Hydrologic & Hydraulic Analysis Technical Support Data Notebook

Task Order HSFE02-09-J-0001 for Passaic River Watershed Hydrologic & Hydraulic Study, New Jersey

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TECHNICAL SUPPORT DATA NOTEBOOK (TSDN)

for

Passaic River, New Jersey

HYDROLOGIC & HYDRAULIC ANALYSIS TSDN

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List of Acronyms

AMC	Antecedent Moisture Condition
cfs	cubic feet per second
CN	Curve Number
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standard
FIS	Flood Insurance Study
GCS	Geographic Coordinate System
GDM	General Design Memorandum
G&S	*Guidelines and Specifications for Flood Mapping Partners*
HLR	Hydrologic Landscape Region
HUC	Hydrologic Unit Code
HWM	High Water Mark
JCUA	Jersey City Utility Authority
LiDAR	Light Detection And Ranging
LP III	Log Pearson Type III
MHHW	Mean Higher High Water
MPE	Multisensor Precipitation Estimator
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NBI	National Bridge Inventory
NCDC	National Climatic Data Center
NEXRAD	Next Generation Weather Radar System
NJ	New Jersey
NJDEP	New Jersey Department of Environmental Protection
NJFHADF	New Jersey Flood Hazard Area Design Flood
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service
NWS	National Weather Service

NY	New York
SCS	Soil Conservation Service
SHP	Shapefile
SSURGO	Soil Survey Geographic
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

A. INTRODUCTION

This study, done for the Department of Homeland Security's Federal Emergency Management Agency (FEMA), provides new flood hazard information along the central and lower portions of the Passaic River in New Jersey (NJ). The study area includes hydrologic modeling for the Passaic River Watershed (937 square miles) and a 41.2-mile hydraulic study reach along the Passaic River (Figure 1). The hydraulic study reach extends from the West Caldwell/Roseland municipality border in NJ, where the Passaic River has a drainage area of 345 square miles, downstream to the river 's confluence with the Second River. At the confluence, the Passaic River's drainage area is 937 square miles. Flood stage flows in the Passaic require 2 to 3 days to peak and require the use of a 96-hour frequency storm for determining 100-year flood elevations.

The upper portion of the 41.2-mile hydraulic study reach consists of an 18.2-mile long unsteady state detailed HEC-RAS model, which includes the Great Piece Meadows as well as portions of the Hatfield Swamp. This unsteady state model links to five separate HEC-HMS models (Upper Passaic, Whippany, Rockaway, Pompton, and Central Passaic) as well as four approximate unsteady HEC-RAS models (Figure 2). New discharge and water surface elevation flood hazard information for this upper 18.2 miles relies on the results of the unsteady state detailed HEC-RAS model. A steady state detailed hydraulic model analysis determines the flood hazard information for the lower 23 miles. Two additional HEC-HMS models are linked to a detailed unsteady state hydraulic model to develop discharges for this steady state detailed HEC-RAS model.

This report summarizes the background, methodology, and results of the combined hydrologic and hydraulics analyses for the 41.2 study reach. The model stream reach identified for flood hazard determination stretches across 5 counties (Morris, Passaic, Essex, Bergen, and Hudson) and 26 communities in the State of NJ. A complete list of the communities that are affected by this analysis can be found in Appendix A. These analyses will revise the effective Flood Insurance Studies (FIS) for these communities and are consistent with FEMA's *Guidelines and Specifications for Flood Mapping Partners* (*G&S*) effective at the time of this study.

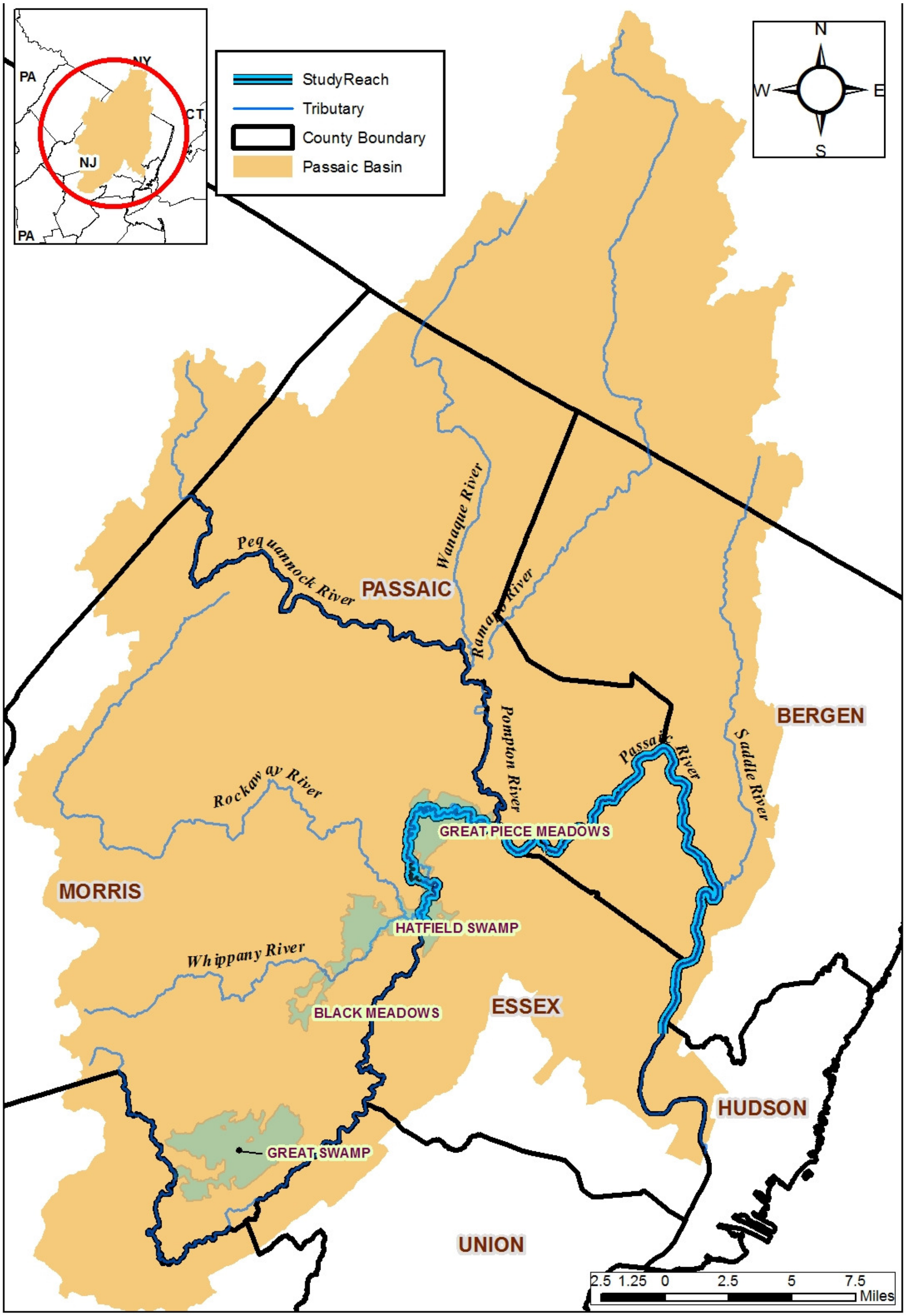


Figure 1: General Location of Passaic River Basin

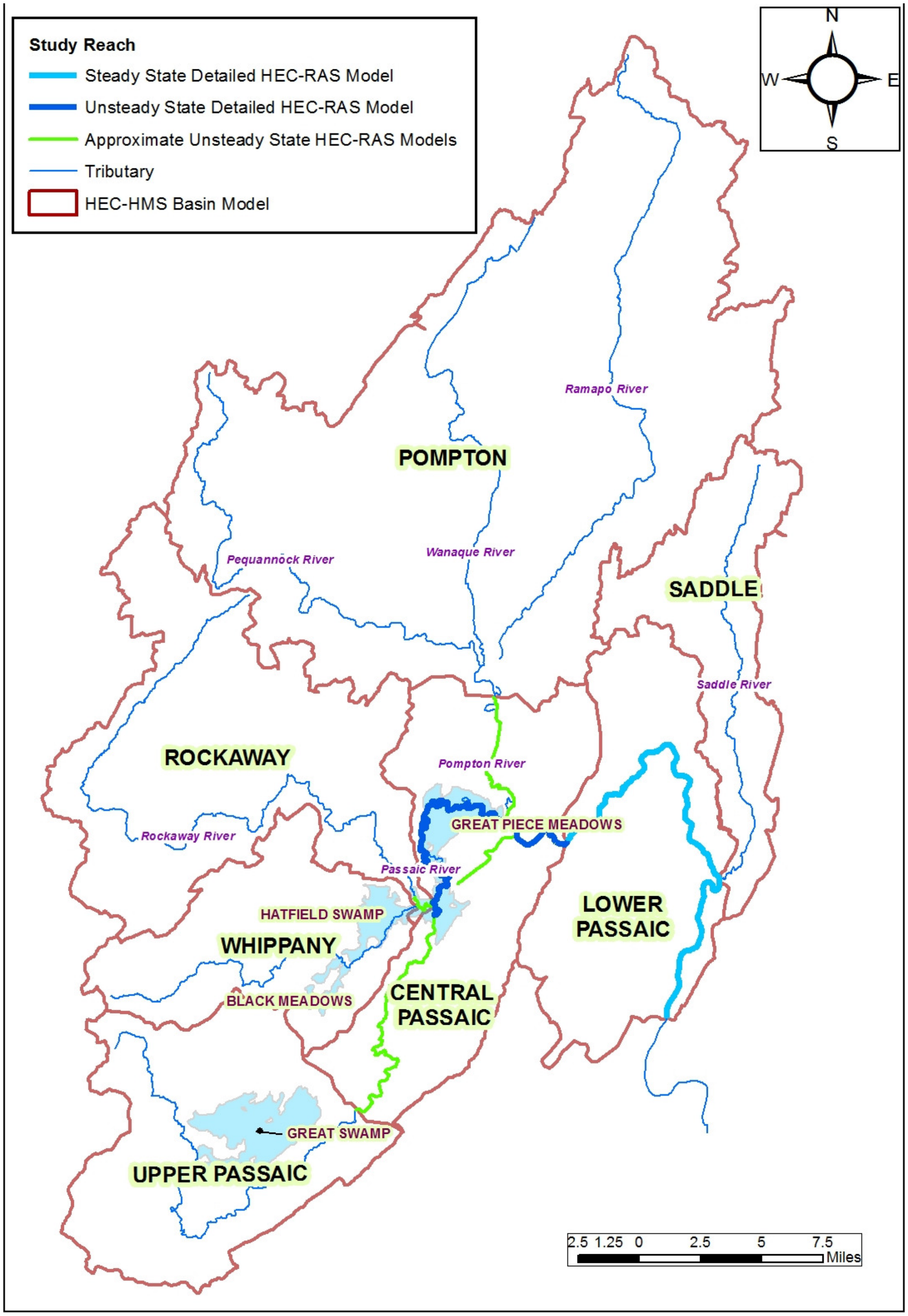


Figure 2: Passaic River Modeling Setup.

A.1 Study Area

The Passaic River Watershed includes portions of northeastern NJ and southeastern New York (NY); the U.S. Geological Survey (USGS) 8-digit hydrologic unit code (HUC8) is 02030103. The watershed area of the Passaic Basin totals 937 square miles. Approximately 84% of the watershed lies in NJ and the remaining 16% lies in NY. The basin borders the Appalachian Mountains in the north and west, the First Watching Mountains in the south, and the Piedmont plain to the east. The basin's main tributaries include the Rockaway, Pequannock, Wanaque, Ramapo, Pompton, and Saddle Rivers. The Passaic Basin includes some large wetlands especially in the upper and central portions of the basin. Wetlands in the basin include Great Swamp, Troy Meadows, Hatfield Swamp, Great Piece Meadows, and Black Meadows (Figure 2).

The basin has a long history of flooding as well as flood related studies. From the 1960s to 2006, nine floods have prompted Federal Disaster Declarations. Some notable events that caused damaging floods occurred in September 1999 (Hurricane Floyd), April 2005, October 2005, April 2007, and the recent March 2010 storm. Along the hydraulic study reach, the storm in March of 2010 caused the highest peak on record at the USGS Pine Brook flow gage (01381900) located on the Passaic.

A.2 Purpose and Type of Study

The effective hydrologic and hydraulic modeling for the study area is over three decades old. The effective discharges were developed by the U.S. Army Corps of Engineers (USACE) using frequency-discharge relationships for gage data recorded at Little Falls (USGS gage No. 01389500) in 1972 (FEMA, 2007). The effective hydraulic analysis is a HEC-2 completed in 1978 (FEMA, 2007). The new study updates this information to reflect current conditions within the watershed and physical changes along the study reach. In order to model the flood hazard for the upper 18.2 miles of the Passaic River, an unsteady state hydraulic analysis was completed. This analysis replaces the effective steady state hydraulic analysis for this portion of the Passaic. The detailed study methods used follow guidance provided in FEMA's *G&S,* Appendix C (November, 2009). Discharges were calculated for the 10% (10-year), 2% (50-year), 1% (100-year), and 0.2% (500-year) annual chance peak flow discharges as well as for the NJ Flood Hazard Area Design Flood (NJFHADF), based on a discharge 25% larger than the 100-year flood discharge. Mapping based on the hydraulic analyses will update the 1% annual chance (100-year), NJFHADF, and 0.2% annual chance (500-year) floodplains.

A.3 Type of Flooding

The 41.2 hydraulic study reach is riverine with a downstream boundary condition determined by tidal conditions. Flow along the Passaic in the Central Basin during flood conditions is subject to reversal upstream of its confluence with the Pompton River. This reversal occurs due to downstream constrictions in the river valley, primarily at Little Falls (USACE, 1995). To determine the flood inundation in this area an unsteady-state model hydraulic model is required for the upper 18.2 miles of the study reach. To develop the hydrographs for this unsteady state modeling, five different HEC-HMS models were required. The lower study reach extends into a tidal area and was studied using steady state hydraulics. This portion of the study is 23.0 miles. Discharges for this reach depend on the inflows from the upstream unsteady state hydraulic model as well two additional HEC-HMS models (Saddle River and Lower Passaic Basin Models).

A.4 Flooding History

Flooding in Passaic County is the result of heavy rainfall produced by hurricanes moving up the coast, large frontal storms from the west and south, and local thunderstorms. The largest storm on record occurred in 1903, with an estimated peak discharge at the mouth of the Passaic River of 39,800 cubic feet per second, and a recurrence interval of approximately 100 years (U.S. Department of the Interior 1904). Other historically large storms that caused widespread flooding and damage occurred in 1902, 1936, 1945, 1951, and 1955. More recently, major flooding occurred along the Passaic in 1968, 1971, 1972, 1973, two in 1975, 1984, 1992, 1999, 2005, 2007, and 2010, all of which warranted Federal Disaster Declarations.

A.5 Other Recent Flood Studies

Since the Flood Control Act of 1936 was first authorized, the USACE has been involved in Passaic River Basin planning. Reports by the USACE recommending plans of action were issued in the years 1939, 1948, 1962, 1969, 1972, 1973, 1987, and 1995. In 1995 a detailed hydrology and hydraulic analysis was completed for the basin as part of General Design Memorandum, (USACE, 1995). The hydrologic modeling completed at that time included a HEC-1 model of the Passaic Basin. This HEC-1 model was coupled with UNET, an unsteady state hydraulic model, that later became the unsteady modeling component for HEC-RAS. An electronic copy of the UNET model was made available for use in this study by the USACE, NY District Office. While an electronic copy of the HEC-1 modeling could not be obtained, most of the details of the model were available in the General Design Memorandum (GDM) published in 1995 by the USACE and recorded from an April 1984 storm event. The current study reflects a partial update of this earlier modeling effort and relies heavily on the modeling and study approaches developed in the 1995 GDM.

A HEC-HMS model completed in 2004, as part of a flood reduction and ecosystem restoration project for the Upper Passaic Watershed, was also obtained digitally from the USACE, NY District Office (USACE and New Jersey Department of Environmental Protection [NJDEP], 2004). Although a digital HEC-HMS version of this model was provided, the model could not be validated using a 2004 rain event and was not used as part of this current study.

In 2008, a three-dimensional, time-dependent, hydrodynamic model (ECOMSED) was developed for Newark Bay and extended up the Passaic River to Dundee Dam (U.S. Environmental Protection Agency [USEPA] and USACE, 2008). This model was developed to predict the movement and concentrations of various chemicals under different management scenarios. The model simulations, however, also included the modeling and mapping of the 100- and 500-year flows from the mouth of the Passaic upstream to Dundee Dam. The modeling results were validated using flows and water surface elevations observed along the Passaic River during Hurricane Donna (1960). Bathymetric data collected along the lower portion of the study reach (approximately 17 miles) as well as aerial survey, with supplemental land survey, were made available by the EPA (Region 2) for use in this study.

B. STUDY AREA CHARACTERISTICS

This section of the report discusses the general features of the watersheds as a whole as well the datasets used in development of the HEC-HMS and HEC-RAS models. Section C provides a more detailed discussion of these datasets.

B.1 Hydrologic and Physiographic Regions

An understanding of the general topographic configuration and storage features of the basin is necessary to appreciate the unique flow conditions along the Passaic. Topography in the basin falls into one of three regions: Highland Area, Central Basin, and Lower Valley (Figure 3). The Highland Area consist of the areas of the basin with high to moderate slopes, which drain, primarily, the Pompton and Rockaway Rivers into the Central Basin. The Central are consist of the areas of the basin with moderate to mild slopes, which drain, Upper and Central Passaic River reaches into the Lower Valley. The Lower Valley Area consist of the areas of the basin with moderate to mild slopes, which drain, Lower Passaic River reach and Saddle Rivers .

The Passaic Basin also consists primarily of three hydrologic landscape regions (HLRs), four, seven, and sixteen (Figure 4). Minor portions of HLRs 9 and 11 are also found in the basin. The Pompton and Rockaway sub-basins are classified almost entirely as HLR 16, which is characterized by semiarid mountains with impermeable soils and bedrock. Both of these sub-basins also fall within the New England Upland physiographic province, which in the NY - NJ highlands section is very complex geologically and is composed predominantly of erosion-resistant, contorted, and strongly metamorphosed crystalline rocks (gneisses and schists) and marble, mostly overlain with glacial till, with many areas of softer limestone and shale, especially in the valleys. The Whippany sub-basin is also located in the New England province but falls within HLR 7, which consists of humid plains with impermeable soils and impermeable bedrock.

Most of the Upper Passaic sub-basin as well as two-thirds of the Central Passaic sub-basin fall within HLR 4, which is a humid plain with permeable soils and bedrock. The remaining portion of the Central Passaic falls within HLR 7, which is a humid plain with permeable soils and impermeable bedrock . These two sub-basins also straddle the New England Upland and Piedmont Lowlands physiographic provinces. The Piedmont province as a whole may be viewed as the non-mountainous portion of the older Appalachian Mountains whose flat plateau surface is the product of erosion and degradation. The Piedmont Lowlands section, also known as the Newark Basin or Triassic Lowlands, is an almost continuous formation of reddish shale, mudstone, and sandstone.

The Saddle River and Lower Passaic sub-basins are located almost entirely within the Piedmont Lowlands physiographic province. Hydrographic landscape regions within the Saddle River sub-basin include HLRs 4, 7, 9, and 16. HLR 9, which is comprised of impermeable soils and bedrock, is the largest HLR in the watershed and is located in the headwater portions of the watershed. The Lower Passaic is comprised of a mix of HLR 4 and 7.

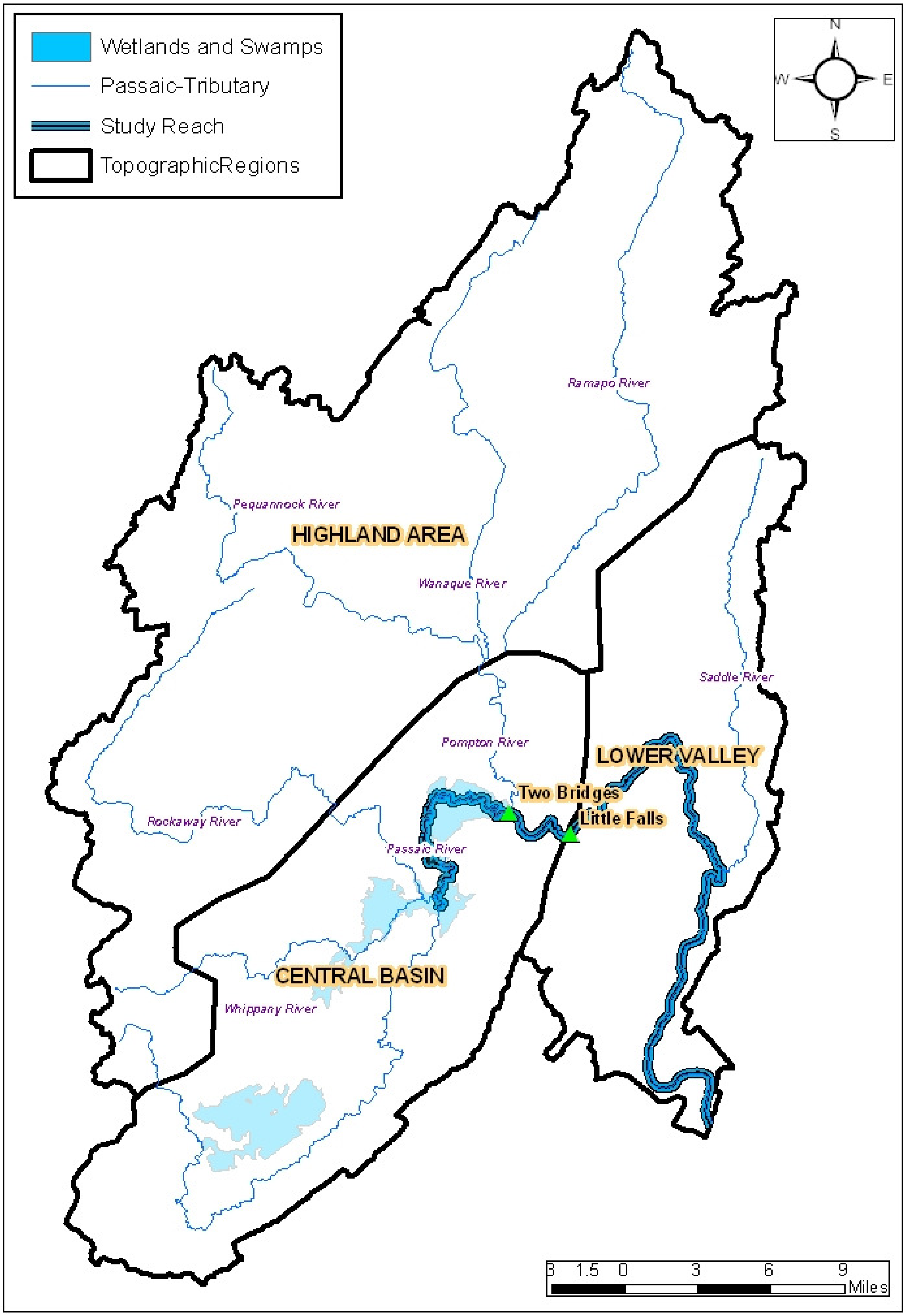


Figure 3. Topographic Regions of Passaic Basin

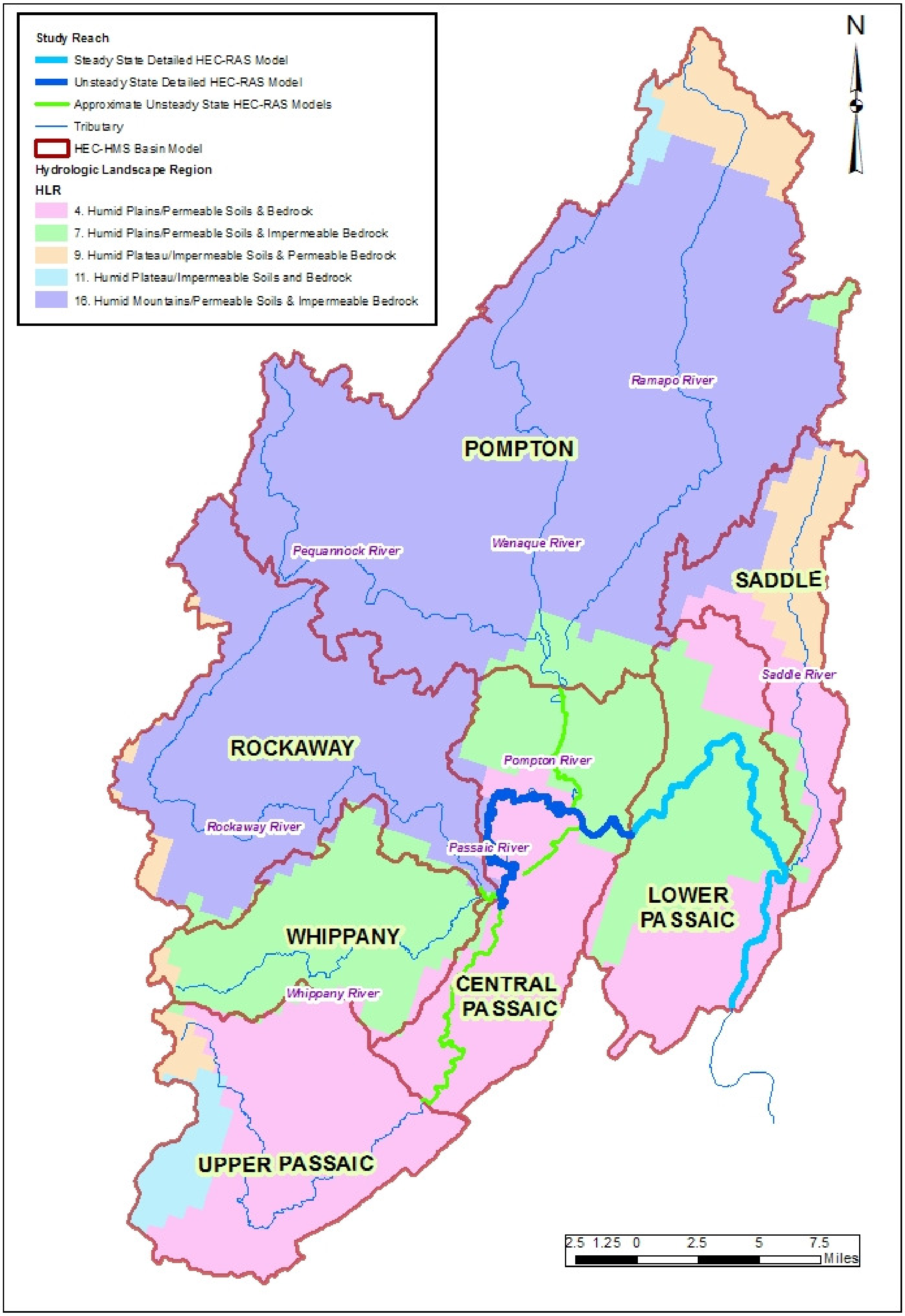


Figure 4. Hydrologic Landscape Regions within the Passaic Basin

B.2 Watershed Size

The total drainage area for the Passaic Basin included in this study is 937 square miles. The drainage areas for the individual HEC-HMS study basins are listed in Table 1.

Table 1. HEC-HMS Basin Areas

HEC-HMS Basin Name	Area (sq mi.)
Saddle	60
Rockaway	137
Pompton	355
Central Passaic	103
Lower Passaic	114
Upper Passaic	99
Whippany	70

B.3 Soils and Topographic Data

Soils data for the entire Passaic Basin, unless otherwise noted, uses data obtained from the National Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database.

Topographic Data Watershed boundaries and other morphological parameters such as stream lengths, slopes, longest flow paths, basin centroid, and centroid elevations were developed using USGS 10-meter Digital Elevation Models (DEM) and the GeoHMS 3.5 extension for ArcGIS software published by the USACE. The longest flow path is the basis for calculation of the lengths and slopes for upland and channel flow paths. The DEMs used in this study were downloaded from the USGS website http://seamless.usgs.gov/website/seamless/viewer.htm, downloaded DEM's are referenced to a Geographic Coordinate System (GCS), and with elevations in meters above the North American Vertical Datum of 1988 (NAVD88). The DEMs were projected to NJ State Plane (FIPS 2900) with the elevation converted to feet. NJ high resolution LiDAR (Light Detection And Ranging) data collected in the fall of 2006 was used in the development of inputs for both approximate steady state and unsteady state hydraulic models used for the development of hydrologic routing inputs.

B.4 Precipitation

Precipitation data for this project was obtained from the National Oceanic and Atmospheric Administration (NOAA). Depending on the method of collection, precipitation data can be divided into two types. The first type of data is called point-gauge data and the second type, which is based on radar technology, is called Next Generation Weather Radar System (NEXRAD) rainfall data. The spatial-temporal characteristics of the datasets, however, are different. Point rainfall is generally collected using rain gauges located at discrete point locations, whereas NEXRAD rainfall data is more spatially distributed. NEXRAD data is generally collected by NOAA’s National Weather Service (NWS). Depending on the type of gauging equipment used, the temporal characteristic of point rainfall data varies from 15 minutes to 1 hour or more. For this study, NEXRAD precipitation data in the form of Multisensor Precipitation Estimator (MPE) data obtained from NOAA was used for calibration of the watershed models to observed events. MPE is a gauge adjusted radar (WSR-88D) rainfall product. It is constructed on 4 x 4-km2 grid on an hourly basis and has been generated by the River Forecast Centers. The MPE precipitation data was processed by ArcGIS for each model sub-basin. A precipitation time’s series was created for each sub-basin for almost all the storm events used in the calibration and validation process. NEXRAD data was not available for the September 1999 storm event.

B.5 Frequency Storm Data

Hypothetical rainfall data (frequency storm) is used to develop frequency storm peak flow discharges. The hypothetical rainfall used in this study was NOAA Atlas 14 data obtained from the Hydrometeorological Design Studies Center of NOAA's NWS (Table 2). As indicated earlier, flood stage flows in the Passaic require 2 to 3 days to peak and require the use of a 96-hour frequency storm for determining 100-year flood elevations.

Table 2. Frequency Storm Data Used for All HEC-HMS Modeling (centroid of Passaic Basin)

Precipitation Frequency Estimates (inches)										
Average recurrence interval (Years)	**5 min**	**15 min**	**60 min**	**120 min**	**3 hr**	**6 hr**	**12 hr**	**24 hr**	**48 hr**	**4day**
10	0.54	1.06	1.95	2.46	2.77	3.6	4.57	5.16	6.04	6.56
50	0.66	1.28	2.54	3.31	3.73	4.95	6.43	7.32	8.44	9.04
100	0.7	1.37	2.79	3.7	4.17	5.6	7.36	8.42	9.62	10.23
500	0.8	1.54	3.37	4.67	5.26	7.28	9.88	11.42	12.75	13.36

Precipitation estimates from depth-duration-frequency studies, such as the NOAA published, are point estimates. To account for rainfall variability over the study basin, reductions in the point rainfall depth are made based on the watershed area. The reduction made by HEC-HMS for a 24-hour storm for drainage areas greater than 200 square miles is approximately 9%. A reduction factor for 935 square miles watershed area and 96-hour storm duration is not available in HEC-HMS. The size of the Passaic Basin (935 square miles) and a review of the recent and historical rainfall events in the basin also indicate that unevenly distributed precipitation events are more likely to be associated with 100-year flows than would a uniformly distributed precipitation event (USACE, 1995). The assumption of a uniform antecedent moisture condition for Soil Conservation Service (SCS) hydrology across the basin is also unlikely to be correlated with 100-year flows.

To address these concerns in the combined HEC-HMS/Unsteady HEC-RAS model and consistent with procedures used by USACE (1995), areal adjustment factors were applied to individual HEC-HMS basin models to match updated Log Pearson Type III (LP III) peak flow frequency gage data along the study reach. These adjustments were made to the NOAA Atlas 14 rainfall amounts for the centroid for the Passaic Basin and for 96-hour storm duration.

Results from individual HEC-HMS basin models (Rockaway, Whippany, Upper Passaic, Pompton, and Saddle) from a hypothetical 24-hour frequency storm were also compared to the LP III analysis for gage data available within those basins. This comparison was done to assess the results of the calibration process for the individual basins and is not directly comparable to the calibration process used for the 96-hour storm used for the Passaic Basin. The results of this analysis have been included in Appendix D. The analysis reflects the ability of the calibrated models to predict the 100-year discharge for the 24-duration storm event in the basin being modeled. The calibration of the 96-hour storm design storm used to develop 100-year discharges is, however, completed using the unsteady hydraulic model, and is discussed in Section D.5.2.7.

C. APPROACH AND METHODOLOGY

C.1 Model Selection and Modeling Framework

HEC-HMS 3.5 developed by the USACE was used for all hydrologic modeling completed in this study. All hydraulic models developed for the study used HEC-RAS 4.1.

As mentioned earlier, seven HEC-HMS Basins, four approximate unsteady state HEC-RAS models, one detailed unsteady state HEC-RAS model, and one detailed steady state HEC-RAS model were used to develop new multi-frequency discharges and water surface elevations for the 41.2-mile study reach. To facilitate the discussion of these models, this report has been organized into two groupings: the Upper Passaic and Lower Passaic Model Groups (Figures 5 and 6). The break between these two study reaches occurs at the Little Falls USGS Gaging Station. Approximate steady state HEC-RAS models were also used in the development of input parameters for Modified Puls routed reaches in some HEC-HMS basin models.

The Upper Passaic Modeling Group consists of five HEC-HMS models, 4 approximate unsteady state HEC-RAS models, and 18.2 miles of detailed unsteady state hydraulics modeling (Figure 5). This modeling system was developed to accommodate the unique storage and flow conditions, which can include flow reversals in the portion of Passaic between the USGS gages at Chatham and Little Falls (Central Basin). For this study reach, final discharges and water surface elevation rely on an unsteady state HEC-RAS analysis.

The Lower Passaic Modeling Group consists of one steady state HEC-RAS hydraulic study reach and two HEC-HMS basin models (Figure 6). The HEC-HMS basin models for this group rely on the discharge hydrograph from the upstream detailed unsteady state HEC-RAS model (Upper Passaic Modeling Group). The final discharges for this study reach depend on HEC-HMS modeling. Water surface elevations rely on a steady state HEC-RAS analysis.

For the Upper Passaic Modeling, the calibration of individual HEC-HMS basin models was completed with available gage data. An unsteady state detailed HEC-RAS model, however, completes the hydrologic model calibration for the Upper Passaic Model Group; it relies on the stage data for USGS gages located along the Passaic.

The Lower Passaic Model Group includes only a calibration of the Saddle Basin HEC-HMS model; no recent gage data was available for use in the calibration of the Lower Passaic HEC-HMS model. The steady state hydraulic model for the Lower Passaic was, however, calibrated using historical high water mark data.

Individual HEC-HMS basin models are most accurate at the downstream gage locations used in their calibration. There are numerous lakes and reservoirs in those basins that are not reflected in these models, but which may be of some local importance. The effects of these features in the basin models were accounted for with adjustments to curve numbers (CNs) and lag times. As a consequence, sub-basins located upstream of gage locations may not accurately predict 100-year flows within these HEC-HMS models. The final calibration of the model is only valid for the HEC-HMS/Unsteady HEC-RAS model linkage, and as such, the final hydrologic model calibration is only valid for the discharges predicted along the 41.2 Passaic River study reach using the unsteady state HEC-RAS model.

