, and 65 river, pond, and reservoir segments. The river segments range in length from 0.40 to 8.84 miles. The smaller watershed and river segments tend to lie adjacent to and within the mainstem of the Housatonic River to support HSPF calibration efforts and to provide boundary condition loads to the receiving water models (EFDC, FCM) within the PSA. Segments tributary to the mainstem are typically larger due to limited calibration data for tributary reaches, and study objectives did not warrant a more detailed segmentation for these areas.

A.4 HYDROLOGY CALIBRATION RESULTS

A.4.1 OVERVIEW OF HSPF CALIBRATION PROCEDURES

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical/chemical characteristics of the watershed and compounds of interest. Fortunately, the large majority of HSPF parameters do not fall in this category. Calibration is based on several years of simulation (at least 3 to 5 years) to evaluate parameters under a variety of climatic, soil moisture, and water quality conditions. Calibration should result in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period. Appendix B in the MFD provides a comprehensive list of model parameters for HSPF, along with definitions, units, and data/evaluation sources.

Calibration includes the comparison of both monthly and annual values, daily values, and individual storm events, whenever sufficient data are available for these comparisons. All of these comparisons, involving both graphical and statistical procedures, should be performed for a proper calibration of hydrology and water quality parameters. In addition, when a continuous observed record is available, such as for streamflow, simulated and observed values should be analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations. All of these components of the model calibration process are discussed as part of the 'weight-of-evidence' approach to model performance assessment included in the QAPP for the Housatonic Modeling Study (Beach et al, 2000b). The QAPP also included target tolerances for model calibration and validation, with a value of ±15% for hydrology and flow. As noted in the QAPP, due to the uncertain state-of-the-art in model performance criteria, the inherent error in input and observed data, and the approximate nature of model formulations, absolute criteria for model acceptance or rejection are not appropriate for this effort. Consequently, the tolerance ranges are proposed as general targets or goals for model calibration and validation for the corresponding modeled quantities. For hydrology, these tolerances are applied to comparisons of simulated and observed mean flows, annual and monthly runoff volumes, and mean storm peak flows, with larger deviations expected for individual sample points in both space and time.

A.4.1.1 Hydrologic Calibration

Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorologic data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. HSPF simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for each characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement. A detailed discussion is presented in Section 4.5.1 of the MFD that identifies the critical parameters and adjustments made to calibrate the model for each of the aforementioned characteristics of the watershed hydrology.

In recent years, the hydrology calibration process has been facilitated with the aide of HSPEXP, an expert system for hydrologic calibration, specifically designed for use with HSPF, developed under contract for the U.S. Geological Survey (Lumb, et al., 1994). This package gives calibration advice, such as which model parameters to adjust and/or input to check, and allows the user to interactively modify the HSPF Users Control Input (UCI) files, make model runs, examine statistics, and generate a variety of plots of observed data and simulated values.

A.4.1.2 Hydraulic Calibration

The major determinants of the routed flows simulated by section HYDR in HSPF are the hydrology results from the watershed model segments, and the physical data contained in the FTABLE; i.e., *the stage-discharge function used for hydraulic routing.* Typically, calibration of the FTABLEs is not required when simulating daily or monthly flows. However, some adjustments may be required when calibrating to individual storm events and if inconsistencies in the stage-discharge function appear to exist for a given reach. For this application, the hydrodynamics simulated by EFDC were used to refine the previously developed FTABLEs within the PSA.

A.4.1.3 Snow Calibration

Since snow accumulation and melt is an important component of streamflow in the Housatonic River watershed, accurate simulation of snow depths and melt processes is needed to successfully model the hydrologic behavior of the watershed. Snow calibration, using module section SNOW, is actually part of the hydrologic calibration. It is usually performed during the initial phase of the hydrologic calibration since the snow simulation can impact not only winter runoff volumes, but also spring and early summer streamflow.

In most applications, the primary goal of the snow simulation is to adequately represent the total volume and relative timing of snowmelt to produce reasonable soil moisture conditions in the spring and early summer so that subsequent rainfall events can be accurately simulated. Where observed snow depth (and water equivalent) measurements are available, comparisons with simulated values are made. However, a tremendous variation in observed snow depth values can occur in a watershed, as a function of elevation, exposure, topography, etc. Thus a single observation point or location will not always be representative of the watershed average. For the Housatonic, snow depth data from Great Barrington Airport, Lanesboro, Berlin 5S, and Dalton were used.

In many instances, it is difficult to determine if problems in the snow simulation are due to the nonrepresentative meteorologic data or inaccurate parameter values. Consequently the accuracy expectations and general objectives of snow calibration are not as rigorous as for the overall hydrologic calibration. Comparisons of simulated weekly and monthly runoff volumes with observed streamflow during snowmelt periods, and observed snow depth (and water equivalent) values are the primary procedures followed for snow calibration. Day-to-day variations and comparisons on shorter intervals (i.e., 2-hour, 4-hour, 6-hour, etc.) are usually not as important as representing the overall snowmelt volume and relative timing within the observed weekly or bi-weekly window of the primary melt period.

Attachment A.4 lists the HSPF hydrologic and snow parameters, along with definitions, units, and calibrated value ranges for the Housatonic Watershed Model.

A.4.2 CALIBRATION RESULTS

Hydrologic calibration was performed for the time period of 1990 through 2000. The available flow data include continuous flow records at the USGS gage sites at Coltsville and Great Barrington for the entire time period, along with recent flow monitoring performed for 11 selected storm events during 1999 and 2000 at both tributary and mainstem sites. The 1999-2000 time period was included in the calibration period to allow calibration of the storm event data and to support the subsequent sediment and water temperature calibration using the water quality data collected during these events. Unfortunately, rating curves were developed only for the mainstem sites (Pomeroy, New Lenox Road, Woods Pond); thus, reliable hydrographs for the storm events were only available at these sites.

The following comparisons of simulated and observed values were made for the calibration period:

- For the Coltsville and Great Barrington gage sites:
    - Annual and monthly runoff volumes (inches)
    - Daily time series of flow (cfs)
    - Scatter plots (cfs)
    - Flow frequency (flow duration) curves (cfs)

- At PSA and mainstem monitoring sites:
    - Storm hydrographs (flow, cfs) for selected storm events

- Additional comparisons:

- Snow depth for selected land uses with available data at Great Barrington Airport, Lanesboro, and Dalton

In addition to the above comparisons, the water balance components (input and simulated) were reviewed for consistency with expected literature values for the Housatonic Region (e.g., Bent, 1999). This effort involves displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
  - Overland flow
  - Interflow
  - Baseflow
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- Deep Groundwater Recharge/Losses

Although observed values are not available for each of the water balance components listed above, the average annual simulated values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to insure that land use categories and overall water balance reflect local conditions in the Housatonic Basin.

A.4.2.1 Annual Runoff - Coltsville and Great Barrington

The first step in calibrating the model was achieving the annual water balance. Table A.4-1 shows the resulting agreement between simulated and observed mean annual inches of runoff at Coltsville and Great Barrington. At Coltsville, the annual percent errors range from -5.3 to 6.5 with an overall percent error of 0.6. The percent errors at Great Barrington range from -9.2 to 17.6 with an overall percent error of 1.6. Unfortunately, one of the largest errors occurring at Coltsville happens in 1999 when the storm event data were collected at tributary and mainstem sites. Nonetheless, the overall errors, annual errors at Coltsville, and the majority of annual errors at Great Barrington are less than the 15% target, specified in Table 4-4 of the QAPP, and most are less than 10%, a conventional HSPF criteria for a 'very good' calibration. In fact, only two of the years at Great Barrington exceed the 10% target for a 'very good' calibration; i.e., 1992 and 1993 have errors of 17.6 and 12.2 percent which are characterized as 'Fair' and 'Good' calibrations, respectively.

Table A.4-1 Annual simulated and observed runoff

	Coltsville				Great Barrington			
	Precipitation	Simulated Flow	Observed Flow	Percent Error	Precipitation	Simulated Flow	Observed Flow	Percent Error
1990	60.57	36.29	36.47	-0.50%	58.86	37.97	35.64	6.50%
1991	50.51	22.30	22.22	0.40%	46.21	22.74	22.84	-0.40%
1992	48.88	22.72	21.43	6.00%	46.21	23.58	20.04	17.60%
1993	49.85	27.52	27.72	-0.70%	48.19	29.23	26.05	12.20%
1994	49.50	25.26	24.74	2.10%	46.38	25.92	25.46	1.80%
1995	50.85	21.99	20.65	6.50%	43.08	20.30	21.02	-3.40%
1996	66.44	41.60	41.71	-0.30%	60.95	39.02	41.41	-5.80%
1997	46.68	21.74	21.95	-1.00%	42.32	21.08	23.23	-9.20%
1998	45.86	23.15	24.10	-3.90%	42.09	22.35	23.93	-6.60%
1999	50.23	20.13	21.26	-5.30%	50.87	24.74	24.78	-0.20%
2000	60.14	32.56	31.36	3.80%	56.10	32.97	30.82	7.00%
Total	579.51	295.26	293.61	0.60%	541.26	299.90	295.22	1.60%
Average	52.68	26.84	26.69	0.60%	49.20	27.26	26.84	1.60%

HSPEXP produces additional annual summaries and error statistics where appropriate throughout the calibration process. The summaries describe the average annual distribution of high and low flows, actual evapotranspiration and PET, and storm volumes and average peaks. Table A.4-2 displays the annual flow summaries and error statistics calculated by HSPEXP. The quantitative criteria listed are the default values of acceptable error for model calibration included with the expert system. All of the errors are well within the ±15% hydrology calibration target specified in Table 4-4 of the QAPP.

Table A.4-2 Annual flow statistics from HSPEXP

	Coltsville		Great Barrington	
	Simulated	Observed	Simulated	Observed
Average runoff, in inches	26.86	26.71	27.28	26.86
Total of highest 10% flows, in inches	10.98	10.74	9.20	8.94
Total of lowest 50% flows, in inches	4.63	4.38	5.35	5.35
Evapotranspiration, in inches	23.16	25.17[1]	22.98	25.68[1]
Total storm volume, in inches[2]	52.56	51.91	42.29	42.35
Average of storm peaks, in cfs[2]	735.12	791.97	2214.87	2287.28
	Calculated	Criteria	Calculated	Criteria
Error in total volume, %	0.55	10.00	1.58	10.00
Error in 10% highest flows, %	2.24	15.00	2.85	15.00
Error in 50% lowest flows, %	5.56	10.00	0.19	10.00
Error in storm peaks, %	-7.18	15.00	-3.17	15.00

1 – PET (estimated by multiplying observed pan evaporation data by 0.73)
2 – Based on 31 storms occurring between 1990 and 2000

A.4.2.2 Daily and Monthly Timeseries - Coltsville and Great Barrington

Once the annual water balance was obtained, the monthly flows were examined to determine the agreement of simulated and observed values on a seasonal basis. The HSPF parameter changes that affect the seasonal distribution (e.g., INFILT) can also have a large impact on the daily flows. Thus, the daily and monthly timeseries are generally examined concurrently and are presented together in this section. Table A.4-3 presents statistics calculated for daily and average monthly flows occurring at Coltsville and Great Barrington during the calibration period. In general, the mean flows are in very good agreement. The correlation coefficient (R) is a measure of the linear dependence between two random variables, i.e. simulated and observed daily flow, and varies from ± 1. The correlation coefficient will be positive if larger than mean values are likely to be paired with larger than mean values (and smaller with smaller) when comparing the two timeseries. If larger than average values appear with smaller than average values (and vice versa), the correlation coefficient will be negative. A high correlation coefficient indicates the stochastic dependence is high and the variables have a joint linear tendency. The correlation coefficients at both Coltsville and Great Barrington are ≥ 0.85 and ≥ 0.95 for daily and monthly flows, respectively. The model fit efficiency (MFE) is a direct measure of the fraction of the variance of the observed data series explained by the model.

Table A.4-3 Daily and Monthly Average Flow Statistics

Coltsville				
	Daily		Monthly	
	Simulated	Observed	Simulated	Observed
Count	4018	4018	132	132
Mean, cfs	113	112	113	112
Geometric Mean, cfs	*71*	*70*	*86*	*85*
Correlation Coefficient (R)	0.87		0.95	
Coefficient of Determination (R^2)	0.76		0.90	
Mean Error, cfs	0.60		0.70	
Mean Absolute Error, cfs	34.8		19.7	
RMS Error, cfs	74.0		28.0	
Model Fit Efficiency (1.0 is perfect)	0.74		0.90	
Great Barrington				
	Daily		Monthly	
	Simulated	Observed	Simulated	Observed
Count	4018	4018	132	132
Mean, cfs	565	556	565	556
Geometric Mean, cfs	393	391	448	441
Correlation Coefficient (R)	0.90		0.95	
Coefficient of Determination (R^2)	0.81		0.90	
Mean Error, cfs	8.8		9.4	
Mean Absolute Error, cfs	139.1		86.3	
RMS Error, cfs	244.4		123.2	
Model Fit Efficiency (1.0 is perfect)	0.80		0.89	

If the model residuals were normally distributed, the MFE would be nearly equal to the coefficient of determination (R^2). Both the MFE and R^2 provide more rigorous tests than the correlation coefficient because they consider the magnitude of the differences between observed and simulated values. The MFE values for average monthly flows at Coltsville and Great Barrington are approximately 0.9. Previous studies have defined an acceptable level of calibration as a correlation coefficient greater than 0.85 and a MFE greater than 0.80 for monthly flows (Beach et al., 2000). Both Coltsville and Great Barrington well exceed these targets. The daily and monthly MFE values at Coltsville and Great Barrington are very similar to the respective R^2 values calculated indicating approximately normally distributed residuals.

Table A.4-4 displays the mean monthly observed and simulated runoff, average residual, and percent error for the calibration time period. The monthly residuals indicate that the model tends to slightly overestimate the runoff during the winter and as a result underestimate the months of April and May. The overall percent error of the average monthly residuals at Coltsville and Great Barrington are 0.56% and 1.58%, respectively. Nearly all of the percent errors are within the ±15% target specified in the QAPP for a 'good' calibration. Figures A.4-1 and A.4-2 display the monthly observed runoff and residuals for Coltsville and Great Barrington, respectively.

Table A.4-4 Average observed monthly flow and residuals

	COLTSVILLE				GREAT BARRINGTON			
Month	Average Observed	Average Simulated	Average Residual (Simulated - Observed)	Percent Error	Average Observed	Average Simulated	Average Residual (Simulated - Observed)	Percent Error
JAN	2.81	2.49	0.32	13.06%	3.13	2.82	0.31	10.85%
FEB	2.07	1.80	0.27	15.15%	2.38	1.96	0.42	21.67%
MAR	4.04	4.02	0.02	0.57%	3.90	3.69	0.21	5.80%
APR	4.35	4.71	-0.36	-7.64%	3.94	4.15	-0.21	-4.97%
MAY	2.46	2.76	-0.30	-10.73%	2.47	2.87	-0.41	-14.11%
JUN	1.72	1.84	-0.12	-6.73%	1.68	1.79	-0.11	-6.10%
JUL	1.00	0.96	0.04	4.33%	1.17	1.18	-0.01	-0.61%
AUG	1.17	1.10	0.07	5.96%	1.15	1.06	0.09	8.23%
SEP	1.06	0.96	0.10	10.03%	1.05	0.95	0.10	10.27%
OCT	1.64	1.72	-0.08	-4.41%	1.64	1.73	-0.09	-5.15%
NOV	2.08	2.00	0.09	4.26%	2.08	2.09	-0.02	-0.78%
DEC	2.44	2.34	0.10	4.09%	2.69	2.56	0.13	5.01%
Totals	26.85	26.70	0.10	0.56%	27.26	26.84	0.13	1.58%

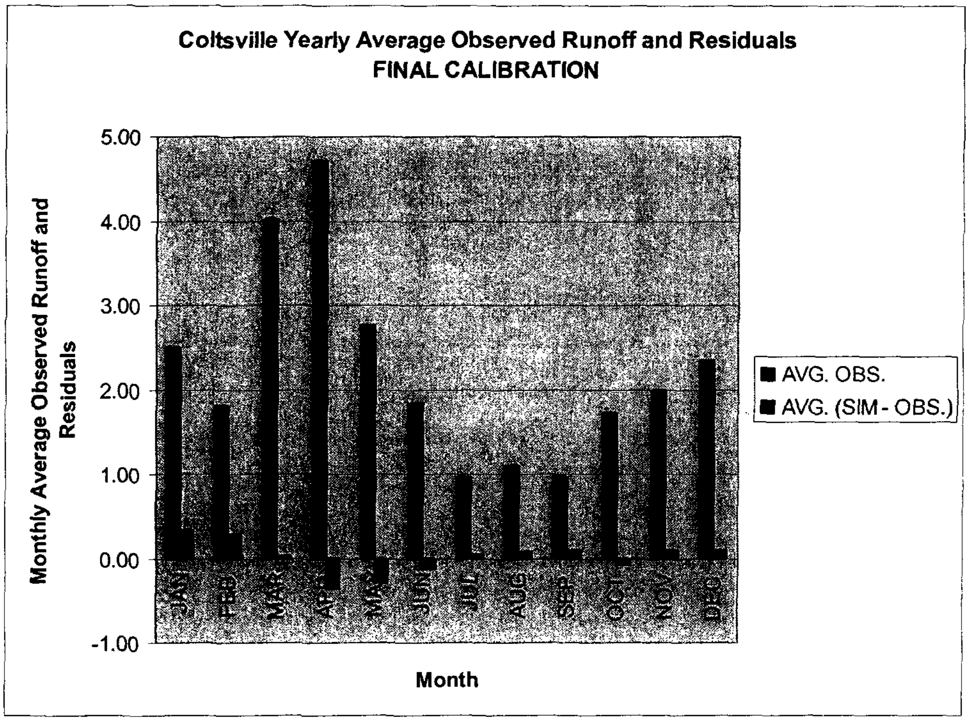


Figure A.4-1 Coltsville observed runoff and residuals

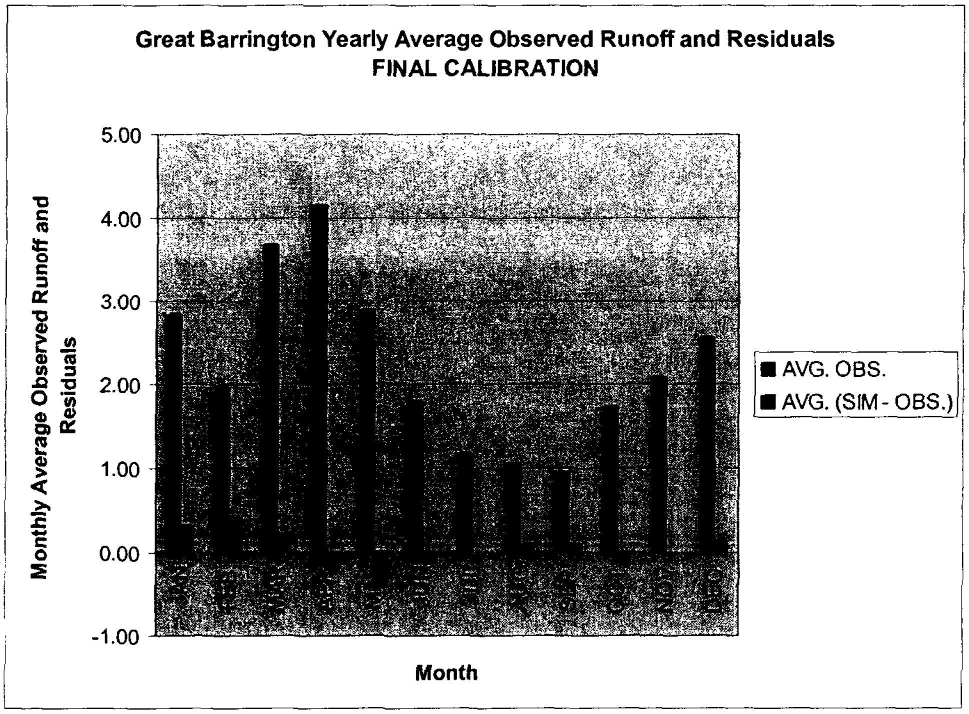


Figure A.4-2 Great Barrington observed runoff and residuals

HSPEXP produces statistics describing the seasonal volume error; defined as the June - August runoff volume error minus the December – mid-April volume error. In addition, the error in runoff for selected summer storms is calculated. These statistics are presented in Table A.4-5.

Table A.4-5 Seasonal flow statistics from HSPEXP

	Coltsville		**Great Barrington**	
	Simulated	Observed	Simulated	Observed
Winter flow volume, in inches[1]	13.78	13.14	14.33	13.24
Summer storm volume, in inches[1]	0.82	0.91	0.66	0.69
	Calculated	Criteria	Calculated	Criteria
Seasonal volume error, %	5.30	10.00	8.94	10.00
Summer storm volume error, %	-12.01	15.00	-4.66	15.00

1 – HSPEXP set to define summer as June – August and winter as December – mid-April

During the calibration of the watershed model, it was evident that snow accumulation and melt processes impact the streamflow in the Housatonic River watershed. Typically, the snowpack is present from the middle of November through March or early April. Several melt events occur during these months augmenting the stream flow and soil moisture. If the model misses a particular melt event the snow pack will remain around, or grow if precipitation fell, for up to several weeks, to melt at a later date. This behavior affects the monthly and seasonal flows and corresponding statistics. Reviewing daily snow pack and flow timeseries, it is clear that the model does indeed miss apparent snowmelt events and simulate false melt events. When this occurs, the resulting error is amplified by precipitation falling as rain instead of snow (or vice versa) during these time periods. See Section A.4.2.3.4 for discussion of the snow calibration results.

The agreement between observed and simulated daily flows is generally quite good at both Coltsville and Great Barrington, although deviations exist for a number of events. Figures A.4-3 through A.4.6 and A.4-7-through A.4-10 show the daily flow simulation for Coltsville and Great Barrington, respectively, for selected years within the 1990-2000 period. Attachment A.2 includes a complete set of annual plots for the entire calibration period. Figures A.4-3 and A.4-7 display the 1995 simulation when the timing of the melt events were generally well represented;

although, the overall magnitudes of the peaks are oversimulated. However, there are years with some obvious deviations in the timing of snowmelt events. In 1993, (Figures A.4-4 and A.4-8), the snow pack begins to melt prematurely, during an event that is incorrectly simulated as rain on snow pack, causing an error in the simulated March 1993 runoff. The premature reduction of the snow pack in March then had a slight impact on the major melt that followed, which was simulated for the most part very accurately. In 1999 at Coltsville (Figure A.4-6), the reverse situation happens when the simulated snow pack fails to melt to the extent the data at Coltsville indicates for numerous winter events. The March event was likely a time when rain was falling on top of the snow pack and enhancing the melt and the model incorrectly simulated precipitation falling as snow. These situations display the importance in having accurate air temperature data, precipitation data, and the correct daily distribution of the two. Generally, the model is adequately calibrated to reproduce seasonal and monthly runoff volumes. However, the daily simulations of selected storm events show wider variations from year to year.

In August 1990 (Figure A.4-5), a flood event was recorded at the Coltsville gage having a 10-year recurrence interval. The simulated and observed storm hydrographs match quite well for this event with the simulated daily average peak being slightly undersimulated. In 1998 (Figure A.4-9) numerous large winter and summer storm events were recorded at the Great Barrington gage. This type of year tests the ability of the model to accurately simulate consecutive storm events and the impact of antecedent soil moisture conditions on storm hydrographs. Although some storm events are under simulated, the simulated and observed values are in good agreement. The model especially does a good job in simulating the time to peak and recession rates of the individual events.

Figures A.4-6 and A.4-10 are included since the tributary data were collected by Weston primarily in 1999. Knowing that the sediment and water temperature calibration will use these data, it is important the hydrology be evaluated for this time period. As noted earlier, it is unfortunate that some of the largest annual water balance errors for Coltsville occur in 1999. Also, the overall storm volumes and peaks are generally low, especially during the January-March time period, largely due to apparent errors in the simulated snow accumulation and melt processes. The undersimulation of late spring and summer storms may be due to inaccurate soil moisture conditions, resulting from improper snow simulation, or inaccurate hourly rainfall intensities. Likely, it is a combination of both factors.

Figures A.4.11 and A.4-12 and Figures A.4-13 and A.4-14 show scatter plots for daily and monthly flows at Coltsville and Great Barrington, respectively. The plots include a 1:1 line, equation of linear regression, and coefficient of variation (R^2). These plots show a very good to excellent correlation for monthly flows, and a good to very good correlation for daily flows. A complete set of daily timeseries plots, flow and snow pack, are presented in Appendix A.2 for the complete calibration period, extending from 1990 through 2000.