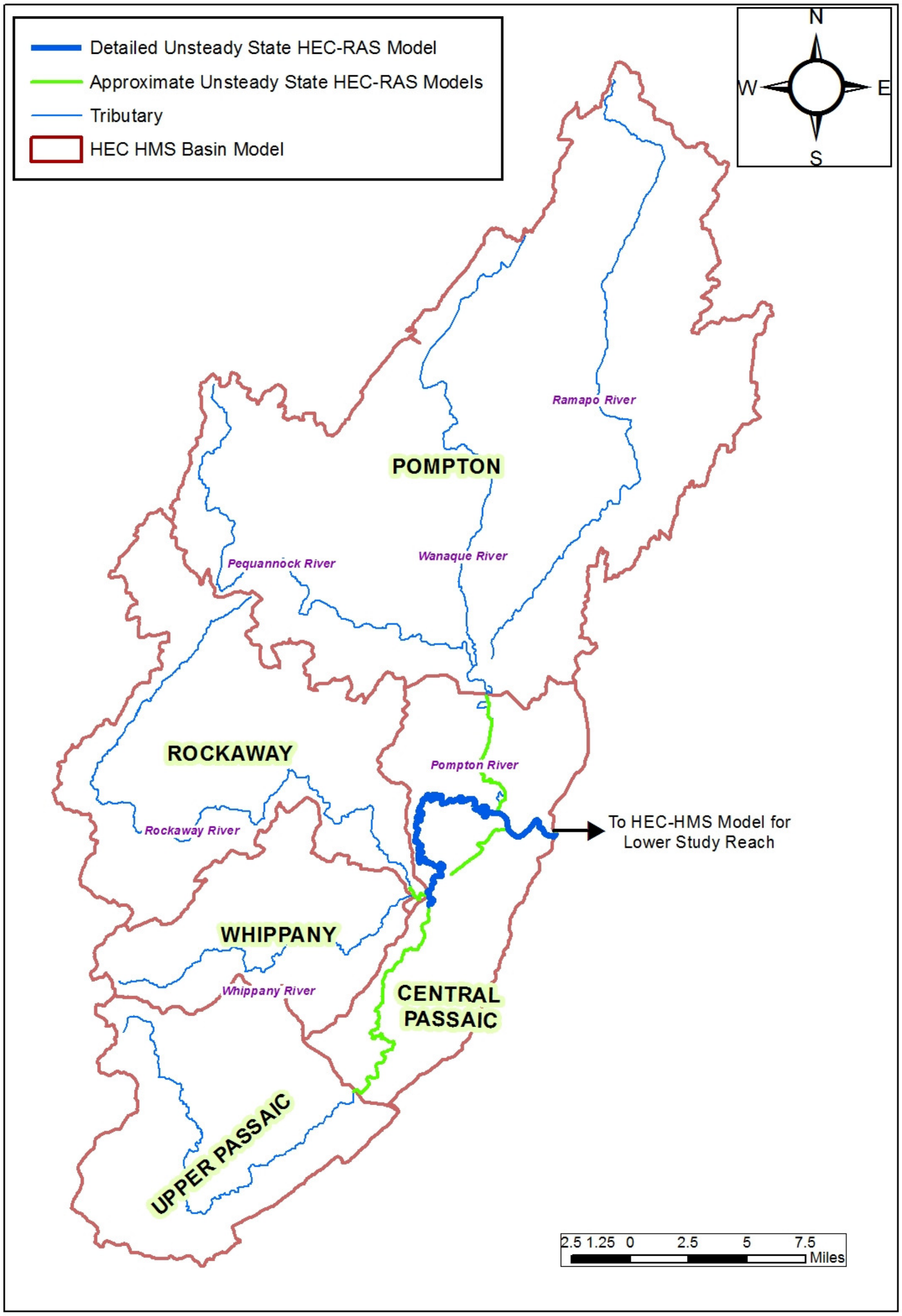


Figure 5. Upper Passaic Model Group

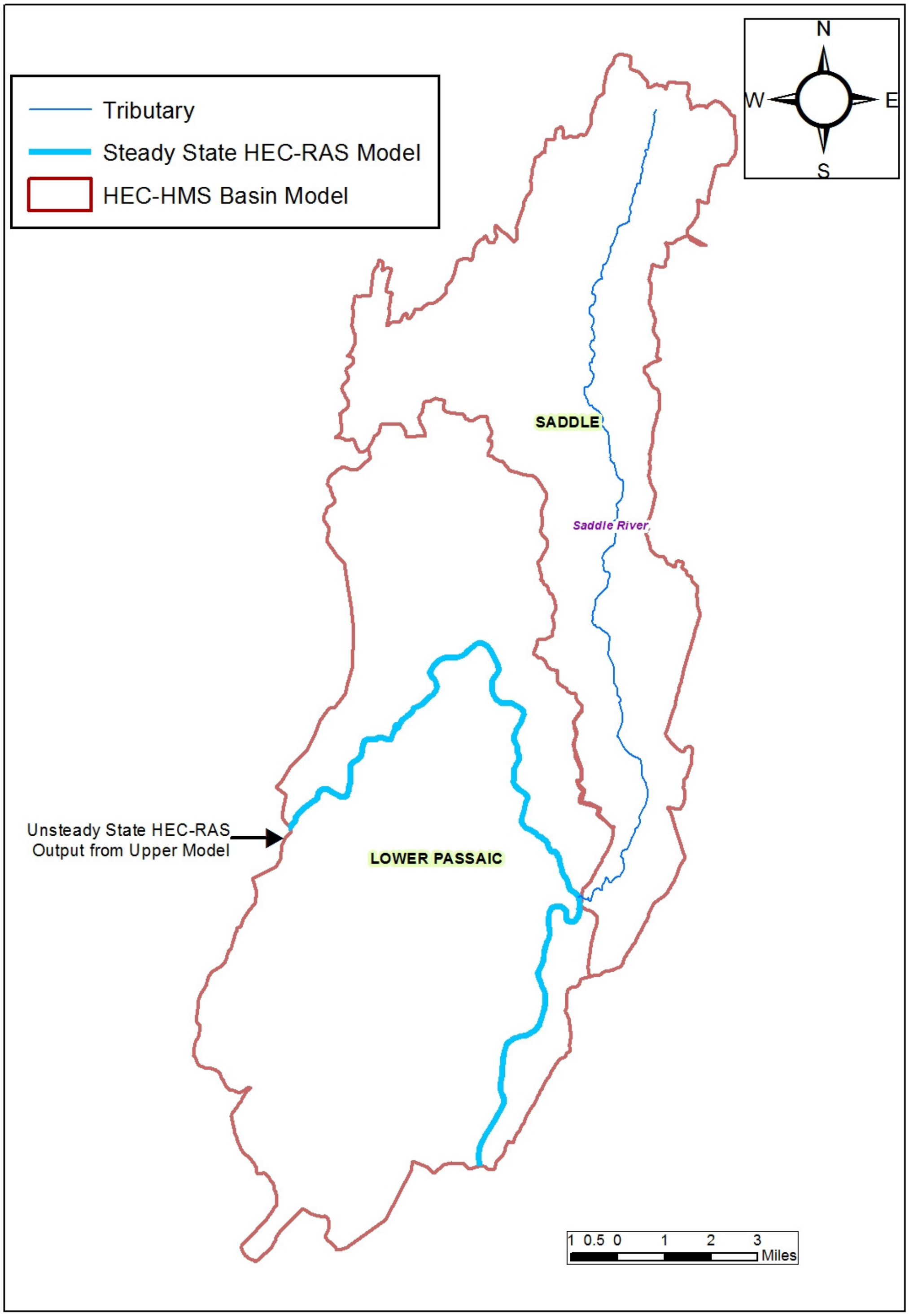


Figure 6. Lower Passaic Model Group

C.2 Watershed Delineations

Watershed boundaries and other morphological parameters such as stream lengths, slopes, longest flow paths, basin centroid, and centroid elevations use USGS 10-meter DEM data and the GeoHMS 3.4 extension for ArcGIS software published by the USACE. The longest flow path is the basis for calculation of the lengths and slopes for upland and channel flow paths. The DEMs used in this study come from the USGS website http://seamless.usgs.gov/website/seamless/viewer.htm referenced to a GCS and with elevations in meters above NAVD88. For the purpose of this project, the DEMs were re-projected into NJ State Plane (FIPS 2900) with the elevation converted to feet.

C.3 Infiltration/Loss Method

This study uses the NRCS CN method to simulate initial abstractions and infiltration rates. The initial runoff CNs were developed from SSURGO soil datasets downloaded directly from the NRCS's website (http://soils.usda.gov/survey/geography/ssurgo/). A discussion on the development of land use data and the assumptions concerning hydrologic conditions has been included under each sub-basin.

C.4 Transformation of Excess Rainfall to Runoff

The NRCS unit hydrograph method was used in all HEC-HMS models for excess rainfall transformation. In order to transform rainfall, lag times were calculated for each sub-basin. Lag time is defined as 0.6 times time of concentration. The time of concentration calculations were based on NRCS procedures outlined in Urban Hydrology for Small Watersheds (USDA, 1986) and the NRCS. These lag time values were refined during a subsequent calibration and validation process as discussed later in this report.

Data required to compute time of calculation, flow lengths, and channel slope were developed using ArcGIS, based on 10-meter USGS DEM topographic data. As per NRCS procedures, time of travel estimates was calculated for upland and channel flows. Upland flows were divided by forest, grass waterway, barren land, and urban, using aerial photography, with a final velocity determined from graphs found in Chapter 15 of the National Engineering Handbook. The transitions from upland to channel flows were determined from USGS 1:24,000 based visible channel mapping (USGS Quad blue lined streams). For channel flow, the average channel velocities were computed from 2-year flow using approximate HEC-RAS 4.0 hydraulic models developed for this study. The 2-year flows were computed from a plot of observed discharge versus drainage area relationship. LP III analysis was used to calculate 2-year flows at available USGS gauging stations near the study area. The travel time through reservoirs was determined from the method published in Chapter 15 of the National Engineering Handbook.

C.5 Channel and Reservoir Routing

Approximate steady state HEC-RAS analyses were developed for a range of discharges in order to develop the storage-discharge table required for Modified Puls reach routing in HEC-HMS. Eight-point Muskingum Cunge procedures were used on reaches where use of the Modified Puls routing procedures was not appropriate. Stage-storage and stage-discharge relationships for reservoirs were obtained from the government agencies in charge of the reservoir or from prior model studies. Appendix B provides details on the development of these rating curves.

Approximate unsteady HEC-RAS models for four tributaries were also developed for hydraulic routing of runoff hydrographs from the HEC-HMS basin model outlets to their respective confluence within the Central Passaic Study Reach. A detailed unsteady state hydraulic model is used for this study reach. USACE's ArcGIS based pre-processor; HEC-GeoRAS was used for generating the geometry file for the hydraulic model. River and cross-sectional geometry data were obtained from field survey for the main channel and extracted from the NJ LiDAR collected in 2006 for detailed hydraulic reaches. Cross-section geometries for the approximate study reaches were also obtained from the LiDAR terrain dataset. Appendix F has detailed information on the LiDAR datasets used in this study.

D. UPPER PASSAIC MODEL GROUP HYDROLOGIC & HYDRAULIC MODELING

This section of the modeling discussion is broken into five sub-sections. Four of these sub-sections (Rockaway, Whippany, Upper Passaic, and Pompton) discuss the details of the HEC-HMS modeling for these basins. The discussion for the Central Basin includes a discussion of the HEC-HMS modeling for this basin as well as the approximate and detailed unsteady state hydraulic routing completed with HEC-RAS for the Central Passaic Study Reach. The contents of each sub-section includes a discussion on simulation methods, assumptions, and model calibration, as well as any special situations encountered in the basin model and its resolution. A summary of final discharges and their comparison with the effective discharge are included in the discussion for the Central Sub-Section.

D.1 Rockaway Basin Hydrology

D.1.1 BASIN CHARACTERISTICS

The Rockaway Basin drains the Rockaway River through a series of small lakes and ponds and is fed along the way by several tributaries. The basin is about 135 square miles in an area upstream of its confluence with the Whippany River. At approximately 35 miles long, the Rockaway River rolls out of Lake Madonna in Sparta Township, Sussex County, before crossing the Morris County Line. The River then turns sharply south and flows east passing through Boonton Reservoir before emptying into Passaic River. The major tributaries to the Rockaway River are Green Pond River, Beaver Brook, and Whippany River. Under high flow conditions, the Rockaway River below the reservoir at Boonton, NJ, is affected by backwater from the Passaic River. Figure 7 depicts the location of Rockaway Basin relative to its major tributaries.

The upper basin is mostly a wooded mountainous valley, while lower portions of the basin consist primarily of suburban land uses. Large water supply reservoirs and recreational dams such as Boonton and Splitrock reservoirs affect the movement of water through the basin. Generally, the topography of the basin is steep at the upstream part and relatively flat near the confluence with the Passaic River. The elevation within the basin ranges from 160 to 1400 feet.

The Rockaway Basin Model includes 15 reaches and 5 reservoirs (Boonton Reservoir, Rockaway Reservoir, Picatinny Reservoir, Green pond Reservoir, and Lake Valhalla). In addition, to reflect the possible backwater effect of the Passaic on the reach downstream of the Boonton Reservoir, routing for this reach uses an approximate unsteady state HEC-RAS model.

The HEC-HMS model for the basin was calibrated and validated using two USGS gaging stations: Rockaway River above the reservoir at Boonton, NJ (gage 01380500) and Rockaway River below the reservoir at Boonton, NJ (gage 01381000).

D.1.2 WATERSHED DELINEATION

Sub-basin boundary delineations reflect differences in land use, topography, river confluences, lakes, and reservoir locations as well as USGS gage locations (Figure 8). Twenty-seven sub-basins upstream of the Rockaway's confluence with the Passaic River are included in the HEC-HMS model for the basin, ranging in size from 0.52 to 16.70 square miles.

Drainage areas delineated for the hydrologic analysis in this study are consistent with the effective FIS and USGS gage drainage areas. As shown in Table 3, the new delineation areas are consistent with both the effective and USGS reported drainage areas at all the locations at which comparative data were available.

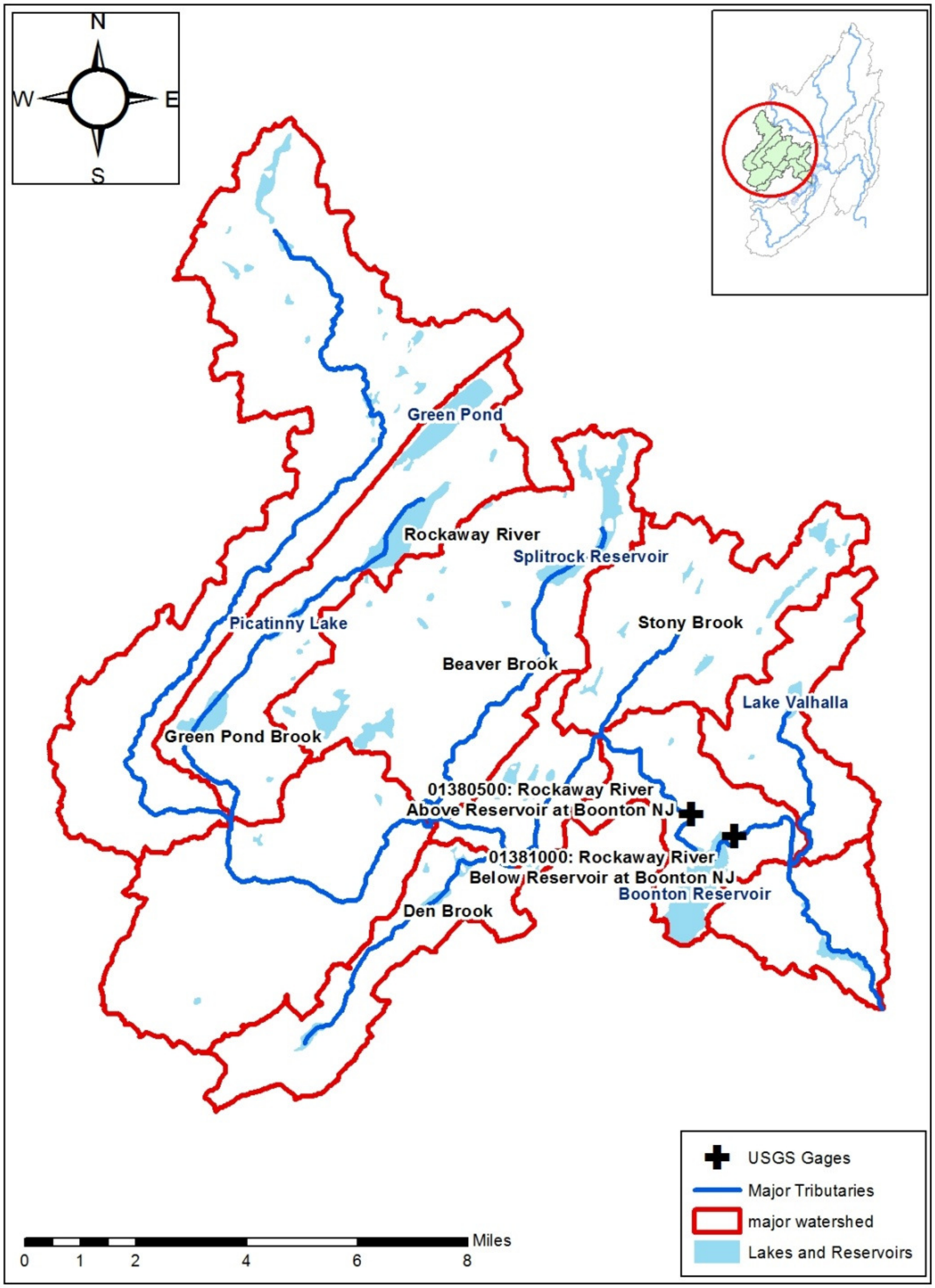


Figure 7: Rockaway River Basin

Table 3: Drainage Area Comparison along Rockaway River and Its Tributary

	Drainage area [sq.mi.]		
	FIS	**New Delineation**	**USGS Gage**
Location along Rockaway River			
Upstream of confluence with Whippany	134.30	134.76	[-]
Downstream of Boonton reservoir	119.00	119.78	119.00
Upstream of Boonton reservoir	116.00	116.45	116.00
Upstream of confluence with Beaver Brook	63.85	64.82	[-]
Confluence with Green Pond Brook	31.19	30.95	[-]
Location along Rockaway Tributaries			
Den Brook-US of the confluence with the Rockaway	8.61	8.48	[-]
Den Brook-US of the confluence with the Rockaway	8.61	8.48	[-]
Beaver Brook-US of confluence with Rockaway	22.6	22.59	[-]

D.1.3 INITIAL SCS CN AND LAG TIMES

The initial set of CN values developed for the HEC-HMS basin model ranged from 73 to 88. The highest values occurred in the lower part of the basin where development is significant while the forested part of the upper watershed had the lowest CN values (Figure 9 and Table 4). Initial lag time estimates use the SCS procedures discussed earlier, except for channel flow velocities, which were obtained from approximate HEC-RAS 4.0 hydraulic models, developed for a 2-year reoccurrence interval. The 2-year recurrence interval discharges were obtained from the plot of observed discharge versus drainage area relationship for selected USGS gauging stations near the study area (Figure 10 and Table 5). Table 3 lists the lag time estimates computed for each sub-basin in Rockaway basin.

Figure 8: Rockaway Sub-basins and Reaches

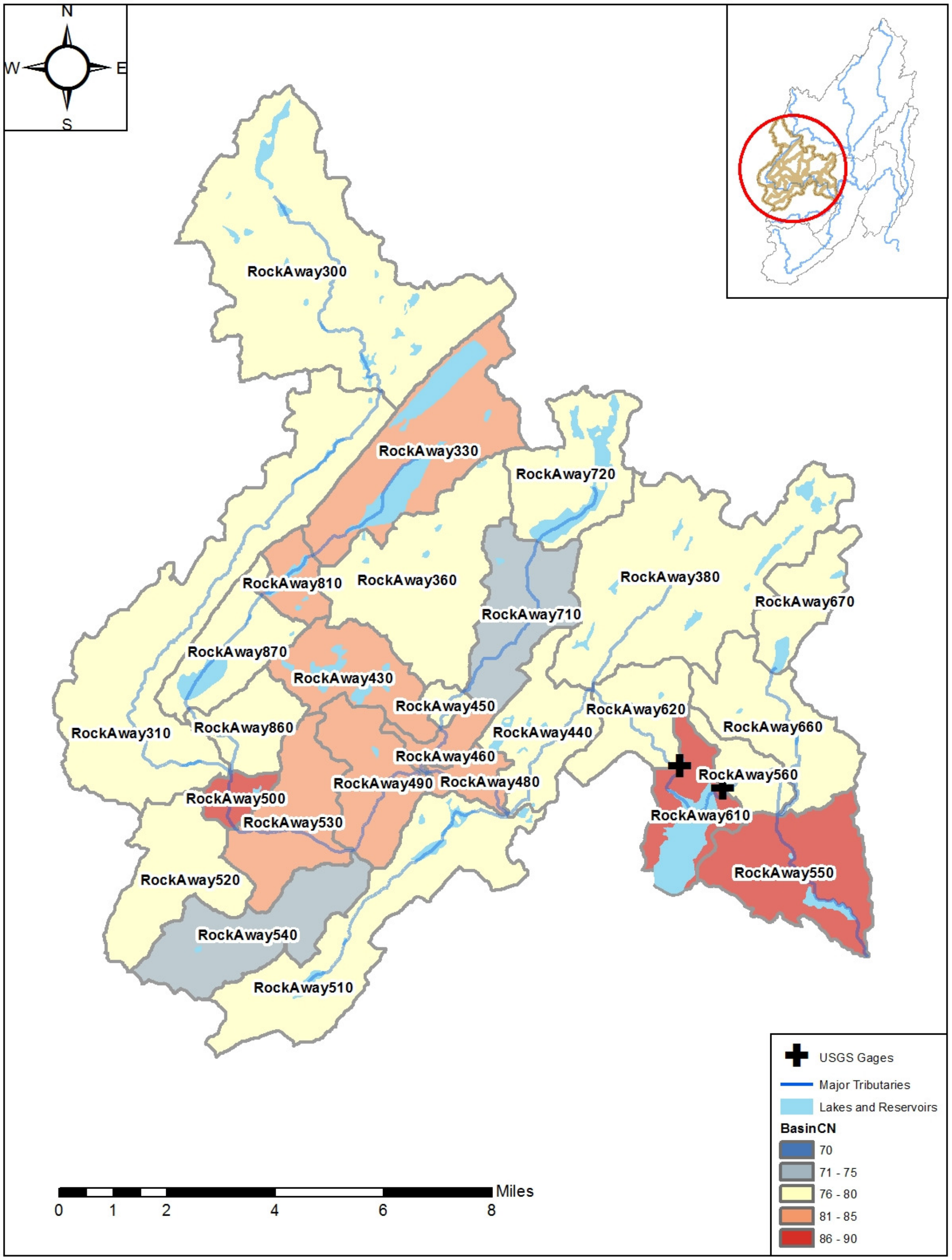


Figure 9: Initial Curve Number Values for Rockaway Sub-basin

Table 4: Sub-basin Drainage Areas in Rockaway Watershed

Sub-basin Name	Drainage Area (sq.mi.)	Initial Basin CN	Initial Basin LAG time [min]
RockAway300	16.70	76	206.32
RockAway310	14.25	76	324.77
RockAway330	7.55	80	80.77
RockAway360	8.06	76	206.09
RockAway380	12.42	76	236.80
RockAway430	3.73	84	44.83
RockAway440	3.80	78	419.16
RockAway450	0.52	80	101.07
RockAway460	1.06	81	81.66
RockAway480	1.15	83	63.08
RockAway490	3.84	83	77.78
RockAway500	0.98	87	91.71
RockAway510	8.48	76	163.73
RockAway520	4.64	77	124.93
RockAway530	4.34	84	162.45
RockAway540	5.11	73	179.38
RockAway550	5.81	86	374.13
RockAway560	1.65	79	107.44
RockAway610	3.33	88	71.60
RockAway620	3.19	79	144.66
RockAway660	4.90	79	91.11
RockAway670	2.62	77	114.55
RockAway710	4.38	73	97.86
RockAway720	4.83	79	145.65
RockAway810	1.49	82	44.03
RockAway860	2.40	80	153.55
RockAway870	3.53	79	168.39

Table 5: USGS Gauging Stations Used to Develop 2-year Flow

Gage#	2Yr flow [cfs]	DA [sq.mi.]	Storage[%]	Slope [ft/mi]
01381400	687.5	13.9	9.25	86.2
01378690	737.1	8.8	5.43	50.2
01379000	813.2	54.2	30.1	7.15
01381800	857.1	68.7	15.4	15.9

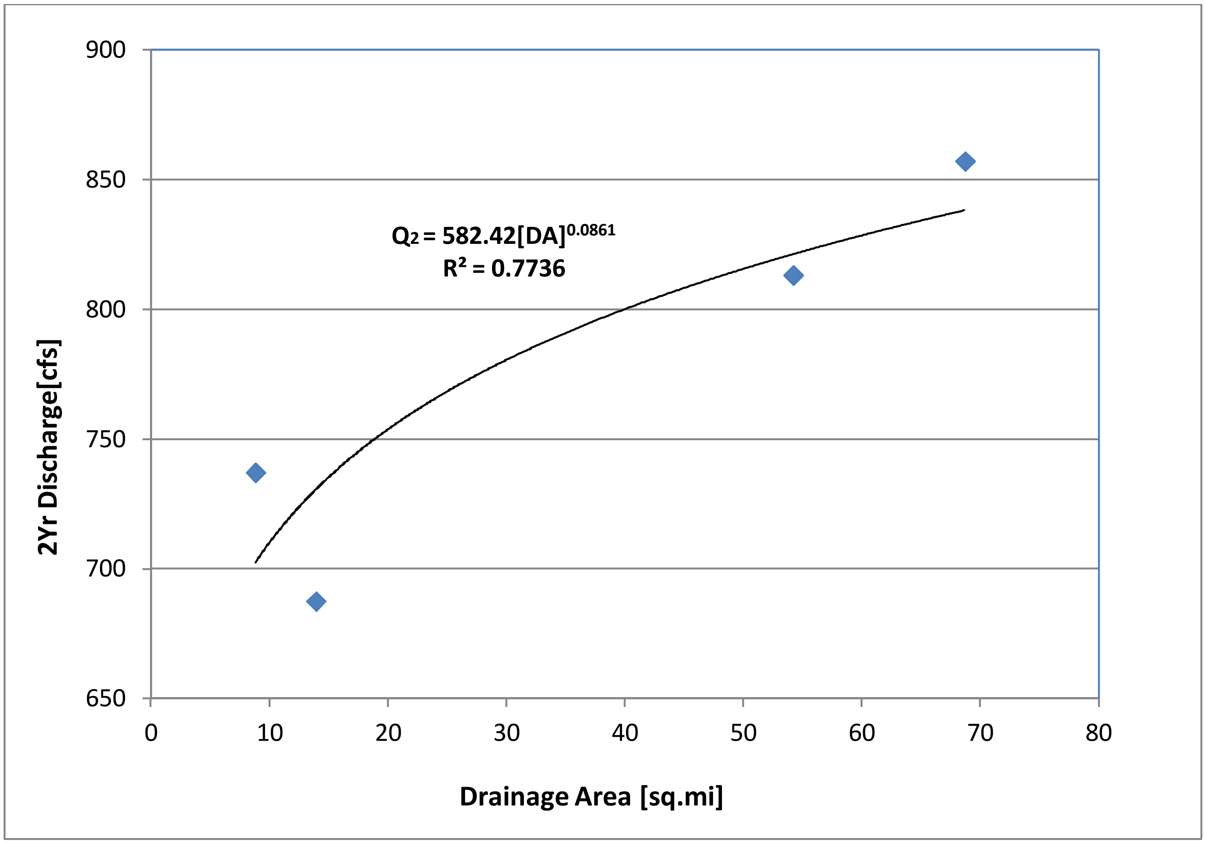


Figure 10: Curve Fitting Plot of the 2-year Discharge Versus Drainage Area: Rockaway Basin

D.1.4 CHANNEL & RESERVOIR ROUTING

Channel flow routing in the Rockaway model uses the Modified Puls method. The storage discharge relationships required for the Modified Puls routings are based on approximate HEC-RAS models developed for this purpose. The geometric data for theses reaches were generated using a Terrain (ESRI) built from the NJ LiDAR data. For reach lengths longer than 2 miles, reaches were divided into sub-reaches as described in the HEC-HMS reference manual.

Backwater effects of the Passaic on the reach downstream of the Boonton Reservoir required the use of approximate unsteady state hydraulic HEC-RAS model for the routing of this reach.

Flow routing through the Boonton, Splitrock, Picatinny, Green Pond, and Lake Valhalla reservoirs uses the stage/storage/discharge relationships developed for each facility. The JCUA provided the spillway crest elevation data for the Boonton, Splitrock, and Lake Valhalla reservoirs. The elevation-storage and/or elevation-area tables, used to route flows through each reservoir, use 10-meter USGS DEM topographic data. Data from the effective HEC-1 model were used to establish elevation-area relationships for the Boonton and Splitrock reservoir. Two smaller reservoirs (Green Pond and Picatinny Lake Valhalla) were also included in the model, but had limited impact on the 100-year discharges. Area-elevation and stage-storage relationships for reservoirs reflected in the Rockaway HEC-HMS Basin Model can be found in Appendix B.

D.1.5 MODEL CALIBRATION AND VALIDATION

Observed discharge data from USGS gauging stations 01380500 and 01381000 were available for use in the calibration/validation processes for the HEC-HMS model. These two gages are located upstream and downstream of Boonton Reservoir

D.1.5.1 *EVENT PRECIPITATION*

After reviewing the stream gage and rainfall data available for model calibration between 1987 and 2009, two large flood events, September 1999 and September 2004, were selected for model calibration and validation respectively. For the September 1999 flood event, the rainfall data were obtained from National Climatic Data Center (NCDC), which were gathered from gaging stations located at Charlottesburg and Bound Brook (Appendix G). Rainfall from these gages is distributed in the model using the inverse-distance-squared weighting technique. Processed MPE rainfall radar data obtained from NOAA was used for the September 2004 validation event.

D.1.5.2 *MODEL CALIBRATION AND VALIDATION PROCESS*

During the calibration process for the September 1999 event, the antecedent moisture/runoff condition was determined to be close to SCS AMC-1 (antecedent moisture condition - dry). A review of the rainfall data and reservoir levels prior to this event supports this assumption. Procedures described by Ponce (1996) were used to calculate AMC-1 values from the AMC-2 or average conditions developed from land use and soils data. Ponce's equation relates the dry antecedent moisture condition (AMC-1) curve number with the average antecedent moisture condition 2 (AMC-2) as shown in Equation 1.

$$\mathrm{CN}_1 = \frac{\mathrm{CN}_2}{22.281 - 0.01281\mathrm{CN}_2} \quad \text{--Equation 1}$$

Where: CN1 is the curve number corresponding to antecedent moisture condition - 1

CN2 is the curve number corresponding to antecedent moisture condition - 2

Table 6 shows a comparison of the AMC-2 CN to AMC-1 values calculated from this equation. The calibrated AMC 1 values are converted back to the average condition (AMC 2) curve number values for the September 2004 model validation event.

To match the observed hydrograph for the calibration event of September 1999, the AMC-1 curve number was reduced by an additional 8%. Initial lag times also required an average 5% reduction to the matching observed hydrographs for the September 1999 event at USGS gage 01380500 (Figure 11). USGS gage 01381000, located below the Boonton Reservoir, measured a discharge of only 200 cubic feet per second (cfs) for the September 1999 event, and an output hydrograph at this gage was not included in this report. The starting water surface levels for both the Boonton and Splitrock reservoirs were not available for either the calibration or validation events. For both events, the water surface elevations in these reservoirs were adjusted to match observed gage data. Table 7 summarizes the calibrated CN and lag times for the Rockaway Watershed sub-basins.

The calibrated model simulated hydrographs were consistent with the observed hydrographs at both the upstream and downstream gages for September 2004 event run. Figures 12 and 13 illustrate the modeled and observed hydrographs at USGS gauges 01380500 and 01381000 for this event. Table 8 and Table 9, respectively, provide comparisons of calibration and validation event data with observed data.

Table 6: AMC-2 and AMC 1 Curve Number for Rockaway Watershed

Sub-basins	Curve Number		Difference [%]
	AMC-2 CN values	AMC-1 CN value	
RockAway300	72	53	26%
RockAway310	72	53	26%
RockAway330	76	58	23%
RockAway360	72	53	26%
RockAway380	73	54	26%
RockAway430	80	63	21%
RockAway440	74	56	25%
RockAway450	76	58	24%
RockAway460	77	60	23%
RockAway480	79	62	21%
RockAway490	79	62	21%
RockAway500	83	68	18%
RockAway510	72	53	27%
RockAway520	73	54	26%
RockAway530	80	64	20%
RockAway540	69	49	28%
RockAway550	81	66	19%
RockAway560	75	57	24%
RockAway610	84	70	17%
RockAway620	75	57	24%
RockAway660	75	57	24%
RockAway670	74	55	25%
RockAway710	70	50	28%
RockAway720	75	57	24%
RockAway810	78	61	22%
RockAway860	76	58	24%
RockAway870	75	57	24%

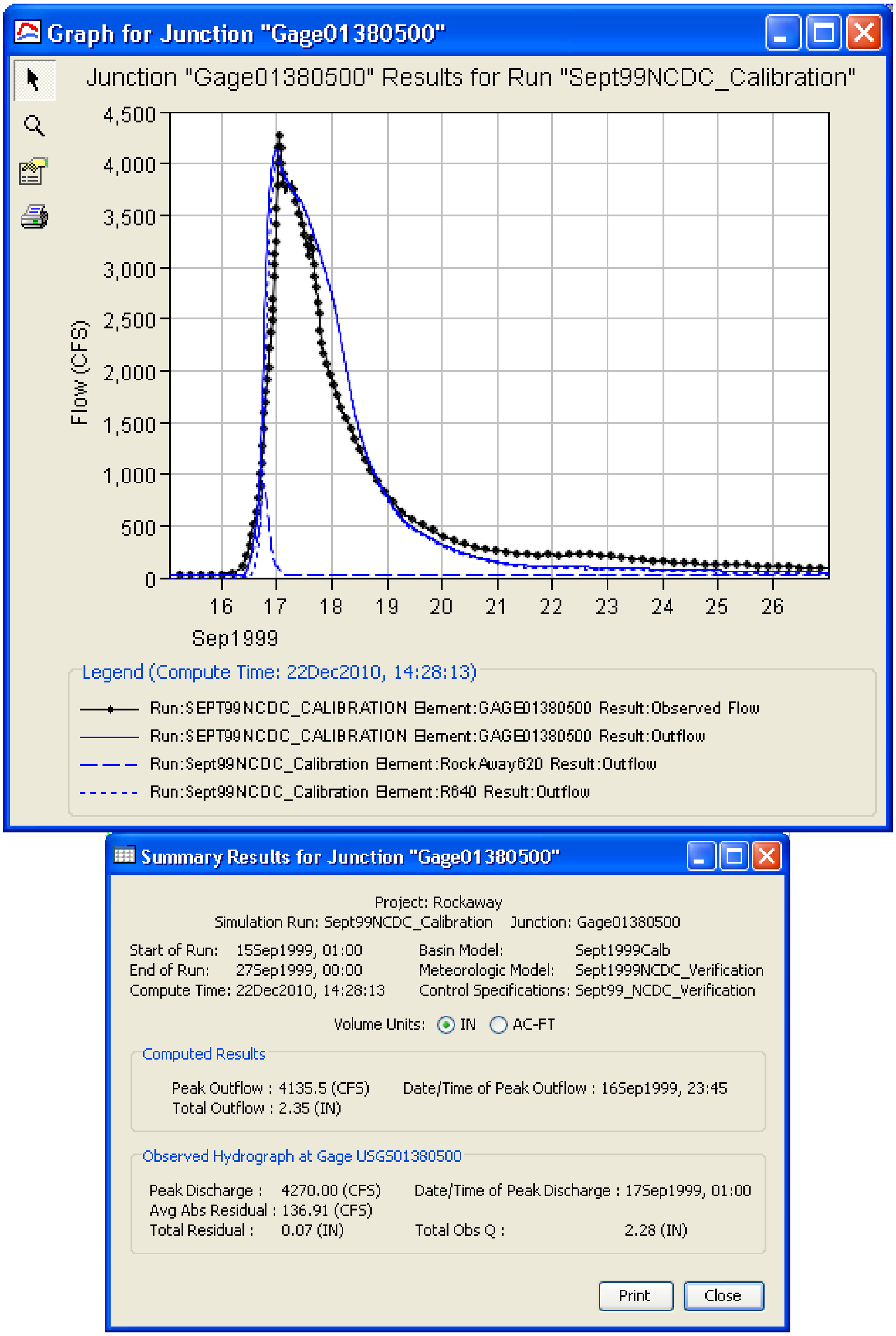


Figure 11: September 1999 Calibration Model Runs Result at USGS Gage Upstream of Boonton Reservoir (01380500)

Table 7: Initial and Calibrated Parameter Values for Rockaway Basin

Sub-basins	Basin Curve Number			Basin LAG time [min]		
	Initial value	Calibration Value (AMC -2)	Initial CN Change (%)	Initial Value	Calibration value	Initial Lag Change (%)
RockAway300	76	72	-5%	206.32	196.01	-5%
RockAway310	76	72	-5%	324.77	308.53	-5%
RockAway330	80	76	-5%	80.77	76.73	-5%
RockAway360	76	72	-5%	206.09	195.78	-5%
RockAway380	76	73	-4%	236.80	224.96	-5%
RockAway430	84	80	-5%	44.83	42.59	-5%
RockAway440	78	74	-5%	419.16	398.20	-5%
RockAway450	80	76	-5%	101.07	96.02	-5%
RockAway460	81	77	-5%	81.66	77.57	-5%
RockAway480	83	79	-5%	63.08	59.93	-5%
RockAway490	83	79	-5%	77.78	73.89	-5%
RockAway500	87	83	-5%	91.71	87.13	-5%
RockAway510	76	72	-5%	163.73	155.55	-5%
RockAway520	77	73	-5%	124.93	118.68	-5%
RockAway530	84	80	-5%	162.45	154.33	-5%
RockAway540	73	69	-5%	179.38	170.41	-5%
RockAway550	86	81	-6%	374.13	355.43	-5%
RockAway560	79	75	-5%	107.44	102.07	-5%
RockAway610	88	84	-5%	71.60	68.02	-5%
RockAway620	79	75	-5%	144.66	137.43	-5%
RockAway660	79	75	-5%	91.11	86.56	-5%
RockAway670	77	74	-4%	114.55	108.83	-5%
RockAway710	73	70	-4%	97.86	92.97	-5%
RockAway720	79	75	-5%	145.65	138.36	-5%
RockAway810	82	78	-5%	44.03	41.83	-5%
RockAway860	80	76	-5%	153.55	145.87	-5%
RockAway870	79	75	-5%	168.39	159.97	-5%

Table 8: Calibration Event Results for September 1999

Calibration September 1999											
Location	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Above Boonton Reservoir	1380500	116	4,136	4270	-3%	14,667	14,186	3%	23:45	1:00	1:15

Table 9: Validation Event Results for September 2004

Validation September 2004											
Location	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Above Boonton Reservoir	1380500	116	2,067	2120	-3%	10,355	11770	-12%	5:00	10:15	5:15
Below Boonton Reservoir	1381000	119	1,907	1,990	-4%	11,930	N/A	N/A	18:45	16:15	2:30

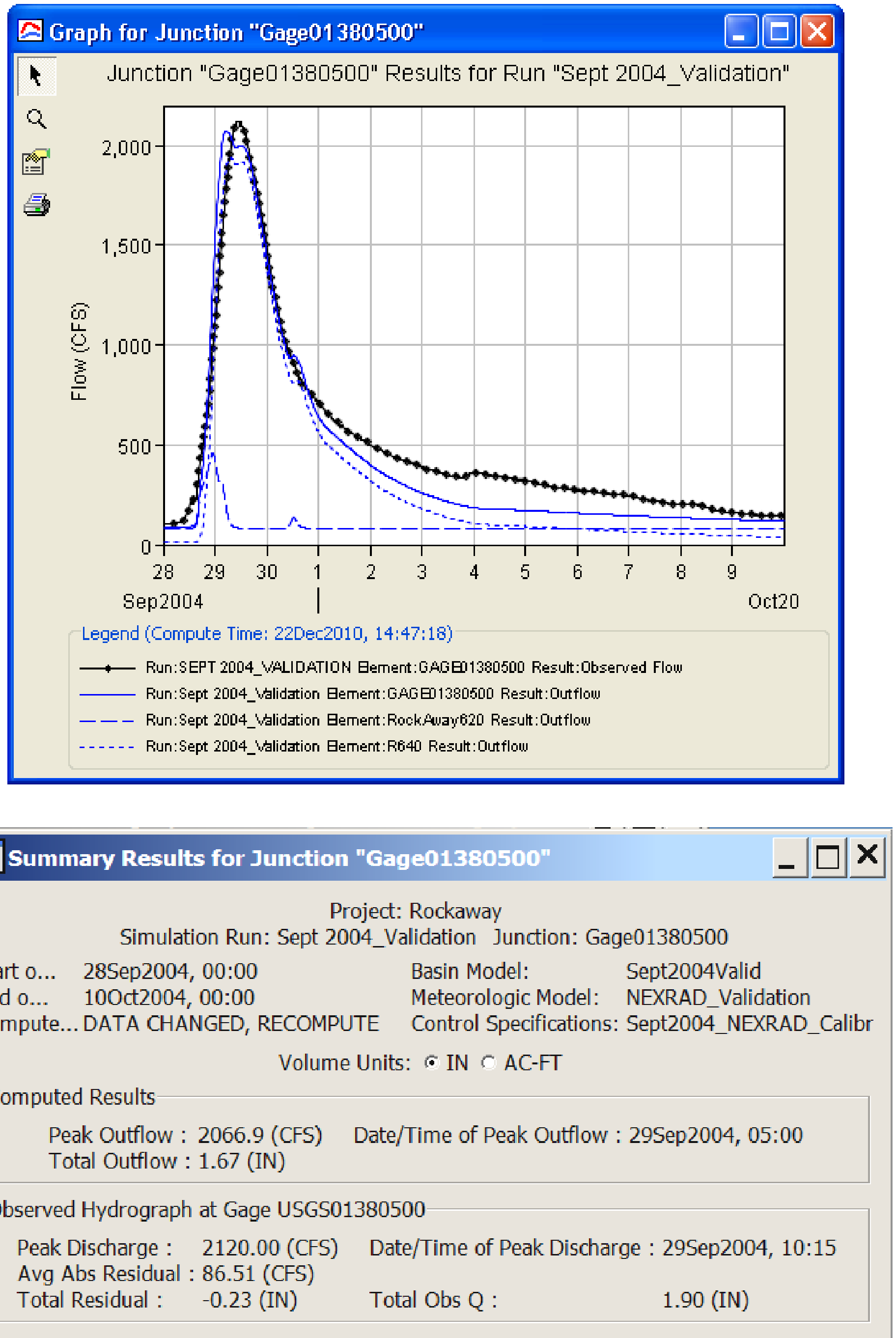
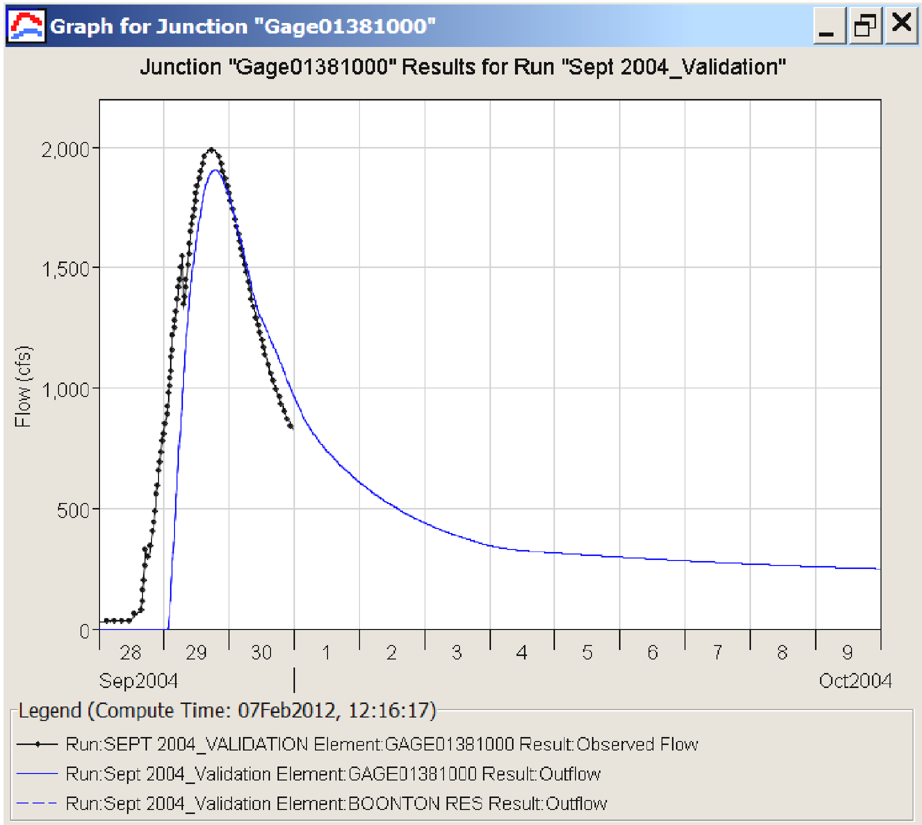
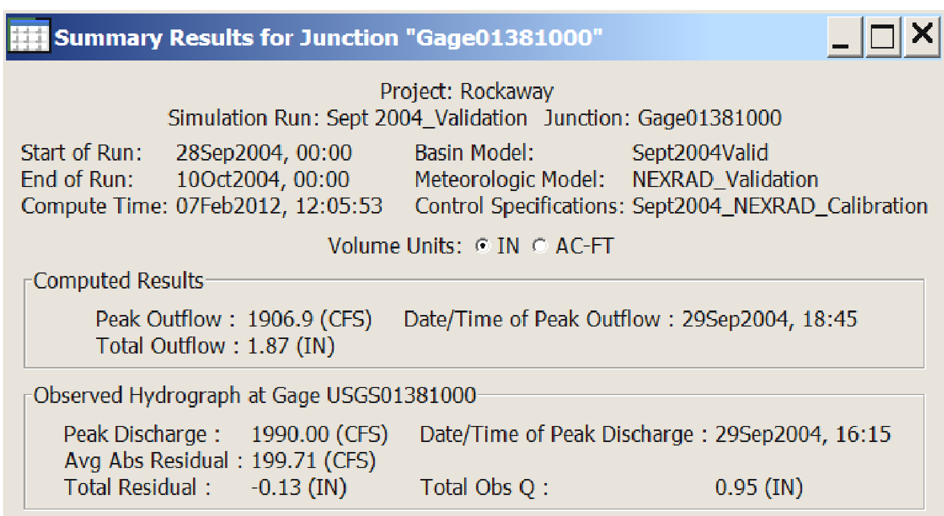


Figure 12: September 2004 Validation Event at the Gage Upstream of Boonton Reservoir (01380500)




Summary Results for Junction "Gage01381000"

Project: Rockaway
Simulation Run: Sept 2004_Validation Junction: Gage01381000

Start of Run:	28Sep2004, 00:00	Basin Model:	Sept2004Valid
End of Run:	10Oct2004, 00:00	Meteorologic Model:	NEXRAD_Validation
Compute Time:	07Feb2012, 12:05:53	Control Specifications:	Sept2004_NEXRAD_Calibration

Volume Units: IN AC-FT

Computed Results

Peak Outflow : 1906.9 (CFS) Date/Time of Peak Outflow : 29Sep2004, 18:45
Total Outflow : 1.87 (IN)

Observed Hydrograph at Gage USGS01381000

Peak Discharge : 1990.00 (CFS) Date/Time of Peak Discharge : 29Sep2004, 16:15
Avg Abs Residual : 199.71 (CFS)
Total Residual : -0.13 (IN) Total Obs Q : 0.95 (IN)

Figure 13. September 2004 Validation Model Run Result at the Gage Downstream of Boonton Reservoir (01381000)

D.2 Whippany Basin Hydrology

D.2.1 BASIN CHARACTERISTICS

The Whippany Basin is located in the southwest portion of Passaic Basin and is completely contained within Morris County, NJ. At its mouth, the total drainage area of the basin is about 68.5 square miles. Figure 14 illustrates the basin's location with the Passaic River Basin. The Whippany River originates in the First Watching Mountains and flows in a westerly direction before merging with the Rockaway River, which ultimately empties into the Passaic River almost within a mile of its confluence with the Whippany. The topography near the confluences is flat and contains many swamps and marshes. The largest of these, the Hatfield swamp, extends from the Black Brook/Whippany confluence to the Rockaway/Passaic confluence. Another large swamp, the Black Meadows, extends from the Black Brook/Whippany River confluence, upstream into Black Brook for a distance of about 1.5 miles.

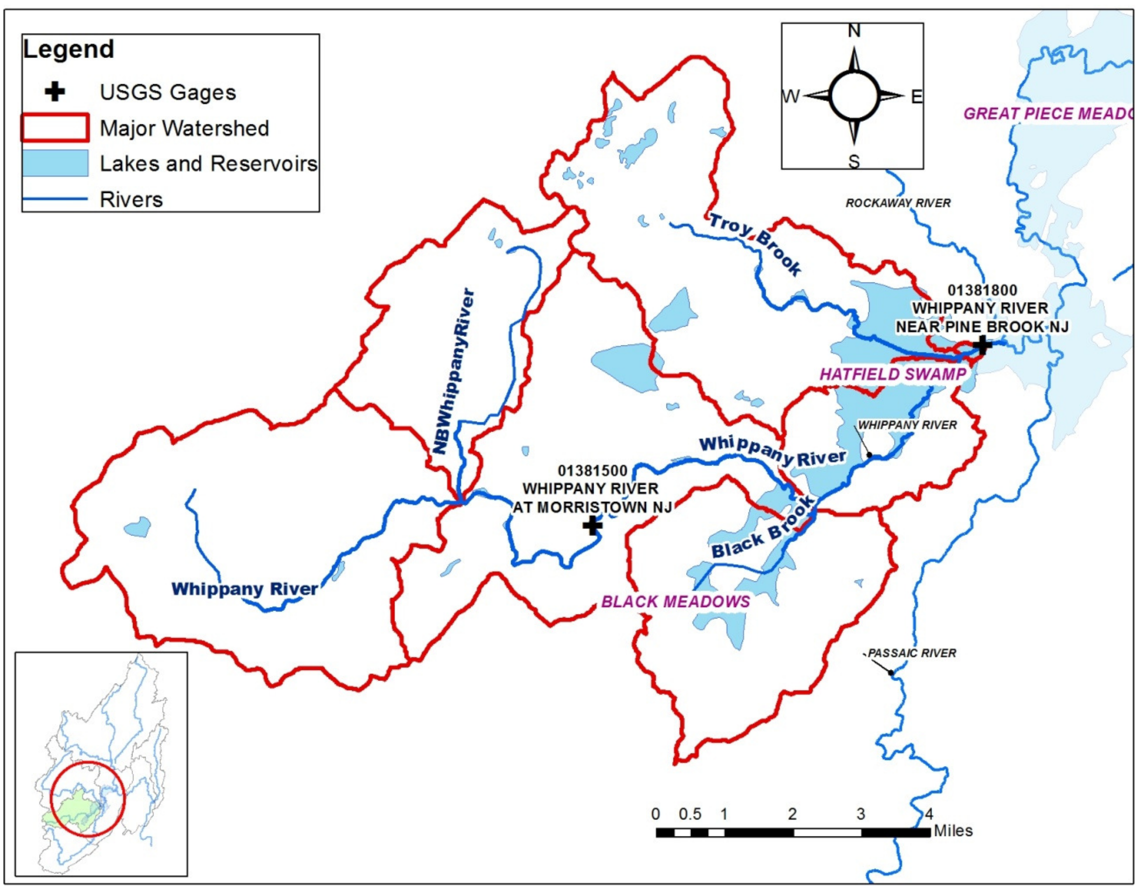


Figure 14: Whippany River Basin Features

D.2.2 RAINFALL-RUNOFF MODEL

D.2.2.1 *MODEL SELECTION*

The Whippany HEC-HMS model includes the complete basin upstream of its confluence with the Rockaway River. Two flow gauges operated by USGS on the river at Morristown, NJ (01381500) and Pine Brook, NJ (01381800) were used for model calibration and validation purposes. During high flows, unique hydraulic conditions prevail in the lower marshy portions of the Whippany River as backwaters from the Rockaway and Passaic rivers influence the flows in the confluence area. The influence of backwaters along the Whippany River may extend from its outlet upstream to its confluence with Black Brook. Reaches along the Whippany River, characterized by swampy conditions, are routed using reservoir routing techniques.

D.2.2.2 *WATERSHED DELINEATION*

Figure 15 illustrates the HEC-HMS sub-basin divisions for the Whippany Model and Table 7 lists their corresponding basin drainage areas. Whippany contains a number of natural storage areas, and the amount of flow attenuation they provide varies. In the current modeling effort the biggest storage area, Hatfield swamp, has been included in the model configuration. Smaller storage areas in the watershed have minimal impacts on the large flow events and are not included in the model. This watershed does not contain any man-made structures such as dams or reservoirs that could affect the flows.

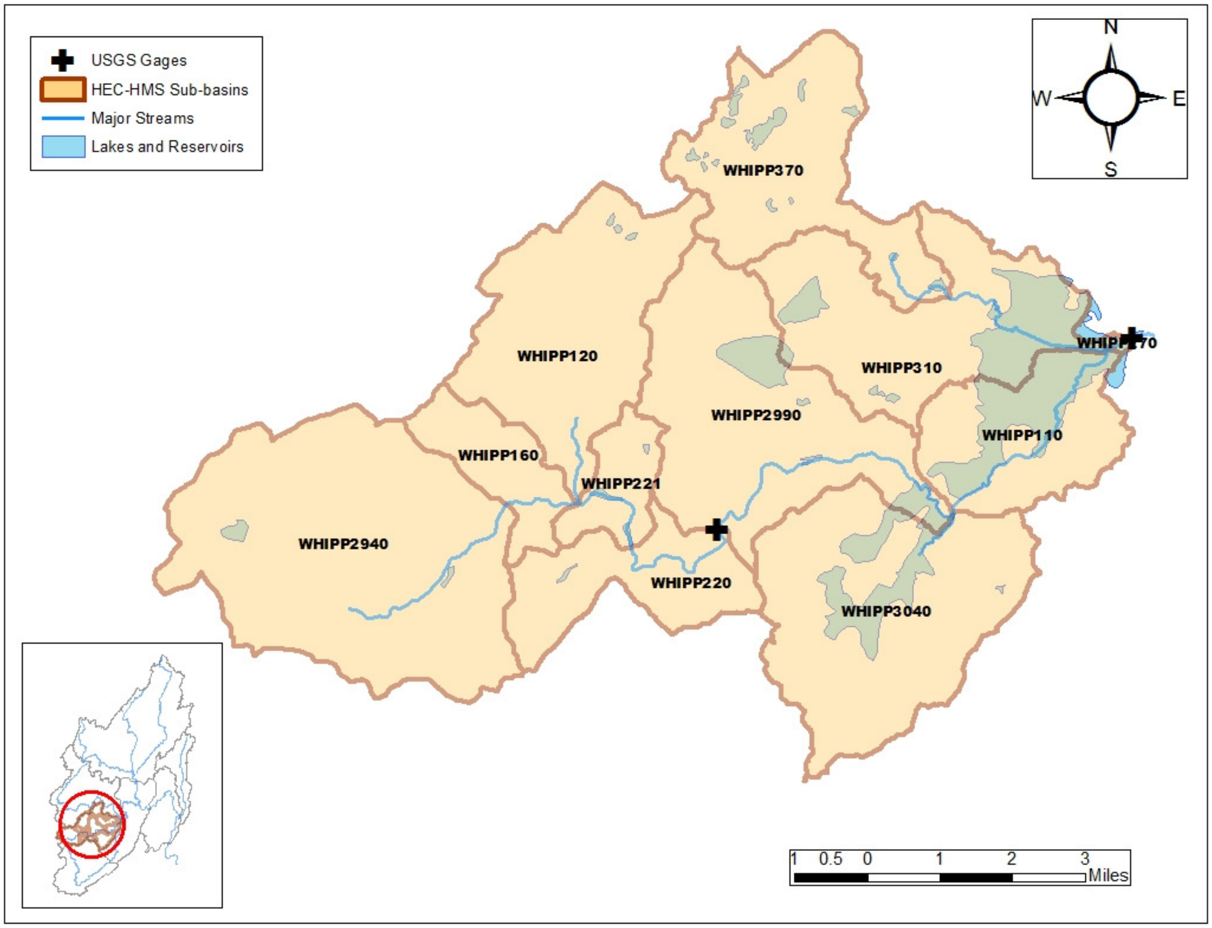


Figure 15: Sub-basin and Reach Configuration of the Whippany Model

D.2.2.3 *Initial SCS CN and Lag Times*

Sub-basin CN values generally ranged from 68 to 87 (Figure 16). Lower values occur in the headwater sub-basins, which consists primarily of forestland while higher values occur in the central and lower sub-basins, which consist primarily of urban land uses. The initial CN and lag times computed using methods discussed earlier in section C.4 are summarized in .

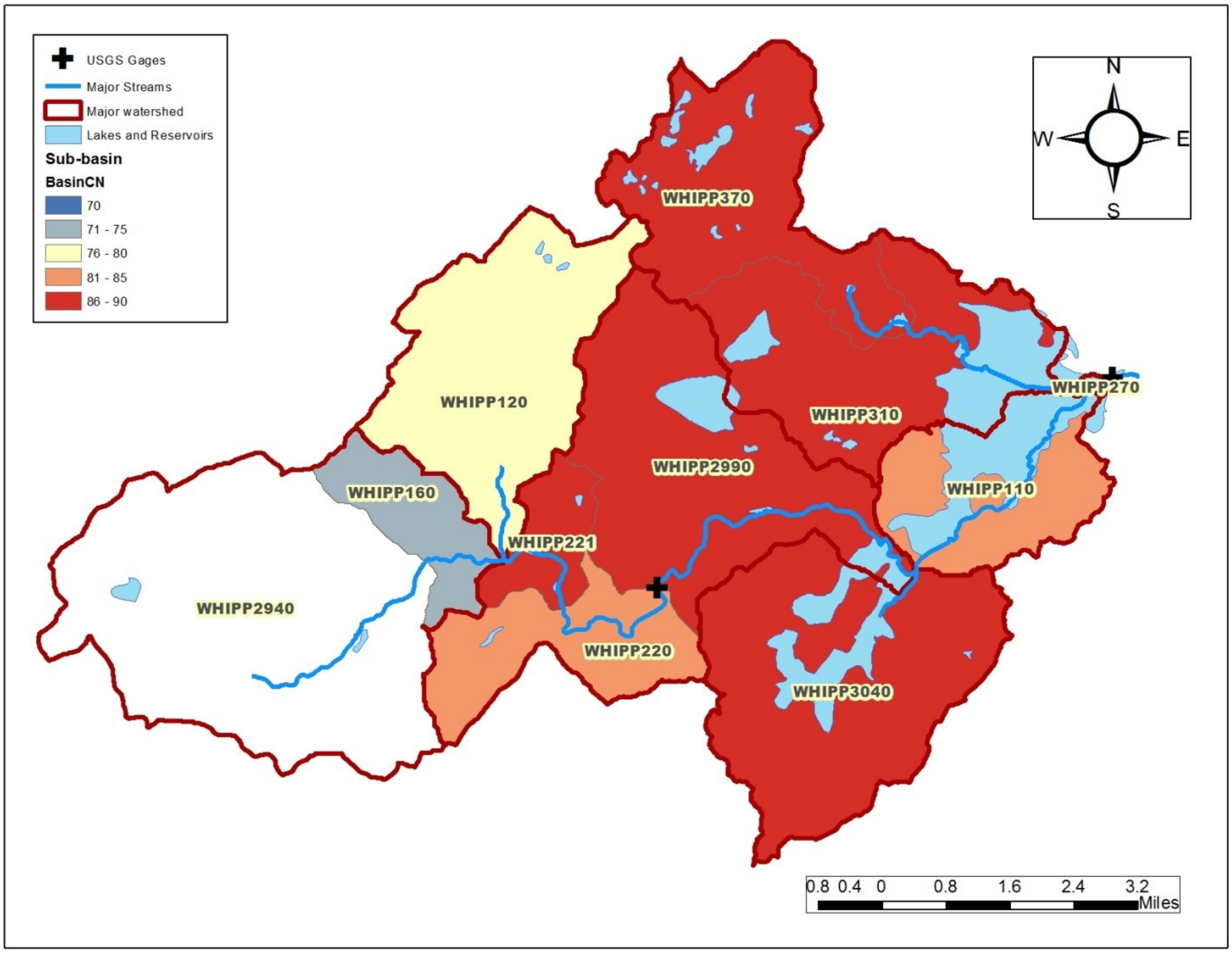


Figure 16: Initial Curve Number Values Developed for the Whippany River Model

Table 10: Whippany River Model Sub-basin Areas

Sub-basin	Area (Sq.Mile)	Initial Basin CN	Initial Lag Time
WHIPP2940	13.93	68	275
WHIPP120	7.75	77	178
WHIPP160	2.40	75	85
WHIPP221	1.90	86	36
WHIPP220	3.90	85	89
WHIPP3040	9.87	86	367
WHIPP2990	9.28	87	237
WHIPP310	7.73	85	301
WHIPP370	6.74	85	201
WHIPP110	4.79	84	186
WHIPP270	0.08	84	30

D.2.2.4 *CHANNEL ROUTING*

The Whippany River Basin Model uses two different hydrologic channel routing methods. The routing approach was adopted based on whether or not free flowing or normal depth assumptions were applicable to a reach. In the upstream portions of the river, free flowing conditions exist during high flows; however, backwater from the Passaic River effects flows in the lower reaches. Therefore, the Modified-Puls hydrologic routing technique was used for the reaches located upstream of Morristown gage. The storage routing along the downstream reaches and the swamp near the Pine Brook gages was accomplished using the reservoir routing technique. The Elevation-Discharge relationship required for reservoir routing was developed using a steady-state HEC-RAS model, and the Elevation-Storage relationship was developed using HEC-GeoRAS. Figure 17 illustrates the model reaches and the adopted techniques employed for routing.

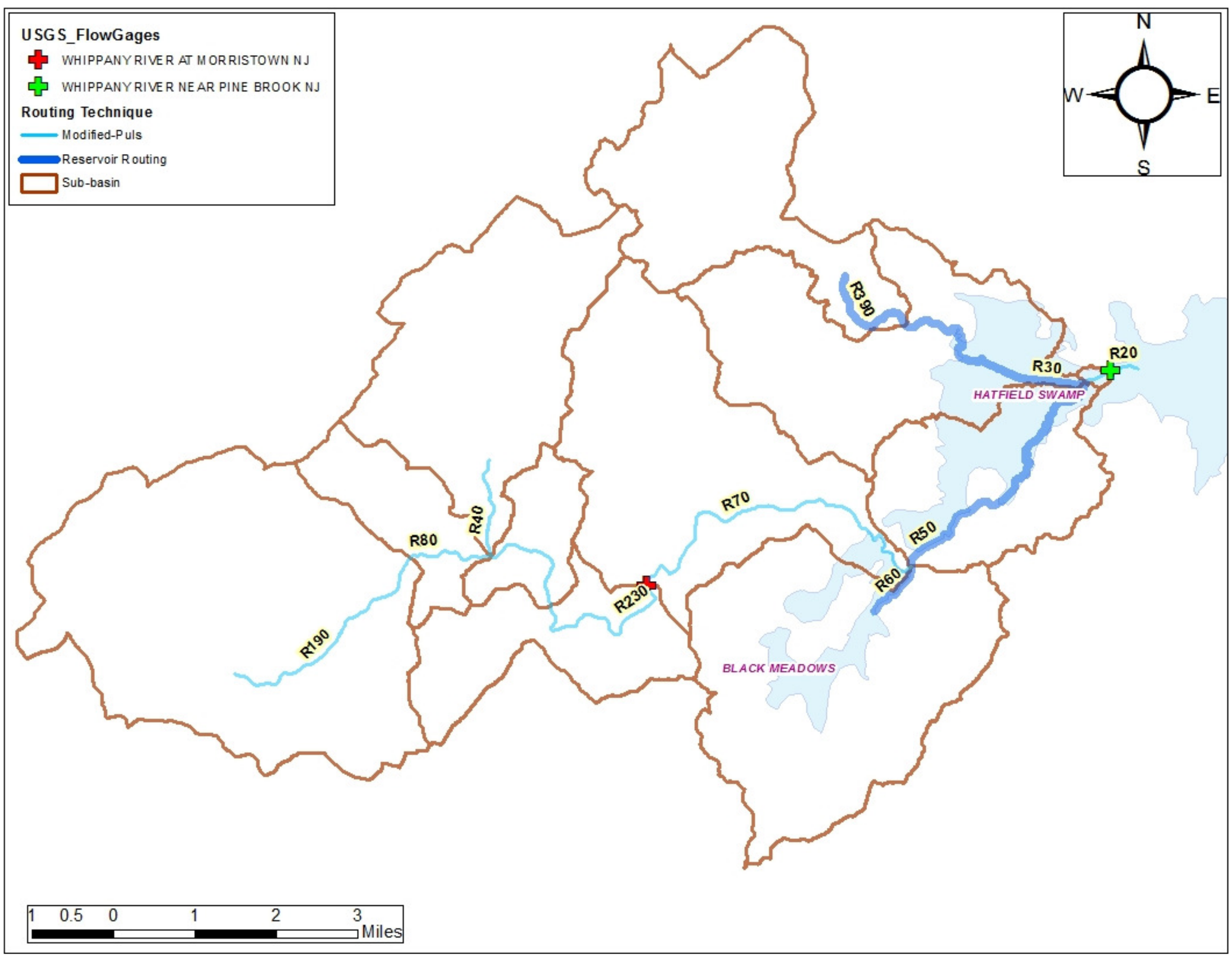


Figure 17: Channel Routing Methods Utilized in Whippany River Model

D.2.2.5 *MODEL CALIBRATION AND VALIDATION*

The model was calibrated and validated to known flood events using observed precipitation and discharge data. Discharges at the two USGS gaging stations, 01381500 (at Morristown) and 01381800 (at Pine Brook), were available for use in the calibration/validation processes for the HEC-HMS model. Adjusted SCS curve number values to match antecedent conditions and lag times to match the time of the peak, the HEC-HMS model was calibrated and verified. The simulated hydrograph and observed hydrographs were compared to determine model performance. USGS's observed discharge data, in 15-minute increments, was available for both model calibration and validation events.

The calibrated model was also run using hypothetical rainfall data (frequency storm) to evaluate its ability to predict the 10%, 2%, 1%, and 0.2% peak flow discharges at both USGS gaging stations (see Appendix D).

D.2.2.5.1 EVENT PRECIPITATION DATA

Flood events for model calibration and validation were selected based on the availability and intensity of rainfall and discharge data. After reviewing the available data, two large flood events, one occurring in September 1999 (Hurricane Floyd) and a second event occurring in September 2004, were used for calibration and validation purposes. The September 1999 event is used for calibration purposes while the September 2004 event was used for validation purposes. For the September 1999 event simulation, 15-minute point rainfall data recorded at two nearby gages (Bound Brook and Charlotteburg) was used. For each sub-basin in the model, rainfall depths relied on the inverse-distance weighting method. For the September 2004 event, MPE radar based precipitation data was developed for each sub-basin in the model.

For the September 1999 calibration event, initial SCS CN values were recalculated to match SCS AMC-1 antecedent moisture condition-values using the procedure described by Ponce (1996). The AMC-1 condition assumption was verified by a review of rainfall data and runoff depths at the gages prior to the 1999 event. In addition, the near 100-year rainfall (8.6 inches) for this event resulted in discharge only at the Morristown gage with a recurrence interval of approximately 10 years. Following the completion of the calibration process for the September 1999 event, the calibrated AMC-1 values were converted back to an average antecedent moisture condition (AMC-2) curve number value. These AMC-2 curve numbers values are used in the September 2004 validation of the HEC-HMS model.

In order to match the observed hydrograph for the calibration event of September 1999, the AMC-1 curve numbers were adjusted by an average of 20%. Initial LAG times were adjusted by an average of 9% percent to match observed hydrographs for the September 1999 event at USGS gage 01381500 (Figure 18). The modeled results at USGS (01381800) Whippany River near Pine Brook could not be matched with the observed data (Figure 19). Peak discharge data at this gage is affected by some combination of attenuation due to the Hatfield Swamp and/or backwater from the Passaic River. Peak flows at this gage often correlated poorly with the upstream gage at Morristown, but were somewhat correlated with the downstream gage on the Passaic (01381900). As an alternative check on the calibration at this gage, a 24-hour design storm was used to assess the model's capacity to simulate hypothetical flood frequencies. Design storms were run using curve number from the normal AMC conditions (AMC-2). This analysis is in section D2 of Appendix D. The simulated results at Pine Brook gage for each of the four flood frequencies (10-year, 50-year, 100-year, and 500-year) were within 5% of the LP III results obtained from 2006 USGS Regression Report from NJ (USGS, 2009).

The validation results for the 2004 event at both gages (Morriston and Pine Brook) were reasonably well simulated by the calibrated model (Figure 20 and 21). The modeled results at the Pine Brook gage also more closely matched the observed data for the 2004 event than for the 1999 event. This improvement in model performance for the validation event is believed to be the result of an AMC-2 event condition in the Hatfield Swamp as well as little or no backwater effects from the Passaic River during the 2004 event. A comparison of the model simulated results against the observed data for calibration and validation events is provided in and respectively.

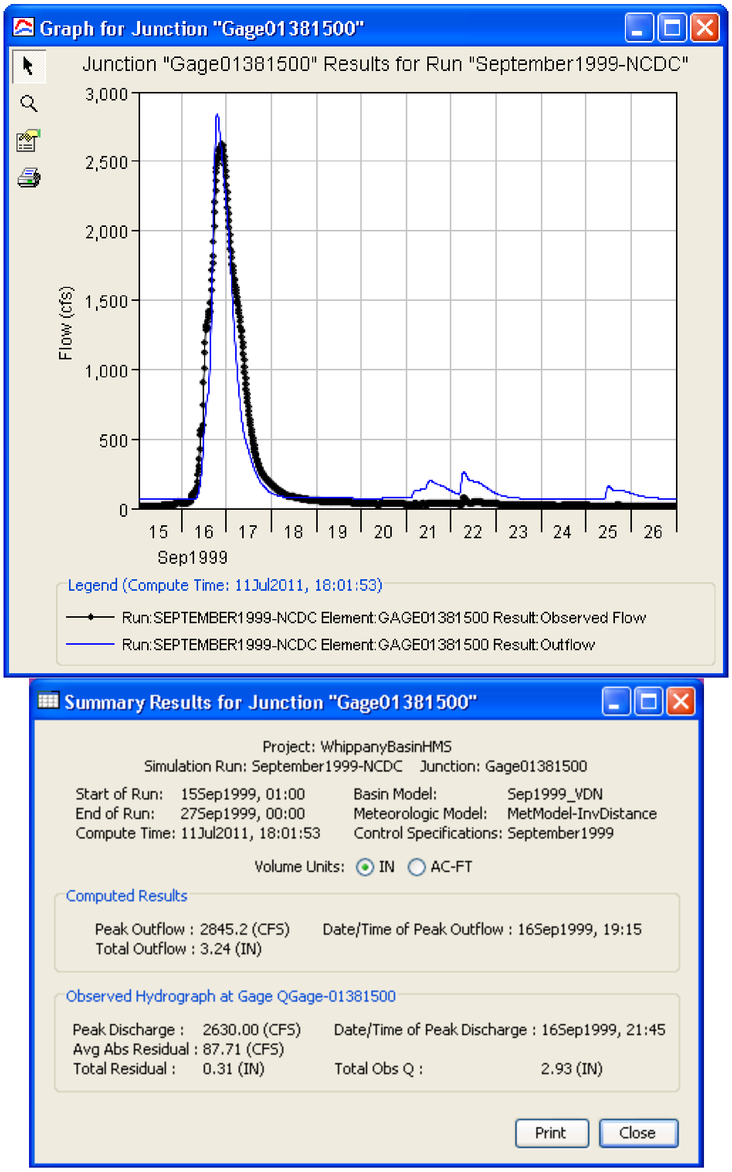
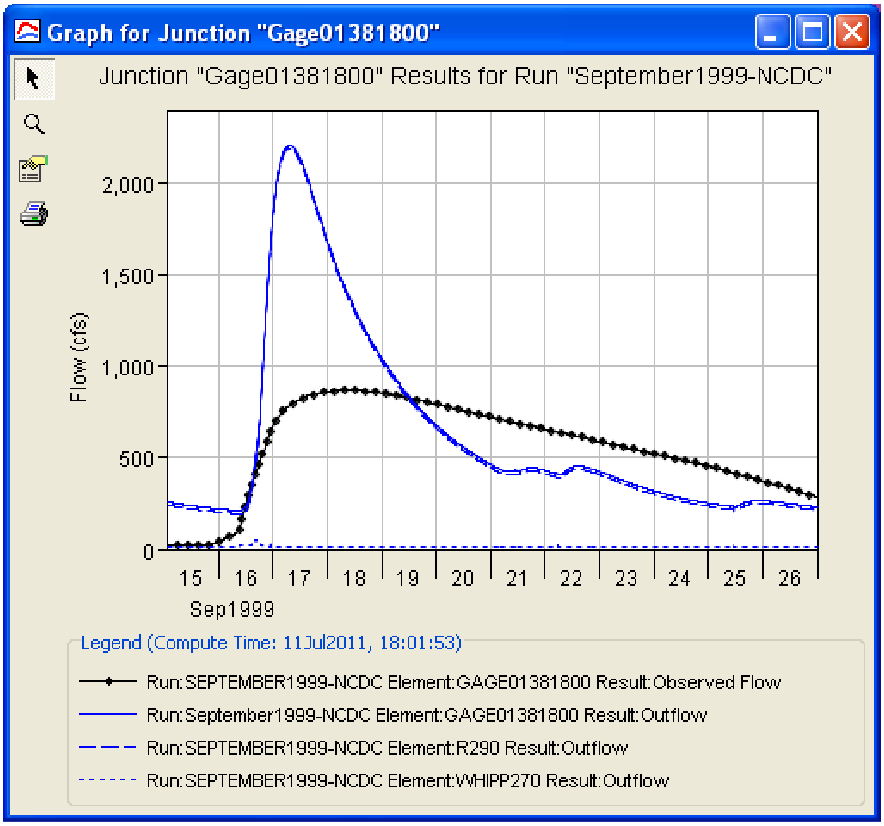


Figure 18: September 1999 Calibration Model Runs Result at USGS Gage at Morristown (01381500)



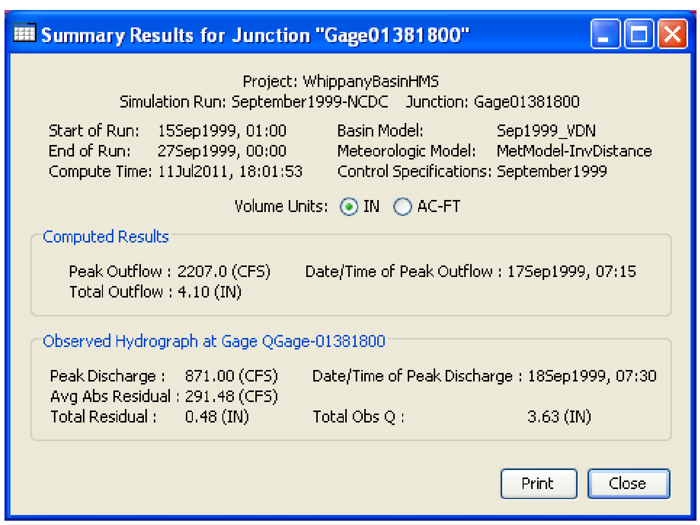
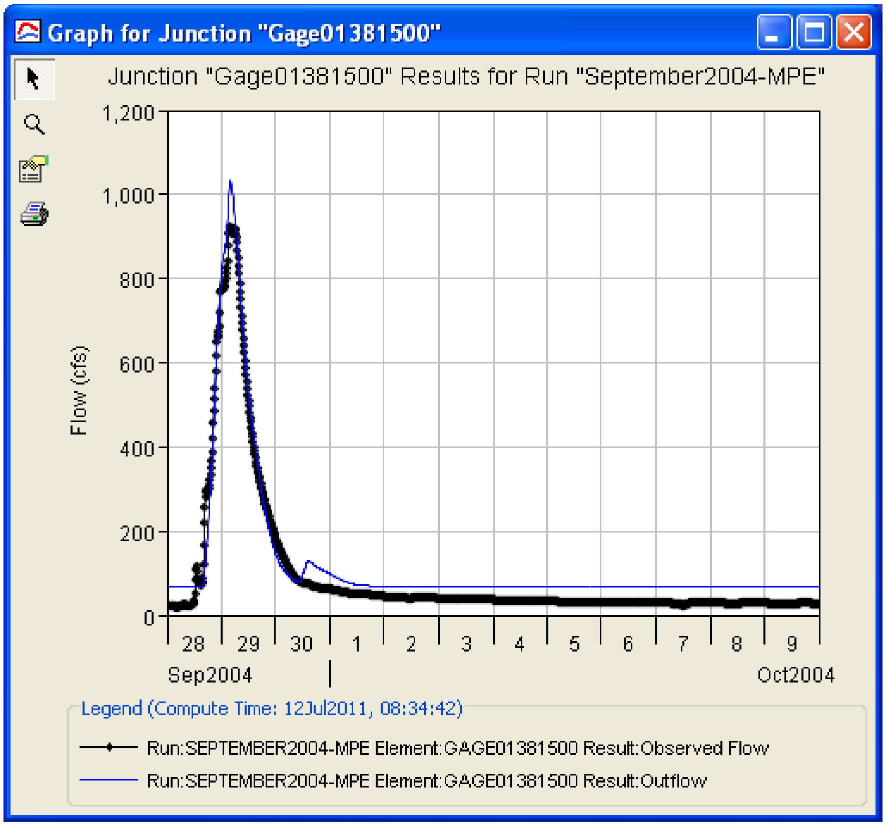


Figure 19: September 1999 Calibration Model Runs Result at USGS Gage at Pine Brook (01381800)