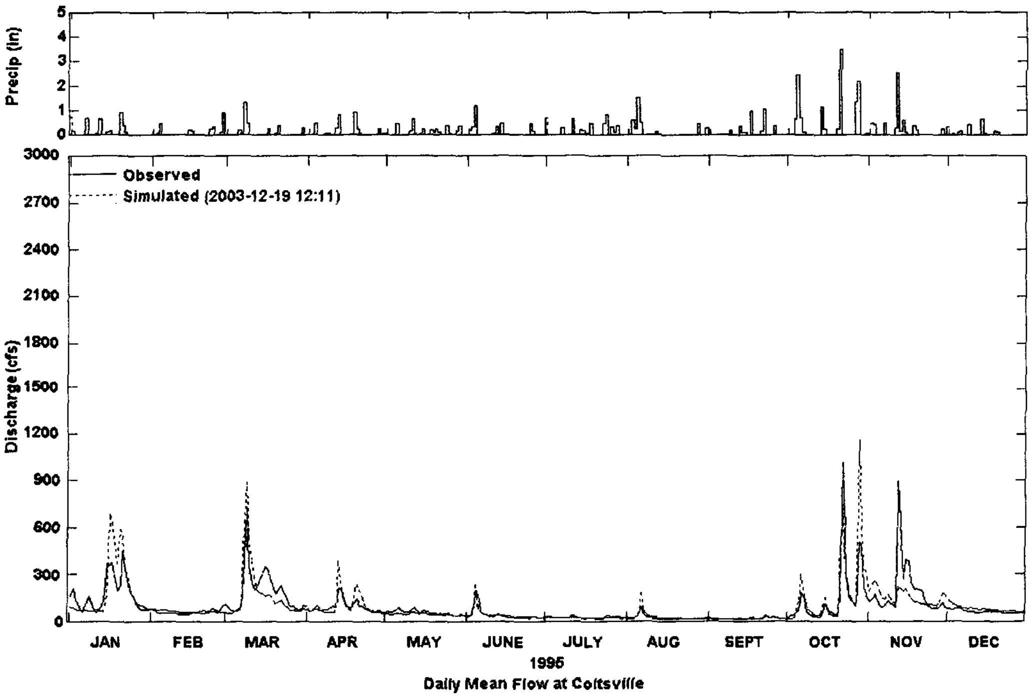


Figure A.4-3 Daily Flow at Coltsville (1995)

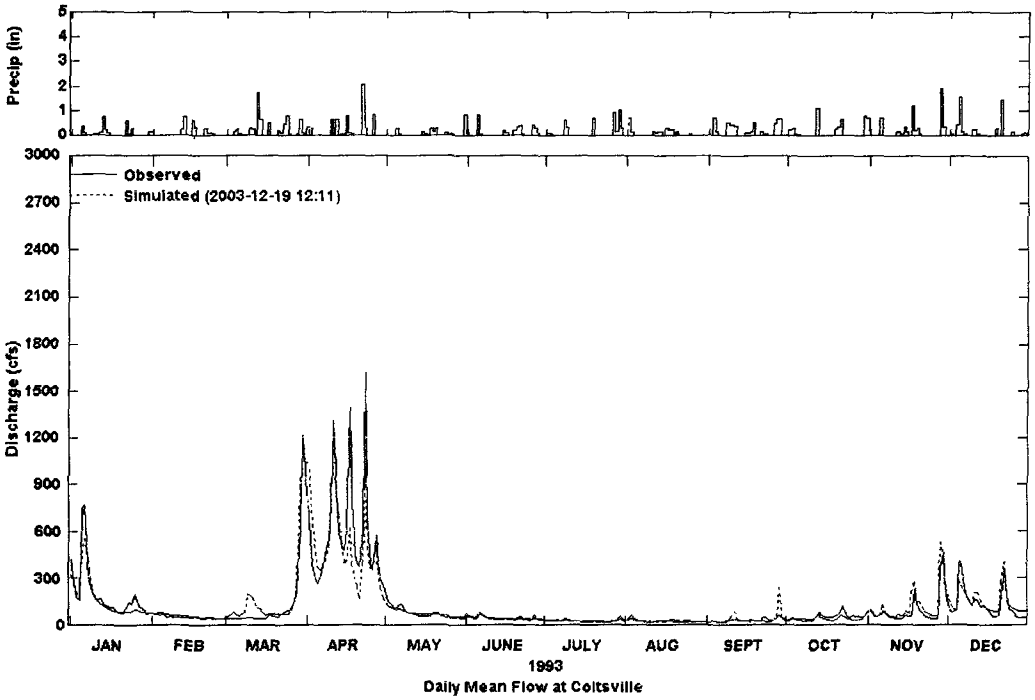


Figure A.4-4 Daily Flow at Coltsville (1993)

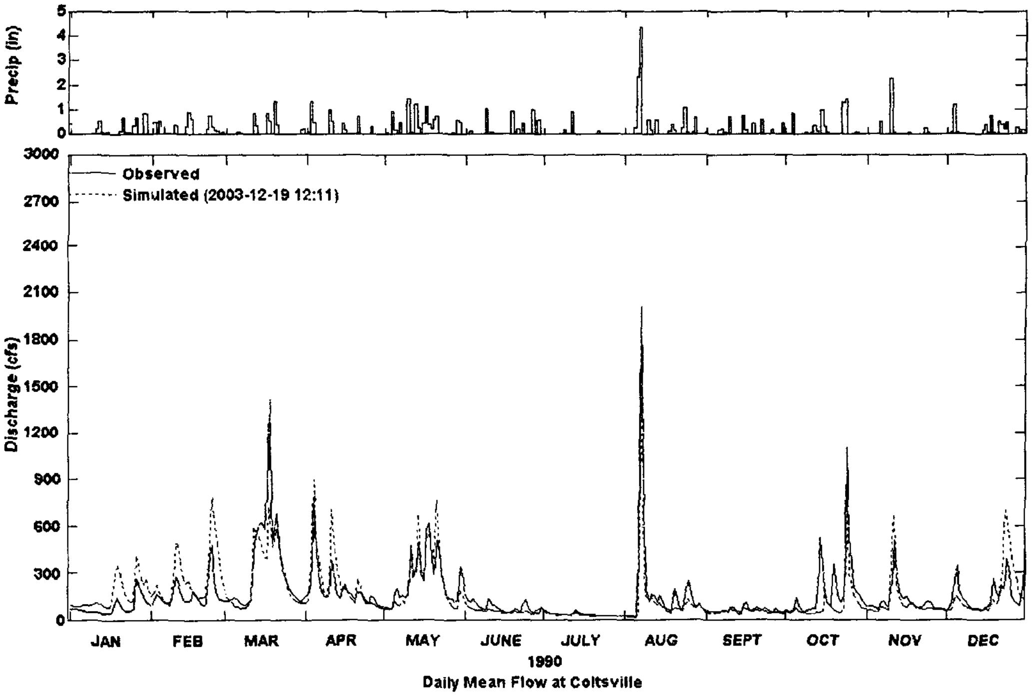
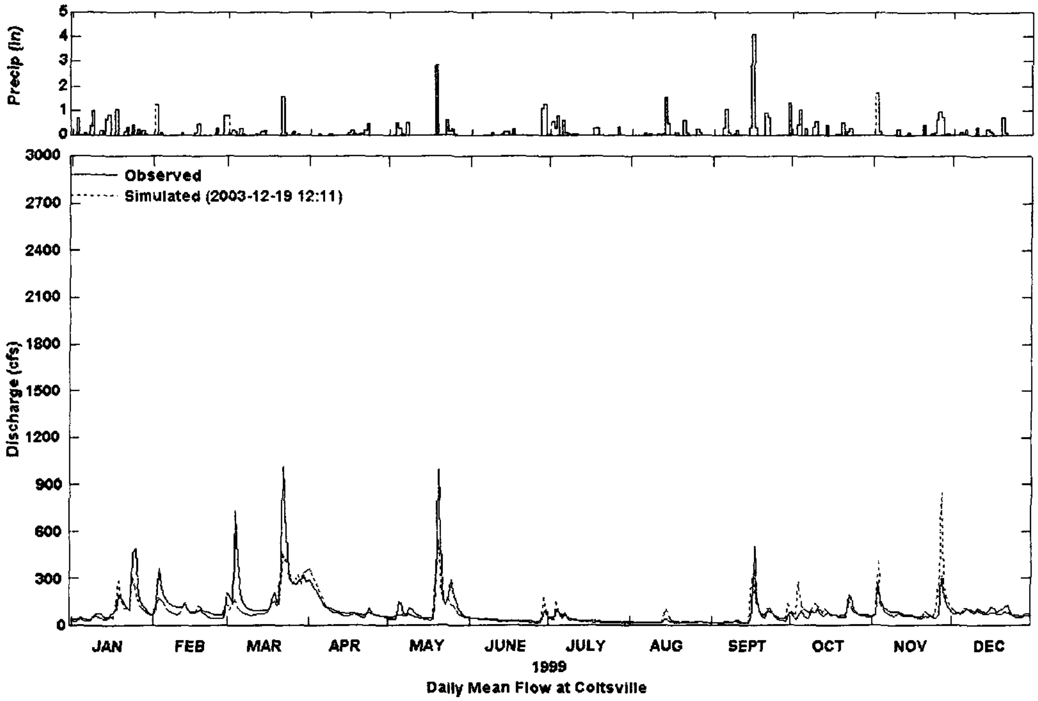
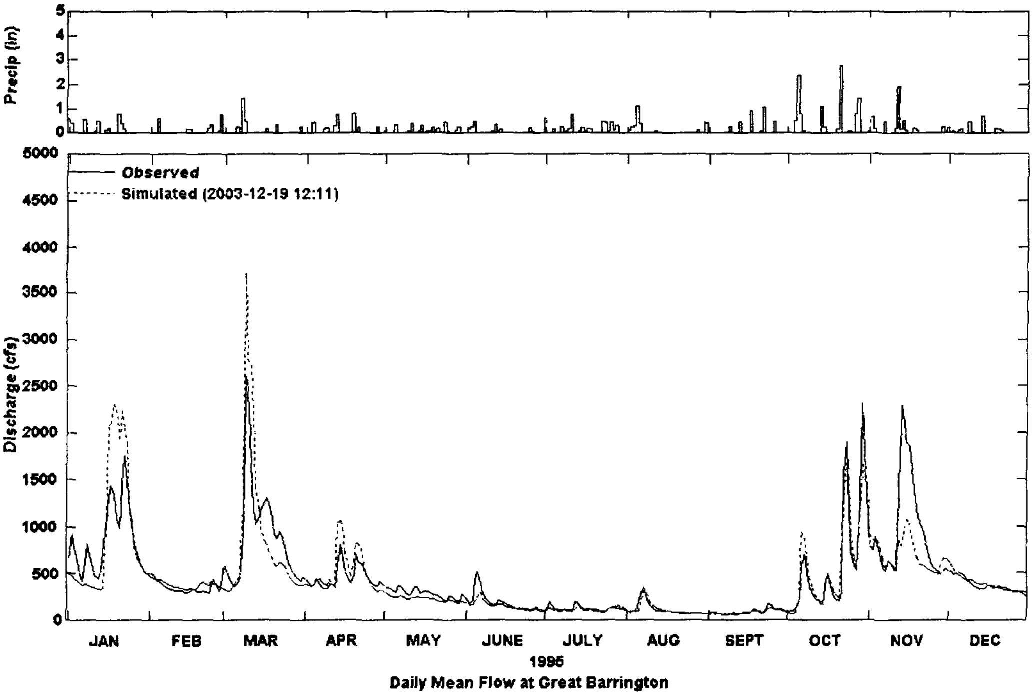


Figure A.4-5 Daily Flow at Coltsville (1990)



1 **Figure A.4-6 Daily Flow at Coltsville (1999)**



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3 **Figure A.4-7 Daily Flow at Great Barrington (1995)**

4

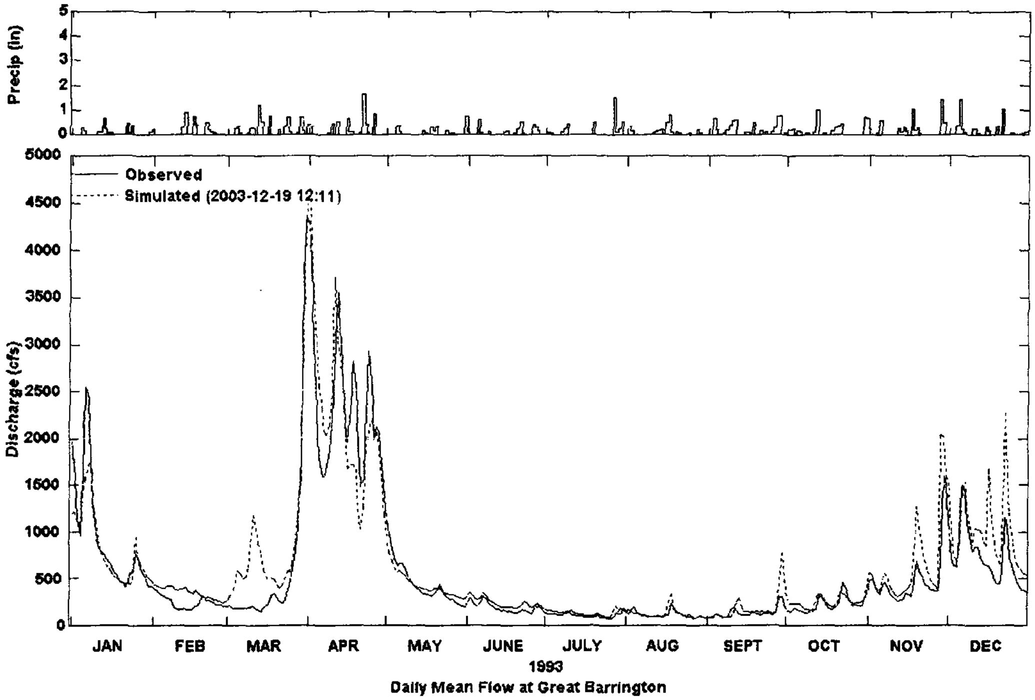


Figure A.4-8 Daily Flow at Great Barrington (1993)

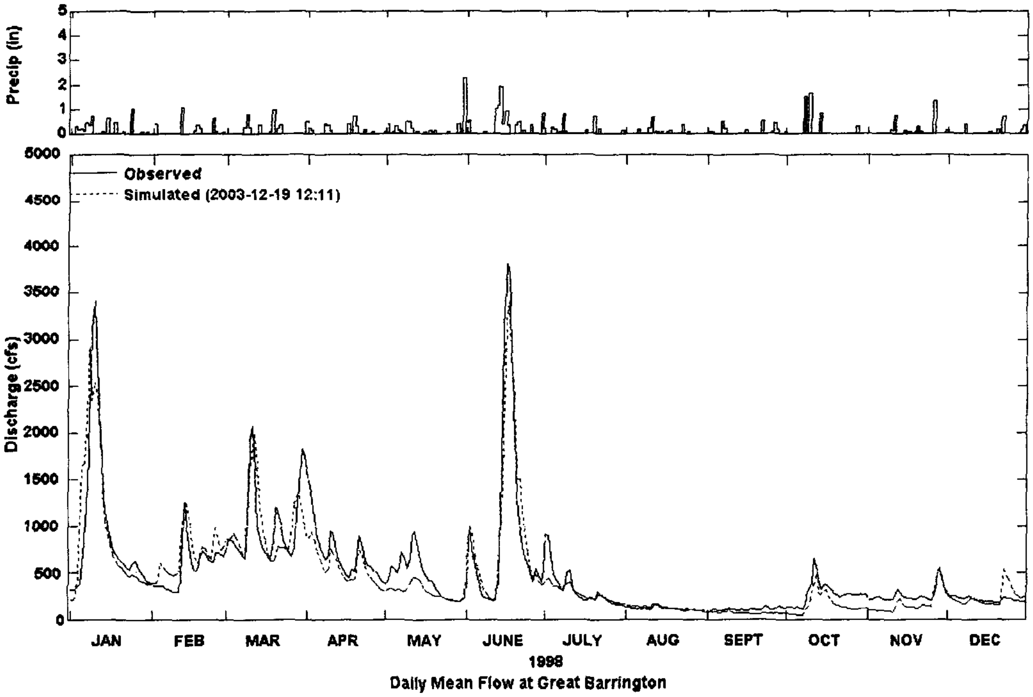


Figure A.4-9 Daily Flow at Great Barrington (1998)

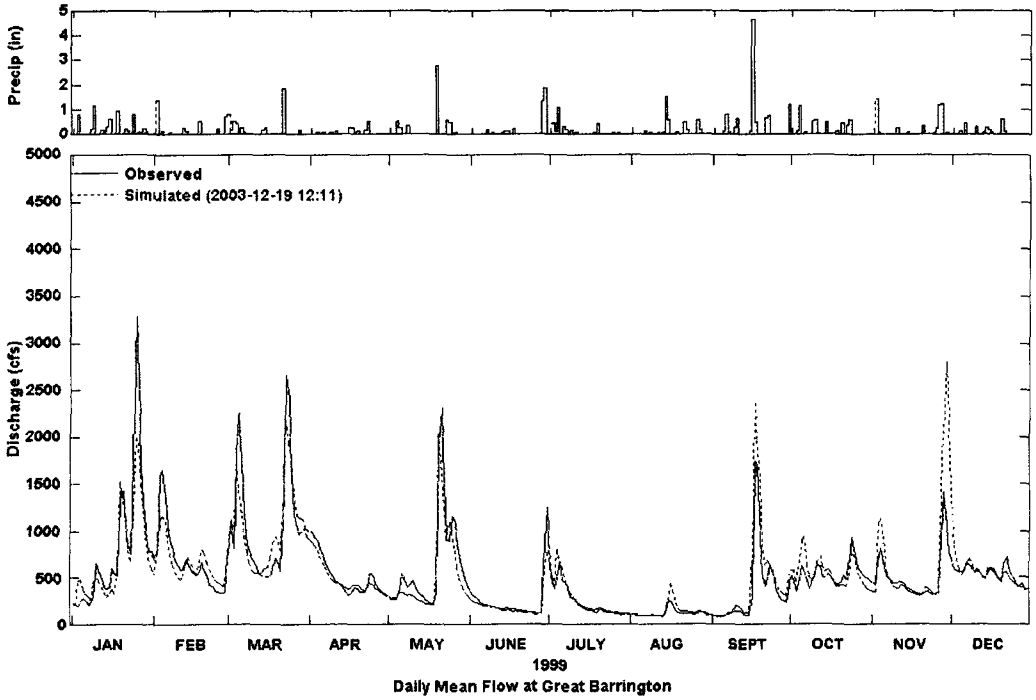


Figure A.4-10 Daily Flow at Great Barrington (1999)

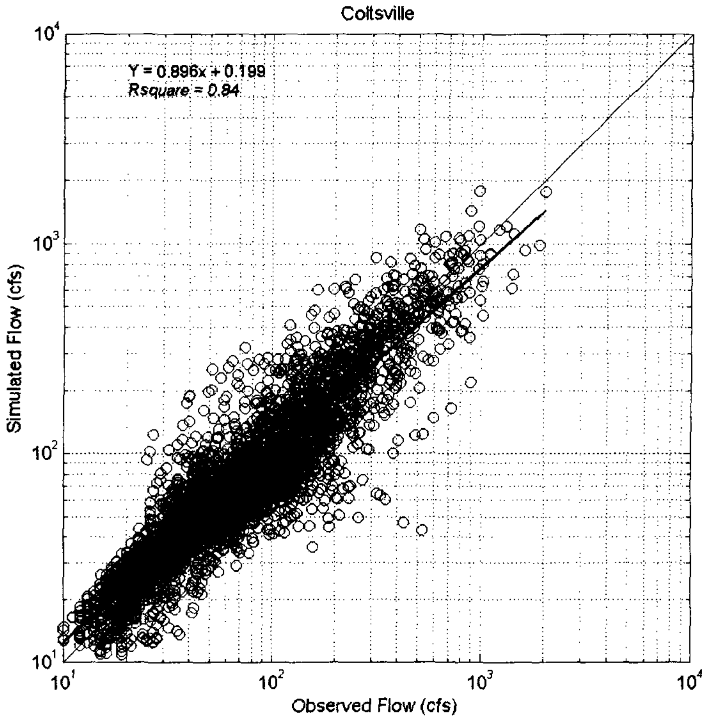


Figure A.4-11 Daily Scatter Plot at Coltsville

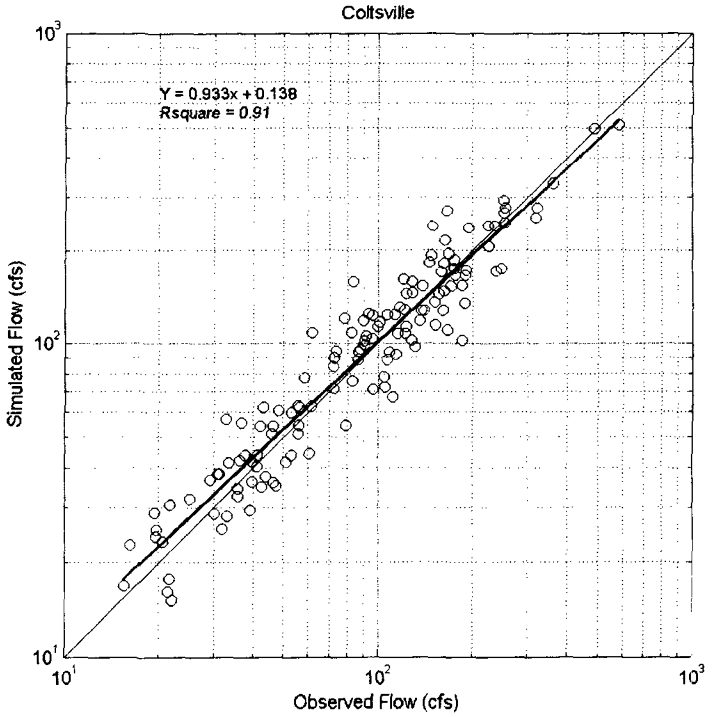


Figure A.4-12 Monthly Scatter Plot at Coltsville

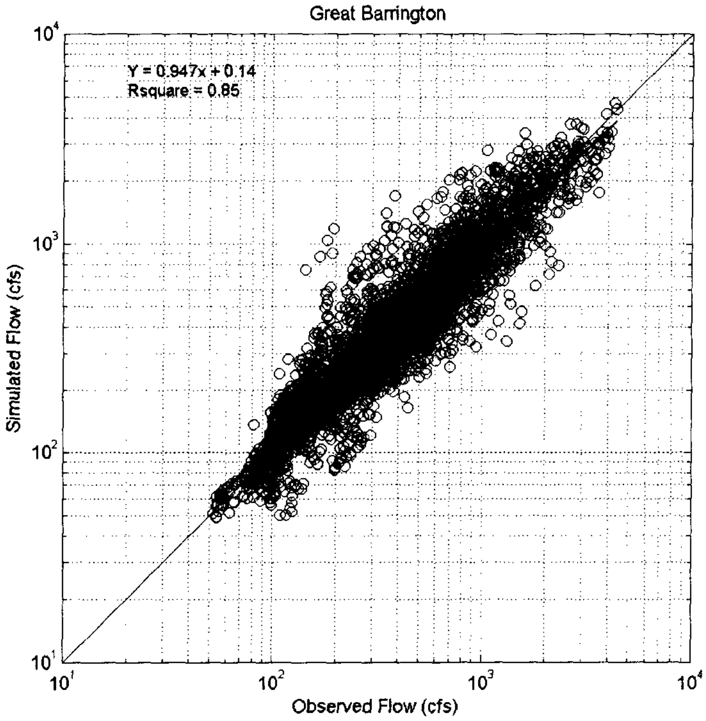


Figure A.4-13 Daily Scatter Plot at Great Barrington

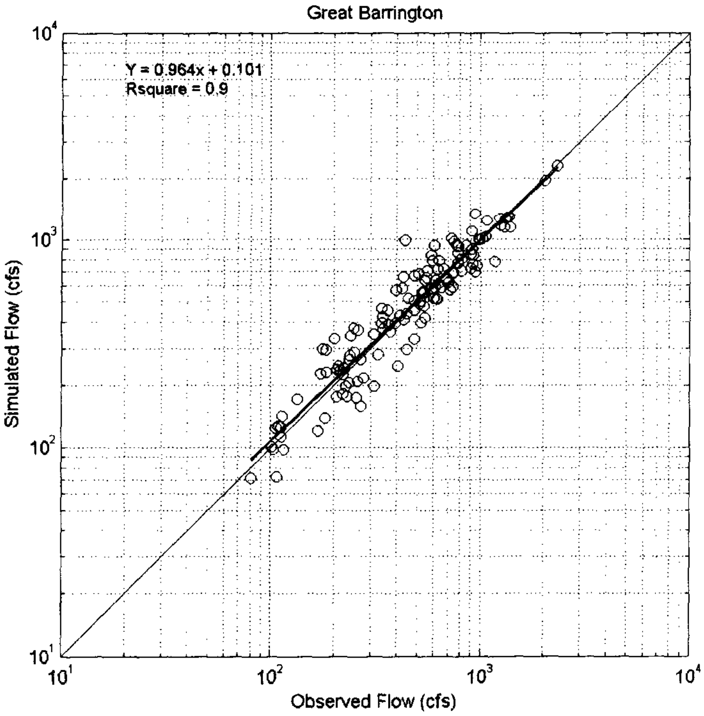


Figure A.4-14 Monthly Scatter Plot at Great Barrington

A.4.2.3 Flow Duration - Coltsville and Great Barrington

The daily and hourly flow duration curves are presented in Figures A.4-15 through A.4-18 for simulated and observed flows at Coltsville and Great Barrington. The simulated flow duration curves at Coltsville and Great Barrington are a close reproduction of the observed curves indicating the model provides a good representation of the watershed rainfall-runoff processes occurring in the watershed over a wide range of hydrologic conditions at both the hourly and daily average time interval. Some small variation is apparent however, in the lower tails of the daily flow duration curves at Great Barrington reflecting slight errors in representing the base flow characteristics of the river as affected by Rising Pond just upstream of the gage. The observed hourly duration curve at Great Barrington (Figure A.4-18) has approximately 2 percent of its data missing which is reported in the database as a value of -999; thus, the curve is vertical at the 98 percent exceeded point. The **daily** flow duration curves are a direct reflection of the daily timeseries comparisons, with some peaks high and some low, but very close agreement through most of the flow range with some slight under-simulation at the extremes. The **hourly** flow duration shows that the model does a very good job of duplicating the short time interval behavior of the watershed even thought the representation of specific individual hourly values and storm events may be higher or lower than observed values.