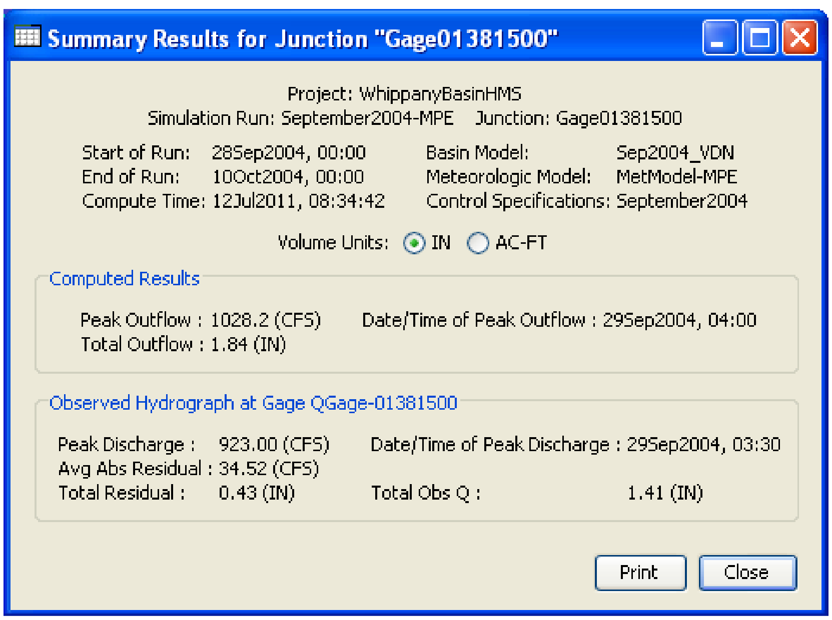
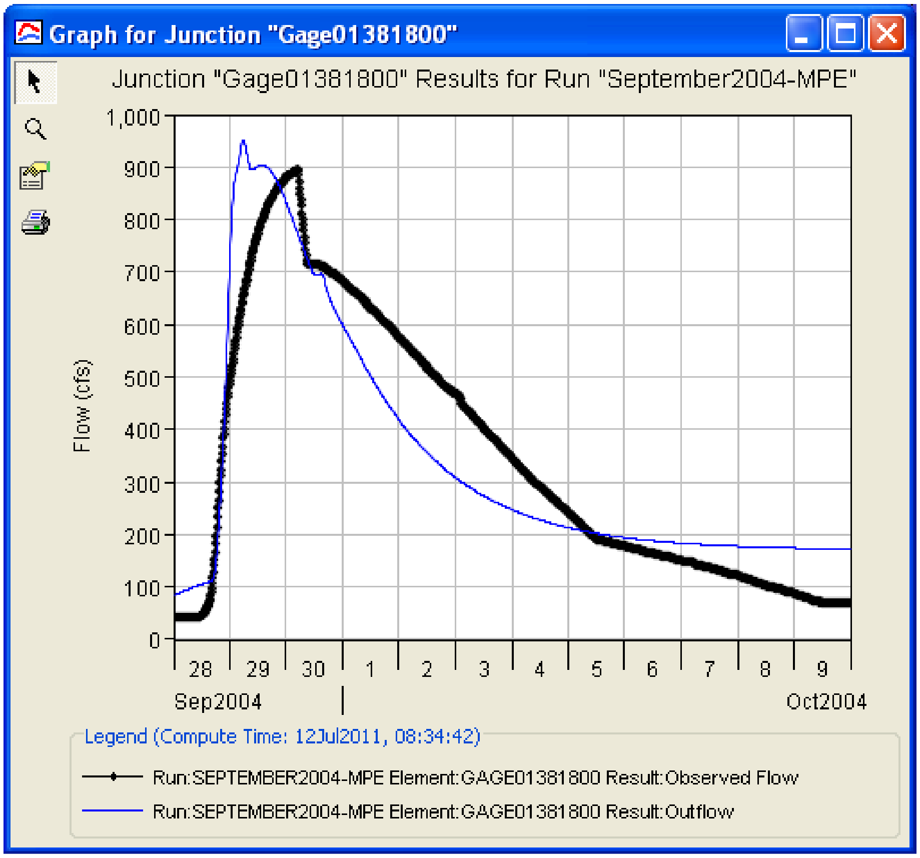
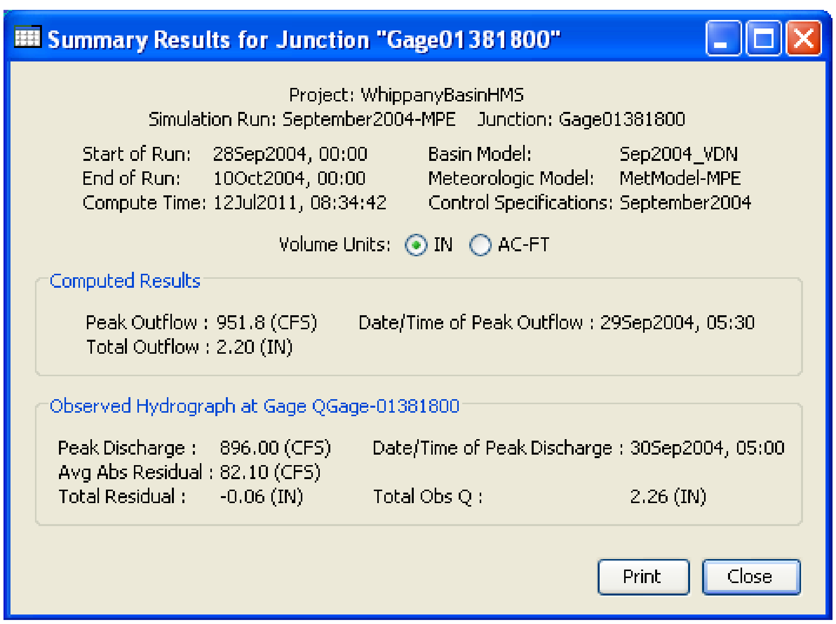


Figure 20: September 2004 Validation Model Runs Result at USGS Gage at Morristown (01381500)




Summary Results for Junction "Gage01381800"

Project: WhippanyBasinHMS
Simulation Run: September2004-MPE Junction: Gage01381800

Start of Run: 28Sep2004, 00:00 Basin Model: Sep2004_VDN
End of Run: 10Oct2004, 00:00 Meteorologic Model: MetModel-MPE
Compute Time: 12Jul2011, 08:34:42 Control Specifications: September2004

Volume Units: IN AC-FT

Computed Results

Peak Outflow : 951.8 (CFS) Date/Time of Peak Outflow : 29Sep2004, 05:30
Total Outflow : 2.20 (IN)

Observed Hydrograph at Gage QGage-01381800

Peak Discharge : 896.00 (CFS) Date/Time of Peak Discharge : 30Sep2004, 05:00
Avg Abs Residual : 82.10 (CFS)
Total Residual : -0.06 (IN) Total Obs Q : 2.26 (IN)

Print Close

Figure 21: September 2004 Validation Model Runs Result at USGS Gage at Pine Brook (01381800)

Table 11: Calibration Results for September 1999

Calibration September 1999												
Location	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Morristown, NJ	1381500	29.4	2,845	2630	8%	5,160	4,662	11%	19:15	21:45	2:30
Near Pine Brook, NJ	1381800	68.5	2,207	871	153%	14,968	13,223	13%	7:15	7:30	0:15

Table 12: Validation Results for September 2004

Validation September 2004											
Location	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Morristown, NJ	1381500	29.4	1,028	923	11%	2,929	2,241	31%	4:00	3:30	0:30
Near Pine Brook, NJ	1381800	68.5	952	896	6%	8,041	8,255	-3%	5:30	5:00	0:30

D.3 Upper Passaic Basin Hydrology

D.3.1 RAINFALL-RUNOFF MODEL

D.3.1.1 *BASIN CHARACTERISTICS*

The Upper Passaic Watershed has a drainage area of approximately 99 square miles and covers area within Morris, Somerset, and Union County in northern NJ. The watershed drains the Passaic River from its origin in southern Morris County and other tributaries. Figure 22 shows the general location of the Upper Passaic Model Watershed and reaches. The topography of the watershed is relatively flat with the higher elevations near the origin of the Passaic River at Mendham in southern Morris County. Elevation within the watershed varies from 165 to 865 feet. The topography near the confluence of Black Brook and the Passaic River is flat and contains a swamp called Great Swamp. Other than natural storage area such as Great Swamp, there are no other such significant features or any man-made features such as lakes or reservoirs.

As with other watersheds studied in this report, USACE HEC-HMS version 3.5 was used to simulate the rainfall-runoff model. The model calibration and verification used two USGS gaging stations: the Passaic River near Millington, NJ, gage (ID 01379000) and the Passaic River near Chatham, NJ, gage (ID 01379500) located at the downstream limit for this model (Figure 22).

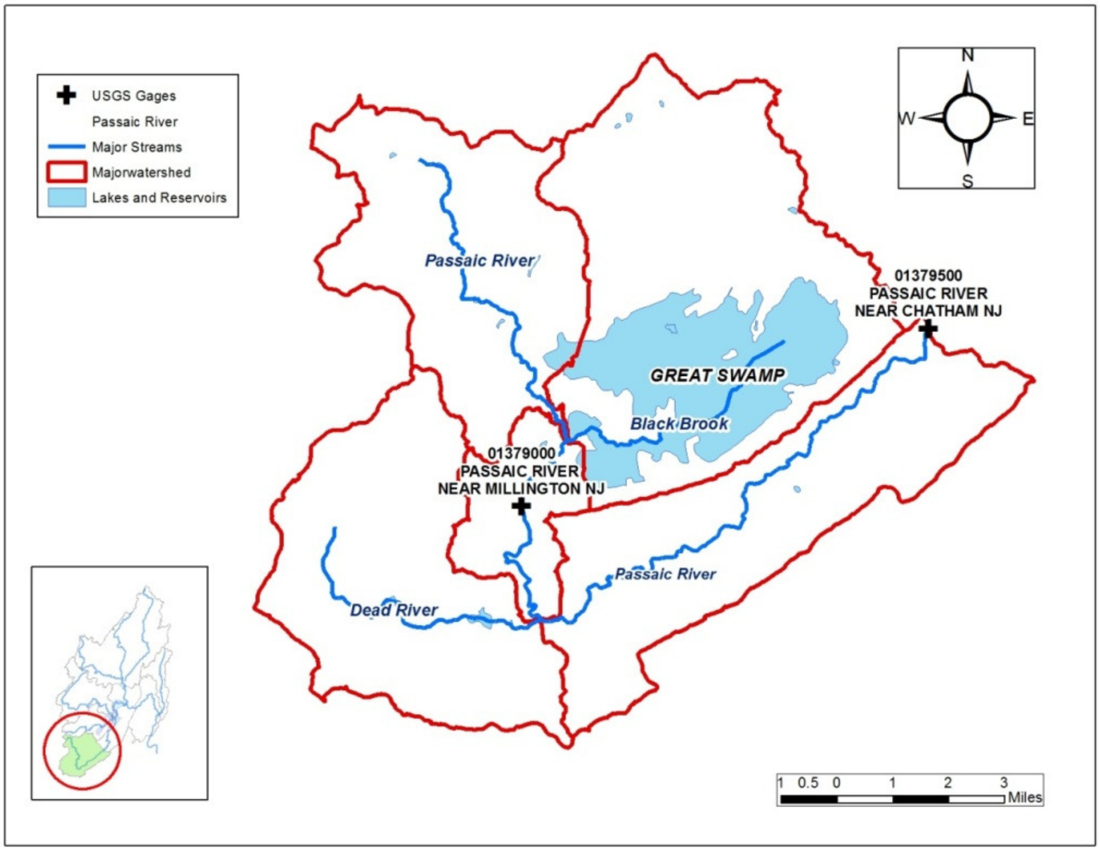


Figure 22: Upper Passaic Basin Features

D.3.1.2 *WATERSHED DELINEATION*

As shown in Figure 23, the Upper Passaic Watershed model was broken into eight sub-basins below the downstream study limit point at USGS Passaic River gauging station 01379500, near Chatham, NJ. The drainage area for the sub-basins within Upper Passaic Watershed ranges from 2.61 to 37.74 square miles (Table 13).

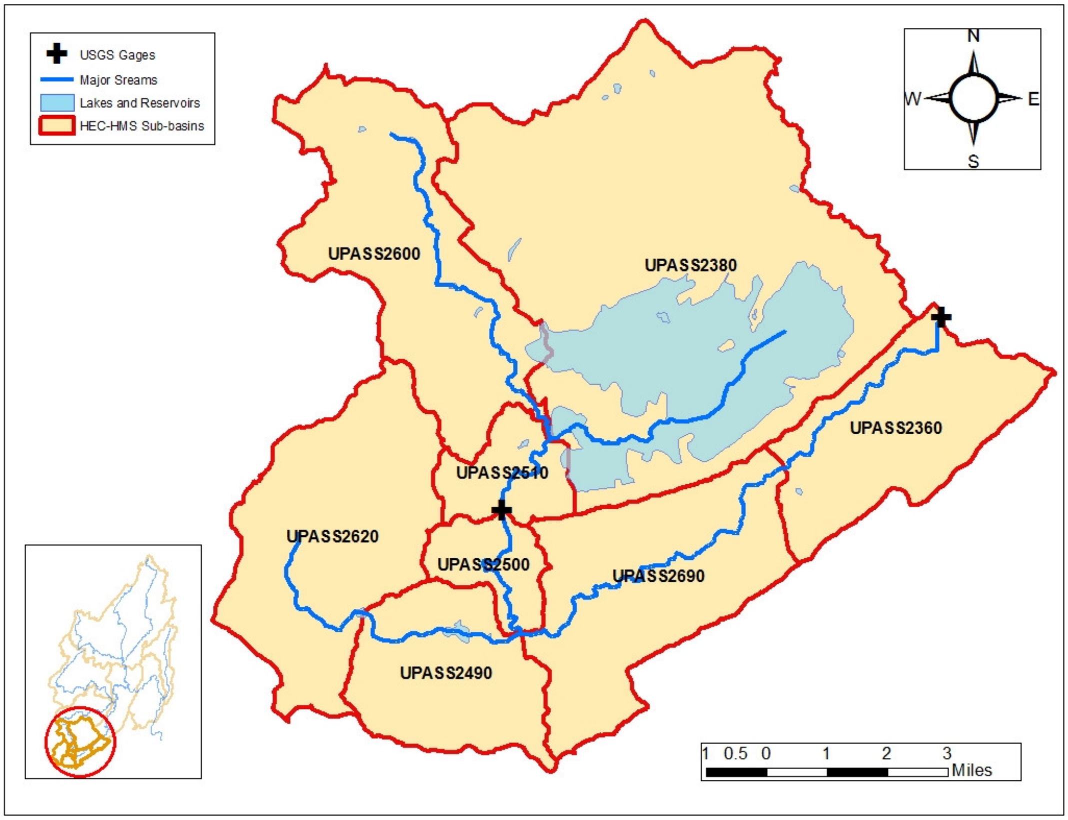


Figure 23: Upper Passaic Sub-basin and Reaches

Table 13: Sub-basin Drainage Areas in the Upper Passaic Watershed

Sub-basins	Drainage Area (sq.mi.)
UPASS2380	37.74
UPASS2600	13.80
UPASS2510	3.08
UPASS2620	13.07
UPASS2490	7.54
UPASS2500	2.61
UPASS2690	12.00
UPASS2360	9.23

The total drainage area of the Upper Passaic Basin is about 99 square mile at the USGS gage station No. 01379500. Drainage areas delineated for hydrologic analysis were consistent with areas at effective FIS locations and USGS gauging stations (Table 14).

Table 14. Drainage Area Comparison at Selected Points in the Upper Passaic Basin

	Drainage area [sq.mi.]		
	FIS	New Delineation	USGS Gage
Location along Passaic River			
Passaic River at Chatham gage No. 01379500	100.00	98.80	100.00
Passaic River at Millington Gage No. 01379000	55.40	54.34	55.40
Upstream of confluence with the Dead River	58.00	56.95	[-]

As discussed earlier, SCS methods were used to determine the initial SCS CN and lag times for the Upper Passaic Basin Model. The initial set of CN values ranged from 73 to 84 (Table 15 and Figure 24). Sub-basin lag times varied from 96 to 891 minutes.

Table 15: Initial CN Parameters and LAG time for Upper Passaic Sub-basins

Sub-basins	Drainage Area [sq.mi.]	Basin CN	Basin LAG time [min]
UPASS2380	37.74	75	891
UPASS2600	13.80	73	263
UPASS2510	3.08	77	186
UPASS2620	13.07	78	246
UPASS2490	7.54	76	528
UPASS2500	2.61	80	96
UPASS2690	12.00	78	888
UPASS2360	9.23	84	350

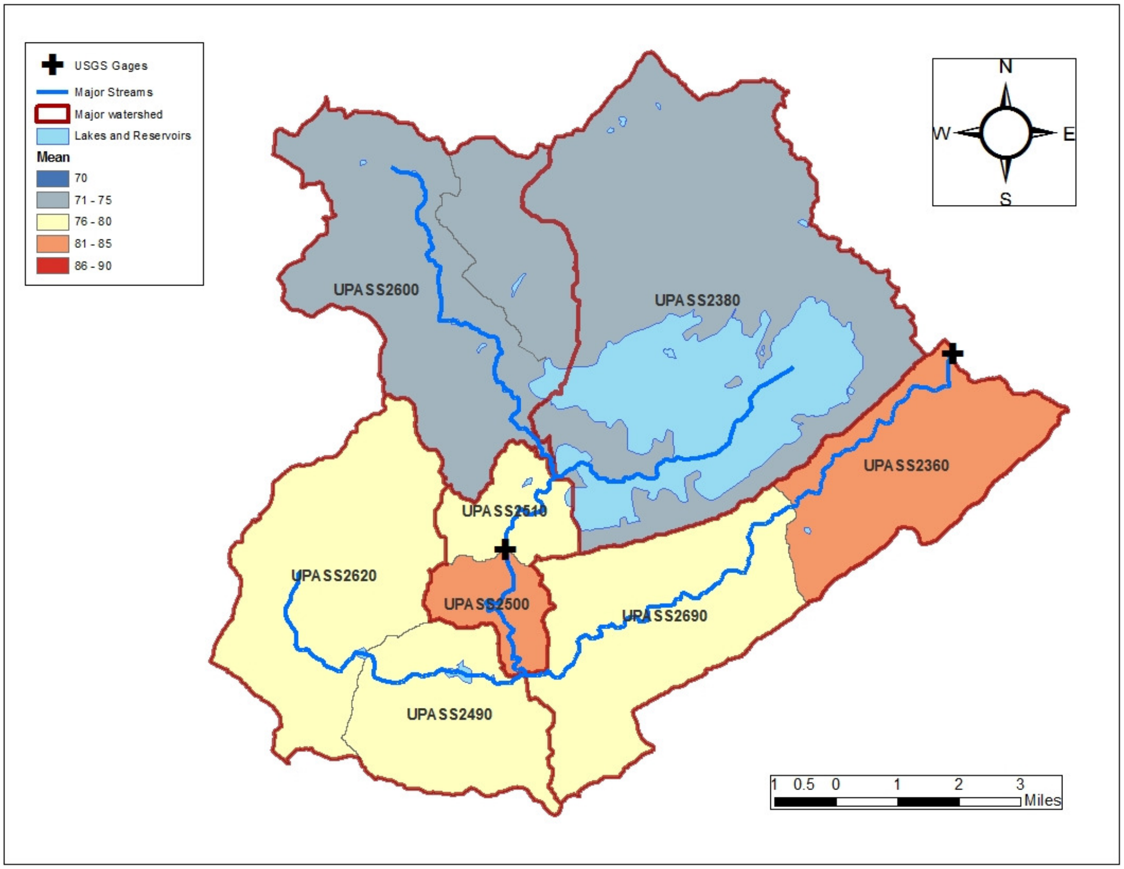


Figure 24: Initial Curve Number Value for Upper Passaic Sub-basins

D.3.1.3 ***CHANNEL ROUTING***

Channel flow routing for sub-basins, as well as routing through the Great Swamp, in the Upper Passaic Watershed used the Modified Puls method. As with other basin models, development of the storage-discharge required for Modified Puls reach routing was based on approximate steady state HEC-RAS models.

D.3.1.4 ***MODEL CALIBRATION AND VALIDATION***

Calibration and validation of the Upper Passaic Basin Model was done with discharge data from USGS gaging stations located at Chatham (USGS gage 0179500) and Millington (USGS gage 01379000). As with other basins, rainfall data from rain gages and MPE radar data for the selected calibration/validation events were used in the model. Hypothetical rainfall data (frequency storms) were used to develop the 10%, 2%, 1%, and 0.2% peak flow discharges at selected locations in the Upper Passaic Basin. Modeling results and analysis of the hypothetical rainfall distribution is included in Appendix D.

D.3.1.4.1 EVENT PRECIPITATION DATA

Following a review of the quality of stream gage and rainfall data available for model calibration between 1987 and 2009, two large flood events, occurring in September 1999 and September 2004, were used for model calibration and validation respectively. For the September 1999 event rainfall data available from the NCDC at two rainfall-gauging stations, Charlottesburg and Bound Brook, was used in model calibration. The inverse-distance-squared weighting technique approach was employed to apply a weighting scheme to measured precipitation at the two gauges. For the September 2004 event, MPE radar-based precipitation data was developed for each sub-basin in the model.

During the calibration process, the curve number and lag time in the HEC-HMS model were changed until the model simulated the observed hydrograph at the two USGS gages. After some trial and error, the initial set of parameters, curve number, and lag time were adjusted until the model simulation predicted the observed discharges. Table 16 lists the initial set of parameters (CNand lagtime) and final calibrated values.

Table 16: Initial and Calibrated Sub-basin CNs and LAG Times for the Upper Passaic Basin

Sub-basins	Drainage Area [sq.mi.]	Basin LAG time [min			Basin Curve number		
		Initial Value	Calibrated Value	Initial Lag Change (%)	Initial Value	Calibrated value	Initial CN Change (%)
UPASS2380	37.74	891	1200	35%	75	66	-12%
UPASS2600	13.8	263	300	14%	73	60	-18%
UPASS2510	3.08	186	200	8%	77	64	-17%
UPASS2620	13.07	246	206	-16%	77	82	6%
UPASS2490	7.54	528	409	-23%	76	82	8%
UPASS2500	2.61	96	489	409%	80	82	3%
UPASS2690	12	888	1300	46%	77	82	6%
UPASS2360	9.23	350	400	14%	85	55	-35%

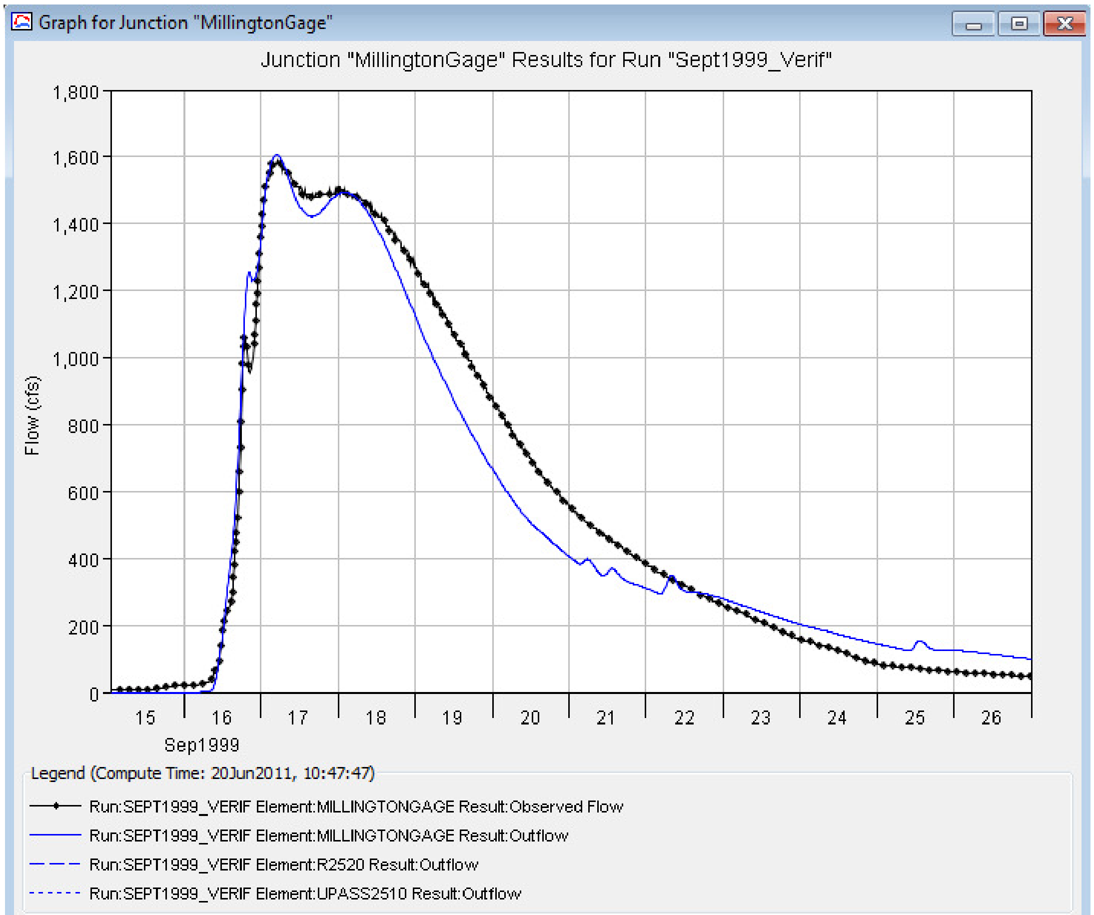
Table 17: Upper Passaic River Calibration for September 1999

Calibration September 1999											
		DA	Peak (cfs)			Volume (ac-ft)			Time (hr)		
Location	USGS Gage #	Area (sq mi)	Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Millington, NJ	1379000	55.4	1,605	1590	1%	11,916	12,579	-5%	4:45	5:00	0:15
Chatham, NJ	1379500	100	2,418	2,210	9%	23,578	23,937	-1%	21:30	17:00	4:30

Table 18: Upper Passaic River Calibration for September 2004

Validation September 2004											
		DA	Peak (cfs)			Volume (ac-ft)			Time (hr)		
Location	USGS Gage #	Area (sq mi)	Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Millington, NJ	1379000	55.4	449	375	20%	3,257	3,333	-2%	13:00	17:00	4:00
Chatham, NJ	1379500	100	709	640	11%	6,622	6,533	1%	6:00	13:30	7:30

Figure 25and Figure 26 illustrate the simulated hydrograph and observed flows at USGS gages 01379000 (Millington Gage) and 01379500 (Chatham Gage) for the calibration event of September 1999. The resulting simulated hydrograph matches well with the hydrograph observed at these two USGS gages. Comparisons of model results against the observed data for calibration and validation are provided in Table 17 and Table 18 respectively.



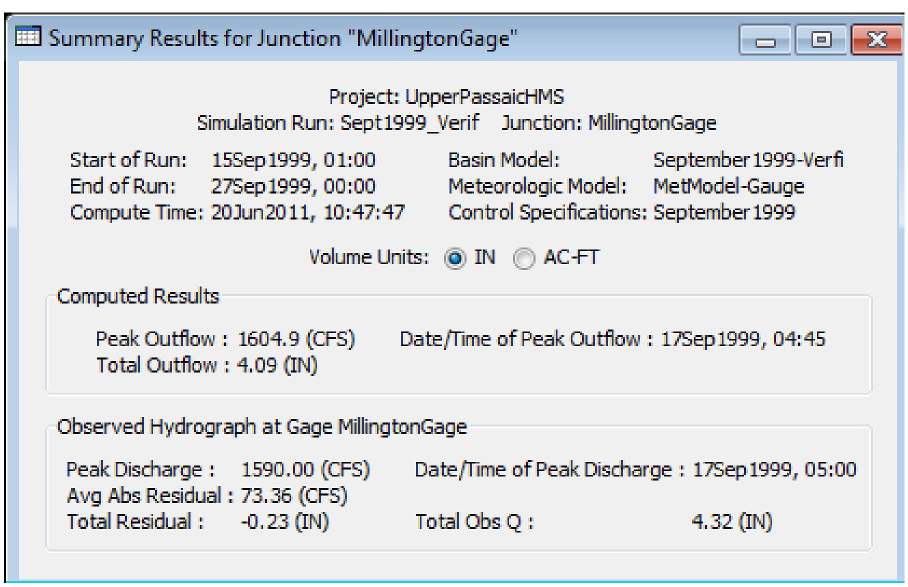
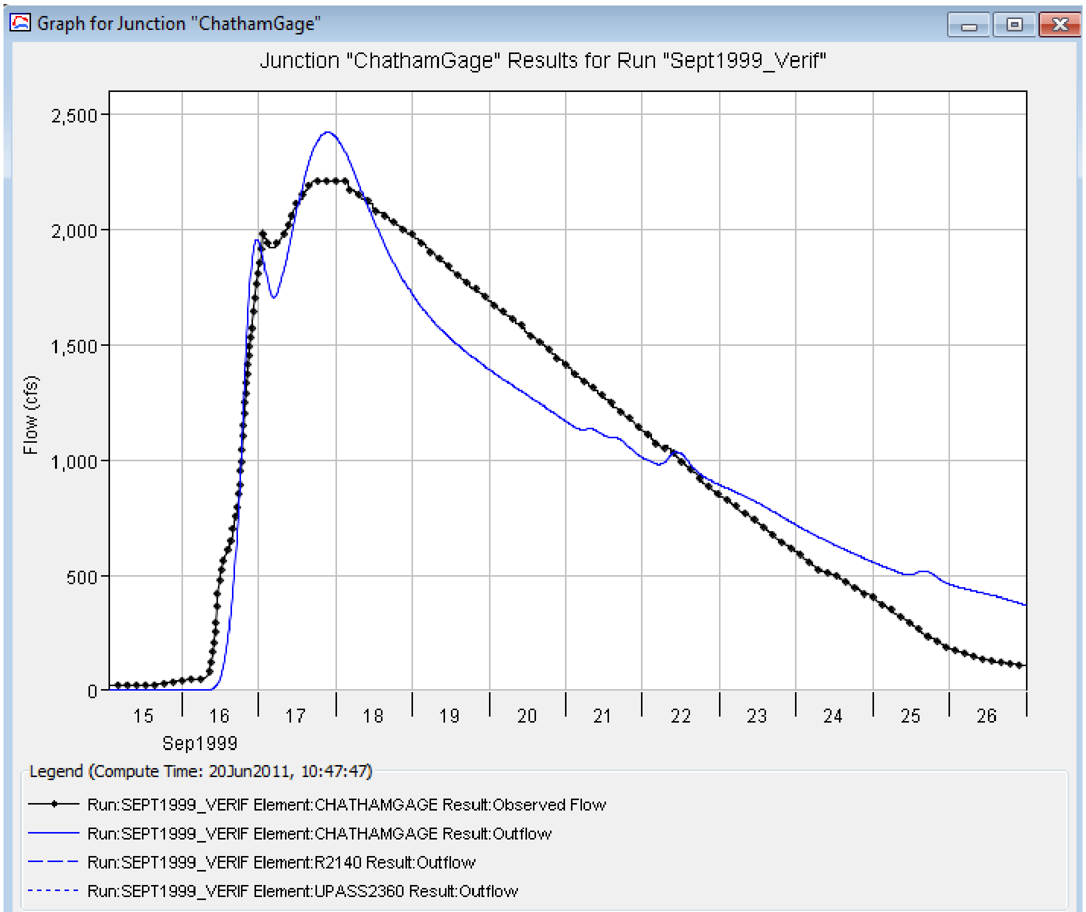


Figure 25: September 1999 Calibration Results at Millington Gage (01379000)



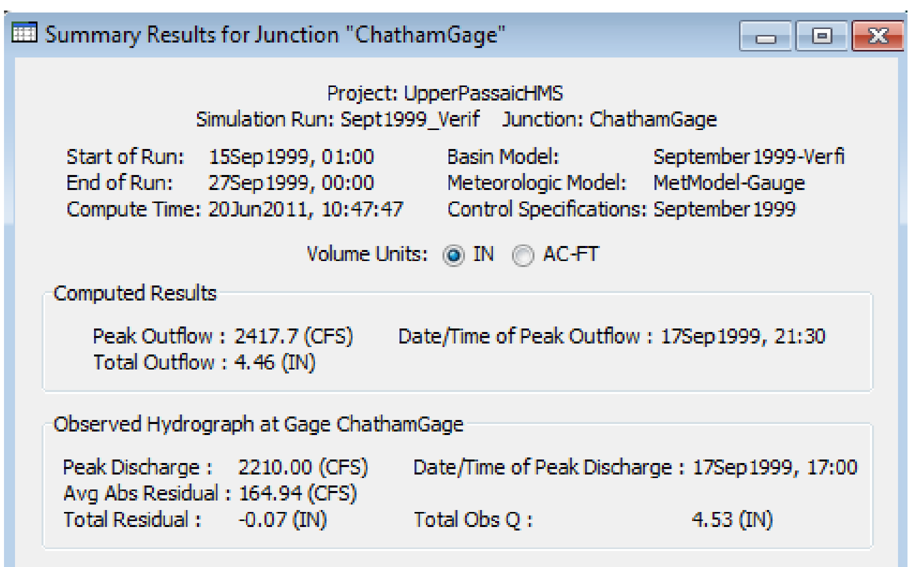
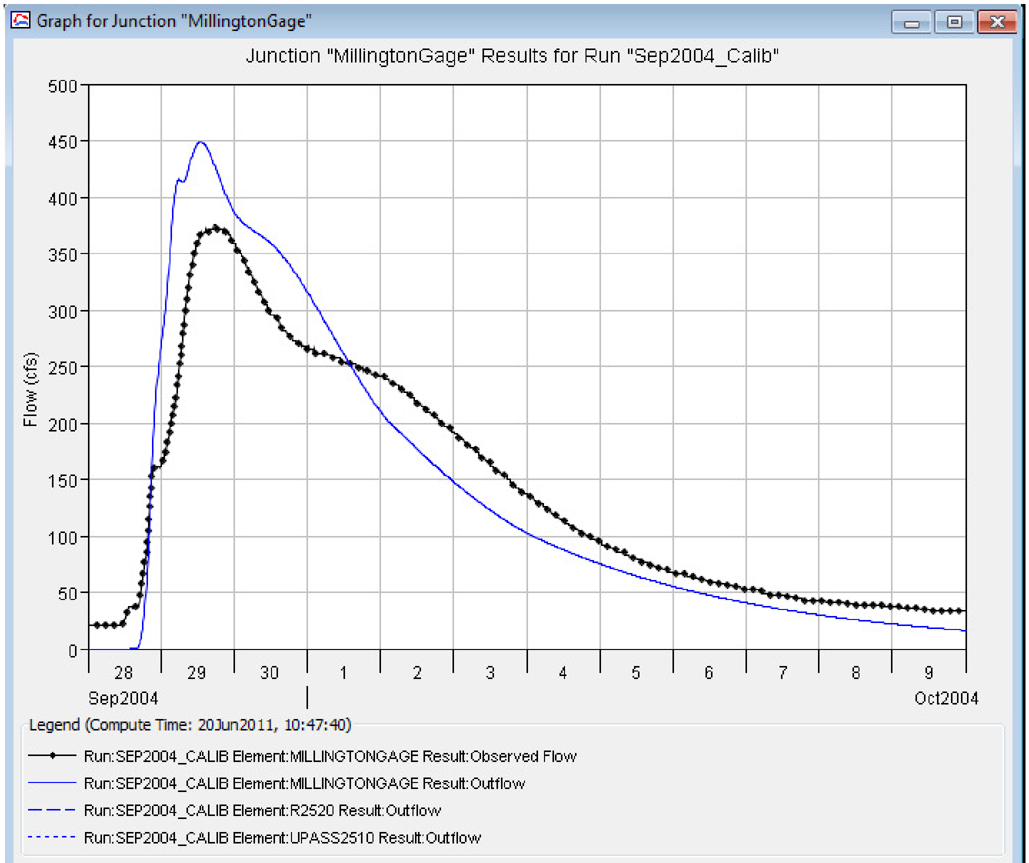


Figure 26: September 1999 Calibration Model Results at Chatham Gage (01379500)

For the validation event, September 2004, the sub-basin curve numbers were changed to account for antecedent soil moisture condition. Table 19 shows the curve number and lag time used for validation model.

Table 19: Calibration and Validation Parameter for Sub-basins in Upper Passaic Basin

	Curve Number [-]			**LAG time [min]**	
	Validation (SCS AMC 2)	**Calibration (SCS AMC1)**	**% difference**	**Validation LAG**	**Calibration LAG**
UPASS2360	80	55	31%	400	400
UPASS2380	75	66	12%	1200	1200
UPASS2490	82	82	0%	409	409
UPASS2500	82	82	0%	489	489
UPASS2510	77	64	17%	200	200
UPASS2600	73	60	18%	300	300
UPASS2620	82	82	0%	206	206
UPASS2690	82	82	0%	1300	1300



Summary Results for Junction "MillingtonGage"

Project: UpperPassaicHMS
Simulation Run: Sep2004_Calib Junction: MillingtonGage

Start of Run:	28Sep2004, 00:00	Basin Model:	September2004-Calib
End of Run:	10Oct2004, 00:00	Meteorologic Model:	MetModel-MPE
Compute Time:	20Jun2011, 10:47:40	Control Specifications:	September2004

Volume Units: (•) IN ( ) AC-FT

Computed Results

Peak Outflow : 448.6 (CFS) Date/Time of Peak Outflow : 29Sep2004, 13:00
Total Outflow : 1.12 (IN)

Observed Hydrograph at Gage MillingtonGage

Peak Discharge : 375.00 (CFS) Date/Time of Peak Discharge : 29Sep2004, 17:30
Avg Abs Residual : 31.06 (CFS)
Total Residual : -0.03 (IN) Total Obs Q : 1.14 (IN)

Figure 27: September 2004 Validation Model Results at Millington Gage (01379000)

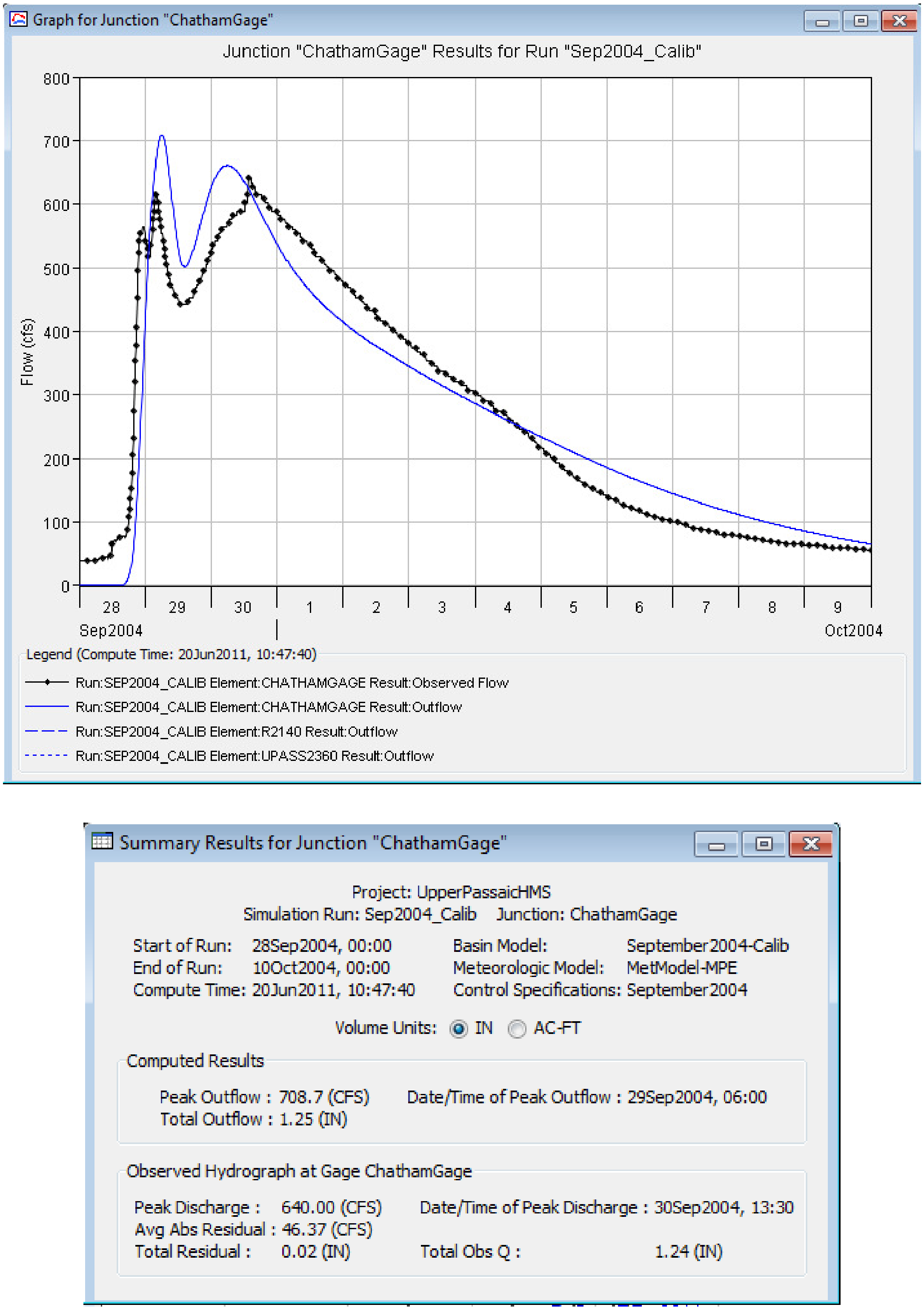


Figure 28: September 2004 Validation Model Run Results at Chatham Gage (01379500)

As shown in Figure 27 and Figure 28, the validation run hydrograph compares well with the observed hydrograph at USGS gages located at Millington (01379000) and Chatham (01379500).

D.4 Pompton Basin Hydrology

The Pompton Basin Model consists of three major watersheds: the Pequannock, Wanaque, and Ramapo (Figure 29). Steep forests, numerous natural lakes and reservoirs, and urban development along river valleys characterize the basin. This basin contributes significantly to the downstream flooding along the Passaic. The unique hydrologic response features of this basin model provide sufficient detail to reflect accurately the basin discharges and runoff volumes at its outlet point (USGS 1388500), but do not necessarily reflect accurately all sub-basin responses. This is true particularly for sub-basins located above the USGS gage locations used in the calibration process (Figure 30). Eight USGS gages were available for use in calibration of the HEC-HMS model for the Pompton Basin Model.

D.4.1 RAINFALL-RUNOFF MODEL

As with the other Passaic Basin models, an SCS Curve Number (CN) loss model and the SCS Unit Hydrograph were used for the HEC-HMS model for the Pompton River Basin. USGS flow data was used to calibrate the modeled discharges to the observed discharge and runoff volume.

The new HEC-HMS model set-up and calibration used calibration procedures employed in an earlier HEC-1 model, completed by USACE in 1995, for the Passaic River Flood Damage Reduction Project. This study adopted HEC-1 as a rainfall-runoff model for hydrology analysis and performed model calibration to three major storm events: in May 1968, November 1977, and April 1984. In this HEC-1 model, peak flow rates and runoff volumes are related to curve numbers that reflect antecedent moisture conditions.

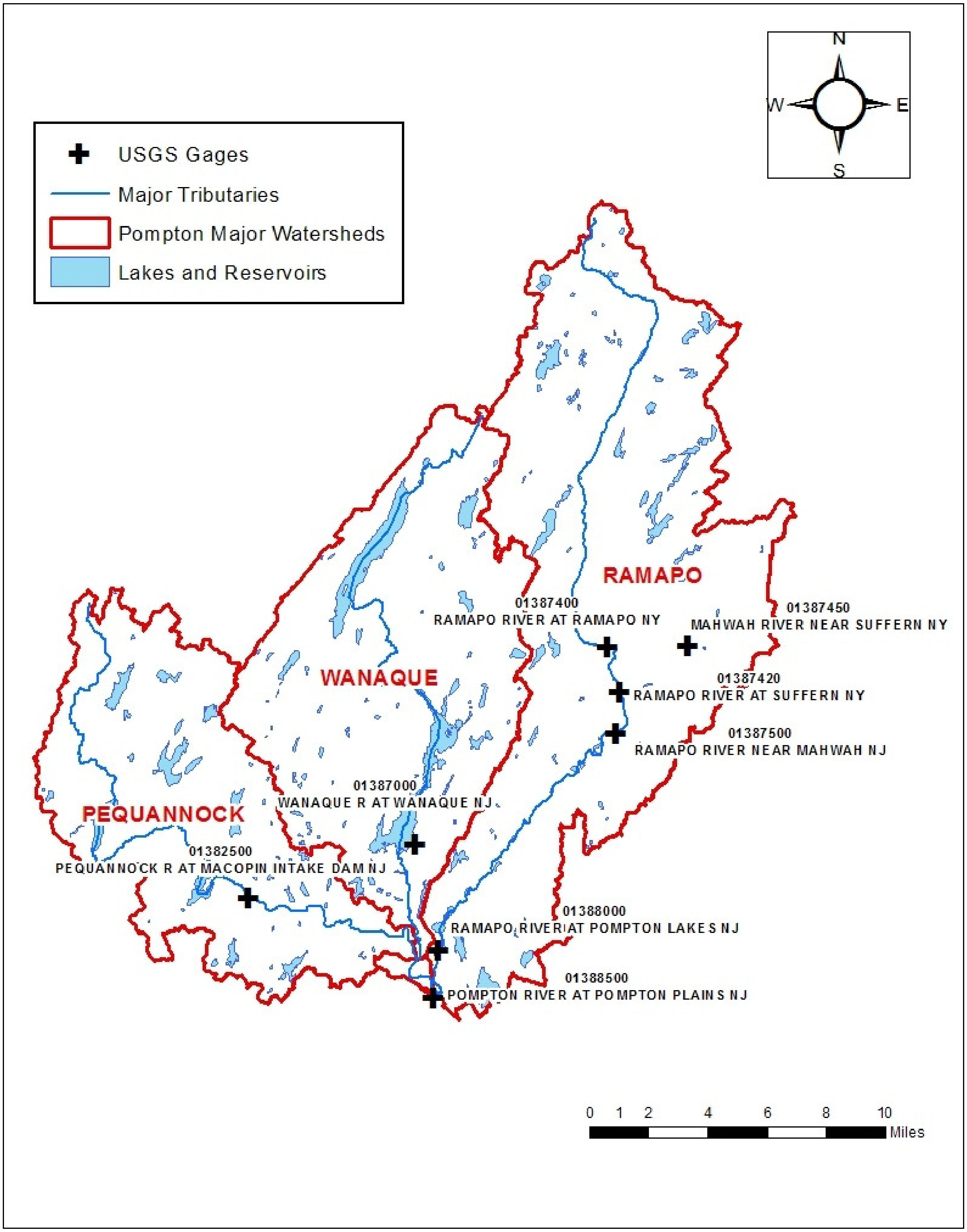


Figure 29. Major Basins and USGS Gage Locations in the Pompton Watershed

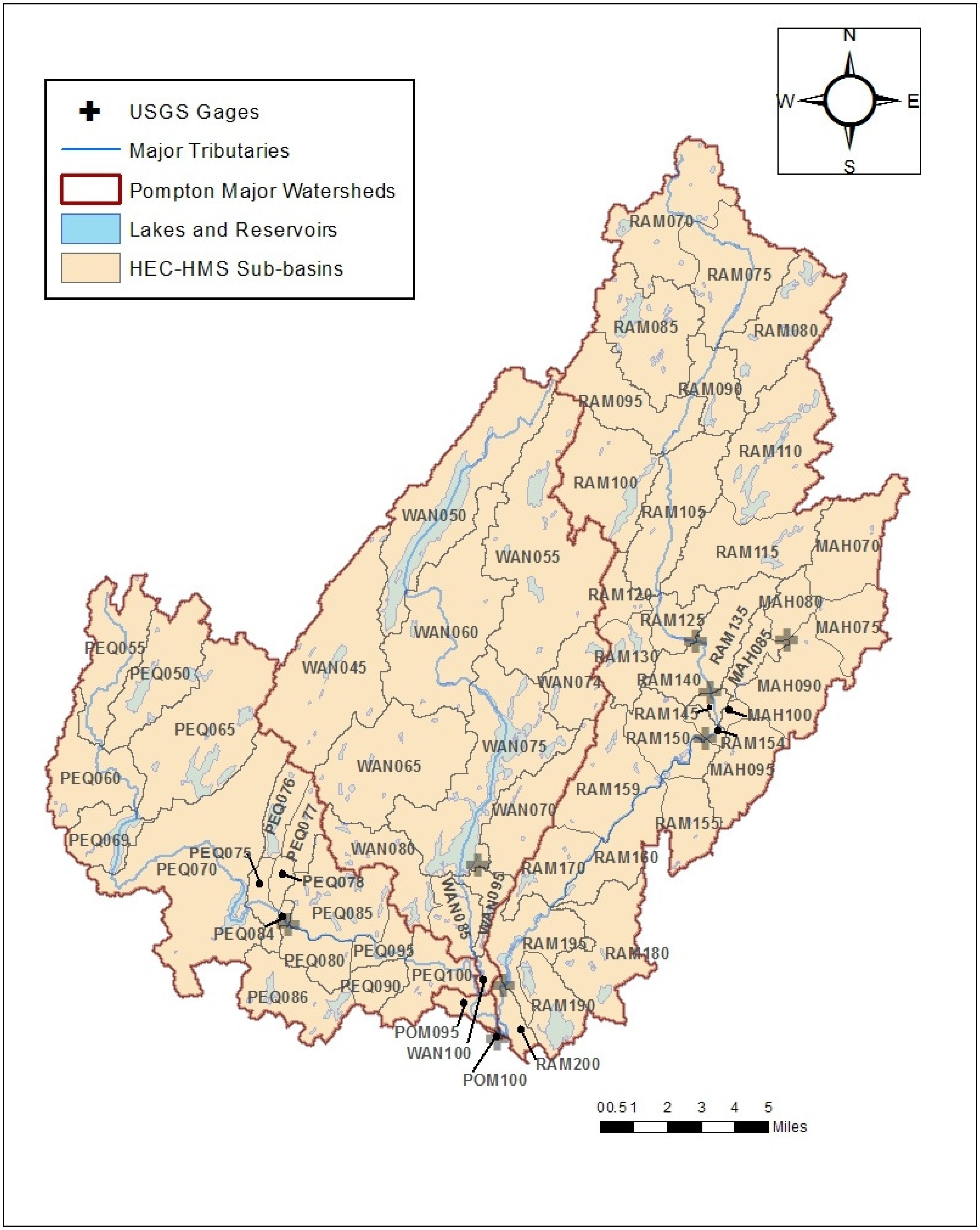


Figure 30. Sub-basin Structure for the Pompton River Basin HEC-HMS Model

D.4.1.1 *BASIN CHARACTERISTICS*

The Pompton River Basin collects flow to the Pompton River from a system of streams and reservoirs that spans 354 square miles. The basin's headwaters are located in southern NY and the basin then flows south over the state line into NJ. In addition to the Pompton, the Pompton Basin includes three other major rivers: the Pequannock, Wanaque, and Ramapo.

The Pequannock River carries flow from the western third of the basin, the Wanaque River from the central third, and the Ramapo River from the most eastern third. The majority of the basin area is wooded mountains; with residential areas of varying density scattered throughout, but as the three main rivers join in the Pompton Plains, NJ, residential and urban development becomes prevalent. Water supply reservoirs located on the Wanaque and Pequannock Rivers significantly impact the discharges in the Pompton River. In particular, the Wolf Den Dam on the Wanaque River (constructed in 1927) and the Charlottesburg Dam on Pequannock (constructed in 1961) have significant impact on flows in the Pompton River.

D.4.1.2 *SUB-BASIN DELINEATION*

Sub-basin boundary delineations reflect land use differences, topography, river confluences, lakes, and reservoir locations as well as USGS gage locations. USGS 10 meter topographic grid data along with HUC delineations for NJ (HUC14) from the NJDEP provide the basis for watershed and basin boundary delineations. Sixty-four sub-basins are included in the model for the Pompton Basin (Figure 30).

D.4.1.3 *Initial SCS CN and Lag Times*

Existing land use and soils data for the Pompton River Watershed were used in the development of the SCS CNs for the basin model. For the NJ portions of the watershed, land use data from the NJDEP was used. In NY, portions of the watershed land-use provided from Orange County and the Rockland County Department of Planning are used. Both land use datasets were checked for consistency with recent aerial photography and then reclassified into the seven different land use classifications shown in Table 20.

Table 20: Land Use Classification System

#	Description
1	Predominately Forest (>85%)
2	Suburban (generally R-4 to R-6 and less)
3	Transportation, Commercial, High Density Urban
4	Deciduous Wetlands, Herbaceous Wetlands, Wetland Rights-of-Way, Managed Wetlands, Former Agricultural Wetlands, etc.
5	Stormwater Basin, Natural Lakes and Artificial Lakes
6	Agricultural - Rangeland/Pasture/Abandoned/Farmland
7	Agricultural - Row/Cereal/etc

Soils data for the entire Pompton Basin was obtained from the NRCS Soil Survey Geographic (SSURGO) Database. A noticeable discrepancy was found in the soil data for the area of the Pompton River Watershed in NY. This discrepancy occurs because the area of interest included two soil surveys, one for Rockland County and one for Orange County. These surveys were conducted at different times, but with slightly different soil classification criteria. This resulted in soil classifications that are labeled differently, but which shared similar soil features. Accordingly and on the advice of a representative from the Rockland County GIS Department, adjustments to the original soil classifications were made in order to provide a consistent basin classification. The reclassified soil and land use data used the HEC-GeoHMS CN generation tool to generate area-weighted CN values (Figure 31, Table 21).

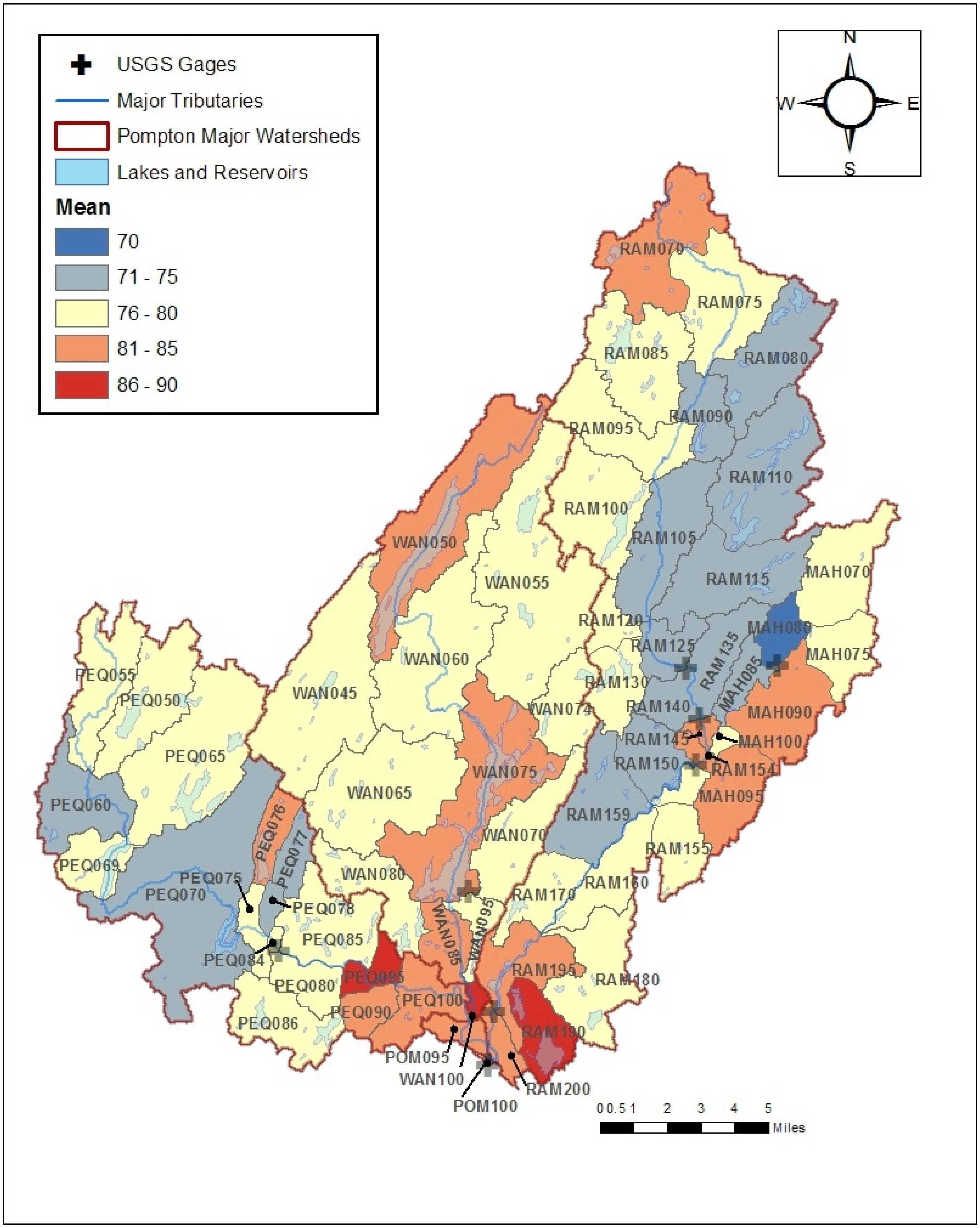


Figure 31. CN Distribution by Sub-basin.

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Table 21: Sub-basin Name and Drainage Area

Sub-basin	Area (Sq. Mile)	Initial Basin CN	Initial Lag Time (min)
MAH070	6.28	76	178
MAH075	3.64	77	308
MAH080	2.04	70	300*
MAH085	2.04	74	300
MAH090	6.38	81	178*
MAH095	4.78	83	111
MAH100	0.53	79	80*
PEQ050	6.94	77	229
PEQ055	6.36	76	289
PEQ060	6.00	75	327
PEQ065	13.22	77	277
PEQ069	3.29	78	52
PEQ070	19.43	74	165
PEQ075	1.66	77	44
PEQ076	2.22	81	113
PEQ077	1.96	73	87
PEQ078	0.86	73	51
PEQ080	2.70	77	120*
PEQ084	0.28	78	56
PEQ085	6.49	79	181
PEQ086	5.46	78	158
PEQ090	1.96	85	120*
PEQ095	1.86	86	120*
PEQ100	4.13	81	138
POM095	1.42	81	103
POM100	0.06	76	55
RAM070	8.65	81	213
RAM075	8.15	78	102
RAM080	7.64	75	137
RAM085	8.71	79	218
RAM090	3.53	72	212
RAM095	6.82	77	175
RAM100	8.26	78	153
RAM105	7.85	74	182
RAM110	10.42	72	221
RAM115	8.51	71	100
RAM120	1.89	77	143
RAM125	2.64	72	143

RAM130	3.51	76	250
RAM135	6.24	73	147
RAM140	0.65	83	109
RAM145	0.79	84	165
RAM150	3.61	73	250*
RAM154	1.05	77	100*
RAM155	3.50	76	252
RAM159	6.65	73	250*
RAM160	4.53	76	200*
RAM170	3.78	76	180*
RAM180	7.13	77	186
RAM190	3.74	87	101
RAM195	5.08	81	120*
RAM200	1.56	85	98
WAN045	14.91	77	314
WAN050	13.96	82	227
WAN055	18.04	76	164
WAN060	13.68	77	173
WAN065	11.84	76	90
WAN070	6.11	79	129
WAN074	4.22	78	91
WAN075	14.35	82	100
WAN080	5.19	78	233
WAN085	2.91	81	100*
WAN095	1.70	80	153
WAN100	0.58	89	51

* Estimated values adjusted during calibration

D.4.1.4 *Recession Baseflow*

Recession baseflow is simulated for selected sub-basins located in the Ramapo and Pequannock River Basins. These sub-basins consisted primarily of forest cover with steep slopes where interflow could be expected. The parameter set-up for these simulations used guidance provided in the HEC-HMS Technical Reference and a review of the observed hydrographs during the calibration process. Table 22 summarizes the sub-basins, as well as the set-up, for sub-basins for which recession baseflow was simulated.

Table 22: Recession Baseflow Sub-basin and Parameter Summary

Sub-basin	Recession Constant	Threshold Type	Ratio to Peak
RAM080	0.8	Ratio to Peak	0.28
RAM085	0.8	Ratio to Peak	0.28
RAM100	0.8	Ratio to Peak	0.28
RAM095	0.8	Ratio to Peak	0.28
RAM110	0.8	Ratio to Peak	0.28
RAM115	0.8	Ratio to Peak	0.28
RAM150	0.8	Ratio to Peak	0.28
RAM159	0.8	Ratio to Peak	0.28
RAM170	0.8	Ratio to Peak	0.28
RAM195	0.8	Ratio to Peak	0.3
PEQ050	0.8	Ratio to Peak	0.28
PEQ055	0.8	Ratio to Peak	0.28
PEQ070	0.8	Ratio to Peak	0.28
PEQ065	0.8	Ratio to Peak	0.28

D.4.1.5 *Channel and Reservoir Routing*

Either an 8-point Muskingum Cunge or Modified Puls method was used for channel flow routing. Both methods are available in HEC-HMS. For the Muskingum Cunge method, the NJ LiDAR terrain data was used for channel slopes and 8-point cross-sections. Best available data sources, including the USACE 1995 study as well as values from the effective FIS, were used for Manning's n values. The Modified Puls method was used to account for storage related attenuation for some stream reaches. Storage discharge relationships for this method are from the approximate HEC-RAS steady flow hydraulic models.

There are numerous lakes and reservoirs within the Pompton Basin. Only reservoirs capable of potentially affecting 100-year discharges were included in the HEC-HMS model for the basin. These included Charlottesburg Reservoir, Clinton Lake, Echo Lake, Greenwood Lake, Monksville Reservoir, Oak Ridge Reservoir, and Wanaque Reservoir. The rating curves and stage storage relationships for these dams have been included in Appendix B. The Echo Lake routing uses the structure's outlet geometry and is included in the model in order to facilitate the calibration process for USGS gage 01382500 (Pequannock River at Macopin Intake Dam).

Canistear reservoir, due to its location on tributary headwater well upstream of the main river system, is not included in the model. In a 1995 study, this reservoir was also identified as providing little flood storage (USACE, 1995). The Pompton Lake dam was also not included in the HEC-HMS model. While the Pompton Lake dam water levels are affected by flood control gates, the conclusion from a study prepared by USACE (2007) was that the impact of the gate operations on the downstream river levels is negligible.

D.4.1.6 *MODEL CALIBRATION AND VALIDATION*

There are a total of 19 USGS gages in the study watershed. Gages without 15-minute flow data between 1999 and 2008 and those collecting flow from drainage areas less than 10% of total drainage area (36 sq. mi.) were excluded from this study. As a result, there were eight gages involved in the calibration and validation process. These include five gages in the Ramapo Basin, and one each on the Pompton River, Pequannock River, and Wanaque Rivers.

Storm events from 1999 to 2008 with return periods of at least 10 years were examined for use in the calibration and validation process. Events prior to 1999 were not selected because of the limitations in the available rainfall data. Four large events were selected for model calibration and validation purposes. Events occurring in September 1999 and October 2004, representing normal antecedent moisture conditions (SCS AMC 2), were used for calibration purposes. Events occurring in April 2007 (wet or SCS AMC 3) and October 2005 (dry or SCS AMC 1) were selected for validation purposes. This selection of storms made the best possible use of the radar based precipitation data, as well as bracketing the possible range of SCS values for this large basin. With a basin area of 354 square miles, uniform rainfall and uniform antecedent moisture conditions are unlikely and this combination of storms best reflected what could be considered normal or average conditions. The selection of validation storms at the two possible extremes for antecedent moisture condition reflects a test of the average conditions assumption made in the selection of the calibration storm events.

The September 1999 and April 2007 events had recurrence intervals of approximately 25 years while the October 2005 event was an approximately 5-year event, but with close to a 100-year rainfall amount. The October 2004 event was a less than 5-year event and was used only to calibrate lag times.

During the calibration process, CN lag times as well recession baseflow parameters were adjusted. In almost all cases, the CNs were lowered during the calibration process with changes varying from an increase of -7% to 30% reduction. On average, CN values were reduced 11% during the calibration process (Table 23).

To match observed hydrograph data at the USGS gage sites, the initial lag time estimates were adjusted on average by a factor of 3 (Table 23). This large increase from the initial estimates is likely the result of some combination of wetland, lake, and reservoir storage. Urban areas located along the river valley; particularly those located along the Mahwah River within the Ramapo Basin also required substantial increases in lag times during the calibration process to match the observed hydrograph data. The reason for the long lag time requirement for these urban areas is unclear, but may be the result of some combination of stormwater management, flat topography, and well draining soils.

Table 23: Calibrated CN and Lag time for Pompton Basin

Sub-basin	Area (Sq. Mile)	Initial Basin CN	Calibrated CN	Initial CN Change (%)	Initial Lag Time (min)	Calibrated Lag Time (min)	Initial Lag Time Change (%)
MAH070	6.28	76	53	-30%	178	900	506%
MAH075	3.64	77	54	-30%	308	900	292%
MAH080	2.04	70	60	-14%	300*	200	67%
MAH085	2.04	74	63	-15%	300	200	67%
MAH090	6.38	81	57	-30%	178*	900	506%
MAH095	4.78	83	58	-30%	111	580	523%
MAH100	0.53	79	67	-15%	80*	90	113%
PEQ050	6.94	77	68	-12%	229	600	262%
PEQ055	6.36	76	67	-12%	289	700	242%
PEQ060	6.00	75	66	-12%	327	304	93%
PEQ065	13.22	77	65	-16%	277	1200	433%
PEQ069	3.29	78	68	-13%	52	359	690%
PEQ070	19.43	74	68	-8%	165	600	364%
PEQ075	1.66	77	65	-16%	44	90	205%
PEQ076	2.22	81	67	-17%	113	180	159%
PEQ077	1.96	73	71	-3%	87	155	178%
PEQ078	0.86	73	65	-11%	51	100	196%
PEQ080	2.70	77	77	0%	120*	800	667%
PEQ084	0.28	78	68	-13%	56	120	214%

PEQ085	6.49	79	79	0%	181	1200	663%
PEQ086	5.46	78	78	0%	158	1200	759%
PEQ090	1.96	85	85	0%	120*	175	146%
PEQ095	1.86	86	86	0%	120*	199	166%
PEQ100	4.13	81	81	0%	138	151	109%
POM095	1.42	81	76	-6%	103	113	110%
POM100	0.06	76	70	-8%	55	61	111%
RAM070	8.65	81	69	-15%	213	1000	469%
RAM075	8.15	78	66	-15%	102	875	858%
RAM080	7.64	75	63	-16%	137	1200	876%
RAM085	8.71	79	67	-15%	218	1200	550%
RAM090	3.53	72	62	-14%	212	270	127%
RAM095	6.82	77	65	-16%	175	600	343%
RAM100	8.26	78	66	-15%	153	800	523%
RAM105	7.85	74	63	-15%	182	240	132%
RAM110	10.42	72	61	-15%	221	800	362%
RAM115	8.51	71	60	-15%	100	300	300%
RAM120	1.89	77	65	-16%	143	60	42%
RAM125	2.64	72	61	-15%	143	60	42%
RAM130	3.51	76	65	-14%	250	250	100%
RAM135	6.24	73	62	-15%	147	480	327%
RAM140	0.65	83	70	-16%	109	30	28%
RAM145	0.79	84	71	-15%	165	30	18%
RAM150	3.61	73	62	-15%	250*	250	100%
RAM154	1.05	77	62	-19%	100*	60	60%
RAM155	3.50	76	61	-20%	252	600	238%
RAM159	6.65	73	62	-15%	250*	300	120%
RAM160	4.53	76	61	-20%	200*	220	110%
RAM170	3.78	76	65	-14%	180*	230	128%
RAM180	7.13	77	61	-21%	186	800	430%
RAM190	3.74	87	70	-20%	101	800	792%
RAM195	5.08	81	65	-20%	120*	200	167%
RAM200	1.56	85	73	-14%	98	108	110%
WAN045	14.91	77	69	-10%	314	1264	402%
WAN050	13.96	82	74	-10%	227	914	402%
WAN055	18.04	76	68	-11%	164	574	350%
WAN060	13.68	77	69	-10%	173	606	350%
WAN065	11.84	76	68	-11%	90	315	350%
WAN070	6.11	79	79	0%	129	1200	930%
WAN074	4.22	78	70	-10%	91	319	350%
WAN075	14.35	82	74	-10%	100	350	350%

WAN080	5.19	78	82	5%	233	1200	515%
WAN085	2.91	81	78	-4%	100*	200	200%
WAN095	1.70	80	81	1%	153	400	261%
WAN100	0.58	89	80	-10%	51	120	235%

* Estimated values adjusted during calibration

Numerous reservoirs in the basin, in particular the Charlottesburg and Wanaque Reservoirs, are not managed as flood control structures, but nonetheless have a significant impact on downstream discharges. During extended dry periods, a significant draw down in the normal pool elevations for these reservoirs occurs. This drawdown creates significant flood storage in these reservoirs. For example, the October 2005 storm event had rainfall amounts close to a 100-year recurrence interval, but was preceded by several months of below normal rainfall amounts and produced only minor flows (<1-year recurrence) from these two reservoirs. As a result, for both calibration and validation modeling purposes, the observed flows from the USGS gage located below these two reservoirs (Charlottesburg and Wanaque) were used as direct inflows to the downstream HEC-HMS model. CN adjustments made to sub-basins below these two gages during the calibration process were, however, reflected in the upstream sub-basins draining to these reservoirs. For the 100-year event, the drainage areas upstream of these reservoirs were reconnected and the reservoirs were assumed to be at their normal pool elevations.

The results of the model calibration to the 1999 and 2004 storm events are summarized in Table 24 and Table 25. The September 1999 storm event was used to calibrate the peak discharges as well runoff volumes, while the October 2004 storm event was to calibrate the timing of flows. A lack of rainfall radar data or spatially distributed point rainfall data, as well as the lack of USGS hydrograph data, for the 1999 event made the calibration of the timing of flows unreliable for this event.

The 1999 calibration relies on the calibration results for the peak discharge data available for four USGS gages located along the Ramapo as well as the USGS gage on the Pompton. As shown in Table 24, the downstream gage on the Ramapo (01388000) matched within 9% while the Pompton USGS gage (01388500) modeled flows were within 17% of the observed flows for the 1999 event and within 6% for the October 2004 event (Table 25). The lack of closer calibration at the Pompton Gage for the 1999 event is believed to be the result of the incorrect timing of the major inflows into the river due to a lack of spatial coverage in the rainfall data available for this event. The relative timing of the inflows from the Ramapo, Pequannock, and Wanaque Rivers, which flow from different directions into the Pompton, is critical to predicting the correct discharge at the Pompton gage. In the Ramapo basin, the model slightly under predicted flows for three of the four gages in the 1999 storm event while over predicting them for three of the four gages during the 2004 event. The over prediction by the model for the flows occurring during the 2004 event was not unexpected and was consistent with the short recurrence interval for this event (<5 year). The CNs in the HEC-HMS model are intended to reflect conditions for events with recurrence intervals of greater than 10 years. Events with recurrence intervals of <5 year are assumed to more likely have conditions dryer than average antecedent moisture conditions assumed in the model. The modeled 10-year discharge would, as result, usually be higher than observed discharge values,

Figure 32 illustrates the partial discharge record available for the 1999 event at the Pompton Gage Site and illustrates a slight mismatch in the modeled timing for this event. As illustrated in Figure 33, the timing and shape of the hydrograph are, however, consistent with the observed data for the 2004 event at this gage location. As a result, the 2004 event was relied on to calibrate the lag times in the HEC-HMS model.

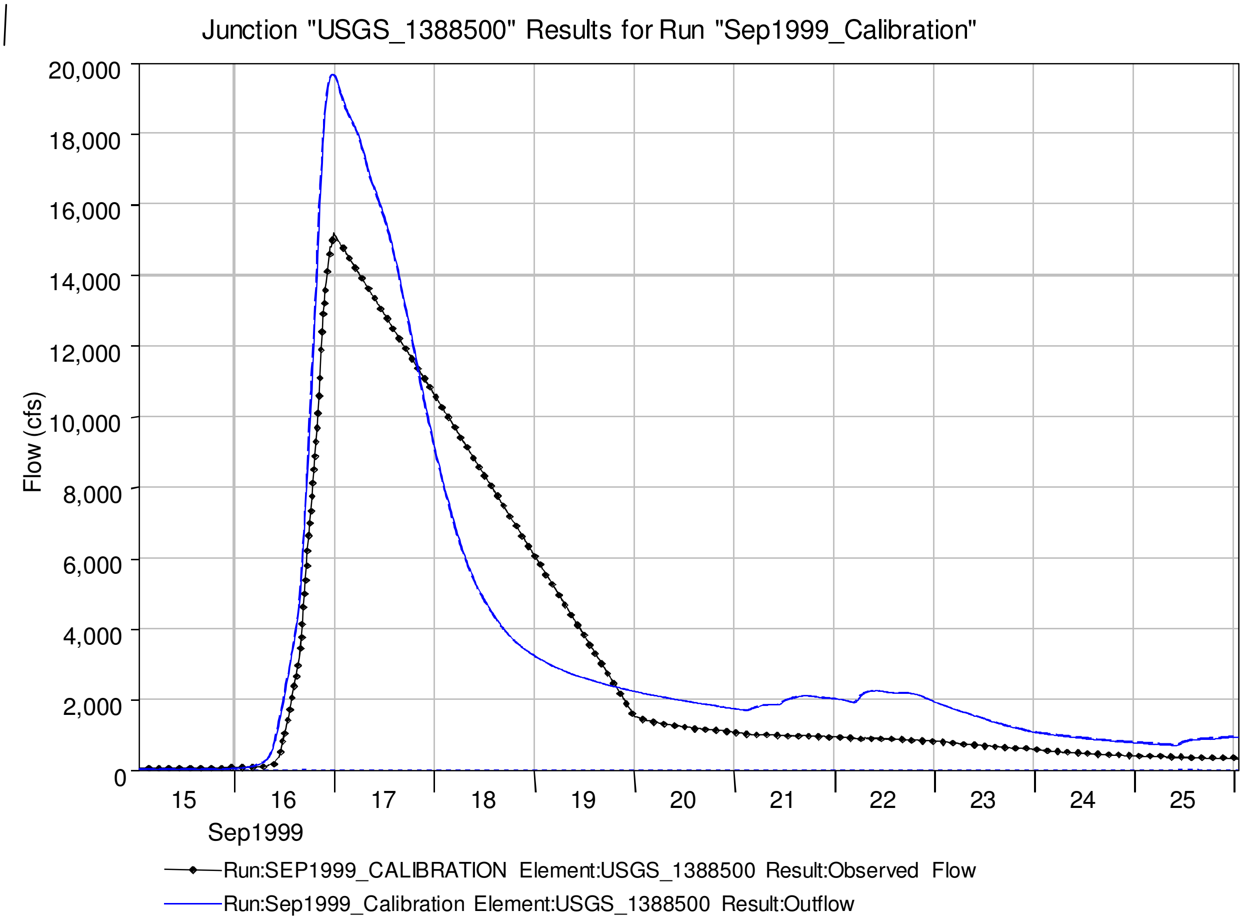

Figure 32. Modeled and Observed Flow Hydrographs at USGS 1388500 (Pompton River) for Sept. 1999 Storm Event (Note: USGS data is incomplete)

Table 24: Calibration for September 1999 Storm Event

Calibration September 1999											
River	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff.**	Model	Obs	Diff.**	Model	Obs.	Diff.**
Ramapo	01387400	86.9	8,212	9,300[5]	-13%	Not available.					
	01387420	93.0	9,293	10,500[2,5]	-13%	Not available.					
	01387500	119.2	11,460	13,800	-20%	40,428	35,022	+17%	23:00	22:00	+01:00
	01388000	159.0	15,323	14,000	+9%	Not available.					
Pompton	01388500	354.3	19,761	16,400*	+17%	Not available.					