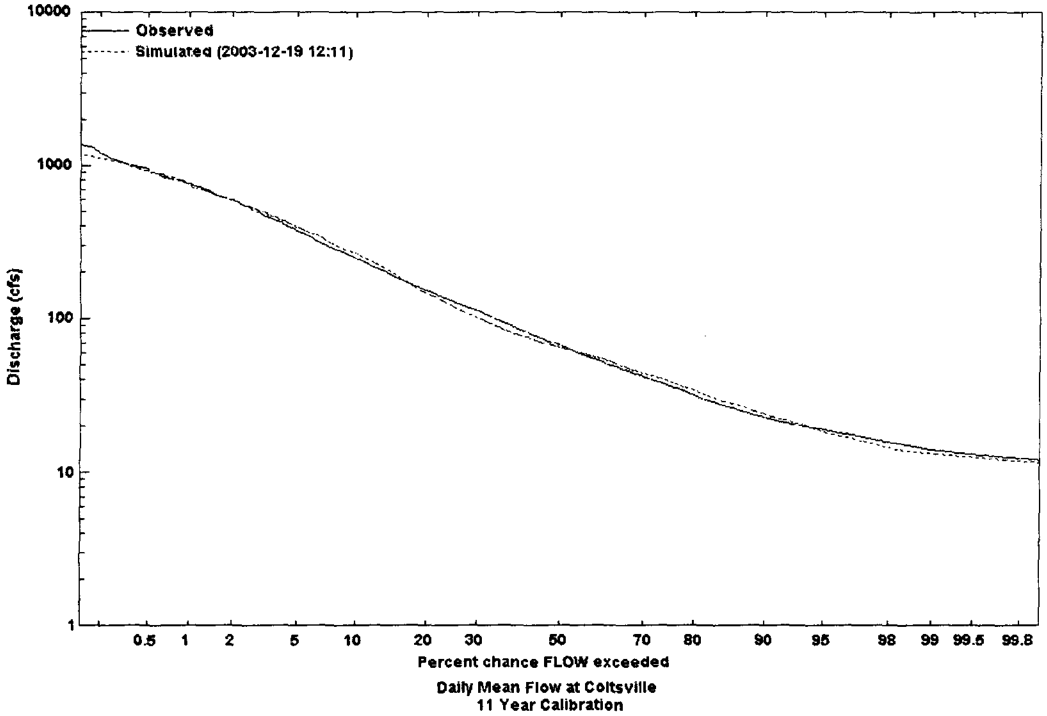


Figure A.4-15 Daily average flow duration curves at Coltsville

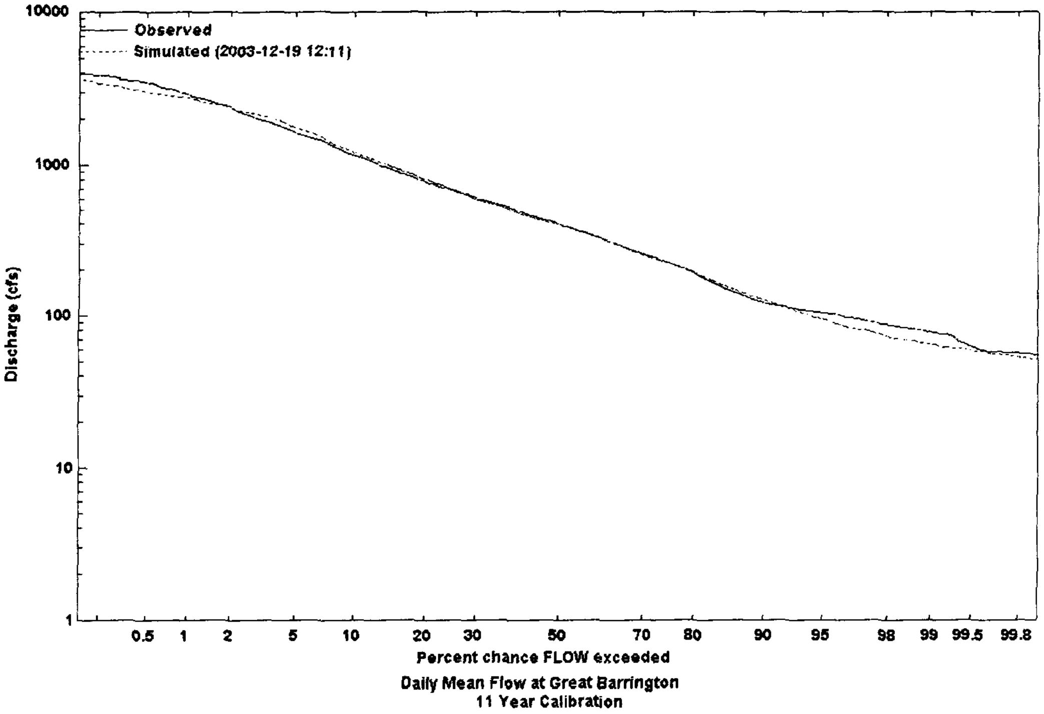


Figure A.4-16 Daily flow duration curves at Great Barrington

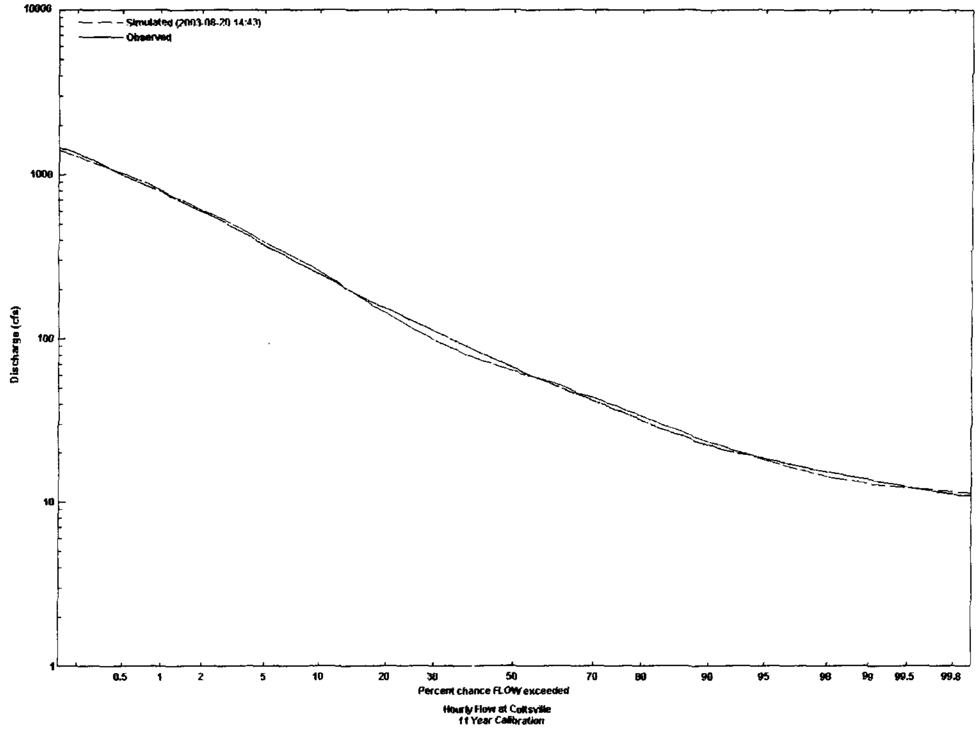


Figure A.4-17 Hourly flow duration curves at Coltsville

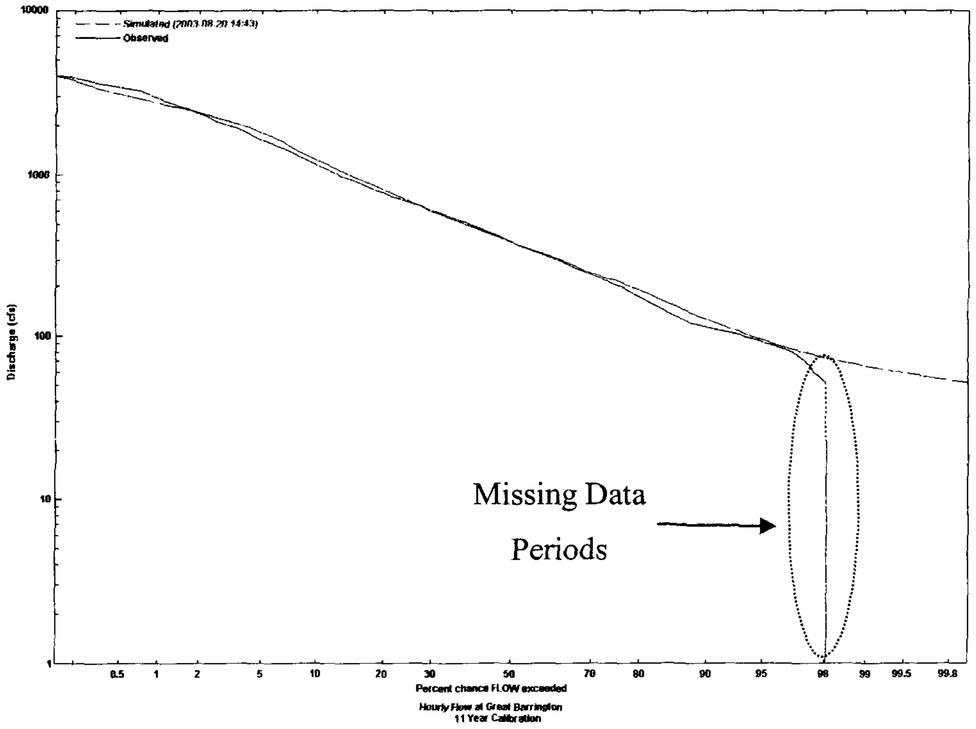


Figure A.4-18 Hourly flow duration curves at Great Barrington

A.4.2.4 Snow Calibration Results

As previously mentioned, the snow depth calibration primarily involved trying to mimic the volume and relative timing of the accumulation and melt of the snowpack as observed at Great Barrington Airport, Lanesboro, Berlin 5S, and Dalton. However, due to the high spatial variability in snowpack measurements, based on site-specific exposure, aspect, elevation, etc. the snow calibration is performed jointly with the flow calibration for the winter and spring melt periods. How well the flow values simulated during these periods compare to the observations is a determining factor in assessing the snow simulation. In other words, evaluating the snow simulation requires assessment of both the comparison to observed snow depth values and concurrent winter and spring flow simulations. Figures A.4-19 – A.4.21 present examples of the type of snow depth plots reviewed during the snow calibration; complete results for all years and additional model segments are included in Attachment A.2. The plots (below) display simulated snowpack depths for forested and agricultural areas at selected elevations within the watershed versus observed snowpack depths at Great Barrington and Lanesboro. As expected, elevation has a major impact on the snow accumulation and depth, largely due to air temperature differences. The land use category also affects the snow simulation primarily by vegetation and shading effects (from solar radiation and resulting melt). From review of the snow simulation plots (below and in Attachment A.2), the following observations are noted:

- The overall timing of the snowpack accumulation and melt predicted by the model compares favorably with the data for most years. The start and end of the snow season agreement within a few days to a week. As expected, snow at the higher elevation segments lasts longer than those at lower elevations, often on the order of 1 to 2 weeks

- The limited observation sites are generally at lower elevations than many of the model segments, resulting in the model results generally higher than the available data. Note that Attachment A.2 includes model results for a number of additional model segments with differing elevations.

- There are significant day-to-day differences between the model and the data, but there are also, significant differences between the two observation sites; Lanesboro is more than 400 feet higher in elevation than Great Barrington, and the differences in observed snow depths can be higher by factors of **two to three**. The simulated values show similar differences, indicating a reasonable model representation of factors controlling snow accumulation and melt in the watershed.

- Figure A.4-20 shows very little snow simulated in December 1992 while the observations reach up to 15 to 20 inches at Great Barrington and Lanesboro. However, the plots in Attachment A.2 indicate that other model segments did experience significant snow accumulations during December 1992, and the flow simulations at both Coltsville and Great Barrington were reasonable and consistent with observed flows. This demonstrates the need to evaluate both the snow and flow simulations for winter periods when assessing the snow calibration.

In summary, the snow simulation does a good job in representing the overall accumulation and melt process, and the resulting flow timing and volumes as measured at Coltsville and Great Barrington. There is some over-simulation of winter monthly flow volumes, in the range of 15% to 20% shown in Table A.4-4, but there are also larger errors in measuring winter flows, with increased uncertainties in the resulting observed winter flow volumes. The overall results of the snow simulation show reasonable variations throughout the watershed and generally good agreement with the limited observations.

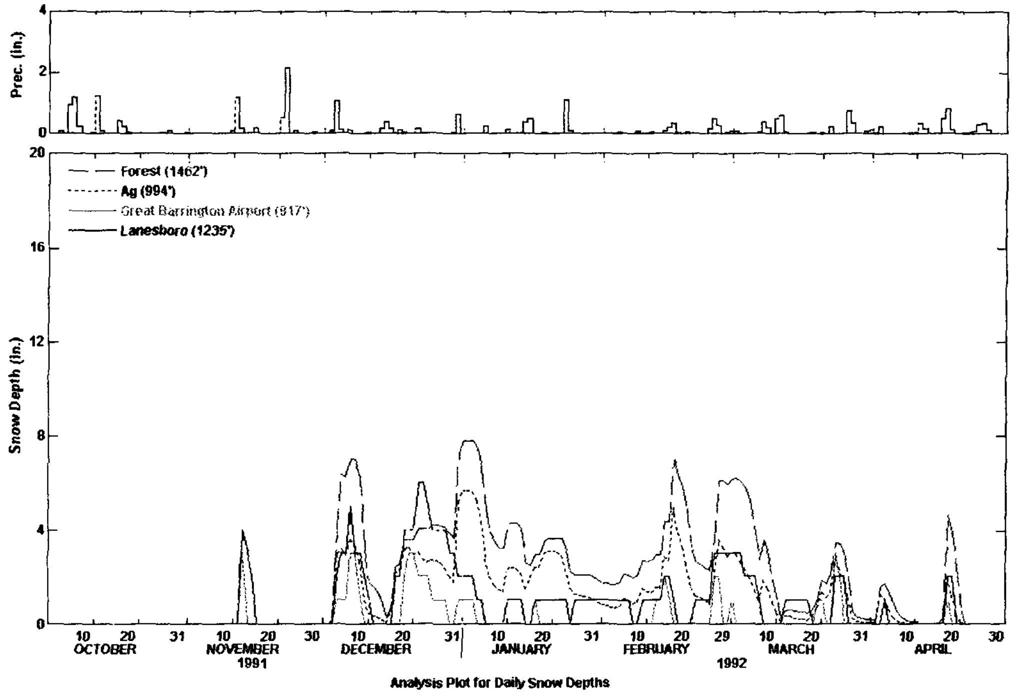


Figure A.4-19 Example Snowpack Timeseries Plot – 1992

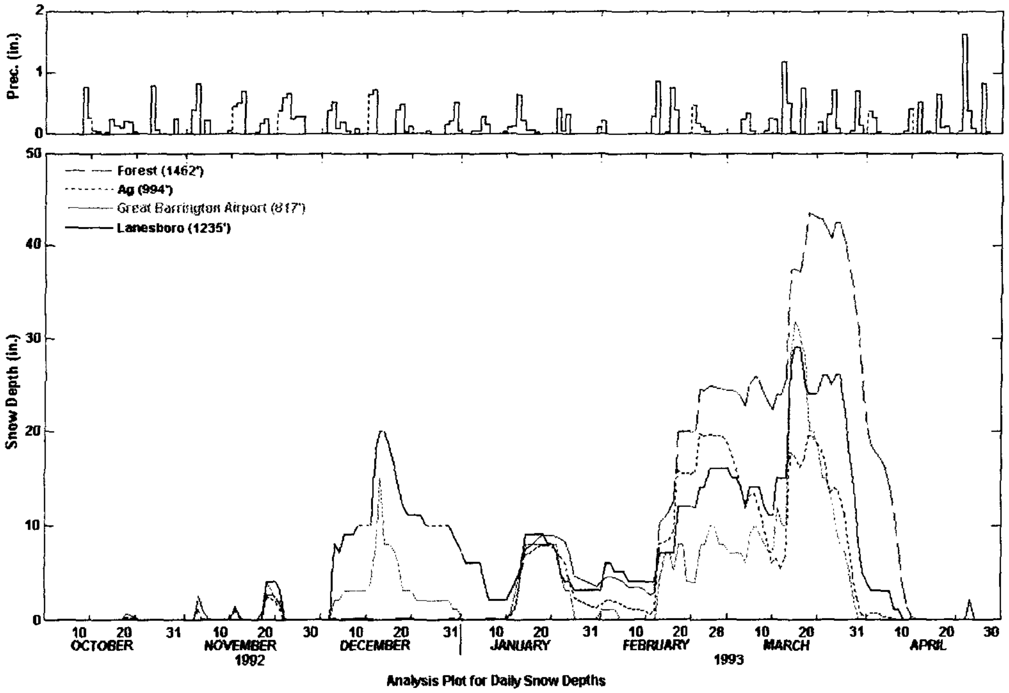


Figure A.4-20 Example Snowpack Timeseries Plot - 1993

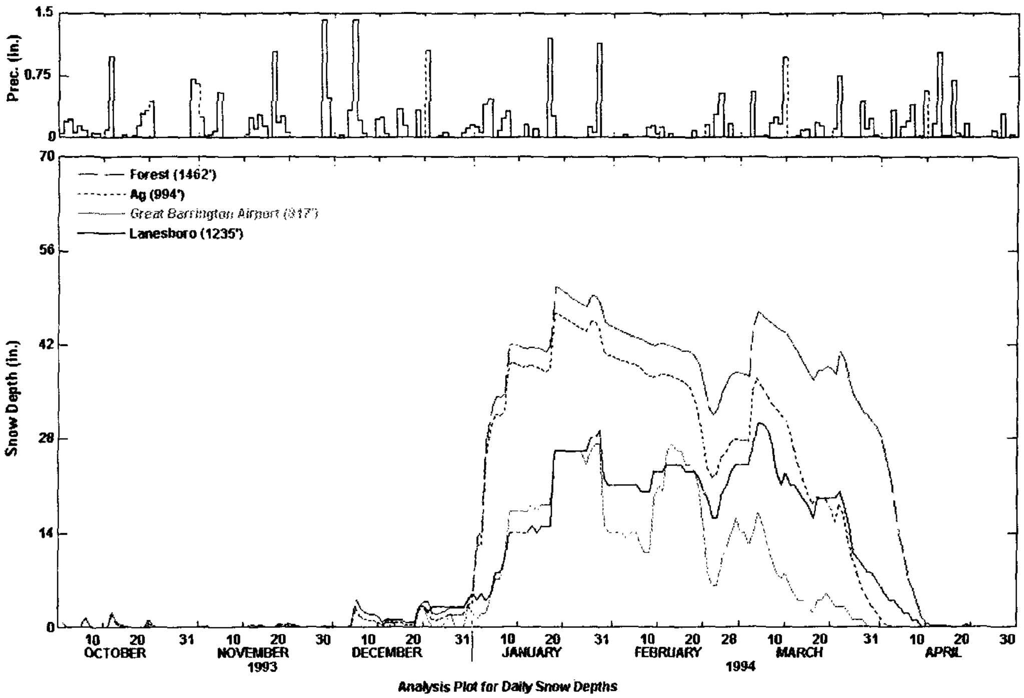


Figure A.4-21 Example Snowpack Timeseries Plot - 1994

A.4.2.5 Water Balance Analysis

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

Precipitation - Actual Evapotranspiration - Deep Percolation

+ ΔSoil Moisture = Runoff

From the water balance equation, if precipitation is measured on the watershed, deep percolation to groundwater and actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. The average annual recorded precipitation, during the calibration period, used for model simulations ranged from 43 to 53 inches. Using these gages and the MFACTs developed by the PRISM model, the area-weighted average annual precipitation for the time period of 1990 to 2000 for the HSA is approximately 49 inches. The average annual runoff recorded at Great Barrington for the same time period was approximately 27 inches. Thus, approximately 22 inches must be accounted for on an annual basis by actual evapotranspiration and deep percolation or other losses. The actual annual evapotranspiration within the region of the HSA is estimated at 20 inches (NWS, 1982a; 1982b); although values are reported as high as 23 inches at Great Barrington Airport (Bent, 1999). Any additional losses within the watershed are small and can be accounted for by percolation and recharge to deep groundwater. Table A.4-6 shows the range of expected and simulated water balance components for the HSA.

Table A.4-6 Average Annual Expected and Simulated Water Balance

	Expected Ranges	Simulated
Moisture Supply	43 - 53	49
Total Runoff	23 - 27	25
Total ET	20 - 23	23
Deep Recharge	1 - 4	1

As previously mentioned, observed values are not typically available for each of the water balance components. However, the simulated values must be carefully reviewed to ensure they are consistent with expected values for the region, as impacted by the individual land use categories. The impact of the land use categories on the components of total runoff (e.g., surface) becomes especially important when the hydrology is used to calculate sediment loadings and when alternative conditions on the watershed are to be evaluated. Table A.4-7 lists the average annual water balance components simulated for the HSA for each land use category in the model.

Table A.4-7 Simulated Water Balance Components by Land Use

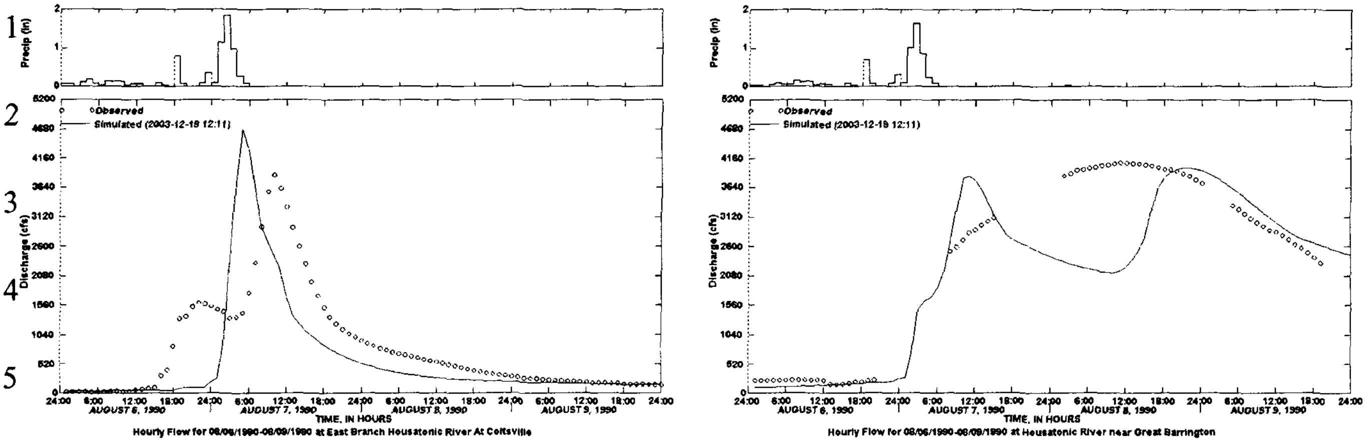
	Forest	Agriculture	Urban Pervious	Wetland	Urban Impervious
Moisture Supply	**49.0**	**48.9**	**49.0**	**49.0**	**48.8**
Total Runoff	**24.3**	**27.2**	**27.3**	**22.4**	**43.6**
Surface Runoff	1.5	9.0	8.4	0.2	43.6
Interflow	10.0	9.1	8.7	4.6	0.0
Baseflow	12.9	9.1	10.2	17.6	0.0
Total ET	**23.9**	**21.3**	**21.3**	**24.0**	**5.2**
Interception/Retention ET	9.0	5.8	6.1	4.3	5.2
Upper Zone ET	8.6	8.1	10.5	11.6	0.0
Lower Zone ET	6.0	7.3	4.6	4.3	0.0
Active GW ET	0.0	0.0	0.0	2.9	0.0
Baseflow ET	0.3	0.1	0.1	0.9	0.0
Deep Recharge	**0.9**	**0.5**	**0.5**	**2.7**	**0.0**

A.4.2.6 Storm Hydrograph Analysis

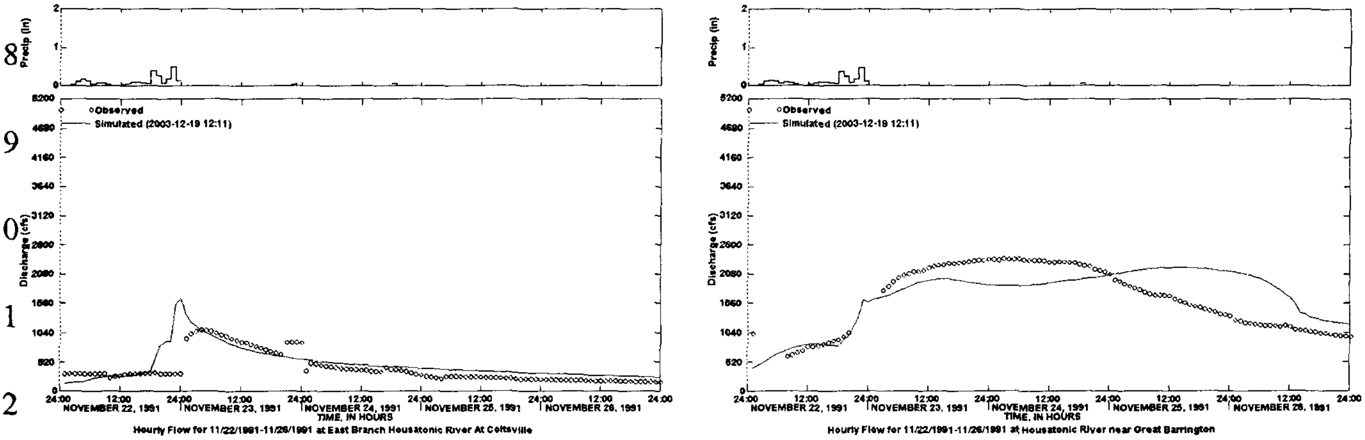
The final step in the hydrologic calibration is analyzing individual storm-event hydrographs, typically at an hourly interval, *for storms occurring throughout the simulation time period.* The goal is to improve the agreement of the simulated and observed storm hydrographs while maintaining the annual/monthly/daily volumes and associated statistics.