* Gage height effected by backwater, USGS estimated value
** Diff. (Q model – Q observed)/Q model
[2] Discharge is an estimate
[5] Discharge affected by unknown degree by regulation or diversion

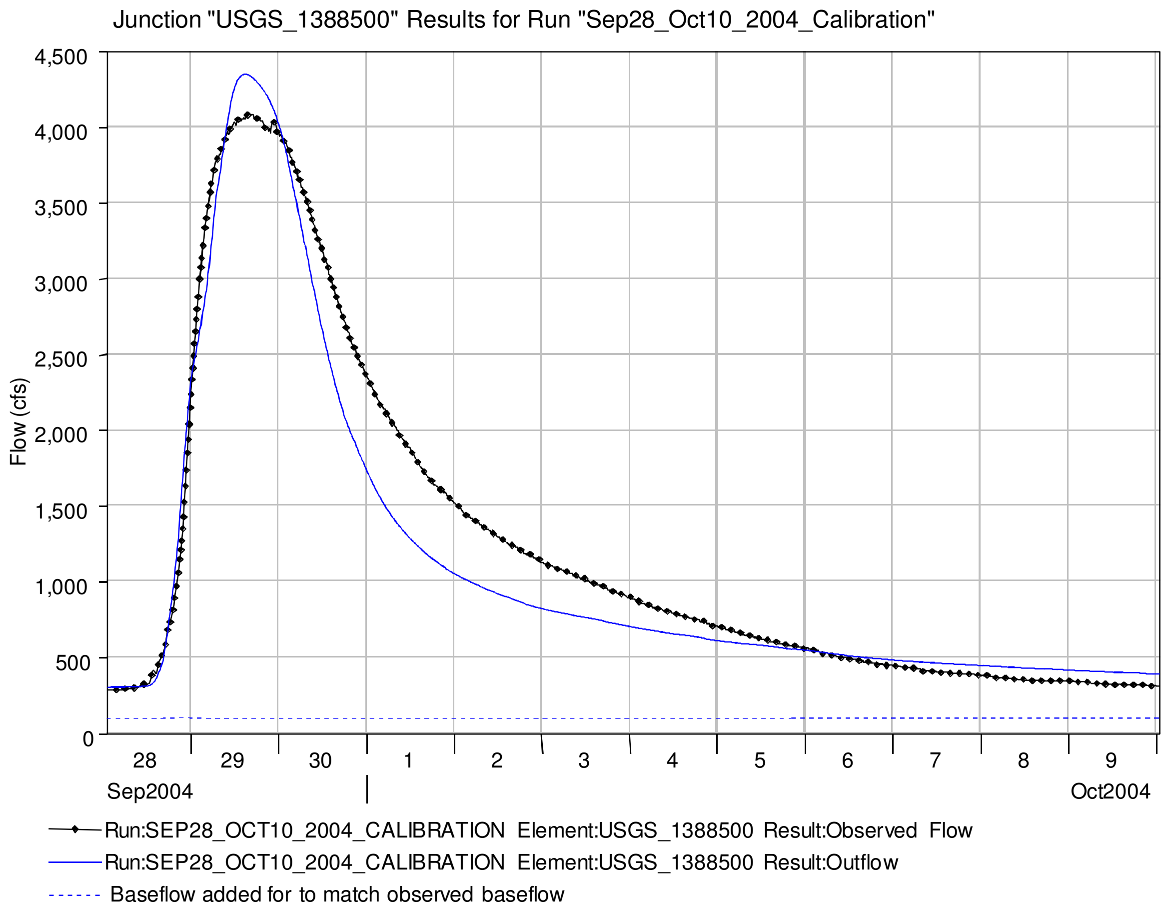

Figure 33. Modeled and Observed Flow Hydrographs at USGS 1388500 (Pompton River) for Sep-Oct 2004 Storm Event

Table 25: Calibration for September/October 2004 Storm Event

Calibration September/October 2004											
River	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff.*	Model	Obs	Diff.*	Model	Obs.	Diff.*
Ramapo	01387400	86.9	1,576	1,630	- 3%	6,945	10,224	-47%	14:45	12:45	+02:00
	01387420	93.0	1,635	1,470	+10%	7,140	9,714	-36%	Not applicable due to double peak		
	01387500	119.2	2,055	1,860	+9%	Not available			06:30	06:45	+00:15
	01388000	159.0	2,687	2,370	+12%	11,789	16,160	-37%	10:30	10.45	-00:15
Pompton	01388500	354.3	4,353	4,090	+6%	26,320	29,247	-11%	15:00	15:45	-00:45

* Diff. (Q model – Q observed)/Q model

For the October 2005 validation event, SCS curve number values were adjusted to reflect AMC I conditions. The resulting curve numbers ranged from 33.0 to 76.3, with a basin wide average of 50.1. For the USGS gage on the Pompton, modeled discharges and volumes consistently over predicted the observed peak flows (23% to 34%) as well as observed runoff volumes (17% to 34%), as shown in Table 26 and in Figure 34. Reductions in CN to values less than AMC I conditions would have been required to more closely match the observed discharge value. This indicates a highly unusually level of infiltration/storage capacity within the Pompton Watershed following an extended dry period. For model validation purposes, the consistency of the over prediction, across all five USGS gage sites, supports the earlier calibration of the model for average SCS AMC Type 2 conditions. As illustrated in Figure 34, the timing of the modeled hydrograph at the Pompton Gage for the October 2005 event is also earlier than the observed basin response and is consistent with the use of the unadjusted AMC II lag times. Antecedent lag times for an AMC I condition would be expected to be longer than that for an AMC II condition.

Table 26: Validation Event October 2005 (SCS AMC I)

Validation Event October 2005											
River	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff.*	Model	Obs	Diff.*	Model	Obs.	Diff.*
Ramapo	01387400	86.9	5,992	3,950	+34%	17,199	11,289	+34%	01:15	23:15	+02:00
	01387420	93.0	6,795	5,190	+24%	18,072	12,912	+29%	02:00	23:30	+02:30
	01387500	119.2	8,101	5,700	+30%	20,781	16,230	+22%	02:15	05:45	-02:30
	01388000	159.0	10,761	7,130	+34%	28,494	19,307	+32%	04:45	07:30	-02:45
Pompton	01388500	354.3	13,756	10,600	+23%	38,542	31,925	+17%	05:00	09:00	-05:45

* Diff. (Q model – Q observed)/Q model

2 Discharge is an estimate

5 Discharge affected by unknown degree by regulation or diversion

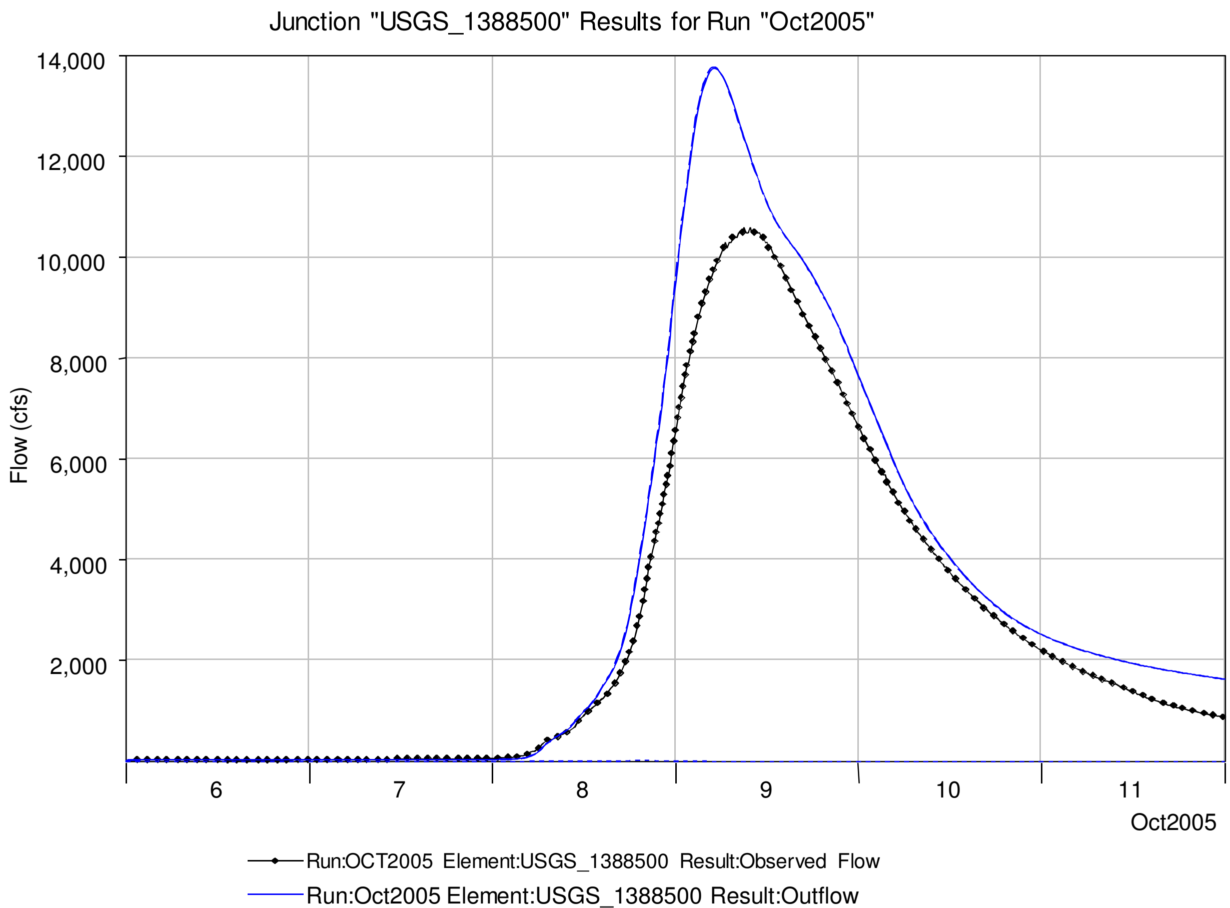

Figure 34. Modeled and Observed Flow Hydrographs at USGS 1388500 (Pompton River) for Oct 2005 Storm Event (SCS AMC1)

For the April 2007 validation event, SCS curve number values were adjusted to reflect AMC III conditions. The resulting curve numbers ranged from 72.5 to 94.5, with a basin wide average of 83.6. The resulting HEC-HMS model over predicted observed discharges and runoff volumes. This was consistently the case for the Ramapo Basin. Modeling results at the Pompton Gage slightly over predicted the peak discharge as well under slightly unpredicted the runoff volume (Table 27 and Figure 35). The observed base flow conditions (averaging around 900 cfs), which are also much higher than the modeled average baseflow conditions, also contributed to the under prediction of runoff volumes at the Pompton Gage.

Table 27: Validation Event April 2007 (SCS AMC III)

Validation Event April 2007											
River	USGS Gage #	DA Area (sq mi)	Peak (cfs)			Volume (ac-ft)			Time (hr)		
			Model	Obs.	Diff.*	Model	Obs	Diff.*	Model	Obs.	Diff.*
Ramapo	01387400	86.9	8,139	6,200	24%	29,422	25,960	12%	02:15	08:45	-06:30
	01387420	93.0	9,021	6,500	28%	30,895	28,832	7%	02:35	09:00	-06:25
	01387500	119.2	11,198	8,870	21%	36,900	35,327	4%	03:40	08.45	-04:55
	01388000	159.0	13,955	9,930	29%	49,023	45,111	8%	05:00	12:15	-07:15
Pompton	01388500	354.3	21,217	18,000	15%	97,458	102,592	-5%	13:00	16:30	-03:30

* Diff. (Q model – Q observed)/Q model

2 Discharge is an estimate

5 Discharge affected by unknown degree by regulation or diversion

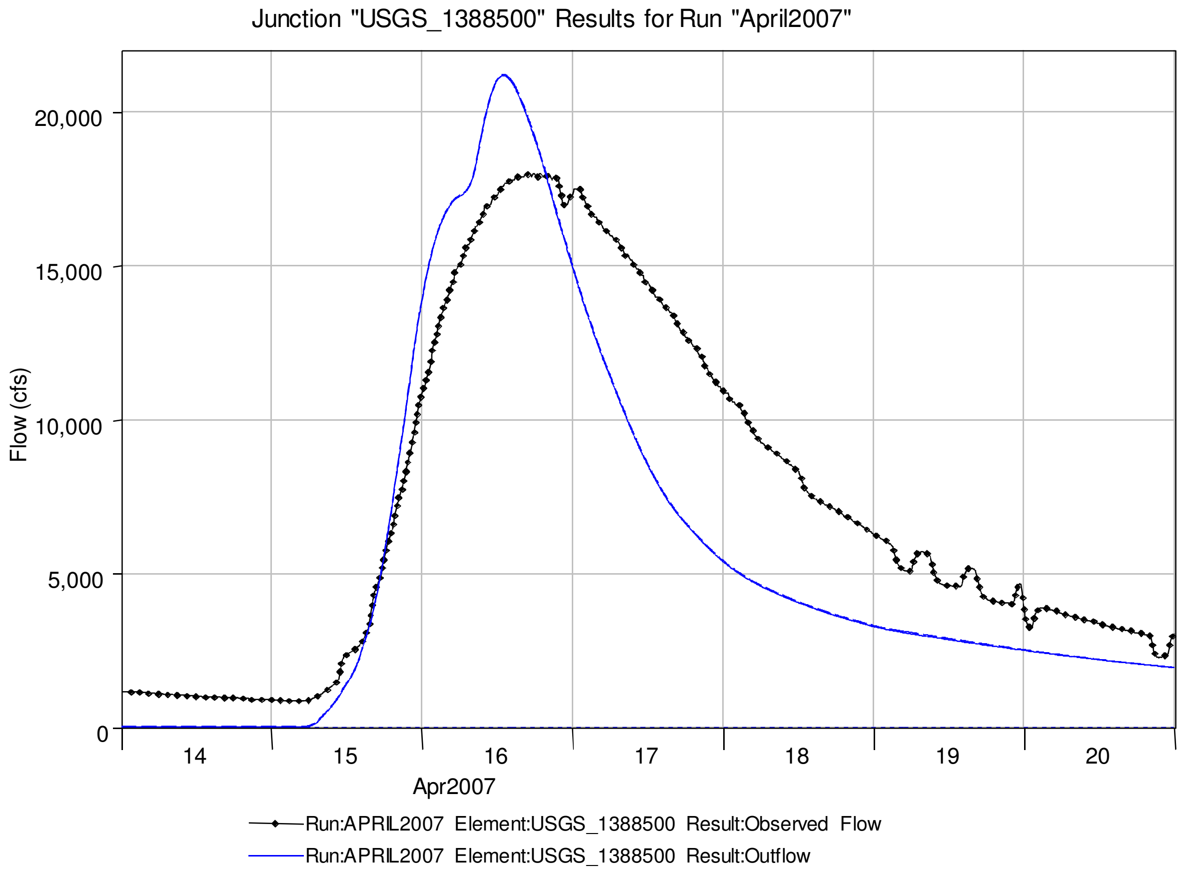

Figure 35. Modeled and Observed Flow Hydrographs at USGS 1388500 (Pompton River) for April 2007 Storm Event (SCS AMC 3).

The primary purpose of the hydrologic model for the Pompton Basin is to provide a representative 100-year inflow hydrograph for the unsteady state hydraulic model calibration process completed for the Central Passaic Basin (Central Passaic Study Reach). The selection of validation storms at the two possible extremes for antecedent moisture condition reflects a reasonable test of the assumption of average conditions made in the selection of the calibration storm events. Based on the range of storm sizes and antecedent conditions modeled, the results at the Pompton Gage site reflect 100-year flow conditions that are consistent with the observed discharges and flow volume at this gage. As shown in Table 28, the HEC-HMS model does this for peak discharges across the range of required recurrence intervals.

Table 28: Pompton Frequency Storms

100 Year Frequency Storm – 24 Hour				
River	Reoccurrence	Peak (cfs)		(Q Model – Q Observed) / Q model
		Model	Obs. (LPIII)	
Pompton* 01388500	10 year	9,253	13,070	-41%
	50 year	18,892	21,420	-13%
	100 year	24,401	25,480	-4%
	500 year	44,032	36,160	+18%

*The gage discharge is affected to an unknown degree by flow regulation or diversion

D.5 Central Passaic Basin Hydrology & Hydraulics

D.5.1 RAINFALL-RUNOFF MODEL

Like other Passaic Basin models, the HEC-HMS model for the Central Passaic Basin uses an SCS Curve Number (CN) loss model and the SCS Unit Hydrograph. The HEC-HMS sub-basins within the Central Passaic Basin model, however, connect directly to either approximate or detailed unsteady state HEC-RAS models (Figure 36). Calibration of the modeled discharges to observed discharge and water surface elevations were completed using a detailed unsteady state HEC-RAS model. The calibrated unsteady state model was used to establish both the recommended discharges and water surface elevations for this study reach.

D.5.1.1 *BASIN CHARACTERISTICS*

The modeling setup in the Central Basin was developed to accommodate the unique storage and flow conditions, which can include flow reversals along the Passaic River (Central Passaic Study Reach) and its major tributaries.

D.5.1.2 *WATERSHED DELINEATION*

Sub-basin boundaries were delineated to reflect land use differences and river confluences along the Passaic River as well as USGS gage locations.

D.5.1.3 *Initial SCS CN and Lag Times*

Application of the SCS CN loss model method was based on existing land use and soils data for the Central Passaic Basin. Land use data was provided from the NJDEP. All land use data was checked against aerial photography for consistency with NJDEP data.

D.5.1.4 *Channel and Reservoir Routing*

There is no hydrologic channel or reservoir routing in the Central Passaic Basin's HEC-HMS model. All HEC-HMS sub-basins connect directly to approximate or detailed unsteady HEC-RAS models for routing purposes.

D.5.2 HYDRAULIC MODELING

Hydraulic modeling in the Central Passaic Basin includes both approximate and detailed unsteady state HEC-RAS models. Approximate models were created for reaches along the Upper

Passaic River, Rockaway River, Pompton River, and Deepavaal Brook (Figure 36). A detailed unsteady state model was developed for the Central Passaic Study Reach. New field survey data was collected only along this study reach. HEC-RAS files for the three approximate and one detailed unsteady models are listed in Appendix H.

To accommodate the effects of storage due to backwater effects, the four approximate unsteady HEC-RAS models were used for hydraulic routing of runoff hydrographs from HEC-HMS modeled tributaries to their respective confluences with the Central Passaic Study Reach. Cross-section data for these four tributaries was generated using the NJ LiDAR terrain dataset. As these models were intended only to accommodate the effects of storage due to backwater conditions, no structure data was coded for these models.

D.5.2.1 *Boundary Conditions and Tie-ins*

Unsteady state HEC-RAS models require either hydrologic or hydraulic boundary conditions. Hydrologic boundary conditions were applied to upstream cross sections as point inflow, lateral inflow, or uniform lateral inflow hydrographs. Hydraulic boundary conditions are generally assigned at the most downstream cross section. For the approximate unsteady HEC-RAS models for the tributaries, the runoff hydrograph from the HEC-HMS models were input as the upstream hydraulic boundaries and normal depth was assigned as a downstream hydraulic boundary condition. For the Central Passaic Study Reach detailed unsteady state HEC-RAS model, runoff hydrographs from approximate unsteady HEC-RAS models and sub-basins from the Central Passaic River HEC-HMS basin model were applied as hydrologic boundary conditions. Normal depth was used as the downstream hydraulic boundary condition. A detailed summary of the hydrologic boundary conditions for the four approximate unsteady HEC-RAS models and one unsteady HEC-RAS model is included in Appendix C. The central Passaic River unsteady model results were used for mapping from Beatties Dam (Sta 124386.7) to 2800 feet downstream of I-280 (Sta 216930.9).

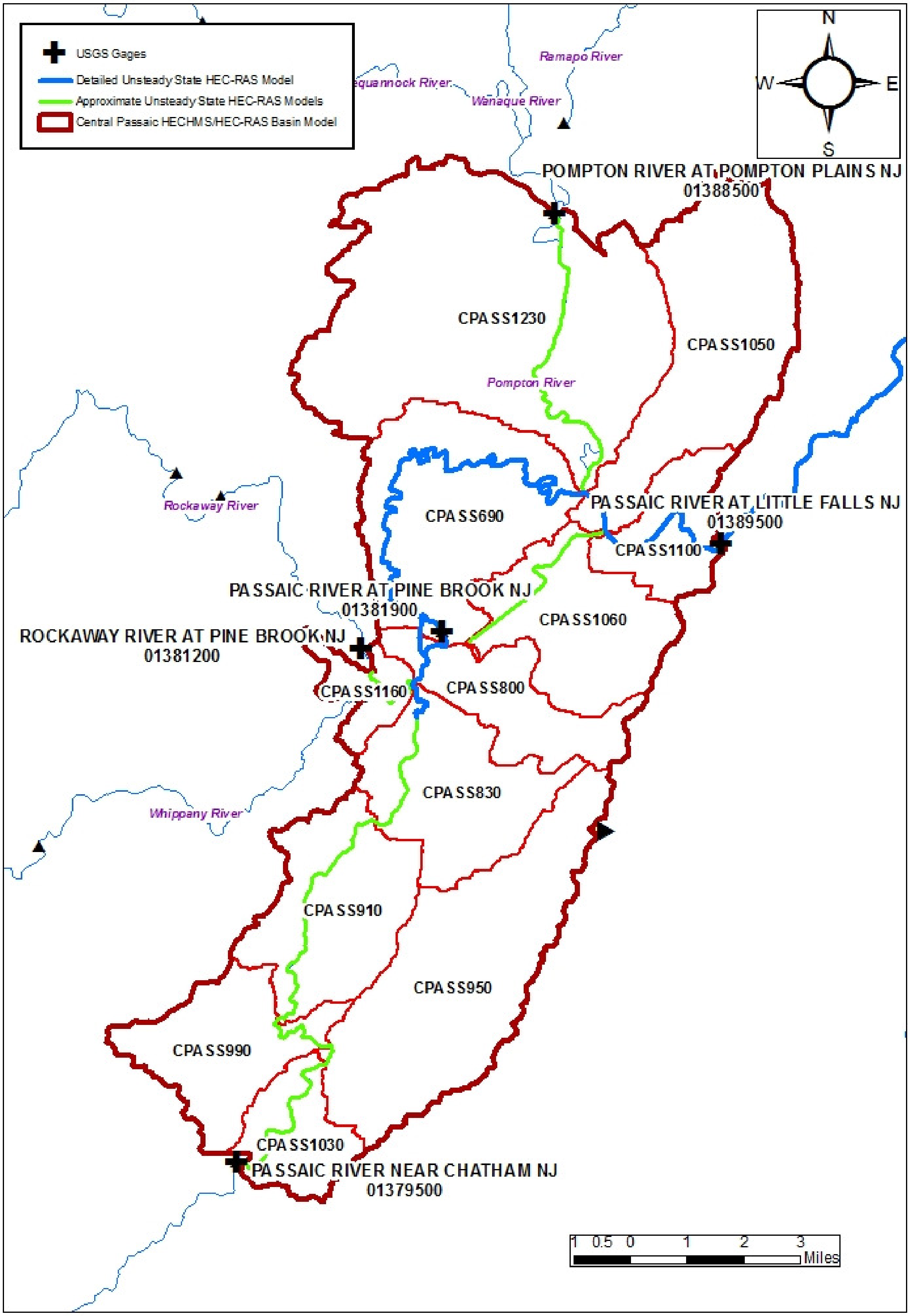

Figure 36. Model Setup Central Passaic Basin

D.5.2.2 *Cross-section Layout*

One hundred and twelve cross sections, with a typical spacing of approximately 800 feet, were placed at representative locations along the detailed study reach (Figure 37). Cross sections were made up of both surveyed and interpolated cross sections. Surveyed cross-section geometries, approximately 2500 feet apart, were obtained by blending a field surveyed main channel with the overbank geometry developed from LiDAR data. Many of the cross-section lengths extend for distances of up to 1 to 1.5 miles with the channel portion of these cross sections extending only several hundred feet. The relative shortness of the channel portion of these cross sections along with the low gradient features of the detailed study reach allowed non-surveyed cross sections to be developed from upstream and downstream surveyed channel sections and blended with overbank geometry taken from the LiDAR data to develop the final cross sections in the model.

All the cross-section geometry in the Upper Passaic River, Pompton River, Rockaway River, and Deepavaal Brook approximate unsteady state HEC-RAS models were obtained directly from the LiDAR terrain dataset.

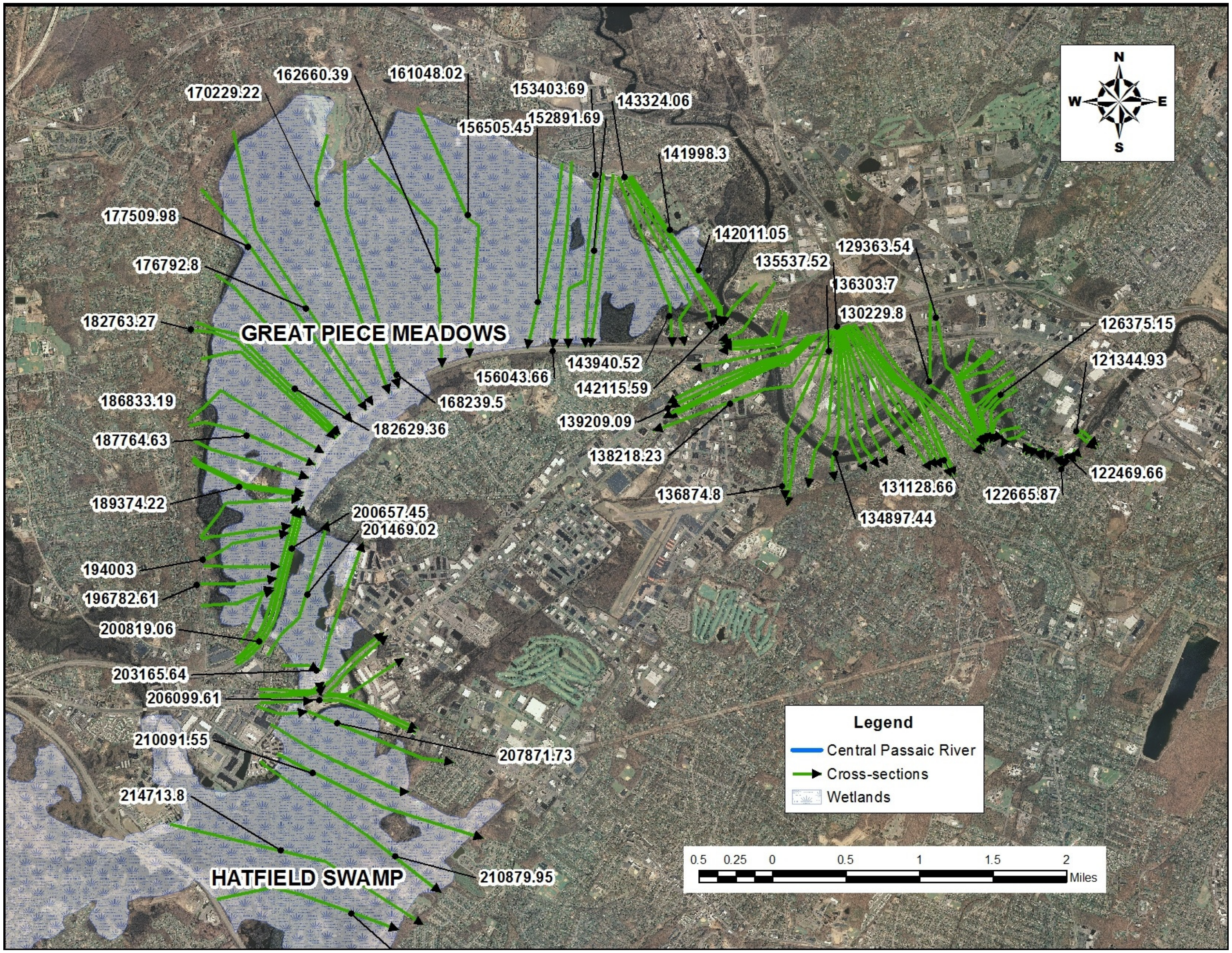

Figure 37: Cross-section Locations along the Central Passaic River

D.5.2.3 *Structures*

Hydraulic structures were modeled only along the Central Passaic Study Reach. Geometry for all the structures along this reach were based on new field survey completed in 2010. In total, sixteen bridges and one in-line dam structure (Beatties Dam) were field surveyed and are included in the model (Figure 38). Contraction and expansion coefficients were set to 0.3 and 0.5 at each structure's upstream and downstream face sections (cross-sections 3 and 2 respectively) and at the approach section (cross-section 4).

D.5.2.4 *Ineffective and Storage Areas*

Ineffective areas, representing overbank flood storage, were modeled in the Central Passaic Unsteady HEC-RAS model. The ineffective areas reflect the impact of obstructions from the buildings, contraction, and expansion near bridges and wide floodplains. Most of these areas consisted of either urban or wetland land uses with most of the urban ineffective areas located between the Two Bridges Road and USGS gage 01389500. Wetlands such as the Great Piece Meadows and West Essex Park were also modeled as ineffective areas.

D.5.2.5 *Cross section Roughness Values*

Manning's coefficient was used to represent the channel and overbank roughness. Manning's n values for the channel section were estimated based on the survey field photos and 2007 aerial imagery. The 2002 Land Use/ Land Cover dataset developed by NJDEP was used to estimate the Manning's n values for overbank areas. Channel n values range from 0.03 to 0.04 and overbank n values range from 0.035 to 0.14. Table 29 lists the Manning's n values estimated for overbank land-uses.

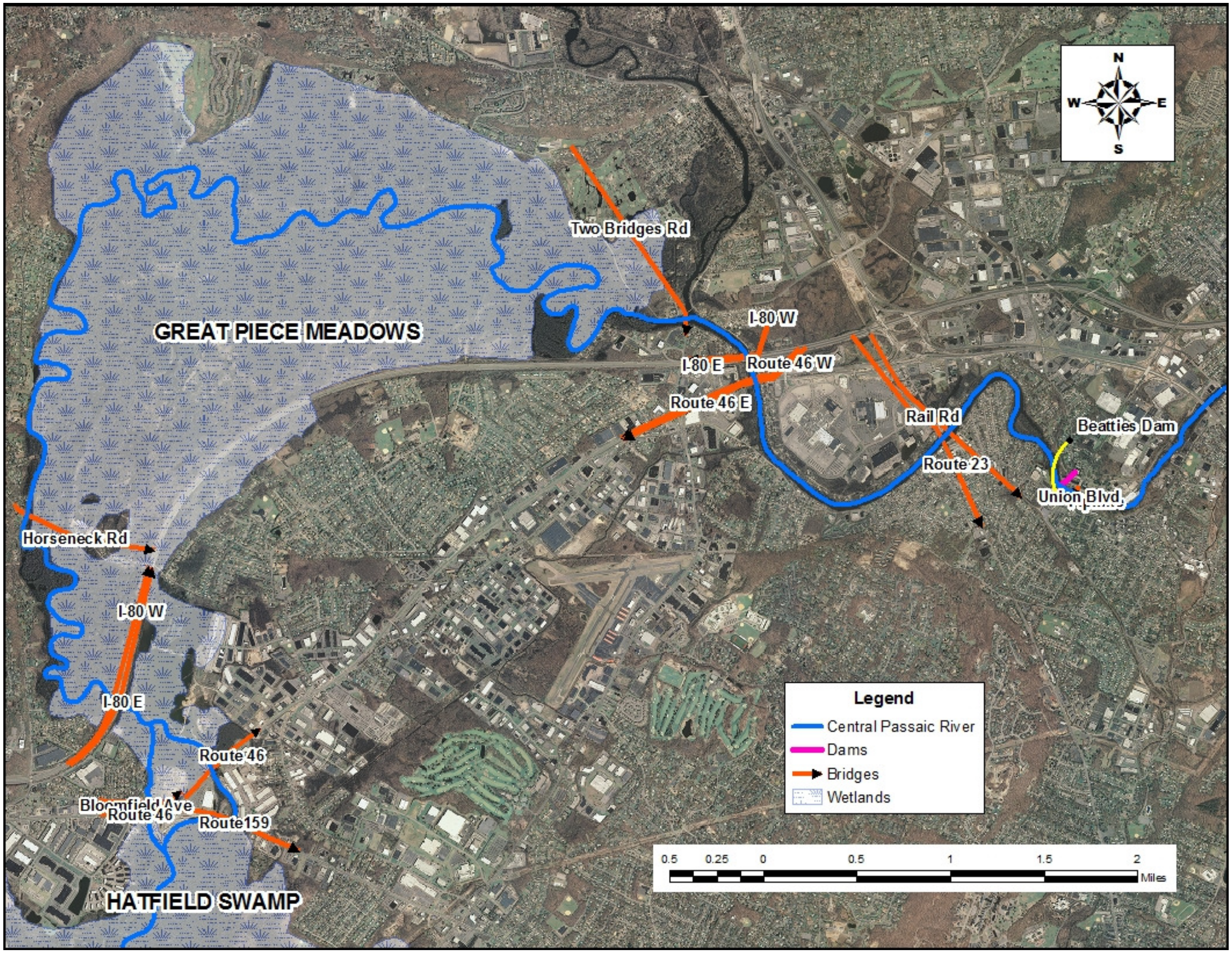

Figure 38: Sixteen Bridges and Beatties Dam Locations along the Central Passaic Study Reach River

Table 29: Manning's N Values

Land-use	Manning's n Value
Agriculture	0.05
Barren Land	0.04
Forest	0.12
Grass Land	0.035
High Urban	0.07
Medium Urban	0.045
Water	0.035
Wetlands	0.14

D.5.2.6 *Split Flow*

A split in flow occurs on the Central Passaic Study Reach at approximately 2500 feet upstream of Bloomfield Avenue/NJ 159. This split rejoins the Passaic at approximately 2500 feet downstream of Route 46 as shown in Figure 39. The split reach is located in the Montville Township, Morris County. This split was modeled in HEC-RAS model as a split with two junctions with the split flows determined using the "Split Flow Optimizations" option in the HEC-RAS Unsteady Flow Analysis. In the effective FIS, the Passaic River follows the Montville and Fairfield township boundary.

D.5.2.7 *MODEL CALIBRATION AND VALIDATION*

USGS rating curve, observed flow, and stage hydrograph data were used in the calibration of the Central Passaic Study Reach HEC-RAS Model. Data from four gage stations located along the study reach were available for use in the calibration process of the unsteady state HEC-RAS hydraulic model (Table 30 and Figure 36). Rating curve data were available for all four gages. For the September 1999 and September 2004 flood events, observed flow hydrograph were available from only two of these gages (01389500 and 01381900). No high water marks were available for the recent flood events along the Central Passaic Study Reach. While consistency with the observed rating curves for the 1999 and 2004 events is important, of more importance for the development of the 100-year water surface profile is the ability of the model predications to simulate the observed water surface data at gaged locations. The gage locations were shown in Figure 40.

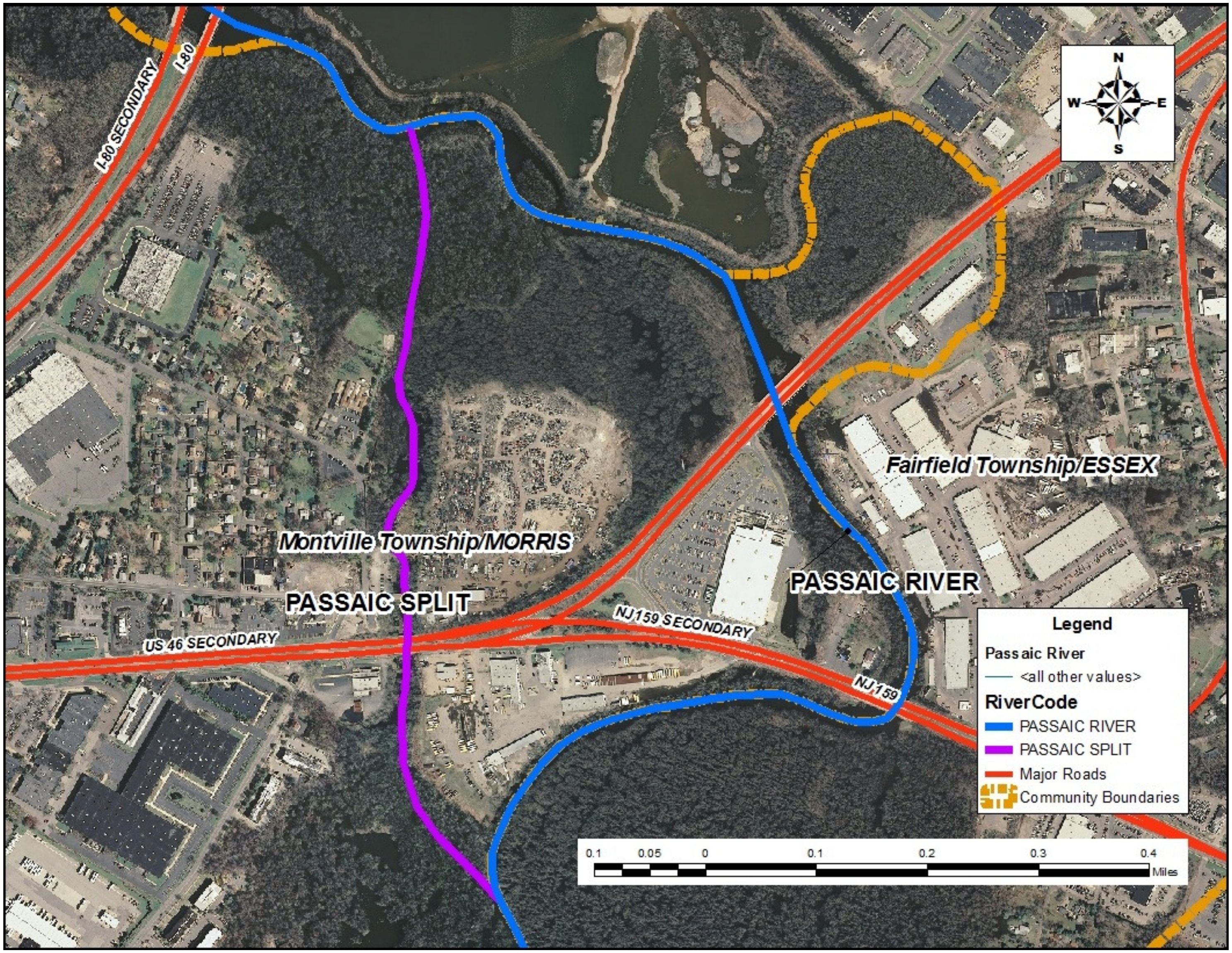

Figure 39: Location of Split Flow along Central Passaic River

Table 30: USGS Gages along the Central Passaic Study Reach

USGS Gage Number	**USGS Gage Name**
01389500	Passaic River at Little Falls, NJ
01389492	Passaic River above Beatties Dam at Little Falls, NJ
01389005	Passaic River Below Pompton River at Two Bridges, NJ
01381900	Passaic River at Pine Brook, NJ

September 1999 Calibration Event

Using the inflow HEC-HMS hydrographs from the five HEC-HMS basin models and an initial un-calibrated unsteady state HEC-RAS model setup, the modeled hydrograph compared well with the observed hydrograph at USGS 01389500 (Little Falls). This was the case for both the magnitude and timing of the peaks, as shown in Figure 41. The magnitude of the simulated peak was 3% higher than the observed peak and appears to be the result of a difference in base flow. After adjusting for differences in base flow, the simulated peak is approximately 2% lower than the observed peak. The simulated peak is also approximately 3.5 hours later than the observed peak. There is also an earlier shorter duration peak in the observed data that is not as distinct in the modeled hydrograph. In the modeled hydrograph, this peak appears to occur later, as part of the rising limb of the main peak. These mismatches are believed to be the result of the poor spatial coverage of the rainfall data available for the 1999 event and its effect on the timing of modeled flows from major tributaries.

At the USGS Pine Brook Gage (01381900), the unsteady HEC-RAS model simulated runoff hydrograph was 16% lower than the observed peak for the 1999 event (Figure 42). The Pine Brook Gage measures discharge only in the main channel of the Passaic River and does not account for flows that by-pass the gage during high stage events. The modeling results for the 1999 event simulated a peak discharge of 3754 cfs. For this event, approximately 600 cfs of the modeled discharge bypass the USGS gage. After accounting for by-passed flows, the simulated hydrograph is within 5% of the observed hydrograph. Another source of the inconsistency in the results for this gage, particularly at high flows, is the looped nature of the rating curve at this site (Figure 48).

The simulated peak at Pine Brook Gage was also approximately 13 hours earlier than the observed peak. As was the case for the gage at Little Falls, this is believed to be the result of discrepancies in the timing of the major tributary inflows into the Passaic (Rockaway, Whippany, and Upper Passaic). These discrepancies are in turn attributable to the lack of quality, spatially distributed rainfall data for this event and are not problems with the model simulation.