The lack of a comprehensive spatial coverage of precipitation data, at an hourly interval, complicates calibration and representation of storm hydrographs on an hour-by-hour basis. However, an effort was made to calibrate individual storm events observed both in the historical time period, i.e. 1979 through 1998, and in the 1999-2000 period of detailed monitoring at PSA sites. The goal was to improve the simulation of these individual events to the extent possible without adversely impacting the model's good representation of annual/monthly/daily volumes and statistics. For the early, historical period, numerous events were chosen for detailed examination, including the August 6th - 9th hurricane Bertha event in 1990, and events with significant flow peaks at Coltsville and Great Barrington in 1990, 1991, 1993, 1996, 1998, and 2000. In addition, for the 11 events for which data were collected in 1999 and 2000 at the PSA sites, three of the events stand out as significant storm events. Thus, calibration efforts focused on these events that occurred on May 19th - 22nd and September 15th - 21st in 1999 and June 6th - 11th in 2000. The simulation results for the historical events are shown in Figures A.4-22 and A.4-23, and the PSA events are shown in Figures A.4.24 through A.4-26. In reviewing these event simulations, keep in mind that there are obviously errors inherent to the model and the input data (e.g., precipitation), but for the PSA events there are also errors associated with the flow data derived from rating curves developed from a short history of paired stage-flow measurements. For comparison purposes, a USGS gage with a 'fair rating' will be expected to have 95% of its daily reported discharges within 15% of the true value (QAPP, 2000).

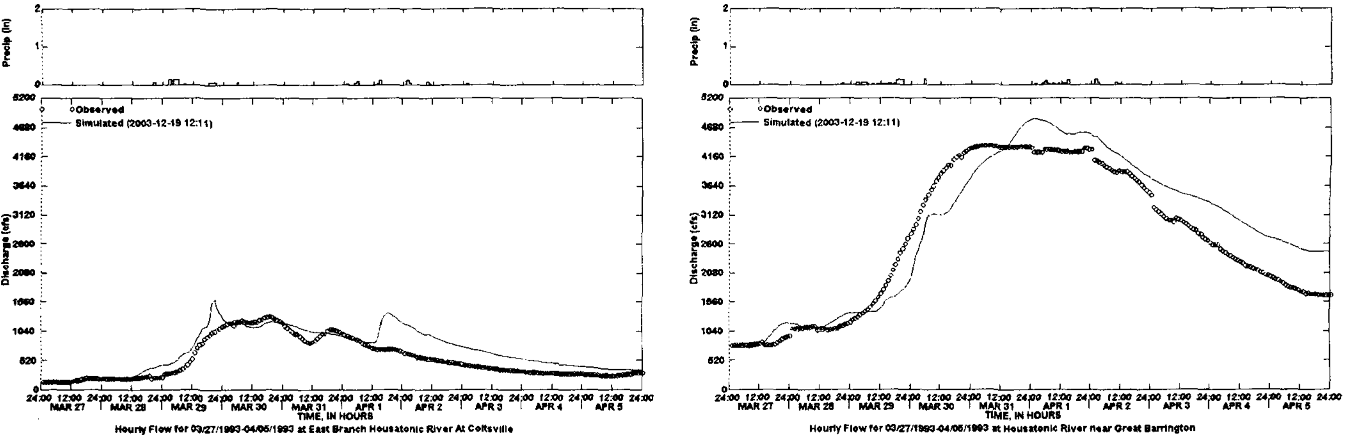
The aforementioned issues proved to be problematic in calibrating the hourly storm hydrographs, especially for those that demonstrated high spatial variability (i.e., scattered thunderstorms) such as the May 1999 and June 2000 storms. Storms that were less spatially variable, such as the September 1999 and a number of the early historical events, tended to be better simulated. In general, the larger storms tend to have relatively uniform rainfall accumulations and intensities across the watershed and are therefore better predicted by the model. Ultimately, the approach to the storm hydrograph calibration was to achieve a good agreement between simulated and observed values for the 99-00 and historical hydrographs to the extent possible and removing any obvious bias (i.e., continually oversimulating the peaks).



Coltsville (8/7-9/90) **Great Barrington (8/7-9/90)**

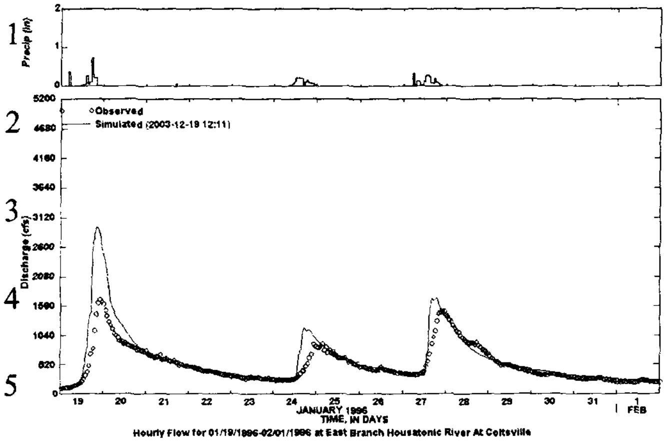


Coltsville (11/22-26/91) **Great Barrington (11/22-26/91)**

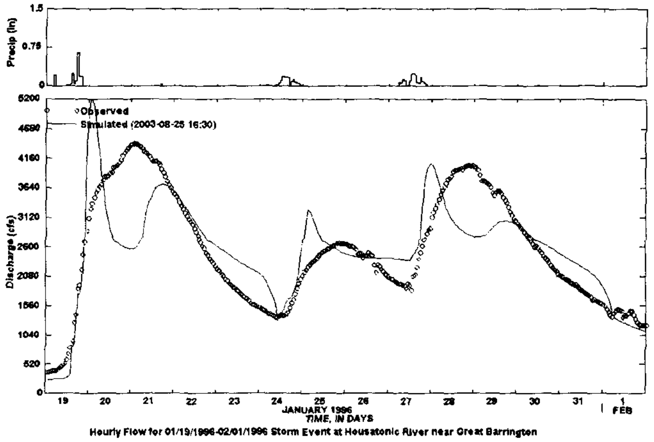


Coltsville (3/27-4/5 1993) **Great Barrington (3/27-4/5 1993)**

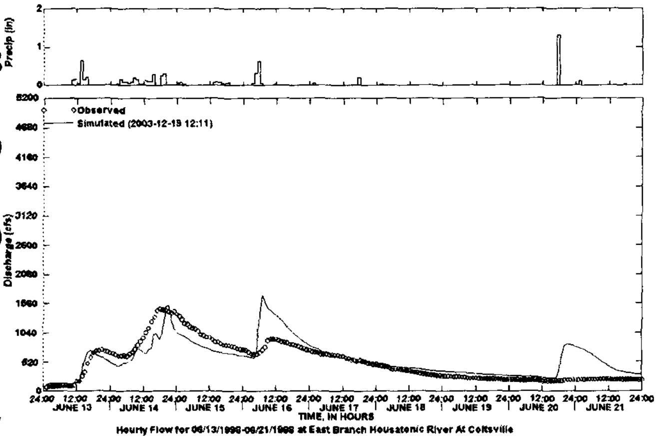
Figure A.4-22 Historical Events at Coltsville and Great Barrington



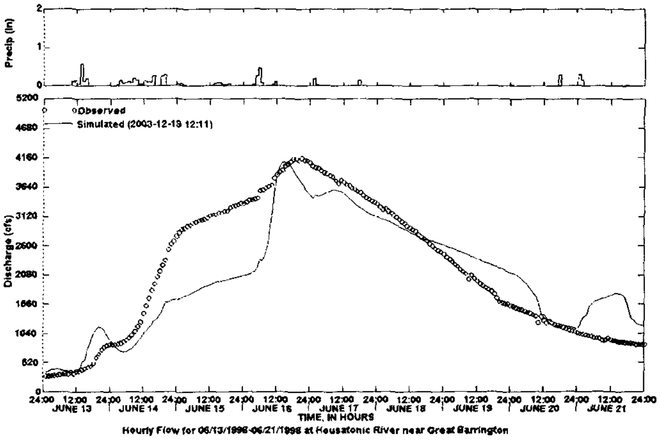
Coltsville (1/19-2/1 1996)



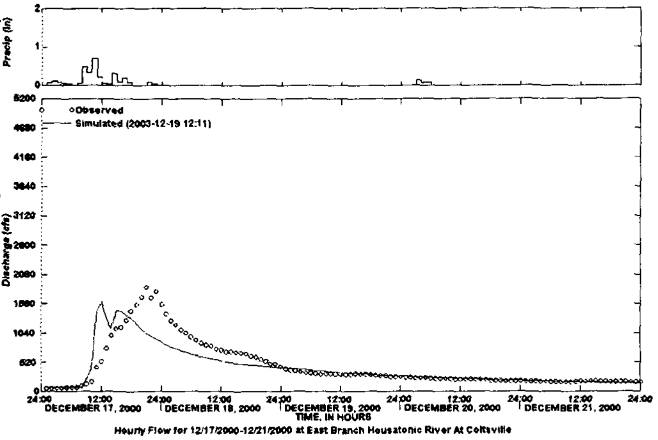
Great Barrington (1/19-2/1 1996)



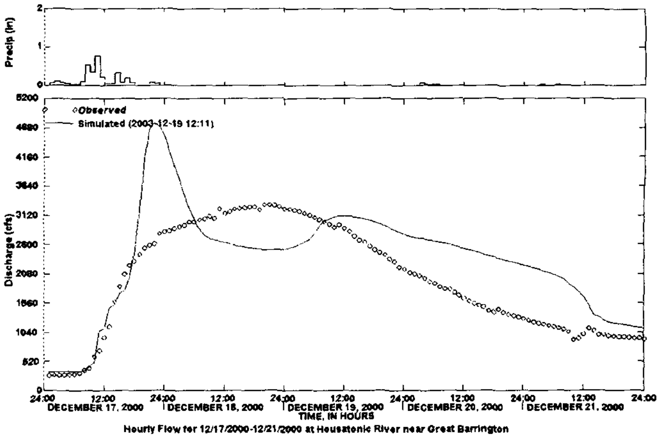
Coltsville (6/13-21/98)



Great Barrington (6/13-21/98)

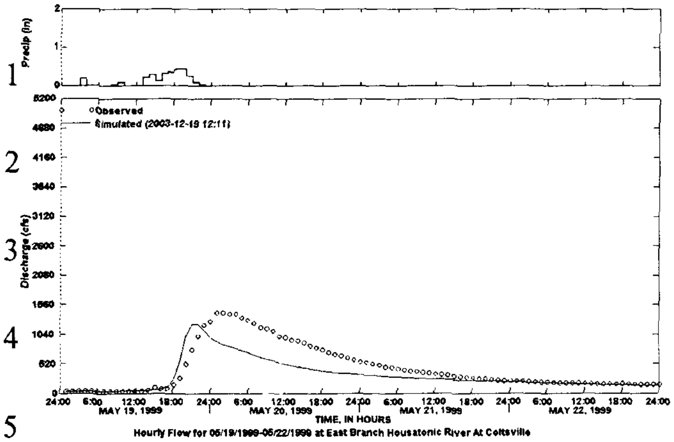


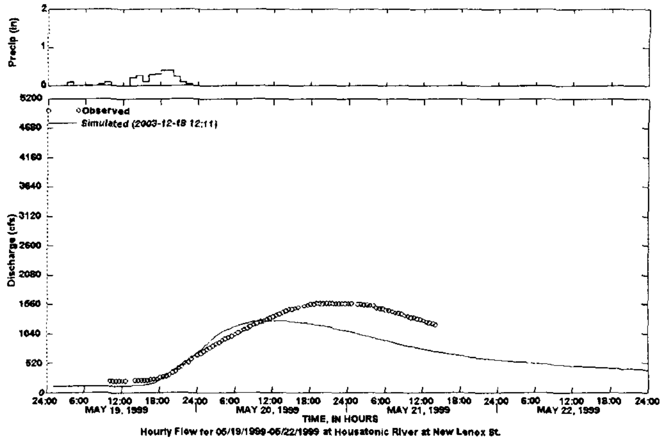
Coltsville (12/17-21/00)



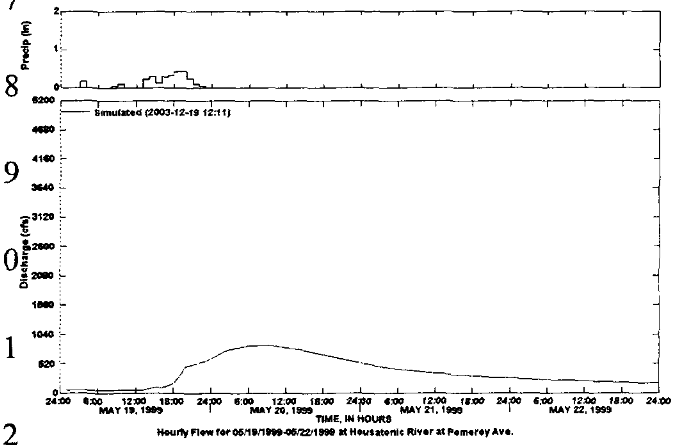
Great Barrington (12/17-21/00)

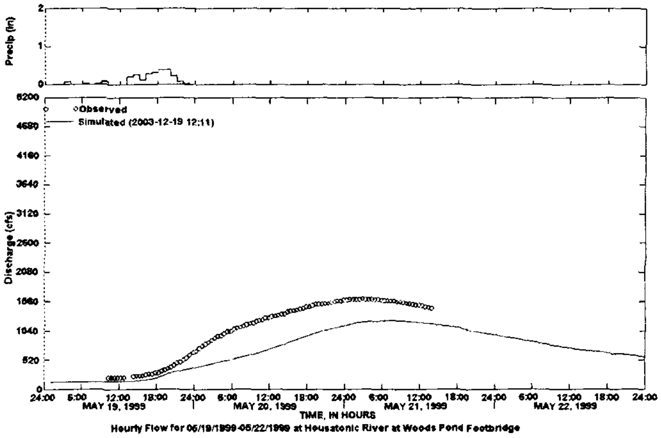
Figure A.4-23 Historical Events at Coltsville and Great Barrington



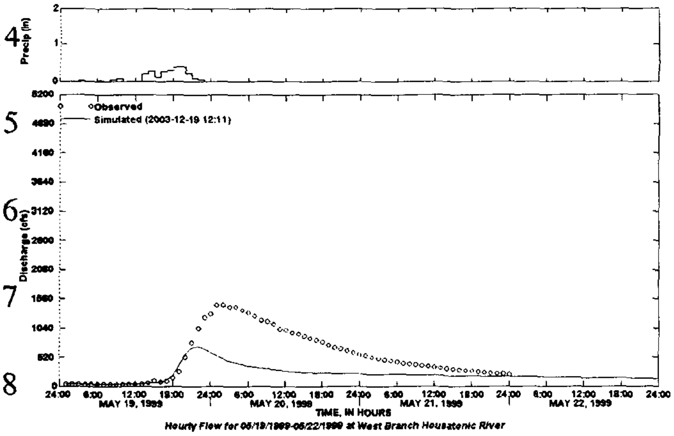


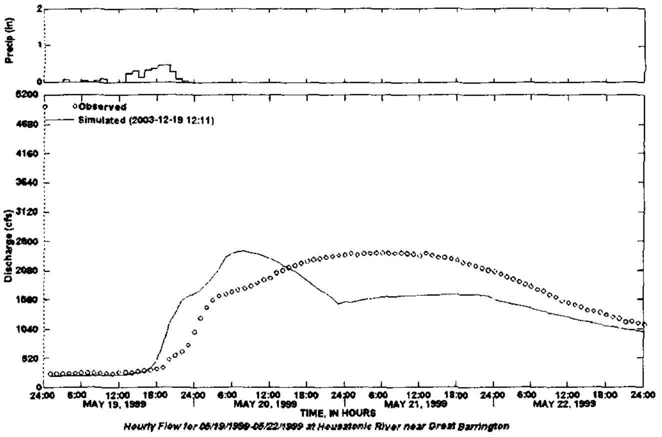
Coltsville **New Lenox**





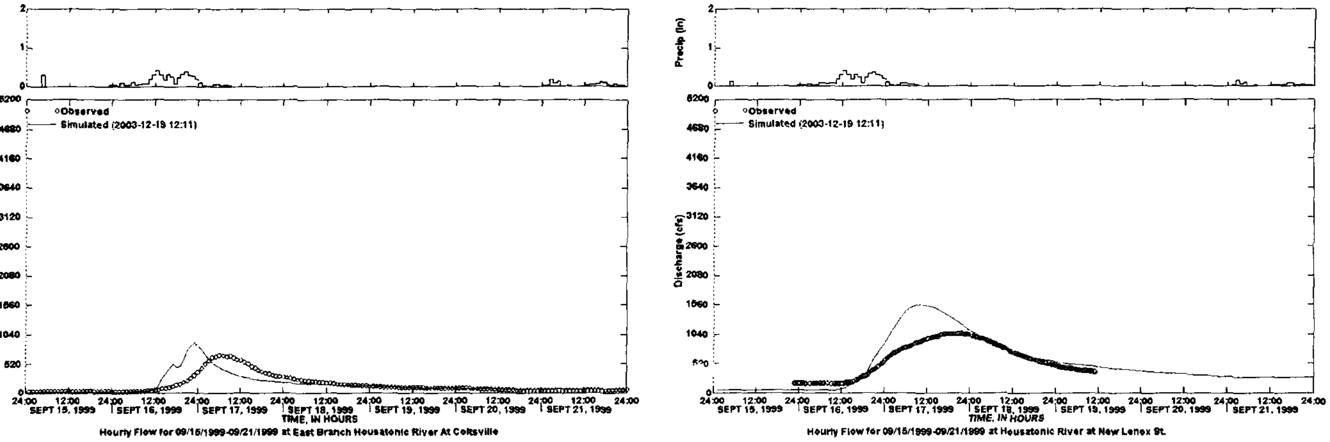
Pomeroy **Woods Pond**



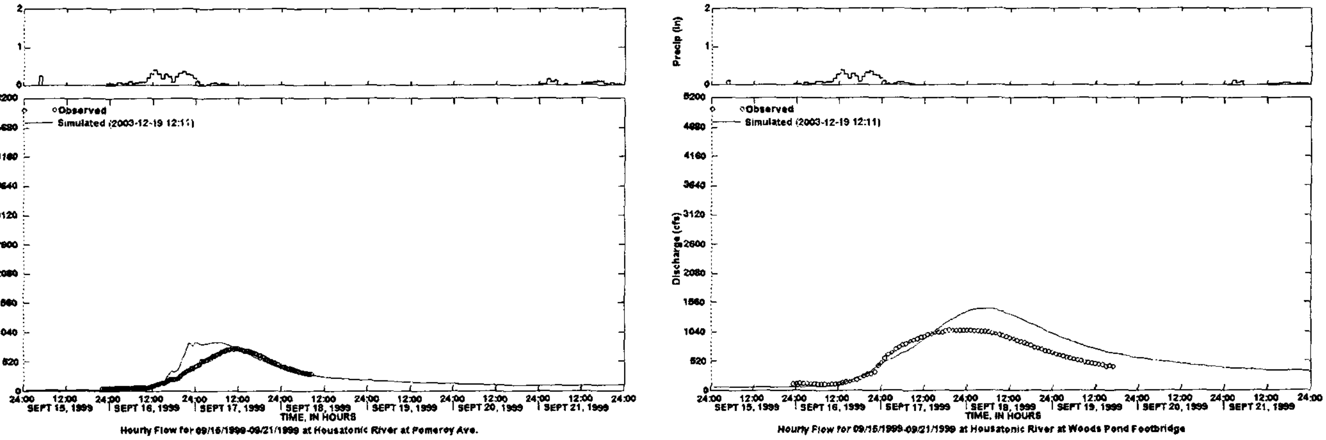


West Branch **Great Barrington**

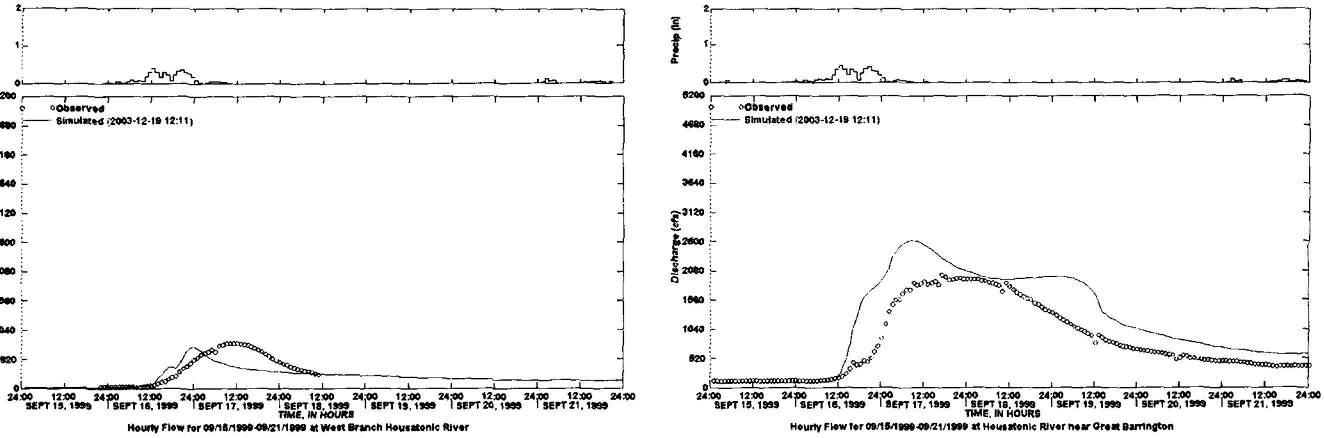
Figure A.4-24 May 19-22, 1999 Storm Event



Coltsville **New Lenox**

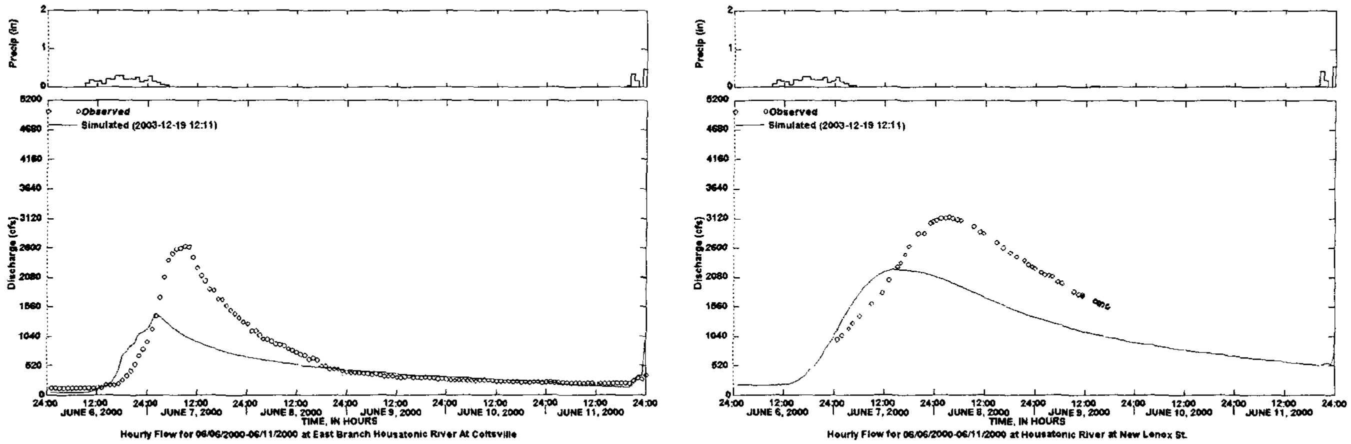


Pomeroy **Woods Pond**

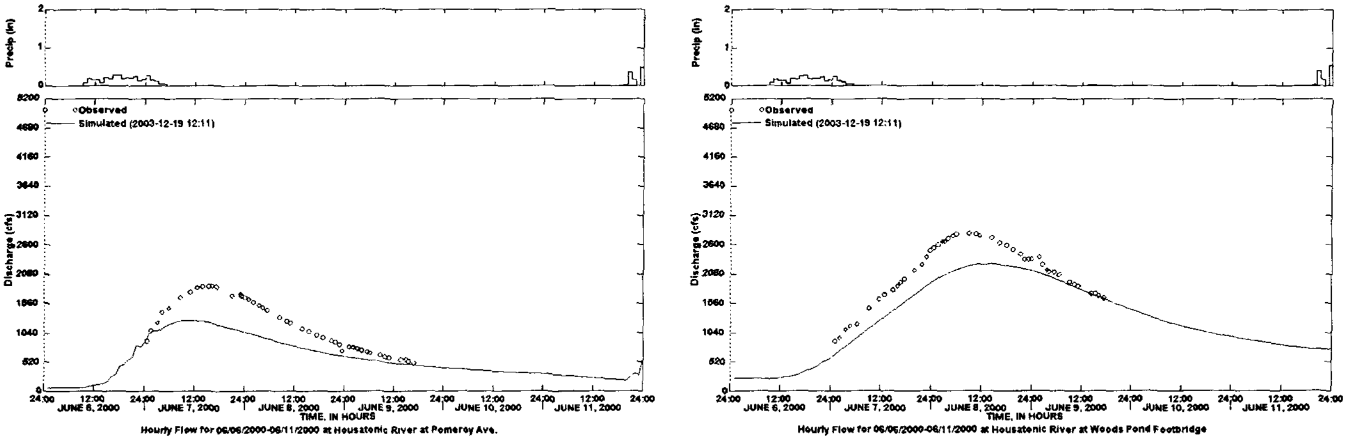


West Branch **Great Barrington**

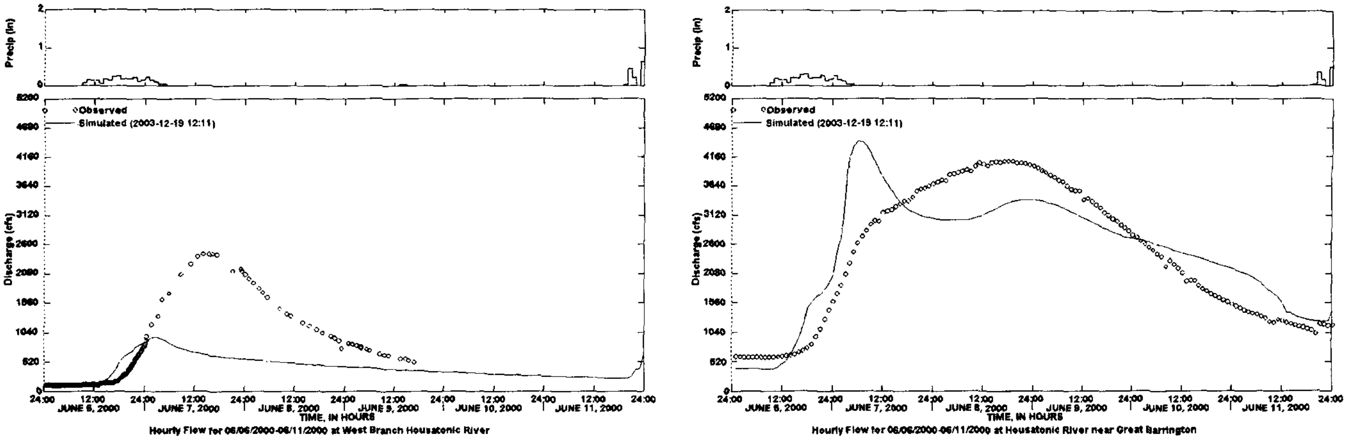
Figure A.4-25 September 15-21, 1999 Storm Event



Coltsville **New Lenox**



Pomeroy **Woods Pond**



West Branch **Great Barrington**

Figure A.4-26 June 6-11, 2000 Storm Event

A.4.3 CONCLUSIONS

Table 4-8 presents a list of the results of various calibration comparisons presented in this section as a summary of the 'weight-of-evidence' for support of the watershed model calibration. Based on the model results presented in Table 4-8, this section, and Attachment A.2, the following observations and conclusions are provided:

1. The overall annual errors and the majority of the yearly errors at Coltsville and Great Barrington are less than the 10% HSPF tolerances, specified in Table 4-3 of the QAPP, for a 'very good' calibration. Some of the largest errors at Coltsville however, occur in 1999 when the majority of the storm event data were collected at tributary and mainstem sites. All of the annual errors calculated by HSPEXP are less than 10% and the majority less than 5%, which are well within the ±15% hydrology calibration target for the watershed model specified in Table 4-4 of the QAPP for this study.