September 2004 Validation Event

The simulated runoff hydrograph shape and recession curve of the unsteady HEC-RAS model compared favorably with the observed runoff hydrograph at the Little Falls Gage (USGS 01389500; Figure 43). The magnitude of the simulated peak, however, was 17% higher than the observed peak. The simulated peak was also approximately 10 hours later than the observed. The attenuation of the observed hydrograph may have been the result of a high initial abstraction of the inflows into the Great Peace Meadows Swamp for this relatively small event.

This appears not to have affected the inflows at the Pine Brook Gage, where the Passaic flows are primarily contained within the main channel and not in the overbank area. For the 2004 event, the Pine Brook Gage observed data and model simulation are also more consistent than was the case for the 1999 event. Unlike the 1999 event, the Pine Brook Gage recorded greater than 90% of the flow for the 2004 event. The magnitude of the simulated peak produced by the unsteady HEC-RAS model simulated runoff hydrograph was approximately 5% higher than observed peak (Figure 44). The simulated peak was approximately 3.75 hours earlier than the observed. The unusual shape of the receding limb of the observed hydrograph during this event is unexplained.

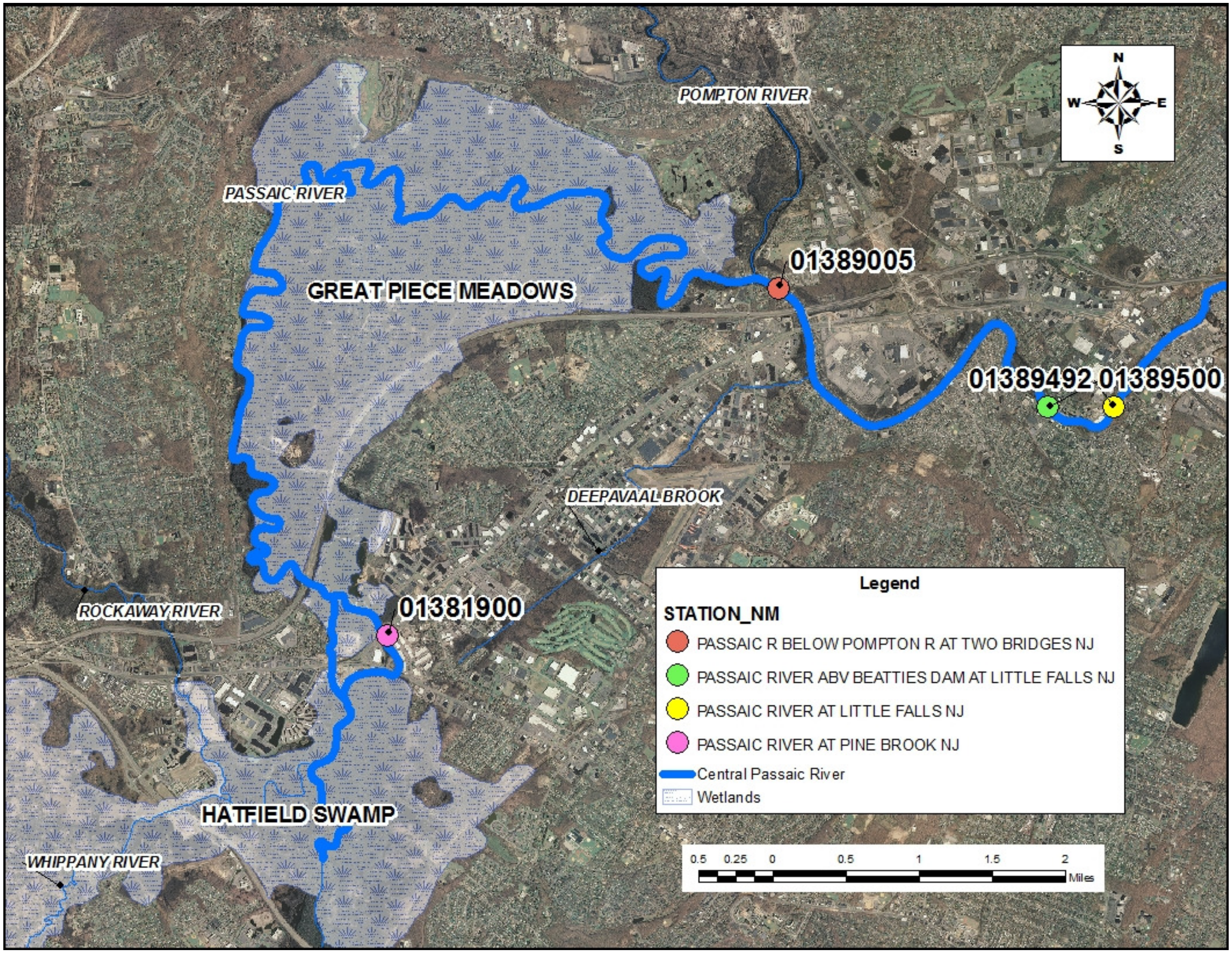

Figure 40: USGS Gages Located on the Central Passaic River

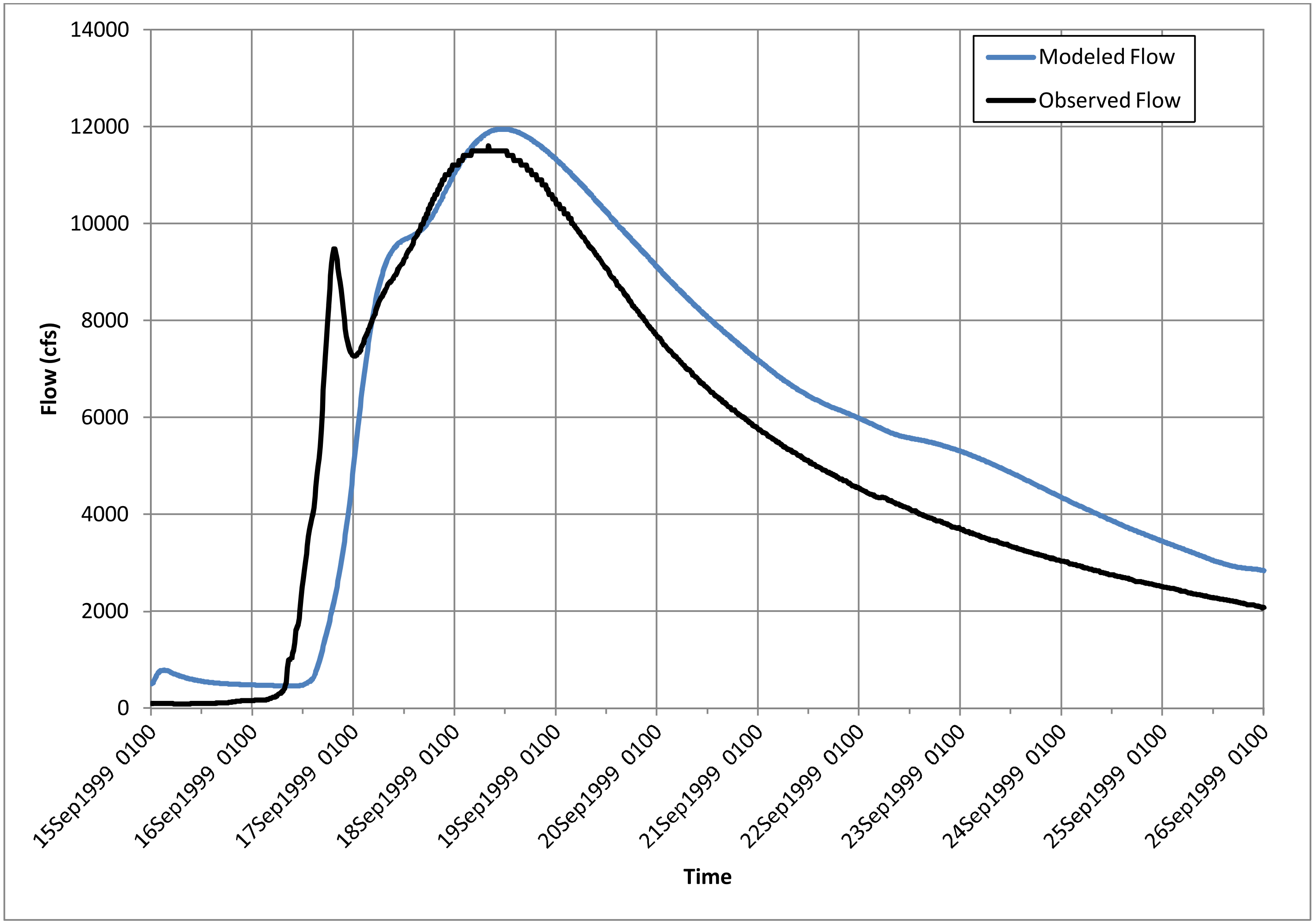

Figure 41: Comparison of Simulated and Observed Runoff Hydrographs at USGS 01389500 (Passaic River at Little Falls, NJ)

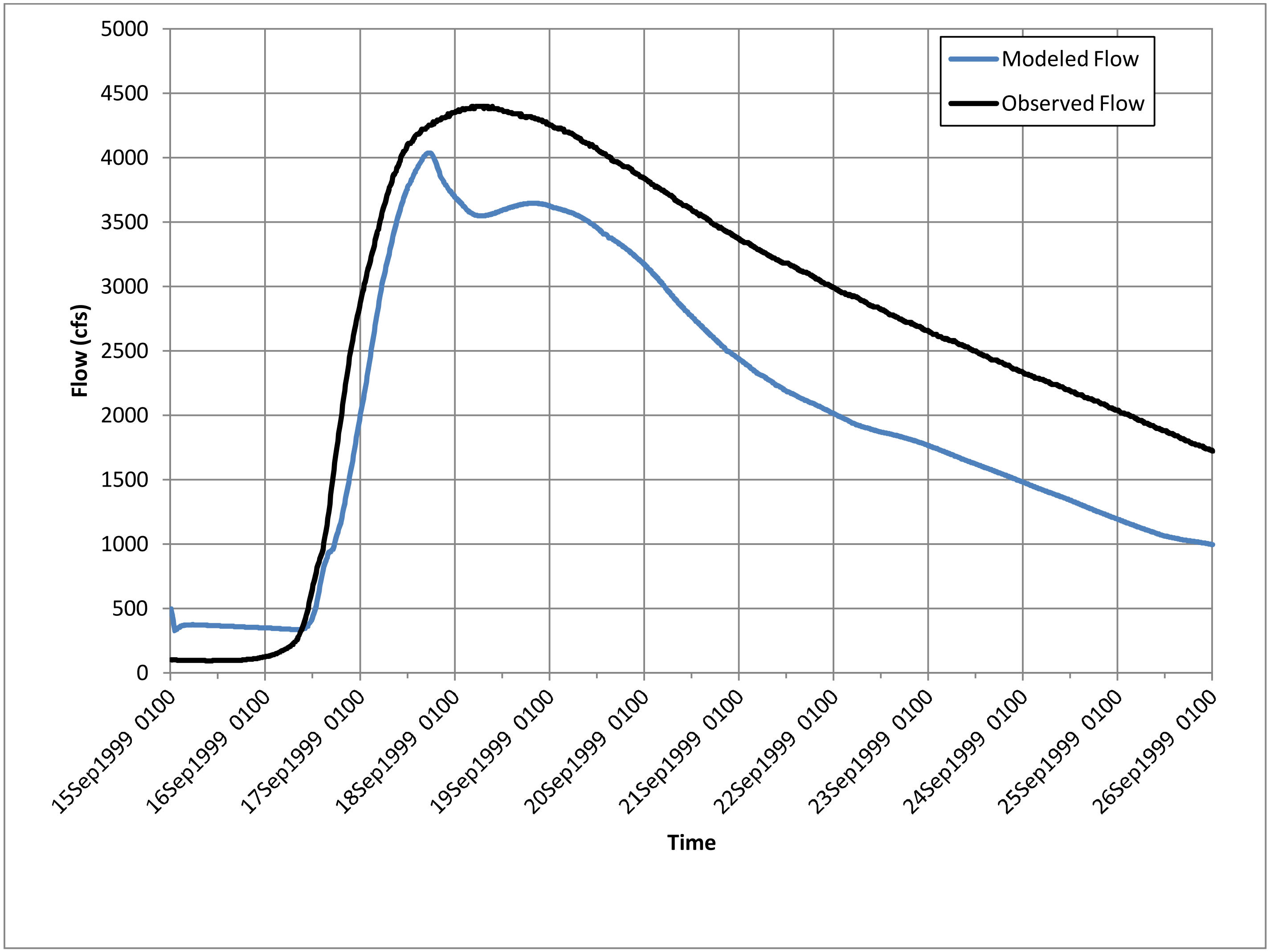

Figure 42: Comparison of Simulated and Observed Runoff Hydrographs at USGS 01381900 (Passaic River at Pine Brook, NJ)

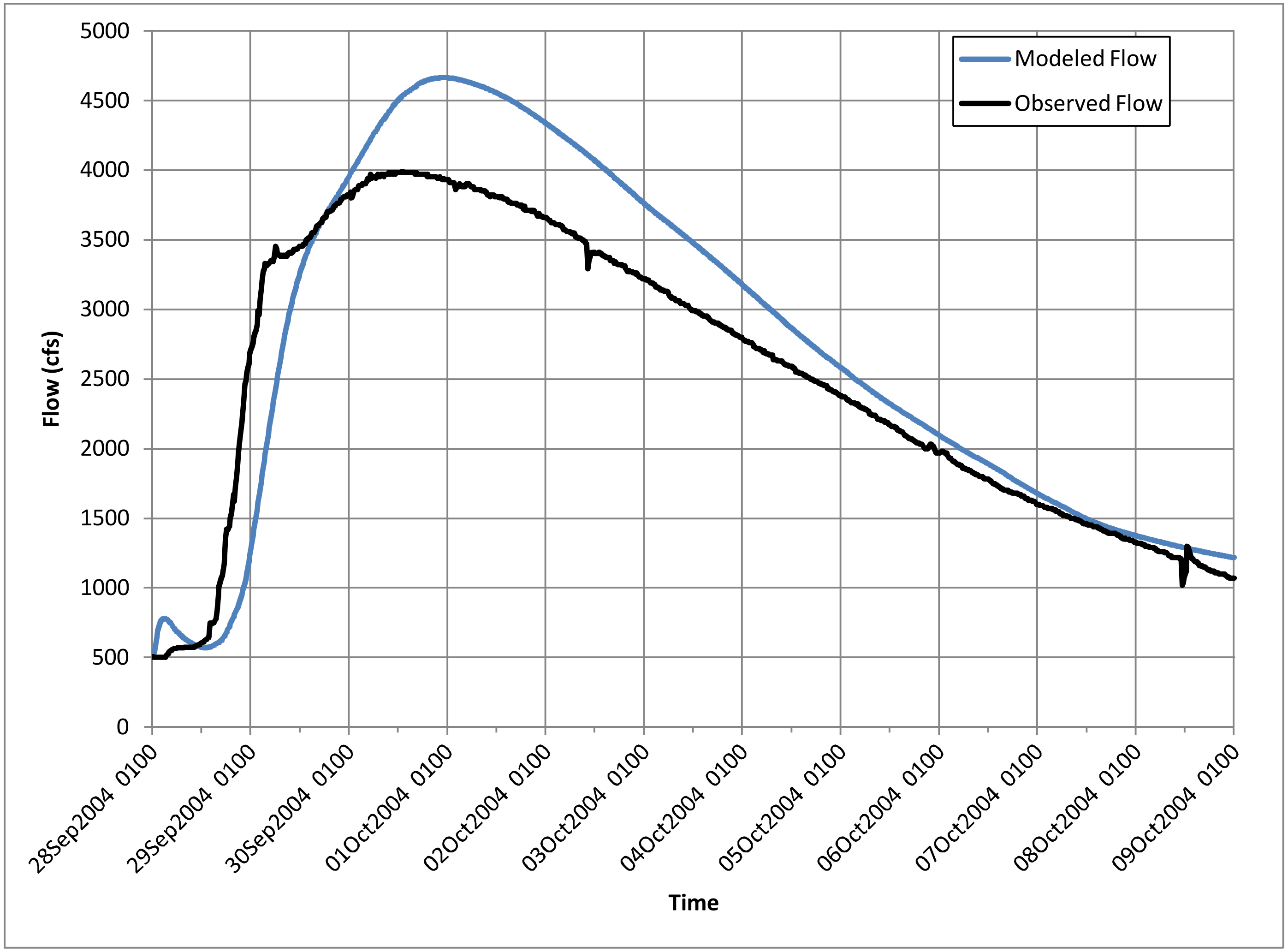

Figure 43: Comparison of Simulated and Observed Runoff Hydrographs at USGS 01389500 (Passaic River at Little Falls, NJ)

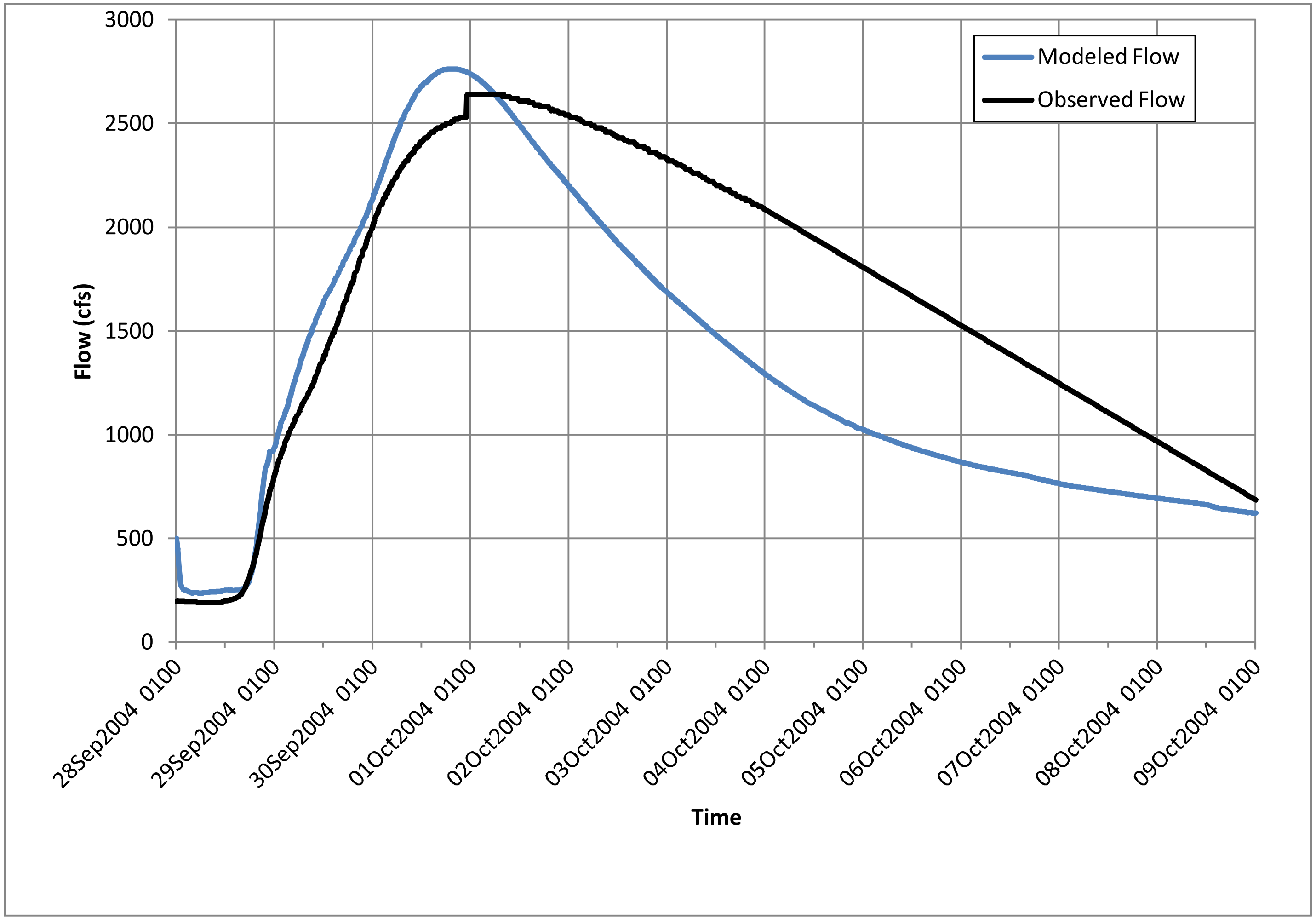

Figure 44: Comparison of Simulated and Observed Runoff Hydrographs at USGS 01381900 (Passaic River at Pine Brook, NJ)

Rating curve data was obtained from four USGS gages and compared with the simulated rating curves in the unsteady HEC-RAS model. The ability of the model to simulate these rating curve relationships is critical for the development of 100-year discharges and the corresponding water surface elevations. Simulated rating curves matched within +/- 0.5 foot of the USGS gage-rating curve at USGS gages 01389492, 01389005, and 01381900, as shown in Figures 46 through 48. At USGS gage 01389500 (Little Falls) the simulated and observed rating curves are average of 6 feet off for lower flows, but are reasonably well match at higher flows. This mismatch is likely the result of difference in the location used for low flow measurements versus the location used for measuring higher flows. USGS staff was contacted concerning the observed discrepancy but could not provide any additional information to help explain the discrepancy. For flows above 11,000 cfs, the simulated rating curve matched within +/-0.75 foot of the USGS gage rating curve, as shown in Figure 45.

The only USGS gage not affected by backwater along the Central Passaic Study Reach is the Beatties Dam gage (01389492), and it has an expected single value-rating curve (Figure 45). The USGS gages at both Two Bridges (01389005) and Pine Brook (01381900) have looped rating curves (Figures 46 and 47). These gages are both affected by inflows from the Pompton River, which reverses the flow in the Passaic River due to the downstream constrictions in the Passaic river channel (Figure 49). This backwater effect results in conditions where the same discharge can occur at two different stages.

The backwater effects on the USGS gage at Two Bridges is less than that seen at the USGS gage at Pine Brook. For the USGS gage at Two Bridges (01389005), the simulated higher stage of the looped rating curve for USGS gage 01389005 matches with the observed rating curve within +/- 0.5 foot. For USGS gage 01381900 at Pine Brook, the simulated higher stages of the looped rating curve are higher than the observed stages, but the lower stages match the modeled stage/discharge relationship within +/- 0.5 foot.

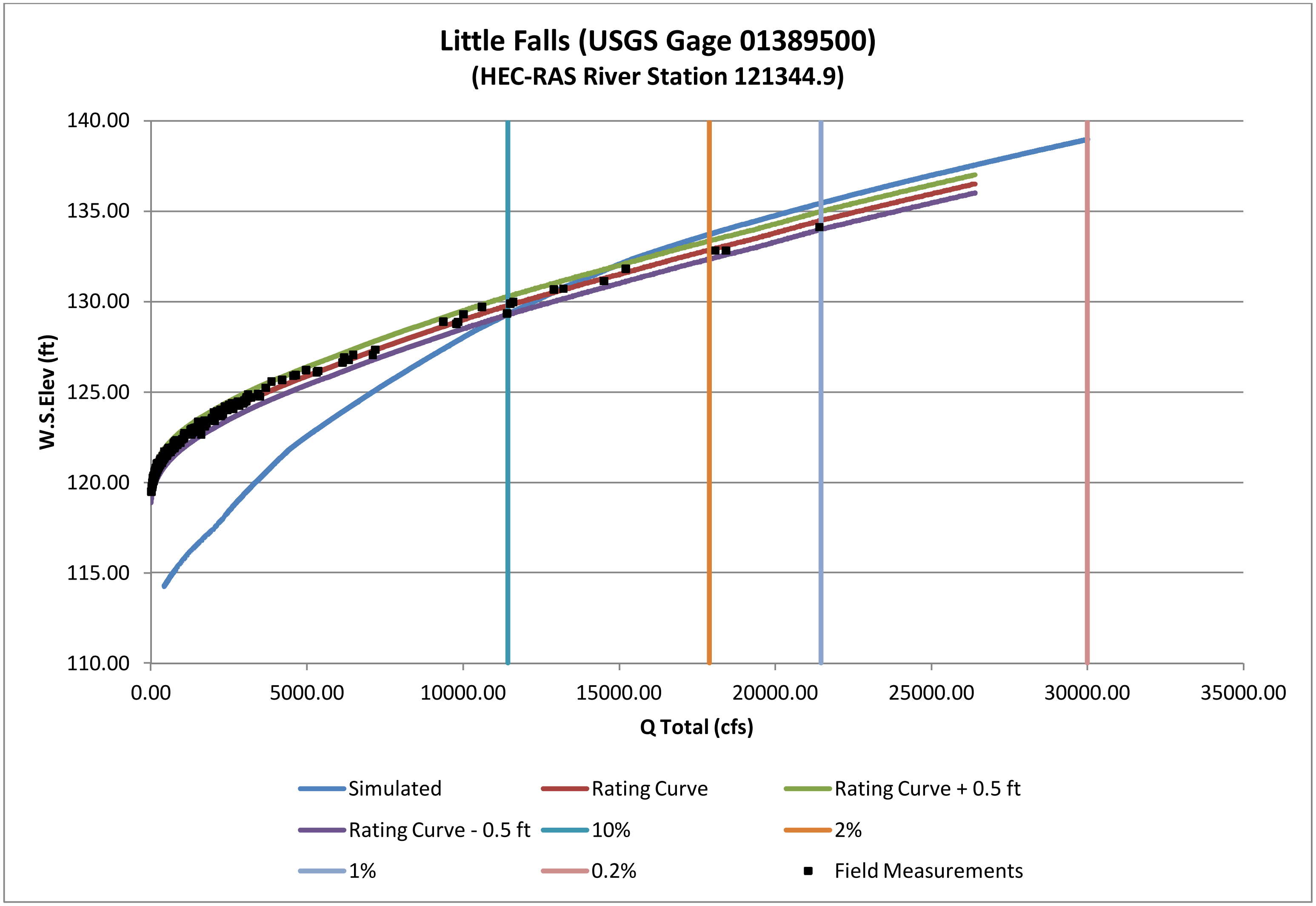

Figure 45: Comparison of Simulated and Observed Hydrographs at USGS Gage 01389500 (at Little Falls)

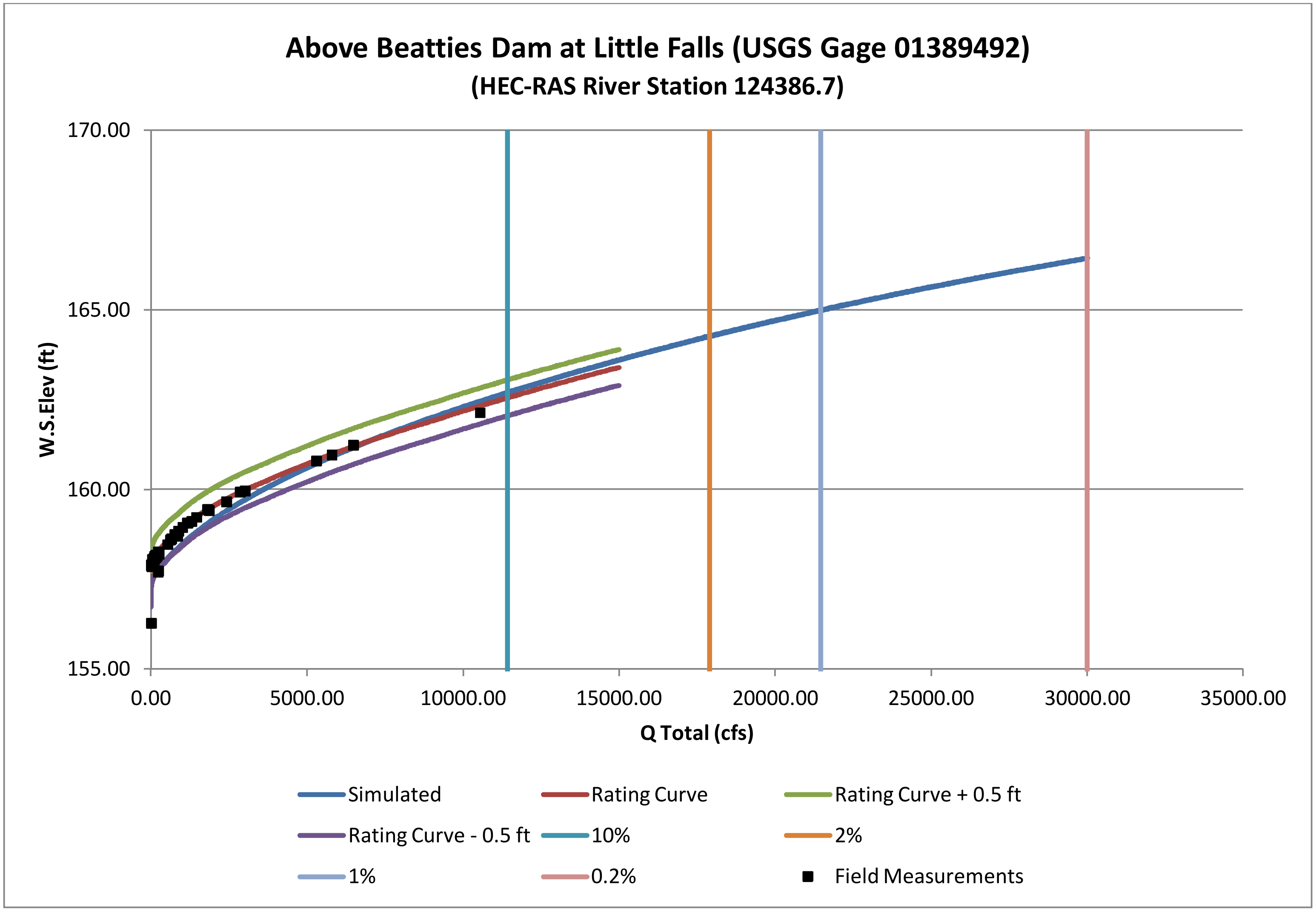

Figure 46: Comparison of Simulated and Observed Rating Curves at USGS Gage 01389492 (above Beatties Dam at Little Falls)

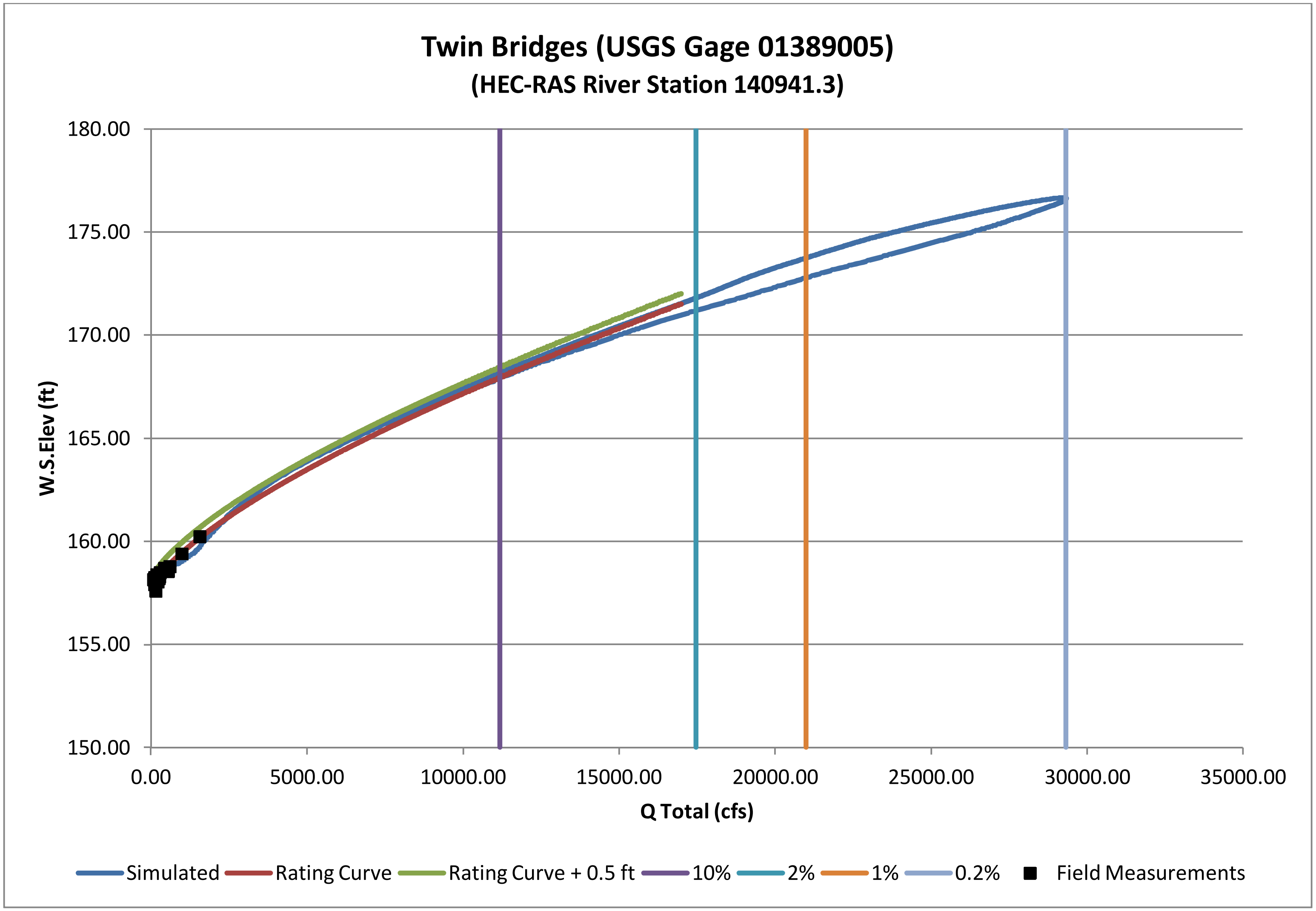

Figure 47: Comparison of Simulated and Observed Rating Curves at USGS Gage 01389005 (Two Bridges)

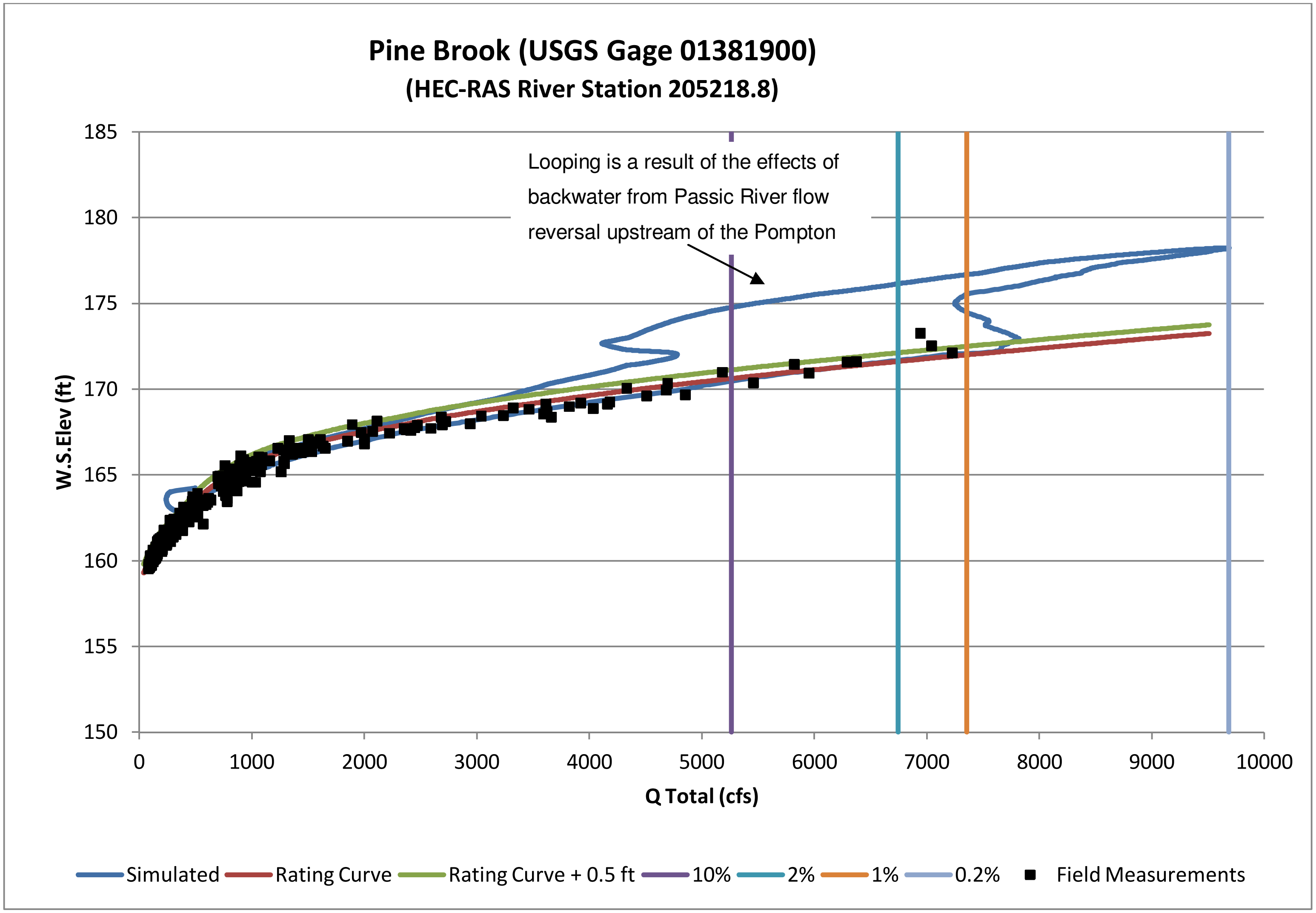

Figure 48: Comparison of Simulated and Observed Rating Curves at USGS Gage 01381900 (Pine Brook)

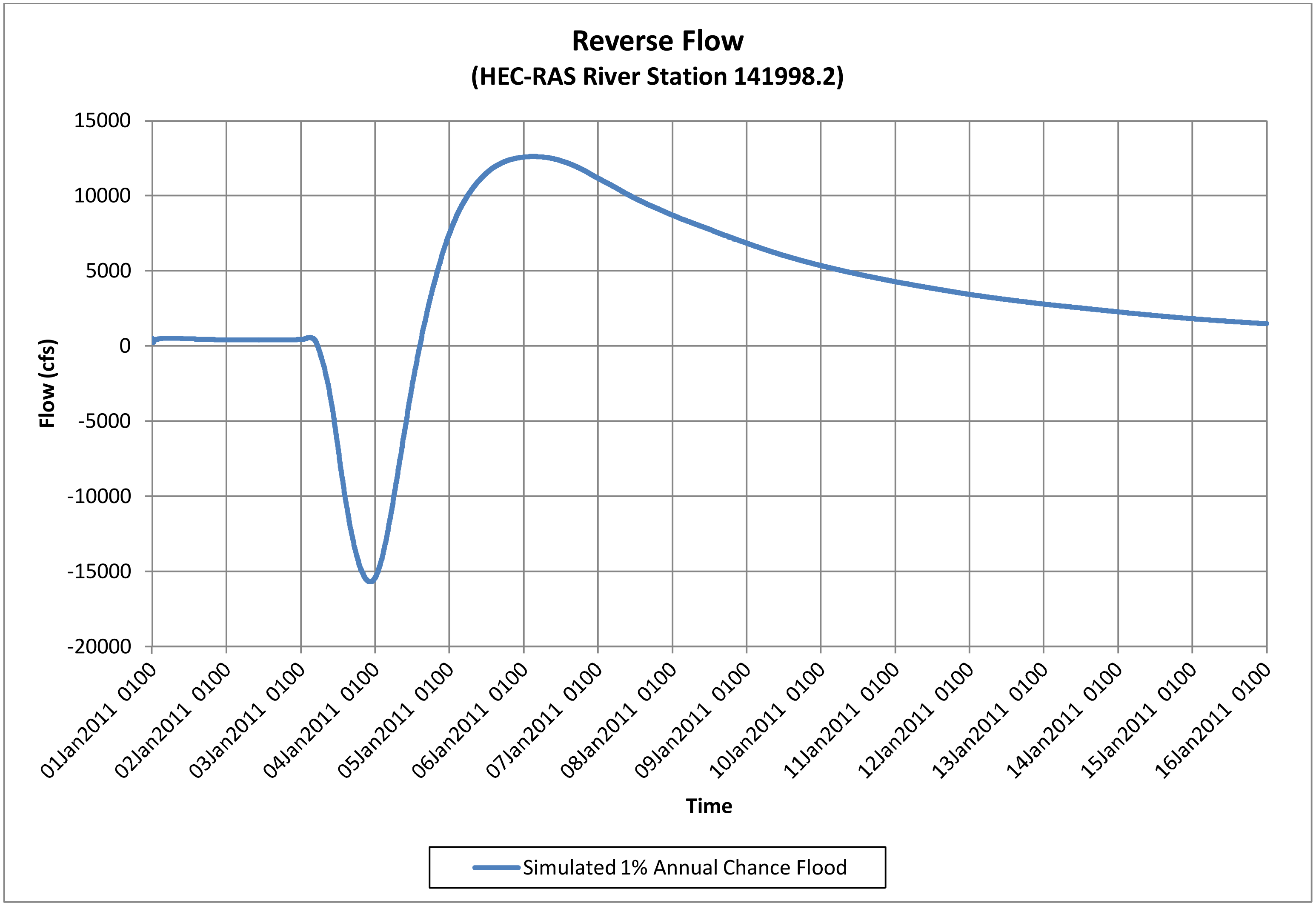

Figure 49: Reverse Flow Hydrograph at Cross Section Located on the Passaic Upstream of the Confluence with the Pompton River

D.5.2.8 *FREQUENCY STORM DATA*

The size of the Passaic Basin (935 square miles) and a review of the recent and historical rainfall events in the basin indicate that unevenly distributed precipitation events are more likely to be associated with 100-year flows than would a uniformly distributed precipitation event (USACE, 1995). The assumption across the basin of a uniform antecedent moisture condition for SCS hydrology is also unlikely to correlate with 100-year flows. To address these concerns and to ensure consistency with procedures used by the USACE (1995), areal adjustment factors were applied to individual HEC-HMS basin models to match updated LP III peak flow frequency gage data along the study reach. These adjustments were made to the NOAA Atlas 14 rainfall amounts for the centroid for the Passaic Basin. Consistent with earlier work by USACE (1995), the 96-hour storm duration was selected for the frequency event.