Table A.4-8 'Weight-of-Evidence' for Watershed Hydrology Calibration

	Coltsville	**Great Barrington**	**Calibration Performance**
Entire Period, % ME	+0.6	+1.6	Very Good
Annual Volume, % ME	+6 / -5	+17 / -9	Very Good
Monthly Volume, % ME	+15 / -10	+22 / -15	Good
Correlation Coefficient, R:			
- Daily R	0.87	0.90	Good / Very Good
- Monthly R	0.95	0.95	Very Good
Coefficient of Variation, R^2:			
- Daily R^2	0.76	0.81	Good / Very Good
- Monthly R^2	0.90	0.90	Very Good
Model Fit Efficiency, MFE:			
- Daily MFE	0.74	0.80	Good / Very Good
- Monthly MFE	0.90	0.89	Very Good
Flow-Duration	Good / Very Good	Good / Very Good	Good / Very Good
Water Balance	Very Good	Very Good	Very Good
Storm Events:			
- Daily Peak, % Error	-7	-3	Very Good
- Storm Volumes, % ME	+1	-.1	Very Good
- 10% High Flows, % ME	+2	+3	Very Good

2. The correlation coefficients at both Coltsville and Great Barrington are ≥ 0.85 and > 0.95 for daily and monthly flows, respectively. The MFE values for average monthly flows at Coltsville and Great Barrington are approximately 0.90. Previous studies have defined an acceptable level of calibration as a correlation coefficient greater than 0.85 and a MFE greater than 0.80 for monthly flows (Beach et al., 2000). The coefficients for both Coltsville and Great Barrington exceed these targets; in fact, Great Barrington nearly meets the criteria at a daily timestep with a correlation coefficient of 0.90 and an MFE of 0.79. Coltsville has a daily correlation coefficient of 0.87 and an MFE of 0.74, which is still close to passing at a daily timestep.

3. The agreement between observed and simulated daily flows is generally quite good throughout the calibration period. However, there are some obvious deviations primarily associated with snow melt events, and selected storms where precipitation patterns over the watershed were not well represented. Overall, the arithmetic and geometric mean flows are in excellent agreement.

4. The simulated flow duration curves, both daily and hourly, at Coltsville and Great Barrington are a close reproduction of the observed curves indicating the model provides a good representation of the rainfall-runoff processes occurring in the watershed over a wide range of hydrologic conditions. Some variation is apparent however, in the lower tails of the flow duration curve at Great Barrington which reflects slight errors of 10-15 cfs in representing base flows in the range of 70-100 cfs at Great Barrington. The hourly flow duration curves show that the model is predicting the large events with similar magnitude and frequency throughout the simulation time period.

5. The simulated annual water balance components are within the range of expected values for the watershed, and reflect differences among land use categories in a logical manner.

6. Based on the entire weight-of-evidence of the full range of model results presented here and in the Appendices, this hydrology calibration demonstrates that the model adequately represents the water balance and hydrologic response of the Housatonic River Watershed for the purposes of providing long term boundary conditions for EFDC, and provides a sound basis for the sediment and water temperature calibration efforts.

A.5 SEDIMENT AND WATER TEMPERATURE CALIBRATION RESULTS

A.5.1 OVERVIEW OF HSPF SEDIMENT AND WATER TEMPERATURE CALIBRATION PROCEDURES

As noted earlier, the purpose of the watershed model is to provide sediment and flow boundary conditions for the EFDC model and water temperature values for FCM. Following the hydrology calibration, the sediment and water temperature calibration is performed for the same time period as the hydrology calibration using the calculated runoff and flow values.

To model sediment loadings and behavior at a watershed scale, two component mechanisms must be represented. First, the model must calculate the amount and nature of sediment that is eroded from the land and delivered to streams, representing the sediment sources and loadings. These processes are a function of the amount of soil exposed directly to rainfall and surface runoff, which in turn is affected by rainfall, land cover (and land use), land slope, soil disturbance, and transport properties of the soil. HSPF simulates the processes of sediment erosion from pervious and impervious areas in the subroutines SEDMNT and SOLIDS, respectively. The second component mechanism is transport in the streams and lakes, including advection, deposition, and scour processes. These instream processes are affected by the quantity and timing of flow, hydraulic properties of the water body (cross-section, hydraulic radius, etc.) and transport properties of the sediment. HSPF simulates these processes in subroutine SEDTRN using relatively simplified algorithms and procedures, compared to the detailed sediment transport modeling performed by EFDC. In this study, the only reason HSPF is being used to model instream sediment processes is to effectively interpret and utilize the sediment data available for calibration, which reflects the impacts of instream mechanisms. This allows greater use of the available sediment data, a realistic representation of the overall sediment budget for the Housatonic watershed, and greater confidence that the sediment loadings are properly calculated.

In order to model instream water temperature needed for the FCM, HSPF represents the heat fluxes across reach boundaries and changes in heat content within the reach. An energy or heat balance approach is used in HSPF with the same driving meteorologic time series that are needed for snow simulation. Heat sources/sinks to a reach include upstream or tributary reaches, nonpoint runoff (i.e., surface runoff, interflow, and baseflow) or point sources, heat exchange with the atmosphere, and conduction from the streambed. Heat outputs from a reach include downstream advection, losses to the atmosphere, and conduction to the streambed. Heat inputs originating from local land segments are simulated by subroutines within the PERLND and IMPLND modules, for pervious and impervious areas, respectively, and the instream heat balance calculations are performed by subroutine HTRCH of module RCHRES.

A.5.2 SEDIMENT CALIBRATION AND RESULTS

A.5.2.1 Overview of Sediment Calibration

Sediment calibration for HSPF and other watershed models involves numerous steps in estimating model parameters, and then determining appropriate adjustments needed to ensure a reasonable simulation of the sediment sources, delivery, and transport behavior within the channel system. These steps usually include:

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices
2. Calibrating the model loading rates to the target rates
3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies
4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations
5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network
6. Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available
7. Repeating steps 1 through 6 as needed to develop a reasonable overall representation of sediment sources, delivery, and transport throughout the watershed system

Rarely is there sufficient observed local data at sufficient spatial detail to accurately calibrate all parameters for all land uses and each stream and waterbody reach. In fact, sediment calibration is often limited to observed data for monthly or storm periods at only selected sites within the watershed. Consequently, model users must focus the calibration on those sites with observed data, and then must review simulations in all parts of the watershed model to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. This is especially critical for sediment modeling due to the extreme dynamic behavior of sediment erosion and transport processes.

For the Housatonic model application, sediment data were limited to selected events in 1999 at Coltsville, the PSA sites, and the upper boundary sites at Pomeroy and West Branch, along with historical data at Great Barrington for 1994-96. Model performance and calibration was evaluated using both quantitative and qualitative measures with these data, involving both graphical comparisons and statistical tests. Additional consistency checks were made to ensure loading rates and stream morphology and behavior were reasonable when field data were limited or non-existent. The calibration focused on the upper boundary and northern PSA sites because the objective was to provide loadings to EFDC, and the sediment algorithms in HSPF have limited capabilities to represent the complex sediment mechanics within the meandering portions of the lower portions of the PSA.

A.5.2.1.1 Sediment Erosion Calibration

Sediment loadings to the stream channel are estimated by land use category from literature data, local Extension Service sources, or procedures like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978; Renard et al., 1997) and then adjusted for delivery to the stream with estimated sediment delivery ratios (SDRs). This delivery adjustment is needed because HSPF, like most watershed-scale (lumped parameter) models, represents landscape loadings to the stream channel, which are less than the field-scale estimates from USLE. These estimated loading rates then become ***'calibration targets'*** for the watershed model.

Model parameters are then adjusted so that model calculated loadings are consistent with these estimated ***'calibration targets'*** and loading ranges. The model-calculated loadings are further evaluated in conjunction with the instream sediment transport calibration (discussed below) that extend to a point in the watershed where sediment concentration and/or load data are available. The objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e. aggrading or degrading behavior), using sediment loading rates that are consistent with the ***calibration targets*** and modeled concentrations that provide a reasonable match with instream sediment data.

Erosion is primarily a function of the amount of soil exposed directly to rainfall and surface runoff, which in turn is affected by rainfall, land cover, land slope, soil disturbance, and transport properties of the soil. The USLE is an empirical equation commonly used to estimate erosional rates as a function of these factors. The USLE formula is stated as follows:

$$\mathbf{A = R * K * L * S * C * P}$$

A = annual soil loss in tons per acre per year

R = rainfall erositivity factor

K = soil erodibility factor

L = slope length factor

S = slope gradient factor

C = cover management factor

P = erosion control practice factor

For the Housatonic watershed, the USLE was used within a GIS platform, using spatial coverages of watershed specific information (e.g., soils, slopes, land use/cover), obtained from MassGIS and the USGS. This provided a more spatially accurate use of the equation and model land use specific estimates of erosional rates by subbasin within the watershed. The target loading rates developed by the USLE in combination with SDRs, along with national averages (AQUA TERRA Consultants, 2002b), and modeled loading rates are presented in Table A.5-1.

Table A.5-1 Target and Modeled Loading Rates (ton / ac-yr)

Model Land Use	Acres	Percent of Area	USLE Target Rate	National Avg. Target Rate	Watershed Model Rates Mean (Range)
Forest	127,056	0.70	0.08	0.01-0.11	0.016 (0.003-0.047)
Agriculture	19,855	0.11	0.90	0.01-1.87	0.507 (0.244 -1.07)
Urban	23,597	0.13	0.28	0.04-0.89	0.191 (0.101-0.457)
Wetland	10,014	0.06	0.01	0.00 -0.02	0.002 (0.001-0.013)

Calibration of sediment erosion and loading rates involves first a parameterization component followed by the actual calibration, or parameter adjustment, to improve agreement between model values, available various field observations, and the estimated target values by landuse. In HSPF, the erosion process on pervious land areas is represented as the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow. On impervious surfaces (e.g. parking lots, driveways), soil splash by raindrop impact is neglected and solids washoff is often controlled by the rate of accumulation of solid materials. The primary sediment erosion solids parameters are as follows:

KRER - Coefficient in soil detachment equation (pervious areas)

KSER - Coefficient in sediment washoff equation (pervious areas)

KEIM - Coefficient in impervious area solids washoff equation

ACCSDP - Accumulation rate of solids on impervious surfaces

Although a number of additional parameters are involved in sediment erosion and solids calibration, such as those related to vegetal cover, agricultural practices, rainfall and overland flow intensity, etc., KRER and KSER are the primary ones controlling sediment loading rates. KRER is usually estimated as equal to the erodibility factor, K, in the USLE (noted above), and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. For impervious surfaces, the rate of washoff is controlled by the KEIM parameter, but the net washoff is most often limited by the accumulation rate, ACCSDP. Attachment A.4 lists the sediment parameters along with values ranges for the Housatonic watershed, definitions and units. Sediment erosion calibration is further described in the QAPP, in the HSPF Application Guide (Donigian et al., 1984), and by Donigian and Love (2003).

In reviewing the target and model loading rates in Table A.5-1, it is important to realize that nonpoint loading rates are highly spatially variable because they are driven by the amount and intensity of precipitation and resulting runoff as well as the physiographic properties and anthropogenic activities of a particular land use. Climate, geology, and land use practices are highly variable spatially, even within the Housatonic Watershed; this level of variability in detail can only be approximated by the USLE and National Average rates and ranges, but the model does provide for adequate spatial detail to allow a wide range in simulated values. In comparing the model and target loading rates in Table A.5-1, the following observations are noted:

- The USLE generally predicts loading rates for all categories that are in the mid to high end of the National Average ranges. This is likely due to the relatively steep slopes for the forested areas of the Housatonic Watershed, the low-intensity type agriculture, and the low to moderate level of intensity of urban development, when compared to areas that would be included in the National Average.
- The mean modeled loading rates are generally lower than the USLE values, and near the low end of the National Average ranges. This is to be expected for the same reasons noted above, i.e. the relatively low level of agricultural and urban development. Also, the high density of the forested areas would produce low sediment loading rates compared to national averages.
- Also, the ranges of the modeled loading rates are about in the lower half of the National Average range, which is consistent with the nature of development in the watershed. The modeled ranges demonstrate a factor of five to an order of magnitude difference between the lowest and highest values, representing diverse conditions across the watershed.
- Wetlands are often a sink for sediment, and it is expected that the 'wetland' categories will have modeled loading rates near the low end of the targets. Wetlands comprise less than 6% of the watershed area and will have little effect on sediment loads.

In summary, the modeled sediment loading rates are reasonably consistent with the available targets, demonstrate a sound variation with land use and spatial variations in watershed characteristics, and provide appropriate ranges for the climate, soils, and land cover conditions in the Housatonic Watershed.

A.5.2.1.2 Instream Sediment Transport Calibration

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. In practice, instream calibration involves steps 3, 4 and 5 as listed and discussed above; these steps involve both parameterization, to establish initial parameter values, and a subsequent adjustment and calibration process. For HSPF, the initial parameterization tasks include the following:

- Divide input sediment loads into appropriate size fractions
- Estimate initial parameter values and storages for all reaches
- Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values

Fractionating the Eroded Material

Although the sediment load from the land surface is calculated in HSPF as a total input, it must be divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e. suspended sediment) and the bed. The sediment load from the watershed was fractionated using the three separate fractionation schemes presented in Table A.5-2. The scheme used for a particular PERLND was determined by the percent of the segment classified as sand, which was derived by analyzing the surface texture information in the MassGIS soils coverage. The IMPLNDs used a single assumed scheme. The fractions reflect the relative percent of the surface material (i.e., sand, silt, clay) available for erosion in the surrounding watershed, but also include an enrichment factor of silt and clay to represent the likelihood of these finer materials reaching the channel. Thus, the sand particles are more likely to be deposited in the overland flow plane, in swales, ditches, depressions, etc. and therefore the sand would be somewhat transport limited, compared to the silt and clay.

Table A.5-2 Sediment Fractionation

		Fractionation of Incoming Load		
Scheme	**Percent of Segment Classified as Sand**	**Sand**	**Silt**	**Clay**
1 – Pervious Areas (PERLND)	≥ 50%	.35	.50	.15
2 – Pervious Areas (PERLND)	< 50%	.25	.60	.15
3 – Impervious Areas (IMPLND)	NA	.10	.50	.40

Estimate Initial Parameter Values and Storages for All Reaches

For HSPF, initial sediment parameters, such as particle diameter, particle density, settling velocity, bed depth and composition, and beginning calibration parameter values can be evaluated from local/regional data, past experience, handbook values, etc., and then adjusted based on available site specific data and calibration. Bed composition data are especially important so that the model results can be adjusted to reflect localized aggradation (deposition) or degradation (scour) conditions within the stream system.

The initial composition (i.e., fraction of sand (>63 μm), silt (10–63 μm), and clay (<10 μm)) and physical characteristics of the streambed along the mainstem, from Coltsville to Great Barrington, were assigned using reach specific data. The initial composition of the mainstem was based on analyses performed by HydroQual on all available grain size data within the top foot of the bed. There were no direct porosity measurements available, therefore estimates were made based on measurements of percent solids and assuming solids specific gravity of 2.65. The remaining tributary reaches relied on a combination of reach specific data that were collected at 15 sites and data extrapolation to assign initial bed composition and porosity. The bed composition and porosity of the reservoirs and initial bed depth for all reaches and reservoirs were based on engineering judgment. Table A.5-3 summarizes the initial bed composition and characteristics for each of the model reaches/reservoirs.

Table A.5-3 Initial Bed Composition and Characteristics

Mainstem **Mainstem PSA**				Reach Endpoints	Initial Bed Composition (fraction)			Porosity	Width	Bed Depth
MFD Segment #	**HSPF Segment #**	**Reach #**	**Reach name - Segment #**	**river miles**	**Sand**	**Silt**	**Clay**	**–**	**(ft)**	**(ft)**
100	10	9	Windsor - 10		.85	.10	.05	0.30	50.	2.
100	10	10	Windsor Reservoir – 10		.60	.25	.15	0.30	1720.	6.
100	10	11	Wahconah – 10		.90	.05	.05	0.30	50.	2.
130	40	12	Cleveland Res. – 40		.60	.25	.15	0.55	1595.	6.
130	40	13	Cleveland Bk. – 40		.90	.05	.05	0.30	20.	2.
110	20	20	Ashmere Lake – 20		.60	.25	.15	0.55	1419.	6.
110	20	21	Bennett Bk – 20		.85	.10	.05	0.30	50.	2.
120	30	30	East Branch – 30		.85	.10	.05	0.30	50.	2.
130	40	40	East Branch – 40		.85	.10	.05	0.30	50.	2.
140	100	100	East Branch (Dalton/Center Pond) - 100		.90	.05	.05	0.30	50.	2.
1000	**110**	**110**	**Housatonic (Coltsville) - 110**	**140.62**	.90	.05	.05	0.30	50.	2.
200	120	115	Unkamet Brook – 120		.20	.40	.40	0.30	50.	2.
1010	**120**	**120**	**East Branch – 120**	**139.24**	.89	.08	.03	0.19	50.	2.
2000	**200**	**200**	**East Branch – 200**	**137.13**	.86	.11	.04	0.30	50.	2.
3000	**300**	**300**	**East Branch – 300**	**136.47**	.92	.06	.02	0.34	52.	2.
4000	**400**	**400**	**East Branch (Pomeroy) - 400**	**135.40**	.94	.04	.02	0.35	52.	2.
4000	**410**	**410**	**East Branch Confluence - 410**	**135.00**	.97	.02	.01	0.27	52.	2.
500	50	50	Town Brook – 50		.85	.10	.05	0.30	50.	2.
510	60	60	Secum Bk – 60		.85	.10	.05	0.30	50.	2.
510	70	70	Pontoosuc Res. – 70		.60	.25	.15	0.55	3478.	6.
520	70	71	West Branch – 70		.85	.10	.05	0.30	50.	2.
530	80	80	Onota Res. – 80		.60	.25	.15	0.55	6787.	6.
530	80	81	Daniels Bk - 80		.85	.10	.05	0.30	50.	2.
550	90	90	West Branch – 90		.25	.50	.25	0.30	50.	2.
540	810	810	Richmond Pond – 810		.60	.25	.15	0.55	3066.	6.
540	810	811	S. West Branch – 810		.25	.50	.25	0.30	50.	2.
550	820	820	West Branch Confluence - 820	135.00	.25	.50	.25	0.30	50.	2.
5000	**500**	**500**	**Housatonic – 500**	**133.97**	.89	.08	.03	0.39	90.	2.
5000	**510**	**510**	**Housatonic – 510**	**133.50**	.86	.10	.04	0.42	80.	2.
560	830	830	Sackett Bk – 830	133.50	.85	.10	.05	0.30	50.	2.
5010	**520**	**520**	**Housatonic – 520**	**132.00**	.90	.07	.03	0.46	75.	2.
5010	**530**	**530**	**Housatonic – 530**	**130.20**	.88	.08	.04	0.48	100.	2.
5010	**540**	**540**	**Housatonic (Test Reach/New Lenox Rd) - 540**	**129.18**	.83	.11	.05	0.52	100.	2.
5020	**550**	**550**	**Housatonic – 550**	**128.10**	.79	.15	.07	0.53	110.	2.
580	840	840	Roaring Bk – 840	128.10	.90	.05	.05	0.30	50.	2.
5020	**560**	**560**	**Housatonic – 560**	**127.33**	.79	.15	.07	0.52	120.	2.
570	850	850	Yokun Bk – 850	127.33	.90	.05	.05	0.30	50.	2.
5030	**570**	**570**	**Housatonic – 570**	**125.44**	.59	.28	.13	0.64	120.	2.
6000	**580**	**580**	**Woods Pond Backwaters - 580**	**124.83**	.54	.30	.15	0.67	140.	4.
6000	**600**	**600**	**Woods Pond – 600**	**124.40**	.33	.48	.18	0.76	1150.	6.
7000	**700**	**700**	**Housatonic – 700**	**123.06**	.98	.01	.01	0.33	50.	2.
700	860	860	October Mtn. Res. – 860		.60	.25	.15	0.55	513.	6.
700	860	861	Washington Mtn. – 860	123.06	.90	.05	.05	0.30	50.	2.
7010	**710**	**710**	**Housatonic (Columbia Mill Dam) - 710**	**122.23**	.98	.01	.01	0.55	95.	6.
7010	**720**	**720**	**Housatonic – 720**	**119.66**	.87	.09	.04	0.48	95.	2.
7010	720	721	Laurel Lk – 720		.60	.25	.15	0.55	1361.	6.
7010	720	722	Laurel Bk – 720		.85	.10	.05	0.30	20.	2.
710	870	870	Greenwater Bk – 870	119.66	.90	.05	.05	0.30	50.	2.
710	870	871	Goose Pond – 870		.60	.25	.15	0.55	1018.	6.
710	870	872	Goose Pond Bk – 870	119.66	.90	.05	.05	0.30	20.	2.

Table A.5-3 Initial Bed Composition and Characteristics

Mainstem				Reach	Initial Bed Composition			Porosity	Width	Bed
Mainstem PSA				Endpoints	(fraction)					Depth
MFD Segment #	HSPF Segment #	Reach #	Reach name - Segment #	river miles	Sand	Silt	Clay	--	(ft)	(ft)
7010	*730*	*730*	*Housatonic – 730*	*117.88*	.92	.05	.03	0.47	95.	2.
720	880	880	Hop Bk – 880	117.88	.50	.30	.20	0.30	50.	2.
7030	740	740	Housatonic – 740	116.68	.93	.05	.02	0.42	95.	2.
730	890	890	West Bk – 890	116.68	.90	.05	.05	0.30	50.	2.
7040	750	750	Housatonic (Willow Mill Dam) - 750	115.43	.81	.13	.06	0.53	95.	6.
7040	*760*	*760*	*Housatonic - 760*	112.87	.89	.06	.05	0.41	95.	2.
740	910	910	Knokapot Bk - 910	112.87	.65	.25	.10	0.30	50.	2.
7040	770	770	Housatonic - 770	110.86	.91	.06	.03	0.48	95.	2.
750	920	920	Stockbridge Bowl - 920		.60	.25	.15	0.55	1667.	6.
750	920	921	Larrywaug Bk - 920	110.86	.80	.10	.10	0.30	50.	2.
7050	780	780	Housatonic (Glendale Dam) - 780	109.00	.93	.04	.03	0.48	95.	6.
7050	790	790	Housatonic - 790	106.01	.76	.16	.08	0.40	95.	2.
8000	800	800	Rising Pond Dam - 800	105.16	.94	.04	.02	0.63	365.	6.
9000	900	900	Housatonic (Great Barrington) - 900	104.52	.64	.27	.09	0.19	95.	2.

In HSPF, the value of bed depth represents the amount of material (calculated from input values for bed width and porosity) that can be scoured from the stream reach; in effect it provides a limit so that the model will inform the user, through a warning message, when the channel has been completely scoured so that the user can make appropriate parameter changes if needed. We often set initial bed depths (i.e., thicknesses) at 2.0 to 5.0 feet for natural (i.e. non-channelized) stream segments to allow a reasonable amount of scour in the upstream natural channel.

Setting Initial Critical Scour and Depositional Shear Stresses

For the silt and clay (i.e. non-cohesive) fractions, shear stress calculations are performed by the hydraulics (HYDR) module and are compared to user-defined critical, or threshold, values for deposition and scour for each size. Thus the key silt and clay parameters are the critical bed shear threshold values for scour (TAUCS) and deposition (TAUCD), and the associated particle characteristics, i.e. effective diameter (D), settling velocity (W), and particle density (RHO). One additional parameter is the erodibility rate (M), which controls the rate of bed scour when scour conditions exist. The silt and clay fractions each have their own set of parameters within each reach.

In HSPF, if the model reach being simulated is a stream or river, the bed shear stress is determined as a function of the slope and hydraulic radius of the reach, as follows:

TAU = SLOPE*GAM*HRAD

where:

TAU = stream bed shear stress (lb/ft2 or kg/m2)

SLOPE = slope of the RCHRES (-)

GAM = unit weight, or density, of water (62.4 lb/ft3 or 1000 kg/m3)

HRAD = hydraulic radius (ft or m)

As part of the sediment parameterization, the model is run with the initial parameter estimates and shear stress values are output for each stream reach. For the silt and clay size particles, the critical shear stress parameters (one for scour and one for deposition) for each size are adjusted so that the model calculates scour during high flow events, deposition and settling during low flow periods, and transport with neither scour nor settling for moderate flow rates; this is shown schematically in Figure A.5-1. In general, the values are set so that scour of clay occurs at lower shear values than for silt (i.e. clay scours before silt), and deposition of silt occurs at higher shear values than clay (i.e. silt deposits before clay).

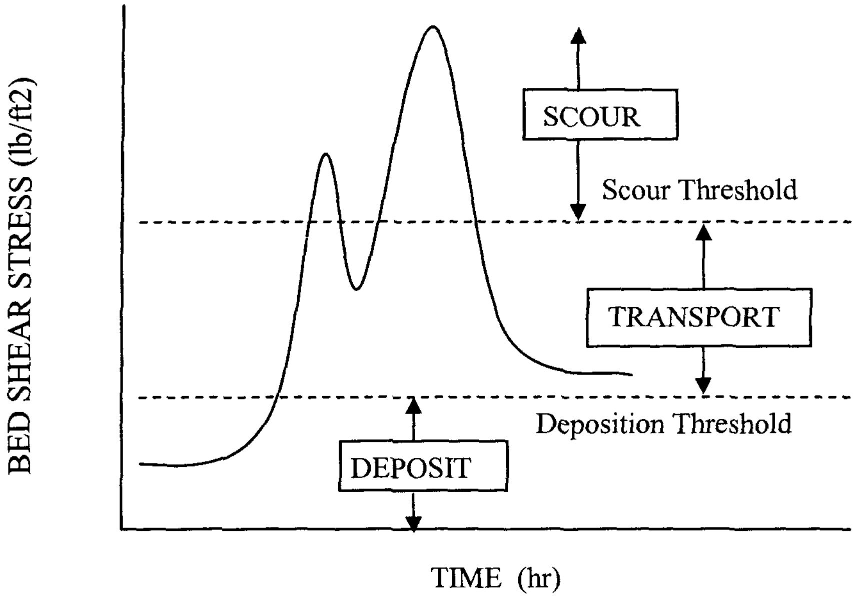


Figure A.5-1 Shear Stress Calculations in HSPF

When the shear stress in each timestep is greater than the critical value for scour, the bed is scoured at the user-defined erodibility rate, controlled by the M parameter; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at the input settling rate, W, input by the user for each size. If the calculated shear stress falls between the critical scour and deposition values, the suspended material is transported through the reach. After all scour and/or deposition fluxes have been determined, the bed and water column storages are updated and outflow concentrations and fluxes are calculated for each timestep. These simulations are performed by the SEDTRN module in HSPF, complete details of which are provided in the HSPF User Manual (Bicknell et al., 2001). TAUCS and TAUCD were set for each reach by reviewing plots such as Figure A.5-2 and then adjusting, as needed, during the calibration. Although TAUCS and TAUCD are defined and calculated as bed shear stress thresholds, the simplified hydraulic calculations and the long stream reaches used in HSPF result in these parameters effectively being **calibration factors** with values that may exceed the normal range for bed shear in natural streams. Calibrated values of these parameters are provided in Attachment A.4.

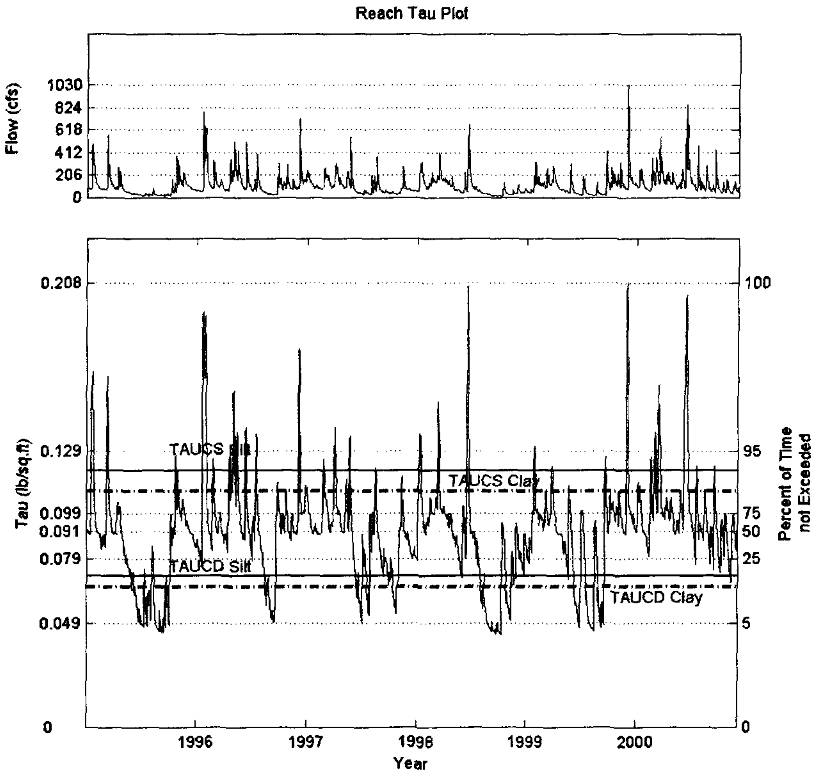


Figure A.5-2 Example TAU Plot

The sand (non-cohesive) fraction was modeled using power function of the average velocity in the channel reach in each timestep to compute a transport capacity. This capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in the channel reach. The key parameters are the coefficient (KSAND) and exponent (EXPSND) of the power function that are the primary calibration parameters. Sand particle characteristics, i.e. effective diameter (D), settling velocity (W), and particle density (RHO) are required as part of the model input, but only the particle density is used in the model; it is used to calculate the bed depth as a function of the bed composition, particle density, and bed porosity. Sand particle characteristics can be derived from available soils data and/or literature values.

A.5.2.2 Sediment Calibration Results

Following initial parameterization, the remaining steps in sediment calibration are as follows:

Step 3: Adjust Instream Scour, Deposition, and Transport parameters

Step 4: Analyze Bed Behavior and Transport Fluxes

Step 5: Analyze Overall Sediment Budgets and Stream Behavior

Step 6: Compare Results with Available Data

These steps are listed together as they normally are performed while reviewing the same tabulations of model results and comparisons with data; bed behavior and sediment budgets need to be reviewed to establish the basis for parameter adjustments on a reach-by-reach basis, while comparing observed and simulated concentration data, and load estimates if available. In many cases, this may be limited to event mean concentrations of total suspended solids (TSS) for selected storm events and nonstorm (baseflow) periods, or time series of TSS concentrations throughout a few events. Rarely is there sufficient observed local data to perform model-data comparisons for each of these steps and to accurately calibrate all parameters for each stream reach. Consequently, the model calibration focuses on sites with observed data, supported by review of model behavior and simulations in all parts of the watershed to insure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. However, other types of comparisons are also possible, such as load estimates and sediment rating curves. For the Housatonic, data or estimates for each of these types of comparisons were available at selected sites within the watershed.

As previously mentioned, stormwater monitoring data collection was performed from 1999 through 2000 for eleven selected storm events at nine mainstem and tributary sites. The data collected included flow rates and water column measurements of TSS. These data, along with all available historical data at these sites, were used by HydroQual to develop estimates of TSS mass flux entering and passing through various points in the PSA (Attachment B.3).

From April 1994 through March 1996, the USGS in cooperation with the Massachusetts Department of Environmental Management (MDEM), Division of Resource Conservation, Office of Water Resources, performed a study of suspended-sediment characteristics in the Housatonic River Basin (Bent, 2000). This study included high-frequency sampling of TSS and concurrent flow measurements at numerous sites within the entire Housatonic River Basin down through Connecticut, including Great Barrington which was the most northern sampling site. As this timeframe falls within the model calibration time period, the data are useful for making overall model to data comparisons for annual sediment loads and yields. Unfortunately, channel characterization data between Woods Pond and Great Barrington is limited, a distance of about 20 miles, and information on the intervening reservoirs is sparse, making detailed concentration comparisons with model results difficult to justify. Consequently only annual loads were compared to assess general concurrence with model results.

The flux analysis by HydroQual was performed at 4 of the 9 sampling locations: the two upstream boundaries of the PSA on the East and West Branches, New Lenox Road near the middle of the PSA, and the outlet of Woods Pond at the downstream boundary of the PSA. These estimates, based on data, allow annual load comparisons to be made with model results. However, there are some uncertainties in the analysis values because a substantial fraction of the TSS measurements did not have concurrent flow data recorded, and the ones that did relied on rating curves developed with limited data points. As part of the flux analysis, concurrent flows were estimated for the TSS measurements that did not have paired flow data.

Additional loading estimates were developed by BBL and QEA (2003) for numerous tributary and mainstem sites within the watershed. These estimates are used in conjunction with HydroQual's estimates to evaluate the model performance for mean annual loads at designated sites.

Table A.5-4 presents the average annual sediment loads predicted by HSPF versus estimates developed by BBL and QEA (2003) and HydroQual along with a calculated percent difference, using the average of the estimates where appropriate. The QEA estimate at Great Barrington is an annualized average of the data collected by the USGS during the April of 1994 through March of 1996 sampling. The percent differences range from -11% to 39% with the majority of the differences between ± 25%. Although some of the differences are relatively large, they are well within the range of the percent differences between site specific estimates developed by QEA and HydroQual, which in some locations exceeds 100% (e.g., Dawes/Pomeroy, Holmes Road). Model calibration relied primarily on HydroQual's estimates, for which the percent differences range from -10% to 3%.

Table A.5-4 Average Annual TSS Loading Comparison (tons/yr)

Location (RCHRES)	BBL & QEA	HydroQual	Ave. Loading Estimate	Simulated	Percent Difference
Coltsville (110)				2,960	
Unkamet Brook (115)				295	
Dawes/Pomeroy (400)	2,400	4,884	3,642	4,943	36%
West Branch (820)	1,672	2,222	1,947	2,150	10%
Holmes Road (500)	3,476	7,107	5,291	7,351	39%
Sackett Brook (830)				252	
New Lenox Road (540)	4,587	5,255	4,921	5,036	2%
Roaring Brook (840)				131	
Woods Pond Headwaters (580)	3,179		2,734	3,179	16%
Woods Pond Dam (600)	1,870	1,797	1,833	1,626	-11%
Great Barrington (900)	4,180		4,180	4,109	-2%

As part of the flux analysis performed by HydroQual, annual loads were estimated for the years of 1988-2001 at the previously discussed four sampling sites. Figure A.5-3 displays the annual loads predicted by HSPF during the calibration time period versus the flux analysis estimates for the years of 1990 through 2000 at each of the sites. The overall average differences are less than ± 10 %, with the annual differences showing much larger deviations up to 139% for some low loading years. These types of differences are expected due to uncertainties and errors within the model, the data, and the loading estimates extrapolated for flow rates beyond the limits of those used in developing the sediment rating curves for the flux analysis. Overall, the agreement between the model and the data driven estimates appear to be reasonable and show very little bias. Table A.5-5 presents the values displayed in figure A.5-3 along with the percent difference calculations.

Table A.5-6 presents a comparison of the loads predicted by the model versus loading estimates generated by the USGS at Great Barrington, based on the data collected during the April of 1994 through March of 1996 sampling. Comparisons are made against data collected over the entire sampling period, calendar year 1995, and water year 1995 (i.e. October 1994 through September 1995). The estimates for water year 1995 compared well with a percent difference of -5%. However, some of the winter storms that occurred late in 1995 and

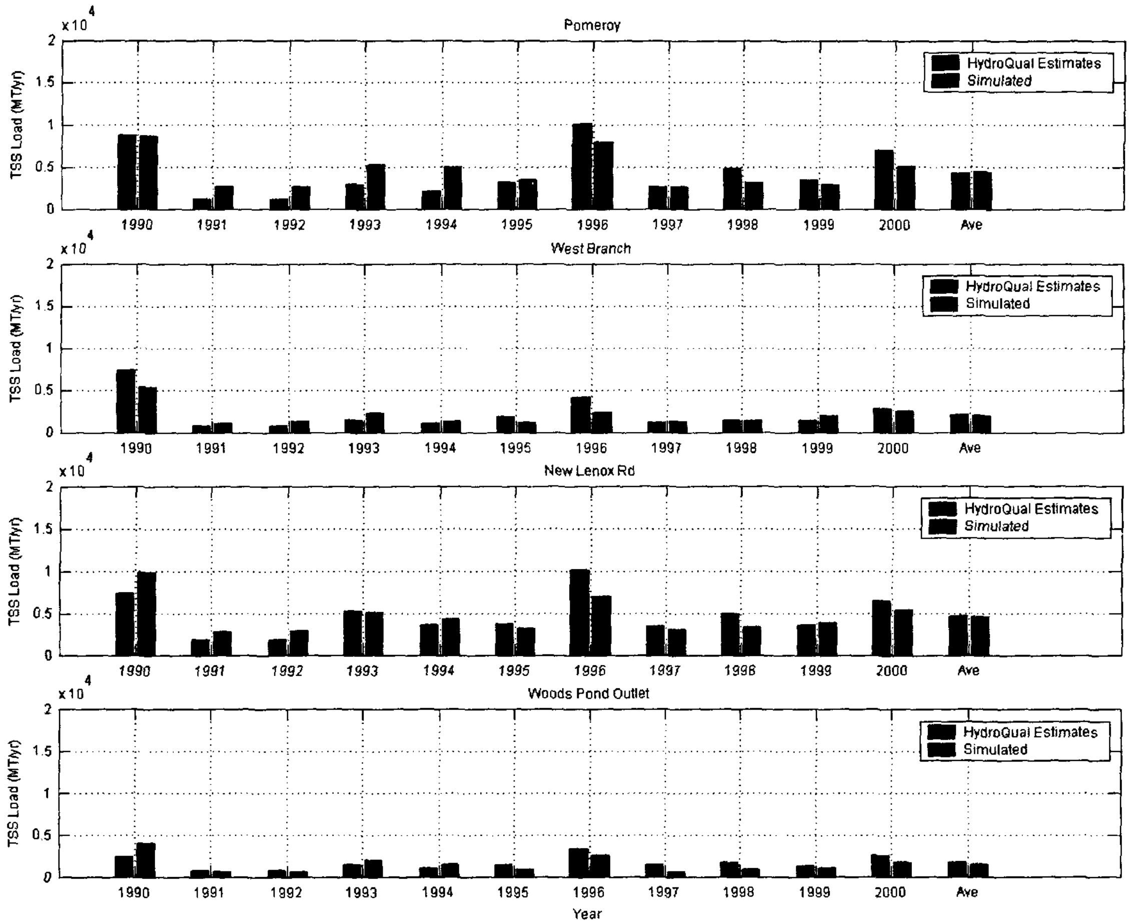


Figure A.5-3 Annual Loads at Primary Sampling Sites (MT/year)

Table A5-5 Annual TSS Loading Comparisons (MT/year)

	Pomeroy			West Br			New Lenox Rd			Woods Pond Outlet		
	HydroQual	HSPF	% diff.	HydroQual	HSPF	% diff.	HydroQual	HSPF	% diff.	HydroQual	HSPF	% diff.
1990	8,792	8,595	-2%	7,317	5,338	-27%	7,414	9,770	32%	2,339	3,990	71%
1991	1,135	2,602	129%	684	978	43%	1,859	2,768	49%	700	551	-21%
1992	1,133	2,707	139%	705	1,234	75%	1,845	2,873	56%	786	644	-18%
1993	2,858	5,204	82%	1,367	2,171	59%	5,154	5,114	-1%	1,368	1,990	45%
1994	2,143	4,976	132%	1,027	1,252	22%	3,584	4,213	18%	1,077	1,438	33%
1995	3,248	3,412	5%	1,864	1,106	-41%	3,718	3,176	-15%	1,454	904	-38%
1996	10,152	8,007	-21%	4,110	2,311	-44%	10,108	6,930	-31%	3,308	2,522	-24%
1997	2,639	2,702	2%	1,103	1,288	17%	3,432	2,984	-13%	1,405	559	-60%
1998	4,799	3,131	-35%	1,382	1,355	-2%	4,868	3,261	-33%	1,722	939	-45%
1999	3,497	2,941	-16%	1,446	1,978	37%	3,612	3,831	6%	1,345	989	-26%
2000	6,973	5,049	-28%	2,750	2,444	-11%	6,373	5,334	-16%	2,461	1,698	-31%
Average	4,306	4,484	4%	2,160	1,950	-10%	4,724	4,569	-3%	1,633	1,475	-10%

Table A.5-6 Average Annual TSS Loading Comparison at Great Barrington (tons/year)

Period	From	To	Simulated (tons)	USGS Estimate (tons)	% Diff
Water Year 1995	Oct. 1, 1994	Sept. 30,1995	2,083	2,190	-5%
Calendar Year 1995	Jan. 1, 1995	Dec. 31, 1995	3,154	4,280	-26%
Entire Sampling Period	March 1,1994	March 30, 1996	7,494	11,600	-35%

early in 1996 were under simulated by model in comparison to the USGS estimates, causing larger differences in calendar year 1995 and the overall totals. In general, the model results are lower than the USGS estimates with an overall difference of -35%. Once again, the general magnitudes of these errors are expected for watershed-scale sediment modeling, and in this case, are acceptable since the primary focus of the sediment calibration was on the PSA region above Woods Pond Footbridge, i.e., areas where the watershed model provides sediment loadings to EFDC.

Sediment rating curves, simulated and estimated/observed, are presented for the flux analysis sites above New Lenox Road, i.e., Pomeroy, West Branch and New Lenox Road, in Figures A.5-*4 through A.5-6. The plots include the equation and trend line of linear fit along with the* coefficient of variation (R^2) for each set of data. The plots present paired daily average flow and TSS for days on which data were recorded. In developing the regressions, for both the concentration and load, all the simulated values below 1 mg/l were ignored. These low concentrations are shown as **black circles** in the figures. Concentrations less than 1 mg/l were ignored in the sediment rating curve comparisons for the following reasons:

a. The reporting limit of the data was 1 mg/l

b. *Analyses indicate that sediment loads at concentrations* less than 1 mg/l are a small fraction, usually less than 5%, of the total annual load at these sites.

c. The long stream reaches used by HSPF ignores local turbulence and scour that contributes to the low observed concentrations in the range of 1 to 5 mg/l.

In general, the trendlines for the simulated concentrations are slightly steeper, indicating that the model tends to slightly overestimate the higher flow concentrations and underestimate the low flow concentrations. However, the results for the New Lenox Road site do not follow this pattern and show trendlines in very close agreement between simulated and estimated/observed concentrations. In addition, the overall data points (blue pluses and red circles) demonstrate similar scatter patterns between the model and the data at each of the sites. There is considerable scatter in both the model and the data, which is indicative of sediment concentrations on natural watersheds, but the scatter patterns are similar. As the hydrology calibration resulted in a good representation of daily average flows, it is not surprising that the loading trendlines (bottom graphs in each figure) are in better agreement than the concentrations.

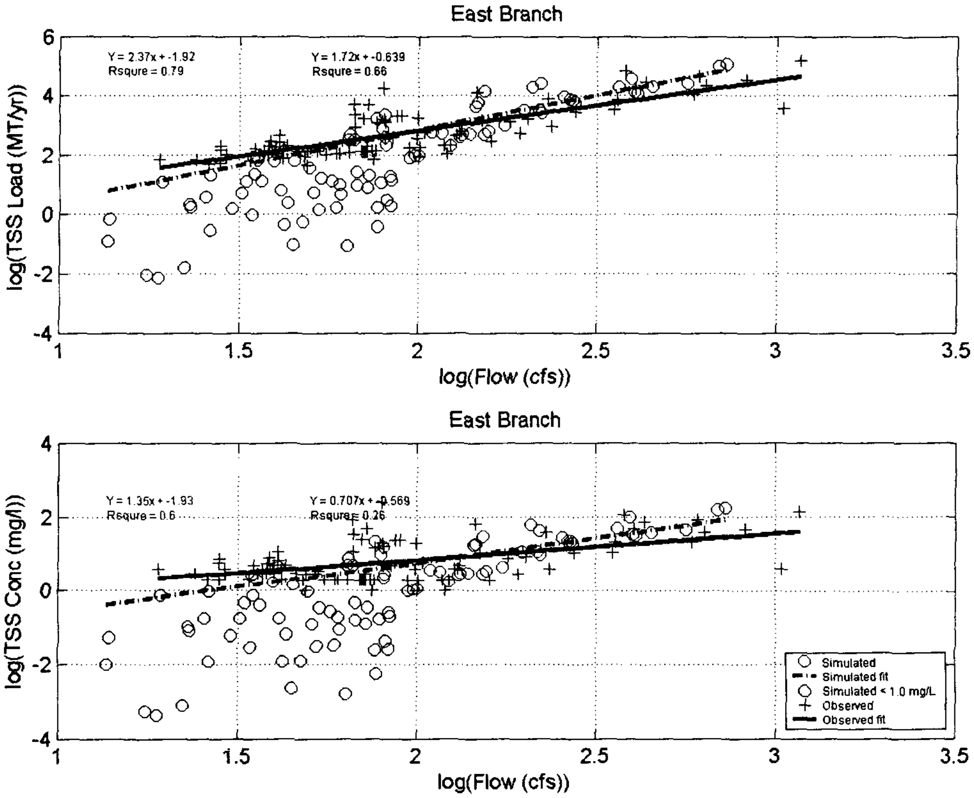


Figure A.5-4 Sediment Rating Curves at Pomeroy

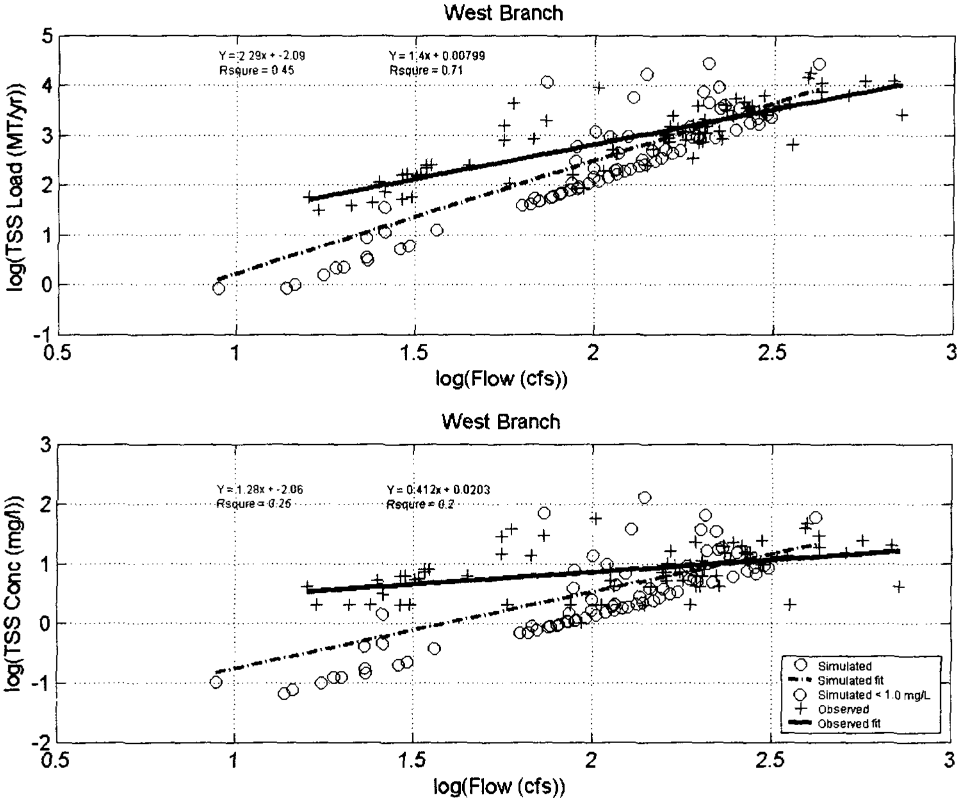


Figure A.5-5 Sediment Rating Curves at the West Branch

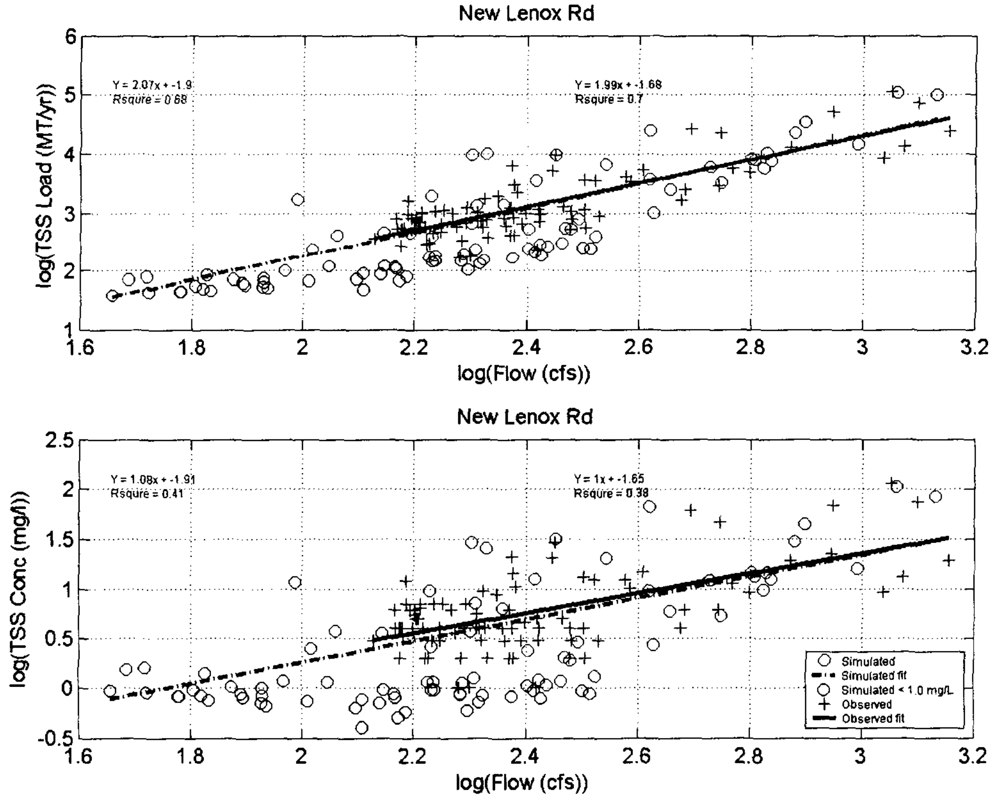


Figure A.5-6 Sediment Rating Curves at New Lenox

Table A.5-7 presents the sediment budget for each RCHRES simulated within the model. PSA reaches are highlighted in light green. The table presents tabulations of the average annual sediment erosion (nonpoint) loads, point loads, upstream and total inflow loads, total outflow loads, and both cumulative and reach trapping efficiencies; the values in the table are averages over the 11-year calibration period.. This information was compared with results from the flux analysis, historical information, field observations, and professional judgment to ensure the model was predicting the 'expected' behavior for each RCHRES. When this information was contrary to the model representation, e.g., the model simulates deposition when the reach is known to be primarily being scoured, reach parameters and/or inflows were adjusted to correct the simulated behavior. For example, review of the trapping efficiencies indicates the following:

a. the reservoir and pond trapping efficiencies are generally in the range of 70 % or greater.

b. Woods Pond trapping efficiency is approximately 40%, in general agreement with other estimates (BBL & QEA, 2003).

c. The cumulative trapping efficiency for the watershed above Woods Pond is about 80%

d. Stream reaches downstream of reservoirs generally show scour conditions, i.e. negative trapping efficiency, or low positive values.

Figures A.5-7 through A.5-8 show concentrations predicted by HSPF versus data collected for 2 major storm events at Coltsville, Pomeroy, West Branch, and New Lenox Road; a complete set of sediment results is provided in Attachment A.3. Each figure shows a single storm event in upstream to downstream fashion for the listed stations. The storms include the events of May 19th – 22nd and September 15th – 19th, which were the largest of storms monitored in 1999. The figures show a reasonable comparison between simulated and observed concentrations for some events and sites, with significant differences up to a factor of two for others. These differences are especially evident for selected peak concentrations, and are to be expected for sediment modeling at the watershed scale, where log scales are commonly used for displaying model-data comparisons. As expected, the model results show better agreement for the larger events where the flow simulations are closer to observed values, providing an improved basis for the transport calculations in the sediment model. The simulations are clearly in the range of the observed data

Table A.5-7 Sediment Budget by Reach for Calibration Period

Reach Segment	Nonpoint (tons)	Point Source (tons)	Upstream In (tons)	Total Inflow (tons)	*Outflow* (tons)	Deposit(+) *Scour(-)* (tons)	Cumulative *Point/NonPt* (tons)	Cumulative Trapping *Efficiency* (%)	Reach Trapping *Efficiency* (%)
RCHRES 9 - Windsor	787.4	0.0	0.0	785.8	632.4	153.4	787.4	19.7	19.5
RCHRES 10 - Windsor Res.	68.6	0.0	0.0	68.5	5.1	69.0	68.6	92.6	92.6
RCHRES 11 - Wahconah	409.3	0.0	5.1	413.5	341.7	71.9	477.9	28.5	17.4
RCHRES 12 - Cleveland Res.	47.6	0.0	632.4	679.9	180.6	529.5	834.9	78.4	73.4
RCHRES 13 - Cleveland Bk	79.8	0.0	180.6	237.0	267.2	-30.2	914.7	70.8	-12.8
RCHRES 20 - Ashmere Lk	266.8	0.0	0.0	266.2	15.0	266.3	266.8	94.4	94.4
RCHRES 21 - Bennett Bk	362.0	0.0	15.0	376.3	403.7	-27.3	628.8	35.8	-7.3
RCHRES 30 - *East Branch*	496.7	0.0	0.0	495.8	556.7	-60.8	[illegible]	-12.1	-12.3
RCHRES 40 - East Branch	645.8	0.0	960.4	1,604.9	1,801.1	-196.0	1,771.3	-1.7	-12.2
RCHRES 100 - East Branch	314.1	0.0	2,410.0	2,723.4	2,742.5	-19.1	3,478.0	21.1	-0.7
RCHRES 110 - Coltsville	110.2	0.0	2,742.5	2,852.5	2,960.2	-107.7	3,588.2	17.5	-3.8
RCHRES 115 - Unkamet Bk	232.9	0.0	0.0	232.4	294.7	-62.2	232.9	-26.5	-26.8
RCHRES 120 - East Branch	151.3	0.0	3,254.9	3,405.9	3,628.0	-222.1	3,972.3	8.7	-6.5
RCHRES 201 - Brattle Bk	246.3	0.0	0.0	245.8	278.4	-32.5	246.3	-13.0	-13.2
RCHRES 200 - East Branch	*161.2*	*0.0*	3,906.4	*4,067.3*	4,383.1	-315.6	4,379.9	-0.1	-7.8
RCHRES 300 - East Branch	124.3	0.0	4,383.1	4,507.2	4,607.0	-99.8	4,504.1	-2.3	-2.2
RCHRES 400 - Pomeroy Brg (4A)	179.4	*0.0*	*4,607.0*	*4,786.1*	4,943.0	-156.7	4,683.6	-5.5	-3.3
RCHRES 410 - East Branch (4A)	2.8	0.0	4,943.0	4,945.8	5,061.4	-115.5	4,686.4	-8.0	-2.3
RCHRES 50 - Town Brook	1,037.0	0.0	0.0	1,035.0	*954.0*	81.1	*1,037.0*	8.0	7.8
RCHRES 60 - Secum Bk	328.0	0.0	0.0	327.4	356.7	-29.2	328.0	-8.7	-9.0
RCHRES 70 - Pontoosuc Res.	183.7	0.0	1,310.7	1,494.1	407.9	1,110.9	1,548.8	73.7	72.7
RCHRES 71 - West Branch	131.9	0.0	407.9	539.5	544.8	-5.2	1,680.7	67.6	-1.0
RCHRES 80 - Onota Res.	540.9	0.0	0.0	539.8	57.7	509.2	540.9	89.3	89.3
RCHRES 81 - Daniels Bk	120.3	0.0	57.7	177.8	186.3	-8.4	661.2	71.8	-4.8
RCHRES 90 - West Branch	171.3	*0.0*	731.1	902.1	*854.6*	47.6	2,513.2	66.0	5.3
RCHRES 810 - Richmond Pond	561.9	0.0	0.0	560.8	137.7	429.5	561.9	75.5	75.4
RCHRES 811 - S. West Branch	1,272.6	0.0	137.7	1,407.8	1,276.1	132.0	1,834.5	30.4	9.4
RCHRES 820 - West Branch	16.6	0.0	2,130.7	2,147.2	2,150.0	-2.7	4,364.3	50.7	-0.1
RCHRES 500 - Housatonic (5A)	240.3	0.0	7,211.4	7,451.2	7,351.4	100.0	9,290.9	20.9	1.3
RCHRES 510 - *Housatonic* (5A)	76.4	0.0	7,351.4	7,427.7	6,163.1	1,264.8	9,367.4	34.2	17.0
RCHRES 830 - Sackett Bk	327.1	0.0	0.0	326.5	252.1	74.5	327.1	22.9	22.8
RCHRES 520 - Housatonic (5A)	158.7	0.0	6,415.2	6,573.6	5,909.3	664.6	9,853.2	40.0	10.1
RCHRES 530 - Housatonic (5A)	77.4	0.0	5,909.3	5,986.6	5,265.2	721.9	9,930.6	47.0	12.1
RCHRES 540 - New Lenox Bridge	207.5	168.5	5,265.2	5,594.9	5,036.2	559.1	10,306.7	51.1	10.0
RCHRES 550 - Housatonic (5B)	67.2	0.0	5,036.2	5,103.3	4,443.8	659.7	10,373.9	57.2	12.9
RCHRES 840 - Roaring Bk	101.2	0.0	0.0	*101.0*	130.8	-29.9	101.2	-29.3	-29.6
RCHRES 560 - Housatonic (5C)	5.6	0.0	4,574.7	4,580.3	4,111.3	469.3	10,480.7	60.8	10.2
RCHRES 850 - Yokun Bk	274.1	0.0	0.0	273.6	261.3	12.3	274.1	4.7	4.5
RCHRES 570 - Housatonic (5C)	233.1	0.0	4,372.6	4,605.2	3,676.0	929.8	10,987.8	66.5	20.2
RCHRES 580 - Woods Pd Htw (5C)	55.7	0.0	3,676.0	3,731.6	2,734.0	1,002.8	11,043.5	75.2	26.7
RCHRES 600 - Woods Pond (6)	102.5	0.0	2,734.0	2,836.3	1,625.8	1,216.6	11,146.0	85.4	42.7
RCHRES 700 - Housatonic	225.4	*0.0*	1,625.8	*1,850.8*	1,962.5	*-111.4*	*11,371.5*	*82.7*	*-6.0*
RCHRES 860 - October Mtn. Res.	29.8	0.0	0.0	29.7	3.7	32.9	29.8	87.7	87.7
RCHRES 861 - Washington Mtn.	217.8	0.0	3.7	221.0	229.6	-8.5	247.5	7.3	-3.9
RCHRES 710 - Columbia Mill	218.9	0.0	2,192.0	2,410.5	1,867.4	543.5	11,837.9	84.2	22.5
RCHRES 721 - Laurel Lk	292.9	0.0	0.0	292.3	130.4	166.1	292.9	55.5	55.4
RCHRES 722 - Laurel Bk	99.1	0.0	130.4	229.4	243.0	-13.5	392.0	38.0	-5.9
RCHRES 720 - Housatonic	300.8	0.0	2,110.4	2,410.6	2,563.9	-153.0	12,530.7	79.5	-6.4
RCHRES 870 - Greenwater Bk	238.3	0.0	0.0	237.8	250.9	-13.0	238.3	-5.3	-5.5
RCHRES 871 - Goose Pond	69.1	0.0	0.0	69.0	41.5	36.7	69.1	40.0	39.8
RCHRES 872 - *Goose Pond Bk*	54.3	0.0	41.5	95.7	112.0	-16.3	123.4	9.3	-17.0
RCHRES 730 - *Housatonic*	487.5	0.0	2,926.8	3,413.3	3,117.6	296.1	13,379.9	76.7	8.7
RCHRES 880 - Hop Bk	*1,050.6*	*0.0*	*0.0*	1,048.6	985.5	63.3	1,050.6	6.2	6.0
RCHRES 740 - Housatonic	146.9	0.0	4,103.1	4,249.7	4,144.6	105.3	14,577.4	71.6	2.5
RCHRES 890 - West Bk	149.8	0.0	*0.0*	149.5	*148.8*	*0.8*	149.8	0.7	0.5
RCHRES 750 - Willow Mill Dam	165.1	0.0	4,293.4	4,458.1	3,708.7	749.9	14,892.3	75.1	16.8
RCHRES 760 - Housatonic	285.7	0.0	3,708.7	3,993.8	4,120.4	-126.3	*15,178.0*	72.9	-3.2
RCHRES 910 - Knokapot Bk	603.0	0.0	0.0	601.9	559.8	42.4	603.0	7.2	7.0
RCHRES 770 - Housatonic	165.1	0.0	*4,680.2*	*4,845.0*	4,687.5	*157.7*	*15,946.1*	*70.6*	*3.3*
RCHRES 920 - Stockbridge Bowl	761.2	0.0	0.0	759.7	21.9	794.5	761.2	97.1	97.1
RCHRES 921 - Larrywaug Bk	274.1	0.0	21.9	295.5	269.2	26.4	1,035.2	74.0	8.9
RCHRES 780 - Glendale Dam	96.5	0.0	4,956.7	5,053.0	4,371.3	682.4	17,077.9	74.4	13.5
RCHRES 790 - Housatonic	122.2	0.0	4,371.3	4,493.2	4,637.9	-144.4	17,200.0	73.0	-3.2
RCHRES 800 - Rising Pond	57.5	0.0	4,637.9	4,695.3	3,981.3	715.9	17,257.6	76.9	15.2
RCHRES 900 - Housatonic (GB)	61.5	0.0	3,981.3	4,042.8	4,109.3	-66.4	17,319.1	76.3	-1.6

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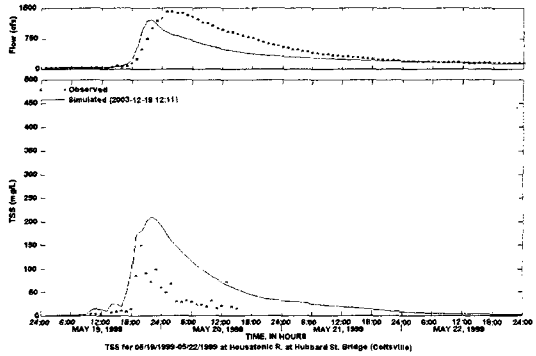
Coltsville



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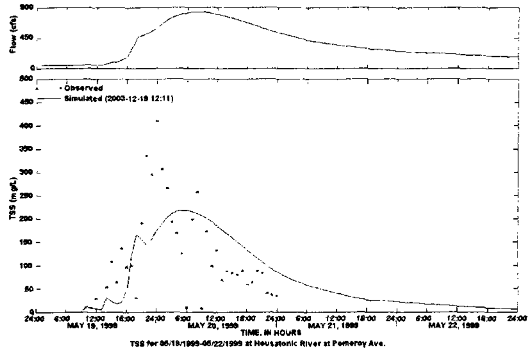

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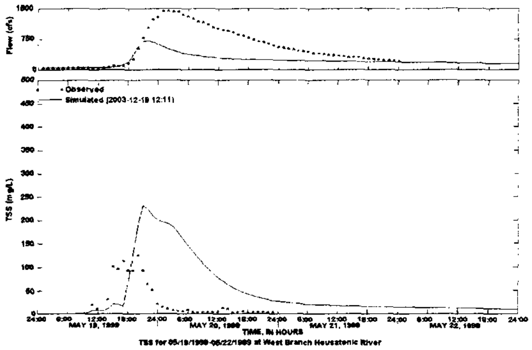

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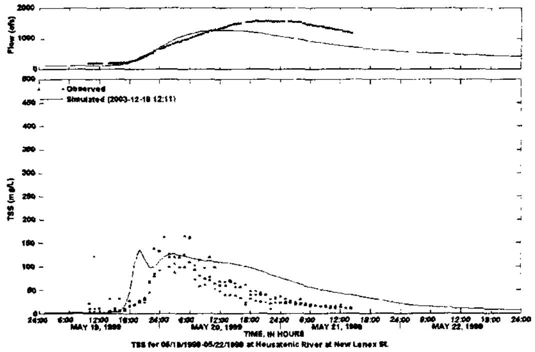
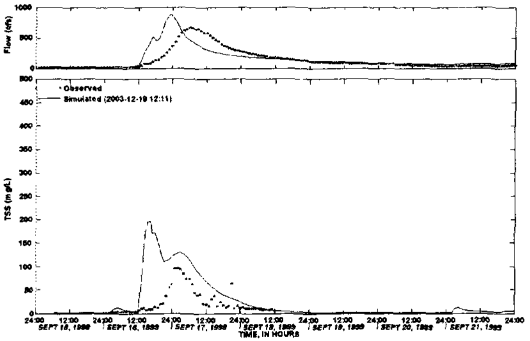


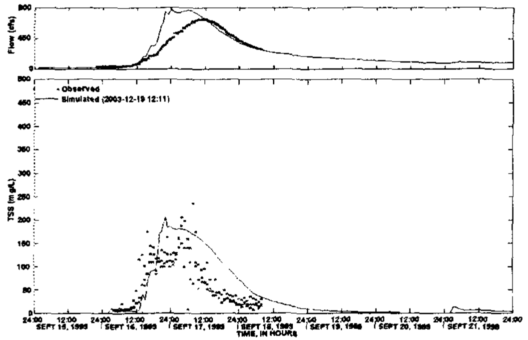
Figure A.5.7 Simulated and Observed TSS for May 19th – 22nd Event

Coltsville



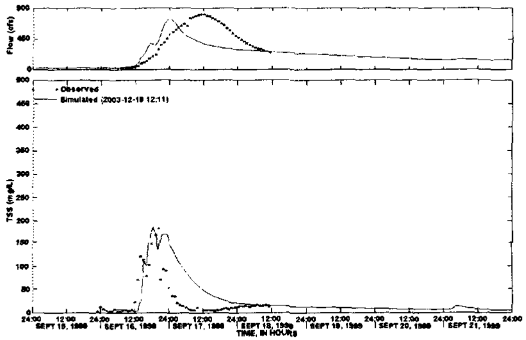
TSS for 09/15/1999-09/21/1999 at Housatonic R. at Hubbard St. Bridge (Coltsville)

Pomeroy



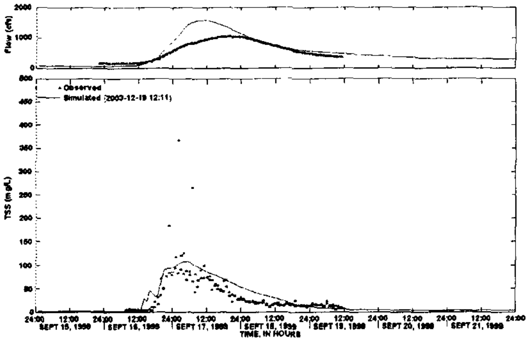
TSS for 09/15/1999-09/21/1999 at Housatonic River at Pomeroy Ave.

West Branch



TSS for 09/15/1999-09/21/1999 at West Branch Housatonic River

New Lenox



TSS for 09/15/1999-09/21/1999 at Housatonic River at New Lenox St.

Figure A.5.8 Simulated and Observed TSS for September 15th – 19th Event

points, and in conjunction with results presented earlier in this section, support the use of the model to provide sediment loads to EFDC.

A.5.2.3 Conclusions

As discussed in this section, sediment modeling and calibration at a watershed scale involves multiple steps and numerous comparisons often with limited observed data distributed in sporadic fashion over the watershed and during the simulation period. Consequently, the weight-of-evidence approach to sediment calibration includes more qualitative assessments and engineering judgment than for the hydrology calibration. Based on the results presented in Section A.5.2.2 and Attachment A.3, the following provides a summary of the 'weight-of-evidence' for support of the watershed model sediment calibration:

- Landscape sediment loadings show reasonable agreement with calibration targets developed using the USLE and are within ranges reported at the national level; thus, providing a sound basis for calibration of the instream sediment processes.
- Differences in mean annual loads of the watershed model versus HydroQual's flux estimates range from -10% to 3% at the upper PSA analysis sites, and are well within the 30% target of the QAPP.
- The trapping efficiency for Woods Pond is modeled at about 40%, which is consistent with established estimates from earlier studies of the watershed
- The larger reservoir/waterbody trapping efficiencies are reasonable, generally in the range of 70% or greater.
- Sediment rating comparisons show comparable flow-TSS relationships for both model and data. The model tends to under simulate very low concentrations, but the general scatter pattern of the model and data points are consistent over most of the concentration range.

- Streambed simulations are consistent with visual observations, professional judgment, and the flux analysis results. Streambeds within the PSA reaches mimic the expected erosional or depositional patterns. The behavior of streambed simulations outside the PSA region is consistent with visual observations and/or professional judgment.

- Comparisons between available data and predicted TSS concentrations during storm events show the model does a reasonable job of representing the general pattern and magnitude of the measured concentrations, within expected accuracy tolerances for detailed point-to-point assessments. As expected, significant differences exist for selected sites and events, but the modeled concentrations are clearly within the range of the observed data points and demonstrate storm patterns consistent with the observations.

Based on the above discussion and the weight-of-evidence results presented herein, the watershed model provides a reasonable representation of sediment loadings within the Housatonic River Watershed that meets the 30% target of the QAPP for the required sediment boundary conditions for EFDC.

A.5.3 WATER TEMPERATURE CALIBRATION AND RESULTS

To model instream water temperature needed for the FCM, HSPF calculates the heat loadings to a reach from all sources, including the runoff components, and then performs a balance of the heat fluxes across the reach boundaries to arrive at the reach water temperature in each model time step. As noted earlier, an energy or heat balance approach is used in HSPF with the same driving meteorologic time series that are needed for snow simulation. Heat sources/sinks to a reach include upstream or tributary reaches, nonpoint runoff (i.e., surface runoff, interflow, and baseflow) or point sources, heat exchange with the atmosphere, and conduction from the streambed. Heat outputs from a reach include downstream advection, losses to the atmosphere, and conduction to the streambed. Below we provide an overview of the model computations and calibration procedures, followed by the calibration results.

A.5.3.1 Overview of Water Temperature Calibration

In order to estimate heat inputs to a reach from local land segments, it is first necessary to estimate the temperature of the runoff flow components (i.e., surface runoff, interflow, and baseflow) originating from these areas. For pervious areas, subroutine PWTGAS estimates the water temperature to be equal to the soil temperature of the layer from which the flow originates, as estimated by subroutine PSTEMP, except the water temperature can not be less than freezing. The surface and upper soil layers associated with surface and interflow, respectively, are estimated using the regression equation shown below:

```
     SLTMP = ASLT + BSLT*AIRTC
where:
     SLTMP = soil layer temperature (degrees C)
     ASLT  = Y-intercept
     BSLT  = slope
     AIRTC = air temperature (degrees C)
```

The temperature of runoff from impervious areas is calculated in a similar manner as the surface runoff from pervious areas, within subroutine IWTGAS, with different coefficients.

For the Housatonic model application, the air temperature was input on an hourly basis and the ASLT and BSLT parameters were varied monthly. Initial parameter values for all land uses were obtained from a recent HSPF study modeling watersheds within the state of Connecticut, including the lower Housatonic River below Ashley Falls, MA (AQUA TERRA Consultants and HydroQual, 2001). The 'forest' land use category was calibrated to reflect the capacity of the forest canopy to buffer air temperature fluctuations. That is to say, the forest temperatures are typically cooler in the summer, warmer in the winter, and slower to respond to temperature changes. This response was achieved by adjusting ASLT accordingly (i.e., lower in summer and higher in the winter) and setting BSLT lower for 'forest' than the 'other' land use categories for all months. Air temperature is also adjusted internally within the model using a lapse rate and the elevation difference between the gage and the mean elevation of the segment.

The soil layer temperature associated with baseflow was also set to be monthly varying; however, the soil temperature was not a function of the air temperature and all land use categories were assumed to behave similarly. This reflects the less dynamic nature of the baseflow temperatures that are more sensitive to long-term averages and seasonal air temperatures. Model segments with significantly higher elevations (e.g., Roaring Brook) used monthly-varying parameters that resulted in lower baseflow temperatures, which was supported by the water temperature data collected at Roaring and Sackett Brooks.

Once instream, HTRCH accounts for inputs and outputs of heat in a reach through three major heat-transfer processes: 1) heat transfer by advection into or out of the reach; 2) heat transfer across the air-water interface; and 3) heat transfer across the streambed-water interface (Taylor, 1998). Heat is considered to be a thermal concentration that is completely mixed or uniform within a reach and assumed to advect at the same rate as the streamflow. The fluxes across the air-water interface consist of shortwave and longwave radiation, evaporation, and conduction/convection. The fluxes are a function of the user supplied meteorological data, model parameters, and the estimated stream temperature. The meteorological data required includes: 1) shortwave solar radiation; 2) cloud cover; 3) air temperature; 4) dewpoint temperature; and 5) wind speed. The transfer of heat across the streambed and the water column interface is driven by temperature gradients between the assumed three layer system (i.e., a water layer, a streambed or mud layer, and a ground layer) within each reach. The temperature of the ground layer (TGRND) is supplied by the user and can be monthly varying, while the temperature of the streambed and the water column are calculated at every interval by the model. The temperatures of the three layers are then used to calculate the heat transfer rates between the layers as a function of the temperature gradients and input parameters KGRND and KMUD.

There are few calibration parameters within HTRCH, and as long as the meteorological inputs are relatively accurate, the default values for the parameters are usually adequate to produce reasonable simulations and comparisons with data. Most of the calibration parameters within HTRCH were set at, or very near, their default values, with the exception of CFSAEX that is set based on site specific information. CFSAEX is the fraction of the reach that is exposed (i.e., not shaded by riparian vegetation or topographical obstructions). Reach specific values of CFSAEX for shading were set using a combination of colored orthophotos, pictures from site visits, and professional judgment. The values assigned ranged from 0.30 for reaches with a dense riparian canopy to 0.90 as a typical value for the reservoirs. Calibrated parameter value ranges are presented in Attachment A.4.

A.5.3.2 Water Temperature Calibration Results

Data were available at numerous sites to make model-data comparisons for water temperature simulations. The data used during the calibration effort included high-frequency samples collected by the USGS at Great Barrington from 4/94 to 4/96, high-frequency samples collected by WESTON at numerous sites during the time period of 5/00 to 9/00, and monthly samples collected by the USGS at Coltsville from 1/90 to 5/93. The WESTON sampling sites included the East Branch above the confluence, the West Branch above the confluence, the mainstem at Holmes Road (~ one mile below the confluence), and Woods Pond at the footbridge. Figures A.5-9 and A.5-10 present the model-data comparisons at the USGS gages.

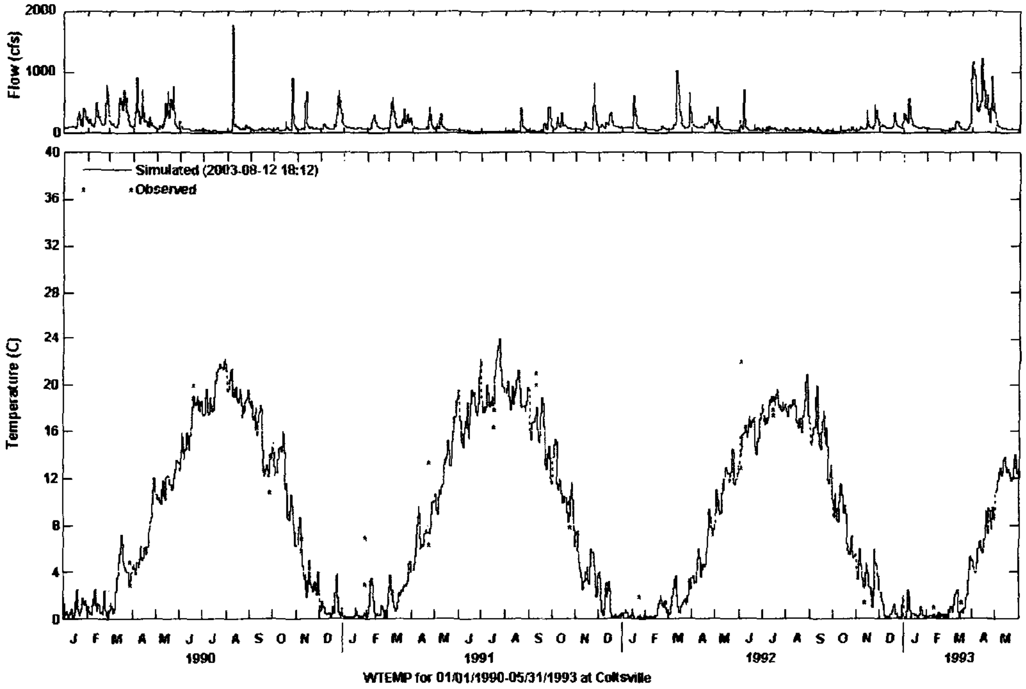


Figure A.5-9 Coltsville Water Temperature Simulation

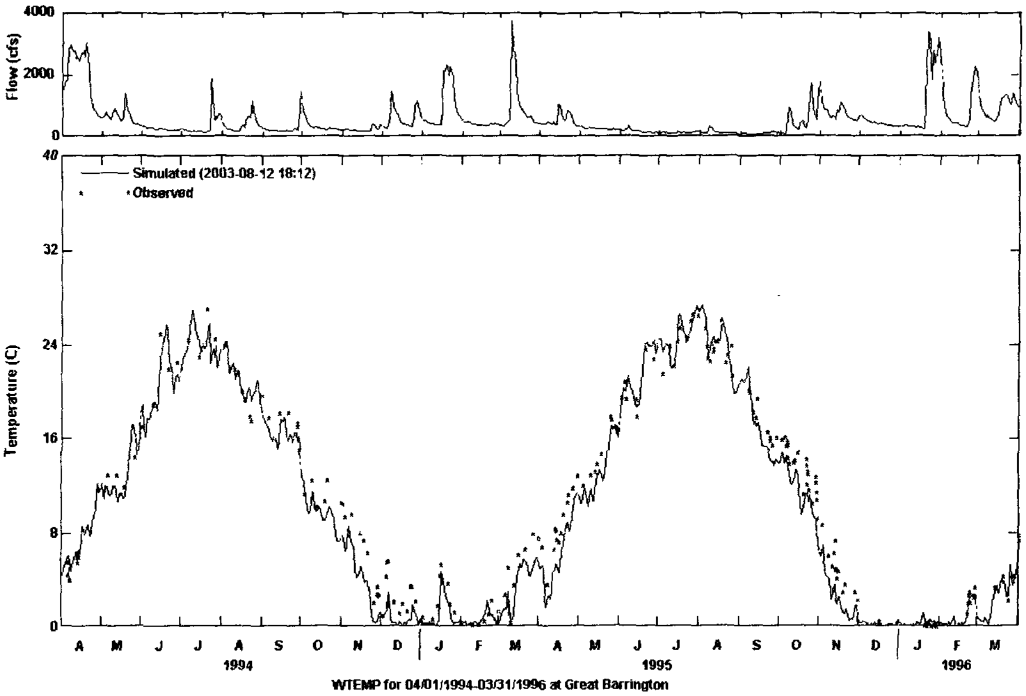
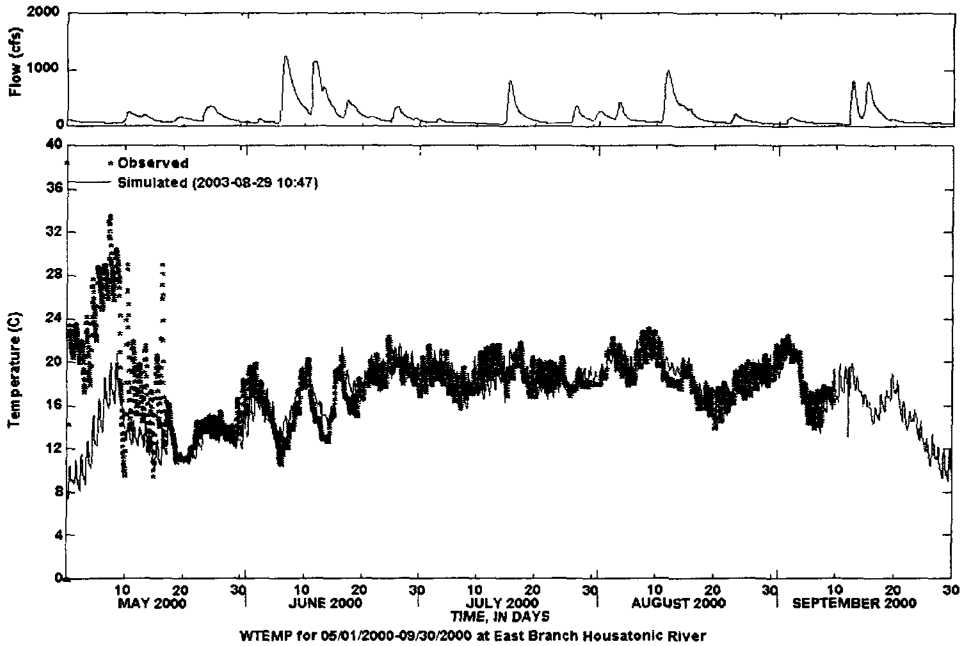
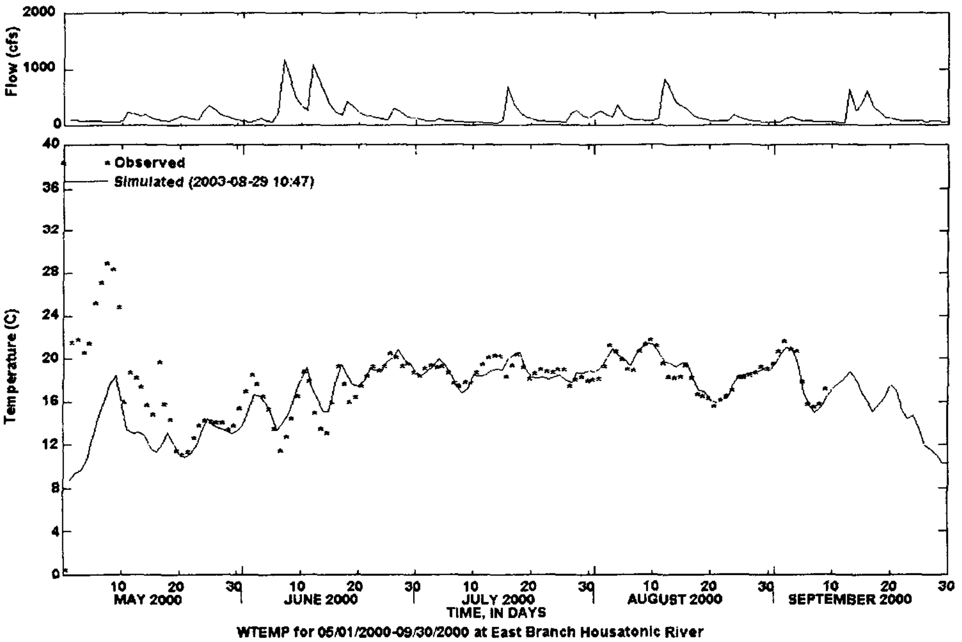


Figure A.5-10 Great Barrington Water Temperature Simulation

From Figures A.5-9 and A.5-10, it is evident that the model does a good job in reproducing the seasonal water temperature pattern over multiple years and flow regimes. Figures A.5-11 through A.5-14 present comparisons of the high frequency data collected by WESTON and the model results at both an hourly and daily average time interval. These figures demonstrate that the model does a very good job in predicting both the hourly and daily average water temperature throughout the summer and beginning of the fall for reaches above and within the PSA. Figure A.5-11 presents data that appears to be erroneous during the month of May, with data values approaching 35° C (95° F), and the simulated values tracking between a more reasonable 8 to 20 degrees C (46 to 68 degrees F).

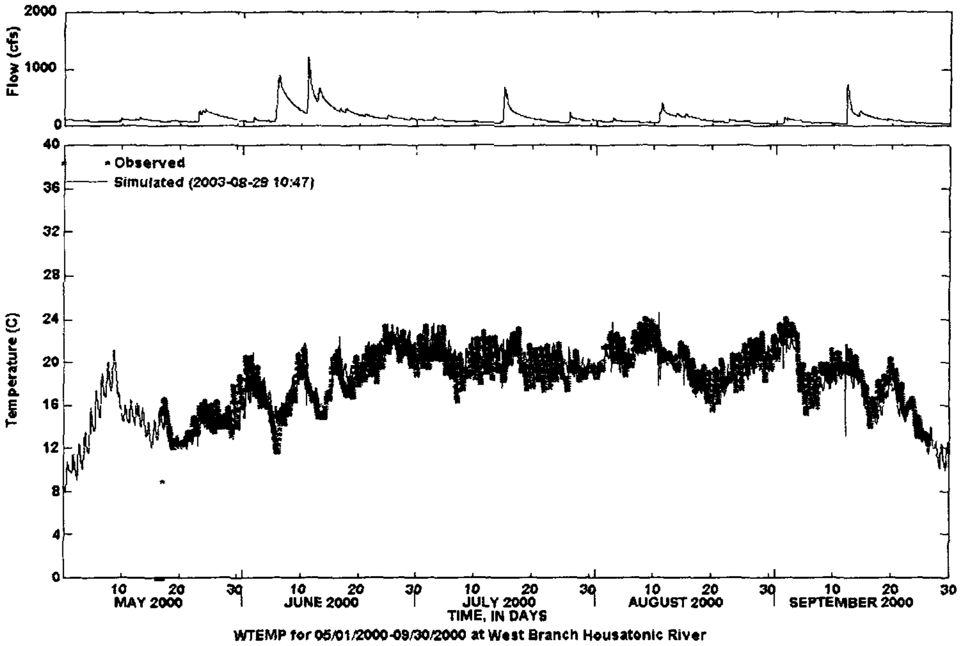


Hourly



Daily Average

Figure A.5-11 East Branch Water Temperature Simulation



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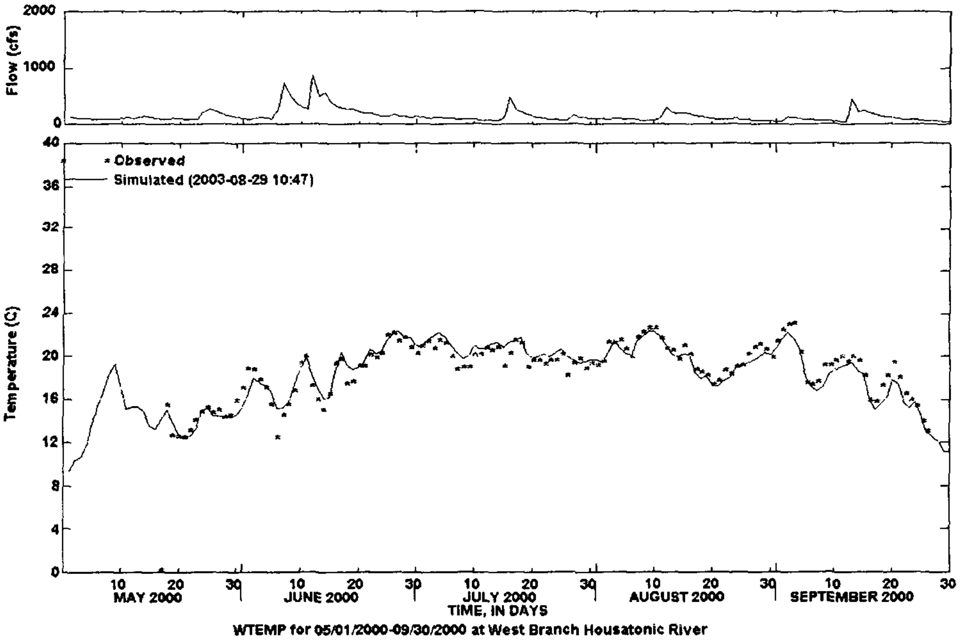
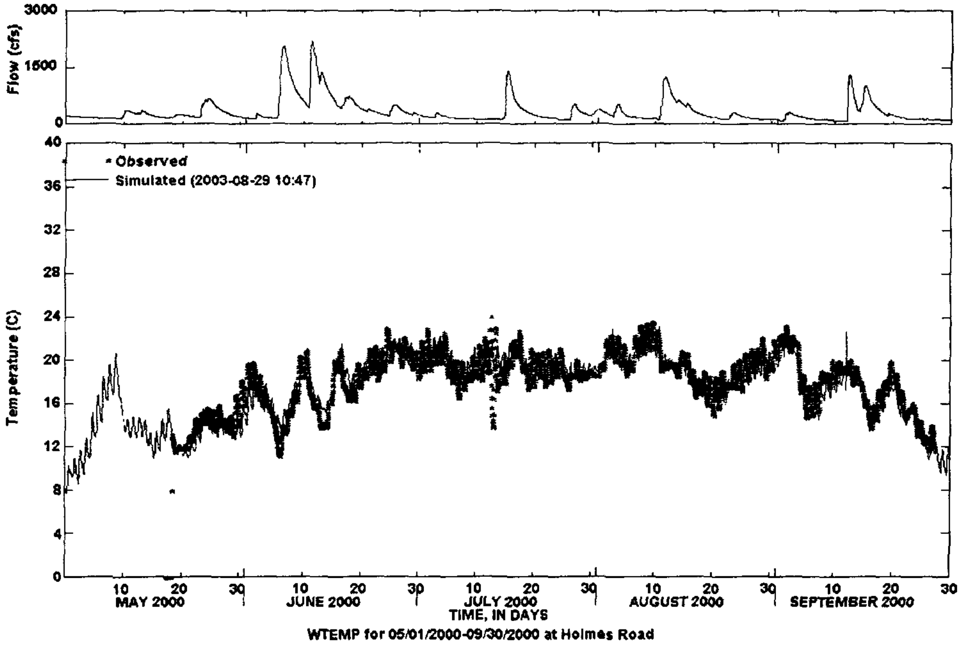
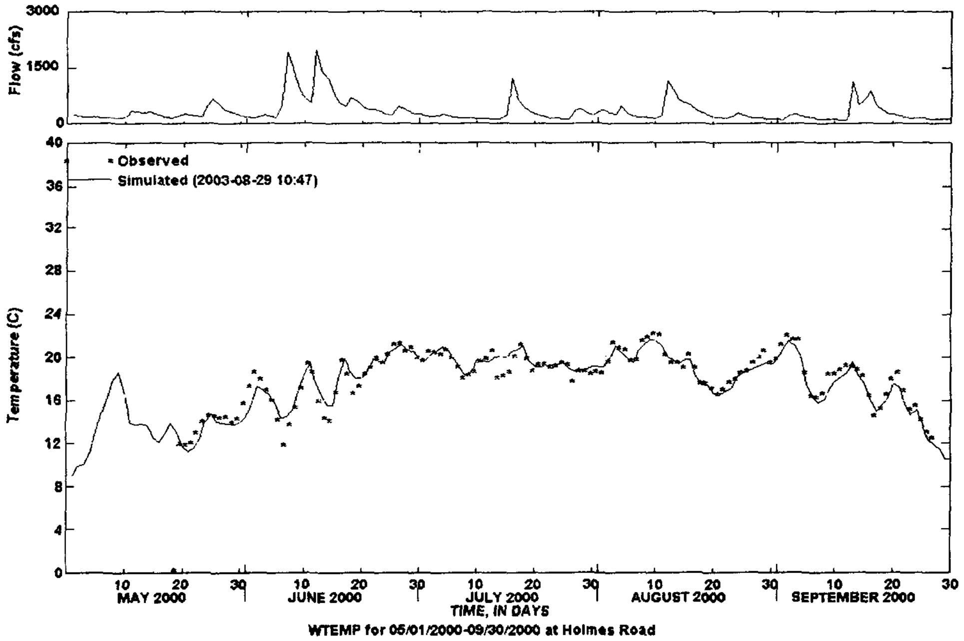


Daily Average

Figure A.5-12 West Branch Water Temperature Simulation

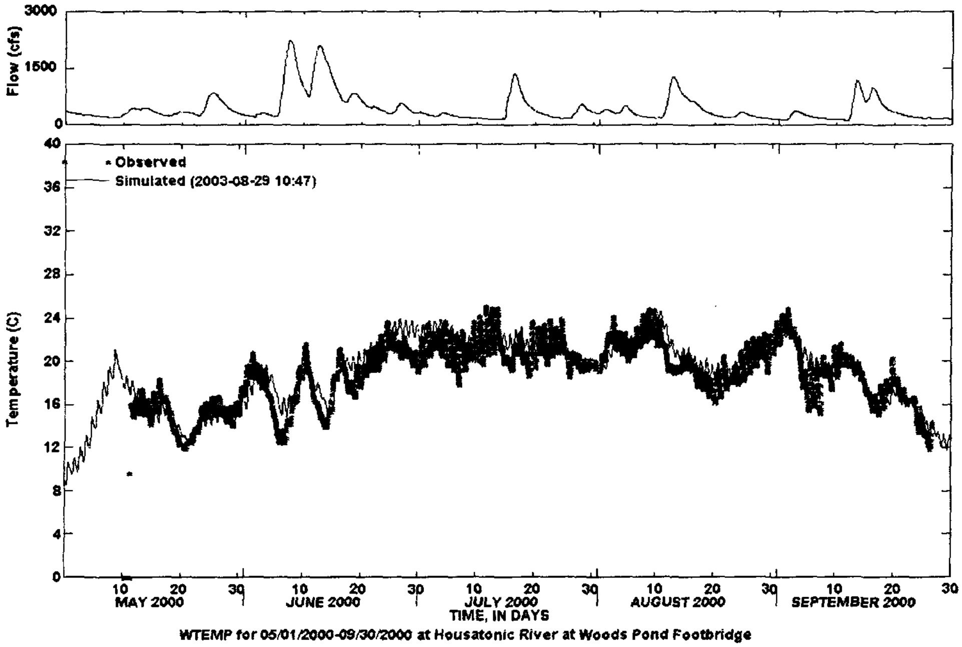


Hourly

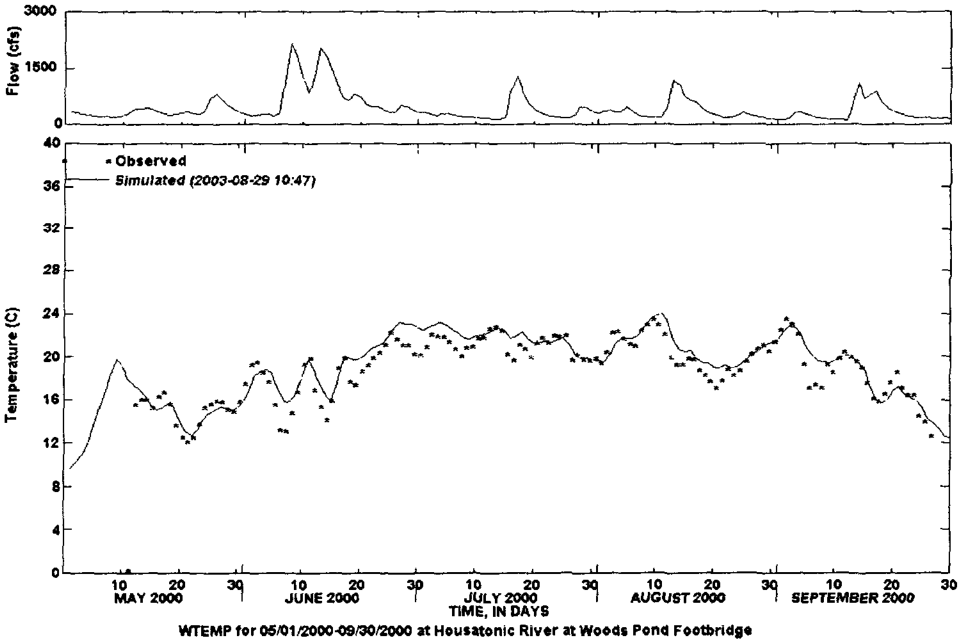


Daily Average

Figure A.5-13 Holmes Road Water Temperature Simulation



Hourly



Daily Average

Figure A.5-14 Woods Pond Water Temperature Simulation

A.5.3.3 Conclusions

Table A.5-8 presents daily average water temperature statistics for the high frequency data collected by WESTON and the USGS versus model estimates. The overall percent mean errors are all less than the target tolerance of ± 10% set in the QAPP, with all but one location having mean errors less than ± 3%. The USGS gage at Great Barrington had an overall error of -8%, which is larger than the other locations but still acceptable, especially since the other statistics such as the R^2 value of 0.96 along with the timeseries plot indicate a very good calibration at this location. In addition, this site is not within the PSA and therefore not within the FCM domain.

Table A.5-8 Water Temperature Statistics

	East Branch		West Branch		Holmes Rd		Sackett Bk		Roaring Bk		Woods Pond		Great Barrington	
	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
Count	114	114	133	133	133	133	131	131	134	134	139	139	221	221
Mean	17.7	17.7	18.6	18.8	17.9	18.1	14.9	15.0	13.2	13.5	19.4	18.9	9.9	10.7
Geometric Mean	17.5	17.5	18.5	18.6	17.7	17.9	14.7	14.9	13.1	13.3	19.2	18.7	4.4	6.4
Std Deviation	2.4	2.4	2.6	2.5	2.5	2.5	2.0	2.2	1.8	2.2	2.8	2.7	8.5	8.1
Avg Ratio of Sim:Obs	1.00		0.99		0.99		0.99		0.99		1.03		0.96	
R	0.95		0.96		0.97		0.90		0.89		0.94		0.98	
R^2	0.89		0.92		0.93		0.80		0.80		0.88		0.96	
Mean Error	-0.03		-0.12		-0.19		-0.16		-0.30		0.48		-0.85	
Mean Absolute Error	0.59		0.61		0.53		0.80		0.86		0.84		1.31	
% Mean Error	0%		-1%		-1%		-1%		-2%		3%		-8%	

Table A.5.9 presents the monthly average water temperature and associated percent errors for the high frequency data collected by WESTON versus the model estimates. The monthly errors range from -6% to 6% and as previously stated the overall errors are less than ± 3%, all of which are less than the QAPP target.

Table A.5-9 Mean Monthly Water Temperature at High Frequency Sites

	East Branch			Holmes Road			West Branch		
	Simulated	Observed	% error	Simulated	Observed	% error	Simulated	Observed	% error
May, 2000	15.0	15.0	0%	15.5	15.6	-1%	16.1	16.1	0%
June, 2000	18.9	19.0	-1%	19.9	19.8	1%	21.0	20.5	2%
July, 2000	19.1	19.0	1%	19.6	19.7	-1%	20.2	20.2	0%
August, 2000	17.5	17.4	1%	18.0	18.5	-3%	18.6	19.3	-4%
Average	17.6	17.6	0%	18.3	18.4	-1%	19.0	19.0	0%
	Sackett Bk			Roaring Bk			Lower Woods Pond		
	Simulated	Observed	% error	Simulated	Observed	% error	Simulated	Observed	% error
May, 2000	13.5	12.7	6%	12.0	11.3	6%	16.5	16.2	2%
June, 2000	15.6	16.1	-3%	13.7	14.6	-6%	22.1	21.0	5%
July, 2000	16.3	16.6	-2%	14.5	15.2	-5%	21.2	20.9	1%
August, 2000	15.1	15.6	-3%	13.5	13.9	-3%	19.8	19.3	3%
Average	15.1	15.3	-1%	13.4	13.8	-2%	19.9	19.4	3%

The consistently high correlation coefficients, low percent mean errors, and timeseries plots for each of the stations show that the simulation is very good both spatially and temporally and well within the QAPP tolerance. Based on the statistics and timeseries plots presented herein and attachment A.3, the watershed model is determined to be capable of providing water temperature input to FCM well within the target accuracy.

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