As shown in Table 31, these adjustment factors ranged from +5% to -34% for the individual basin models. For the entire Passaic Watershed, the adjustment factors ranged from -2% to -14%. The -10% adjustment factor for the 100-year event is consistent with published point areal reduction factor guidance for watersheds up to 400 square miles in area (USACE 2009). No specific guidance for watersheds as large as the Passaic Watershed could be found in reference literature.

Table 31. Rainfall Areal Correction Factors

Basin	D.A. (sq. mls.)	10	50	100	500
Pompton Basin	355	-5%	-11%	-13%	-16%
Upper Passaic Basin	99	19%	9%	5%	-2%
Whippany Basin	70	-17%	-29%	-34%	-43%
Rockaway Basin	137	-10%	-18%	-21%	-28%
Saddle Basin	60	11%	2%	-3%	-12%
Central Passaic Basin	103	0%	0%	0%	0%
Lower Passaic Basin	114	0%	0%	0%	0%
Passaic Watershed (all Basins combined)	938	-2%	-8%	-10%	-14%

After the completion of the areal adjustments to rainfall, the observed gage frequency data (LP III analyses) matched reasonably well with the modeled discharges at most USGS gage locations in the Basin (Table 32). The Whippany River near Pine Brook (01381800) and Passaic

River at Pine Brook (01381900) showed the greatest difference between the observed and modeled discharge values. These two gages are affected by the hydro-dynamics associated with large wetlands, and the reliability of the rating curves for these gages may account for the observed differences. Updates to the rating curves for these gages, as well as for other gages in the watershed, have been included in the recent recommendations of the Passaic River Basin Flood Advisory Commission (2011).

D.5.3 Comparison of Effective and Proposed Discharges at Effective FIS Locations for Central Passaic Basin

At the USGS gage (01389500) at Little Falls, the new 10%, 2%, 1% and 0.2% annual chance flows increased by 8%, 10%, 10% and 15% respectively, compared with the effective FIS flows (Table 33).

Passaic River upstream of the confluence of the Pompton River: The new 10%, 2%, 1% and 0.2% annual chance flows increased by 28% , 34%, 65%, and 36% respectively, compared with the effective FIS flows, which were calculated incorrectly. In the effective FIS, flows upstream of the confluence of the Pompton River were computed by transferring the LP III flows of the USGS gage at Pine Brook (01381900) downstream. The USGS Pine Brook gage is located on the main channel of the Passaic River and measures the discharge only in the main channel. At this location, however, there is a split flow and the USGS gage does not measure a significant portion of the discharge, particularly at high flows. As a result of this split flow, the use of the USGS gage at Pine Brook for an LP III analysis is not feasible, and this type of analysis cannot be transferred downstream to a location upstream of the confluence of the Pompton River as was done in the effective FIS.

Passaic River downstream of the confluence of the Rockaway River, the new 10%, 2%, 1% and 0.2% annual chance flows vary by 14% , 0%, -6% and -18% respectively, compared with the effective FIS flows (Table 33).

From the unsteady Central Passaic River HEC-RAS model, 1%, and 0.2% annual chance floodplain boundaries were delineated. In addition, 10%, 2%, 1%, NJFHADF and 0.2% annual chance flood profiles were generated. The NJFHADF flood profile was generated by multiplying the 1% annual chance inflow hydrographs by 1.25, and this profile was developed only for the Central Passaic River hydraulic model.

Table 32. Comparison of Observed and Model Discharges at USGS Gage Locations

Gage Location	10% annual chance flood			2% annual chance flood			1% annual chance flood			0.2% annual chance flood		
	LPIII	Modeled	% Diff	LPIII	Modeled	% Diff	LPIII	Modeled	% Diff	LPIII	Modeled	% Diff
POMPTON RIVER AT POMPTON PLAINS NJ (01388910)	13,600	13,458	-1%	23,000	22,665	-1%	27,800	27,702	0%	40,700	40,747	0%
PASSAIC RIVER NEAR CHATHAM NJ (01379500)	2,150	2,163	1%	3,000	3,013	0%	3,380	3,377	0%	4,350	4,359	0%
WHIPPANY RIVER AT MORRISTOWN NJ(01381500)	1,700	1,699	0%	2,450	2,468	1%	2,780	2,767	0%	3,610	3,580	-1%
WHIPPANY RIVER NEAR PINE BROOK NJ(01381800)	1,230	1,563	27%	1,670	2,085	25%	1,870	2,263	21%	2,390	2,735	14%
ROCKAWAY RIVER ABOVE RESERVOIR AT BOONTON NJ (01380500)	3,770	3,746	-1%	5,570	5,602	1%	6,410	6,423	0%	8,550	8,546	0%
PASSAIC RIVER AT PINE BROOK NJ (01381900)	5,540	5,265	-5%	7,370	6,747	-8%	8,140	7,356	-10%	9,950	9,687	-3%
PASSAIC RIVER AT LITTLE FALLS NJ (01389500)	13,100	11,437	-13%	19,500	17,903	-8%	22,400	21,469	-4%	30,100	30,008	0%
SADDLE RIVER AT LODI NJ (01391500)	3,190	3,164	-1%	4,890	4,919	1%	5,680	5,610	-1%	7,680	7,636	-1%

Table 33. Comparison of Effective and Proposed Discharges at Effective FIS Locations for the Central Passaic Study Reach.

Location	Drainage Area (mi^2)	Discharges (cfs)											
		10% annual chance flood			2% annual chance flood			1% annual chance flood			0.2% annual chance flood		
		FIS	New	%Diff	FIS	New	%Diff	FIS	New	%Diff	FIS	New	%Diff
At the USGS gage(3895) at Little Falls	762	12,300	**11,437**	-7%	18,600	**17,903**	-4%	21,700	**21,469**	-1%	30,200	**30,008**	-1%
Upstream of confluence of the Pompton River	361	4,900	**7,335**	50%	6,930	**10,660**	54%	7,890	**12,612**	60%	10,800	**16,345**	51%
Downstream of confluence of the Rockaway River	345	6,194	**6,612**	7%	9,927	**9,482**	-4%	11,969	**10,845**	-9%	18,382	**13,545**	-26%

A comparison of new and effective base flood elevations at upstream and downstream locations of all the bridges located along the Central Passaic Study River is shown in Table 34. New base flood elevations between Beatties Dam and State Route 23 have decreased by a range of 1.2 to 3.1 feet compared with effective FIS elevations. The new base flood elevations between Route 46 and Route 159, upstream of the confluence with the Pompton River, have increased by between 0.07 to 2.70 feet. These increases are due to the increase of 1% annual chance flood flow by 60% and are due to the corrections in hydrology analysis along this reach as well as replacement of the steady state HEC-RAS model with an unsteady state model, which now includes the effects of flood storage due to backwater.

Table 34: Comparison of New and Effective FIS Water Surface Profile Elevations

Road Names	Location (US/DS)	1% annual chance flood (NAVD)		
		Effective WSE	New WSE	Difference
		ft	ft	ft
Beatties Dam	US	167.0	165.0	-2.0
Beatties Dam	DS	150.8	147.7	-3.1
Conrail	US	170.4	169.2	-1.2
Conrail	DS	170.1	168.9	-1.2
Route 23	US	170.8	169.4	-1.4
Route 23	DS	170.6	169.3	-1.3
Route 46	US	171.5	172.9	1.4
Route 46	DS	170.8	171.5	0.7
I80	US	171.5	173.2	1.7
I80	DS	171.3	173.1	1.8
Two Bridge Rd	US	172.0	174.1	2.1
Two Bridge Rd	DS	171.8	174.1	2.3
Horseneck Rd	US	172.4	174.4	2.0
Horseneck Rd	DS	172.4	174.4	2.0
I80	US	172.4	174.9	2.5
I80	DS	172.4	174.9	2.5
Route 46	US	172.8	175.2	2.4
Route 46	DS	172.5	175.1	2.6
Route 159	US	173.3	175.6	2.3
Route 159	DS	172.8	175.5	2.7

D.5.3.1 *Floodway*

The effective FIS floodway is based on a steady state hydraulic model; in this model the floodway encroachment stations were obtained by the equal conveyance reduction method. Encroachment in the floodplain will not affect the flows downstream. However, in an unsteady hydraulic model, encroachment stations not only reduce flow conveyance but also take away flood storage. Flood elevations computed by unsteady flow analysis are sensitive to the conveyance and storage available in the floodplain. Therefore, surcharges computed using unsteady flow analysis would be generally higher than those computed using a steady flow analysis. According to FEMA's *G&S*, Appendix C, if modeling was performed using an unsteady model, the floodway should also be modeled using the same unsteady state model.

Because the Passaic River is a restudy, the effective floodway encroachment stations were evaluated to determine whether acceptable surcharge of 0.2-foot conditions were met. However, the surcharges for this trial were higher than 0.2 foot. In the second trial, a steady state model was developed. The steady state model's discharges were developed by importing peak flows (for each cross-section) from the unsteady state HEC-RAS model. Floodway encroachment stations were computed using the equal conveyance reduction method and specifying a target surcharge of 0.2 foot. These encroachment stations were then imported into the unsteady floodway run model and surcharges were computed. However, this trial also produced surcharges above the acceptable limit.

In the final trial, the floodway encroachment stations were produced by encroaching the flood fringe using engineering judgment. The two big swamp areas, Great Piece Meadows and Hatfield, were not encroached; for the rest of the areas, the encroachment stations were estimated by encroaching based on the floodplain boundaries and engineering judgment.

E. LOWER PASSAIC MODELING GROUP HYDROLOGIC AND HYDRAULIC MODELING

This section of the modeling discussion is broken up into three sub-sections. Two of these sub-sections (Saddle and Lower Passaic) discuss the details of the HEC-HMS modeling for these basins. The contents of each sub-section includes a discussion on simulation methods, assumptions, and model calibration, as well as any special situations encountered in the basin model and its resolution. A summary of final recommended discharges for the Lower Passaic Study Reach and their comparison with the effective discharge are included in the discussion for the Lower Passaic Sub-Section. A third sub-section discusses the detailed steady state hydraulic HEC-RAS model completed for the Lower Passaic Study Reach.

E.1 Saddle Basin Hydrology

E.1.1 RAINFALL-RUNOFF MODEL

E.1.1.1 *BASIN CHARACTERISTICS*

The Saddle River Basin is located just to the southeast of the Pompton River Basin along the lower reach of the Passaic River Basin (Figure 50). At its outlet, the drainage area for Saddle Basin is about 61 square miles. Unlike other basins, Saddle Basin can be characterized as urbanized, with some limited areas of forest located in the northeast sections of the basin. In the lower areas of the basin, along Saddle River, there is off-channel storage (Paramus Area). The northernmost parts of the Saddle River Basin also extend over the state line into Rockland County, NY, but the majority of the basin area is contained within Bergen County, NJ. No dams or reservoirs in the basin are capable of providing significant flood attenuation in the watershed, except the off-channel storage capacity located in the lower reaches of the basin.

As with other Passaic Basin Models, the HEC-HMS model for the Saddle River Basin used a SCS Curve Number (CN) loss model and the SCS Unit Hydrograph. Calibration of the modeled discharges to observed discharge and runoff volume used USGS flow data.

E.1.1.2 *WATERSHED DELINEATION*

The HUC delineations for NJ (HUC14) from the NJDEP were used for watershed and basin boundary delineations. In a few instances, watershed boundary adjustments were necessary to ensure that basins remained hydrologically homogenous across the area of interest. The model configuration includes only one sub-basin to the gage at Ridgewood, NJ, because of its uniformity in land use and soil characteristics. In addition, the calibration of this sub-basin was assisted by the long-term gage. After completing these adjustments, the final watershed delineation resulted in eight individual sub-basins. The final basin structure for the Saddle River watershed is shown in Figure 51.

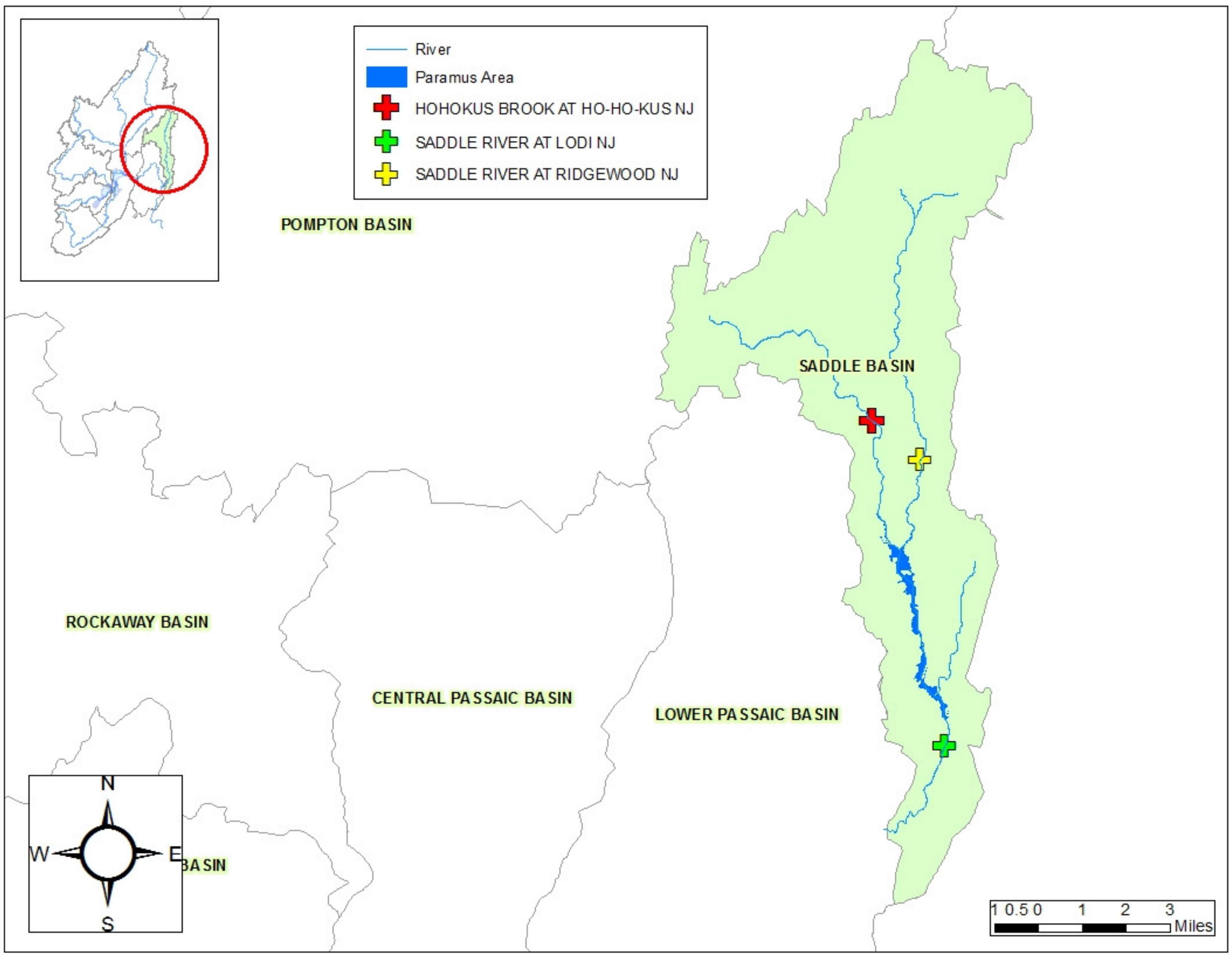

Figure 50. Location of Saddle River within the Passaic Basin

E.1.1.3 *Initial SCS CN and Lag Times*

Sub-basin CN values ranged from 74 to 90 (Figure 52 and Table 35). Lower values were found in the headwater sub-basins, which include some forestland uses, while higher values were found in the central and lower sub-basins, which are dominated by urban land uses. The initial CN and lag times were computed using methods discussed in section C.4. The parameter values calculated for the sub-basins are also listed in Table 35. These values were initially used to parameterize the model and were later adjusted for calibration and validation purposes.

Table 35: Saddle River Sub-basins and Initial Model Parameters

Sub-basin	Area (Sq. Mi)	Impervious Cover (%)	Initial Basin CN-AMC 2	Initial Basin CN-AMC 1	Initial Basin CN-AMC 3	Initial Lag Time (min)
Sub-basin-1	21.6	10	79	62	90	198
W350	9.3	10	78	61	89	102
W360	5.5	10	74	56	87	86
W410	1.6	10	87	75	94	99
W400	3.8	10	81	65	91	201
W250	1.3	10	80	64	90	138
Sub-basin-2	13.0	20	83	68	92	106
W300	4.9	10	89	78	95	163

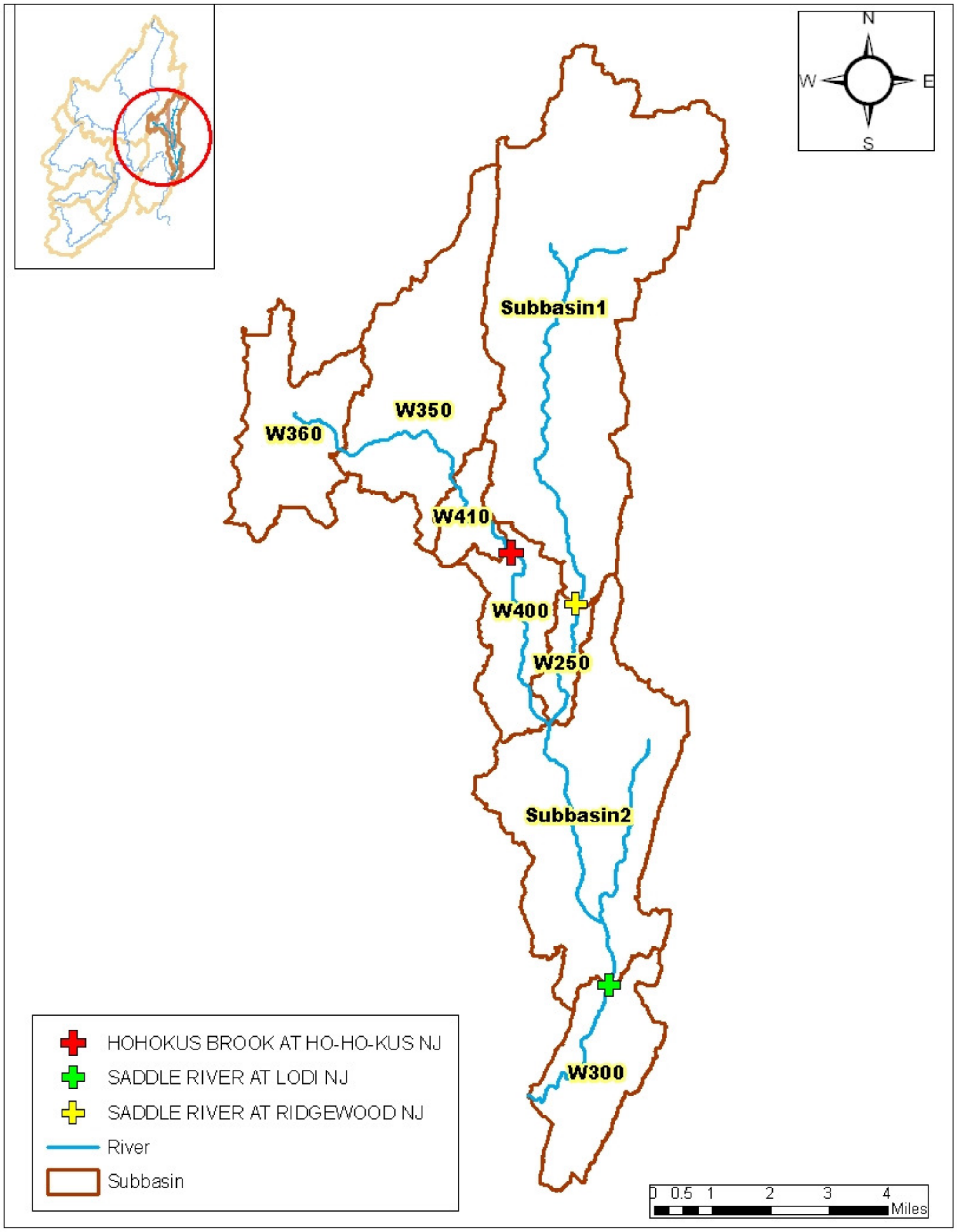

Figure 51. Sub-basin Structure for the Saddle River Basin.

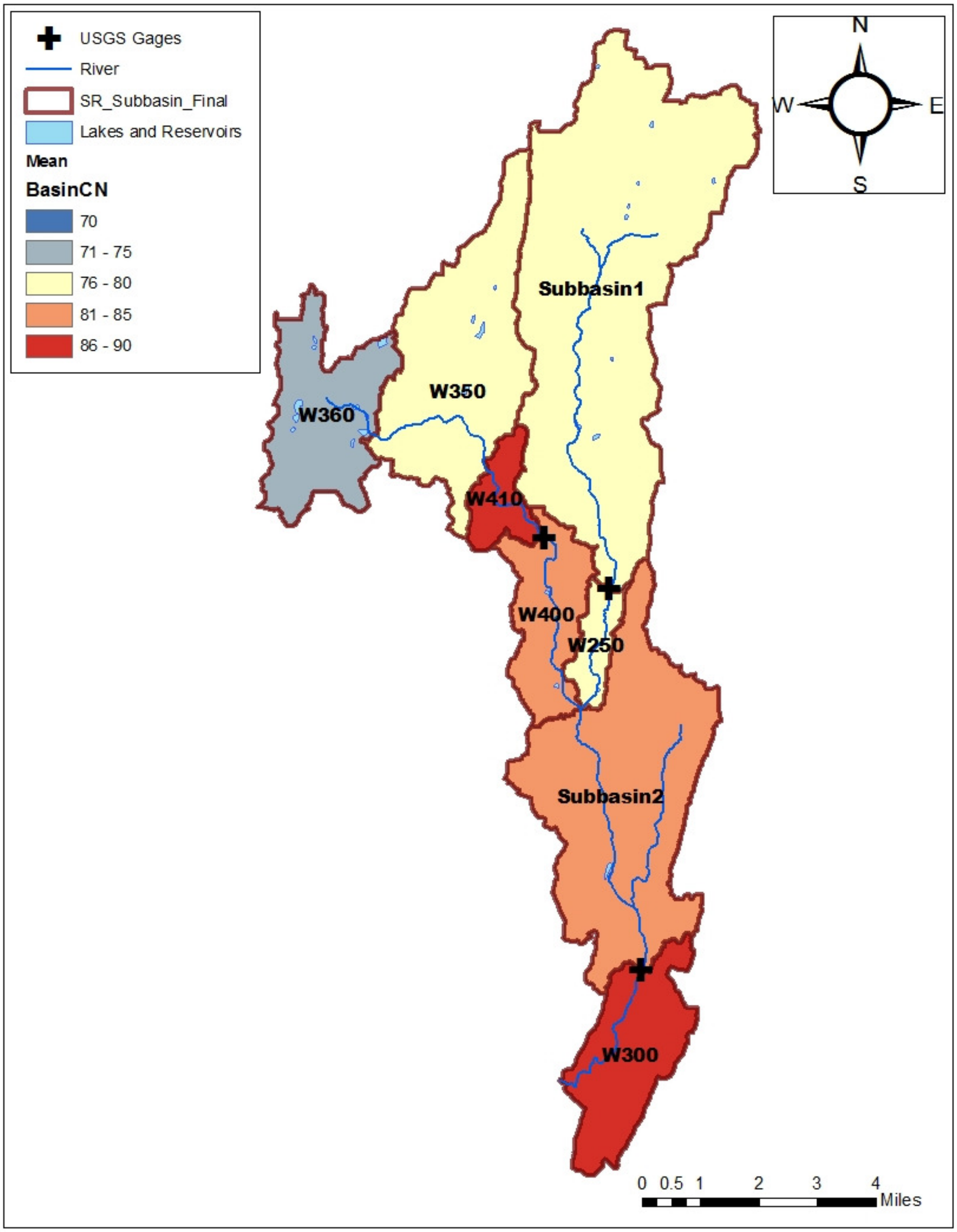

Figure 52.Saddle River Sub-basin CN values

E.1.1.4 *CHANNEL ROUTING*

The model contains six reaches that are representative of the channels within the basin. Two routing methods, Muskingum Cunge and Modified Puls, were used for channel routing purposes. The Muskingum-Conge method was adopted for the four upstream reaches that are characterized by high to medium slopes, and the Modified Pulls method was applied to the downstream reaches, in the Paramus area. Considerable off channel storage and moderate to flat slopes characterize the reaches within the Paramus area, located adjacent to the Saddle River. The parameters and channel geometric data required for the two routing techniques were developed using approximate the HEC-RAS models developed as part of the current effort. These approximate HEC-RAS models utilized channel geometry and other topography developed from the LiDAR dataset.

E.1.1.5 *MODEL CALIBRATION AND VALIDATION*

Observed discharges at three USGS gages in the study watershed were used in the calibration and verification of the HEC-HMS model for the basin. These included the Saddle River at Ridgewood gage (01390500), Hohokus Brook at Ho-Ho-Kus Brook gage (01391000), and Saddle River at Lodi gage (01391500). The availability and sources of precipitation used in the calibration process are described in section B.4 of this report. In addition, hypothetical rainfall data (frequency storms) to develop the 10-, 2-, 1-, and 0.2- percent annual chance flood were obtained from NOAA Atlas 14 data (Appendix D). This frequency data was used to develop an inflow hydrograph to the Lower Passaic HEC-HMS Basin Model.

Events prior to 2000 were not used in the calibration or validation process for the Saddle River Basin Model. Although the September 1999 event was used for other basin models within the Passaic, this event was not a good candidate for Saddle as radar rainfall was not available and the available point rain gage data was located too far away to provide a representative rainfall suitable for calibration purposes. A review of peak annual flows from 2000 to the present indicated that the three largest events during this period occurred in April 2007, October 2005, and September 2004. Observed discharge data was available for all three gages for the October 2005 (dry or SCS AMC 1) and September 2004 (normal or SCS AMC 2) events; therefore, these events were chosen for calibration and validation purposes. The April 2007 event occurred under saturated soil conditions closely representative of an SCS AMC 3 type condition. Though the flooding that occurred in April 2007 is one of the significant events, it was not considered for model calibration because the flooding was caused due to the melting snow that accumulated during the prior winter months.

Although smaller than a 10-year event, the September 2004 event was chosen as the calibration event because it had normal AMC (AMC II) conditions. The October 2005 event had AMC conditions drier than AMC 1, and it was used for model validation.

During the calibration process, curve numbers and lag times were adjusted as necessary to match observed data. In all cases, the CNs were lowered during the calibration process, with changes varying from an increase of 5% to 21%. On average, CN values were reduced 14% during the calibration process (Table 36). To match observed hydrograph data at the USGS gage sites, lag time was adjusted on average by a factor of 1.75 (Table 36). The large increase from the initial estimates is believed to be the due to some combination of soil conditions and storm water management facilities in the watershed.

Simulated discharge peaks were within 7% to 17% of the observed discharges at the three gages used in the calibration process, while runoff volumes slightly under predicted the observed discharges (Table 37). The timing of the peak discharges match was also consistent with the observed peaks for two of the three gages for which data were available (Figure 53 and Figure 54).

For model validation to the October 2005 event, all parameters were fixed and the CN values were adjusted to AMC I conditions. The CN values obtained from the September 2004 event were converted to AMC I conditions according to the procedure described by Ponce (1996). No further adjustments were made to the model. After adjusting AMC I values, the HEC-HMS simulated discharges over predicted the observed discharges by 13% to 15% (Table 38 and Figure 55, Figure 56 and Figure 57). Runoff volumes as well as the timing of peak flows matched more closely. This pattern is similar to that observed for the 2005 HEC-HMS simulated discharge for the Pompton Basin and is indicative of a dryer than the AMC I antecedent moisture condition for the 2005 event.

Table 36: Calibrated/Validation CN and Lag Time for Saddle Basin

Sub-basin	Area (Sq. Mi)	Initial Basin CN-AMC 2	Calibrated CN - AMC2	Initial CN Change (%)	Initial Lag Time (min)	Calibrated Lag Time (min)	Initial Lag Time Change (%)	Validation CN – AMC1
Sub-basin-1	21.6	79	65	18%	198	350	77%	45
W350	9.3	78	70	10%	102	150	48%	51
W360	5.5	74	70	5%	86	400	368%	51
W410	1.6	87	73	16%	99	120	21%	54
W400	3.8	81	70	14%	201	175	-13%	51
W250	1.3	80	70	13%	138	125	-10%	51
Sub-basin-2	13.0	83	70	16%	106	500	373%	51
W300	4.9	89	76	15%	163	163	0%	58

Table 37: Calibration for September 2004 Storm Event

Calibration September 2004											
			Peak (cfs)			Volume (ac-ft)			Time (hr)		
River	USGS Gage #	DA Area (sq mi)	Model	Obs.	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Hohokus	1391000	16.4	1,371	1,610	-15%	Not available.					
Saddle	1390500	21.6	1,399	1310	7%	1,046	1,127	-7%	12:45	12:45	0:00
	1391500	54.6	2,217	2,450	-10%	3,046	3,466	-12%	16:45	17:15	0:30

Table 38: Validation for October 2005 Storm Event

Validation October 2005											
			Peak (cfs)			Volume (ac-ft)			Time (hr)		
River	USGS Gage #	DA Area (sq mi)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)	Model	Obs	Diff. (Mod/Obs)
Hohokus	1391000	16.4	2,585	2,240	15%	2,421	2,422	0%	23:30	23:15	0:15
Saddle	1390500	21.6	1,563	1380	13%	1,630	1,536	6%	2:15	1:30	0:45
	1391500	54.6	3,511	3,080	14%	5,879	5,621	5%	6:00	7:15	1:15

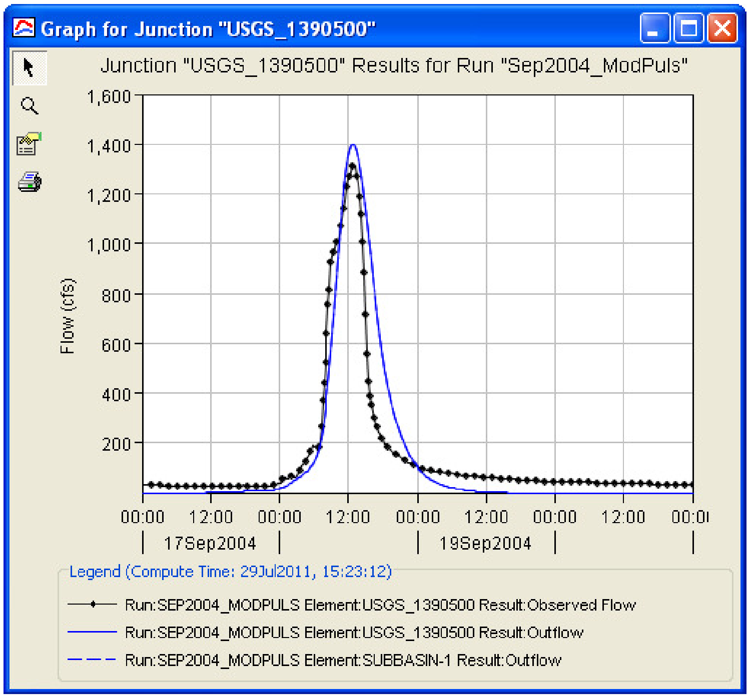

Figure 53. Model Calibration – September 2004 at Upper Saddle Gage (01390500)

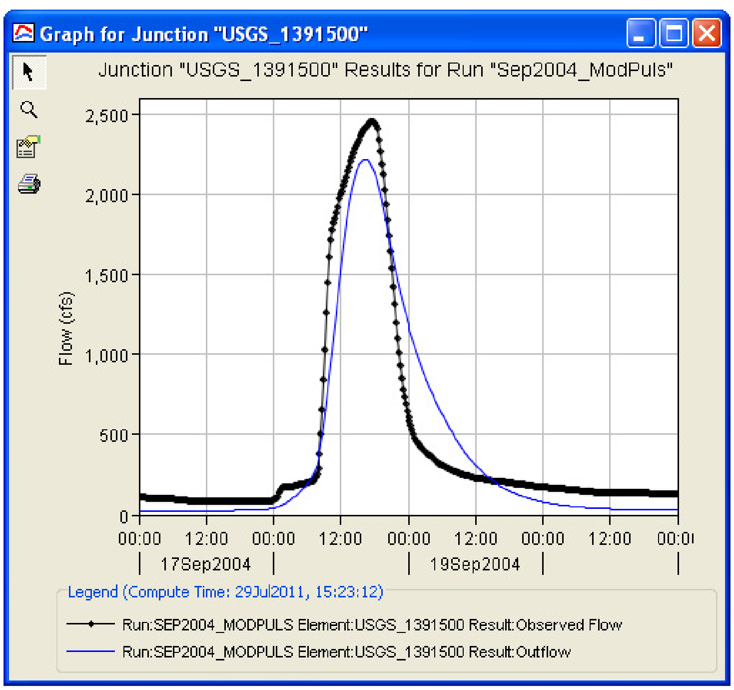

Figure 54. Model Calibration – September 2004 at Lodi Gage (01391500)

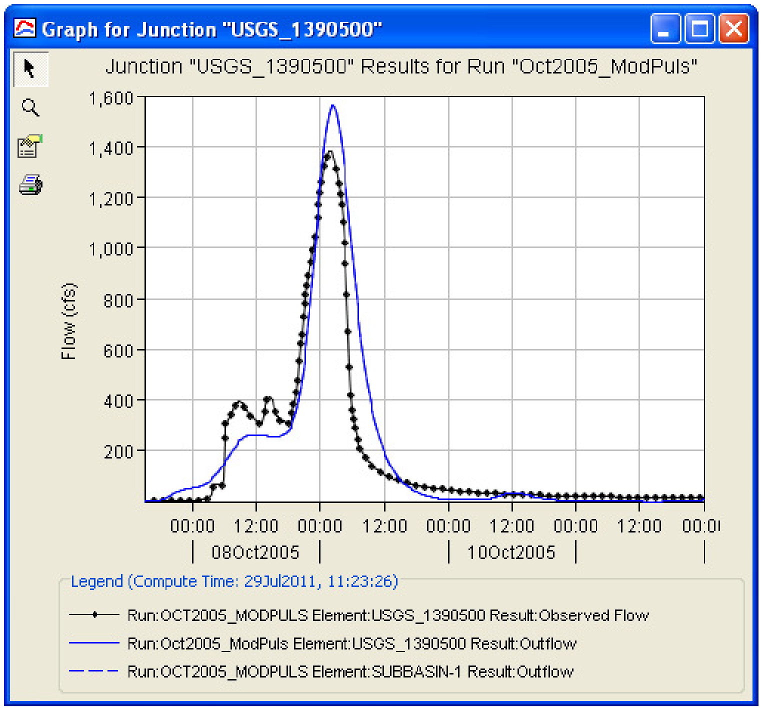

Figure 55. Model Validation – October 2005 at Upper Saddle Gage (01390500)

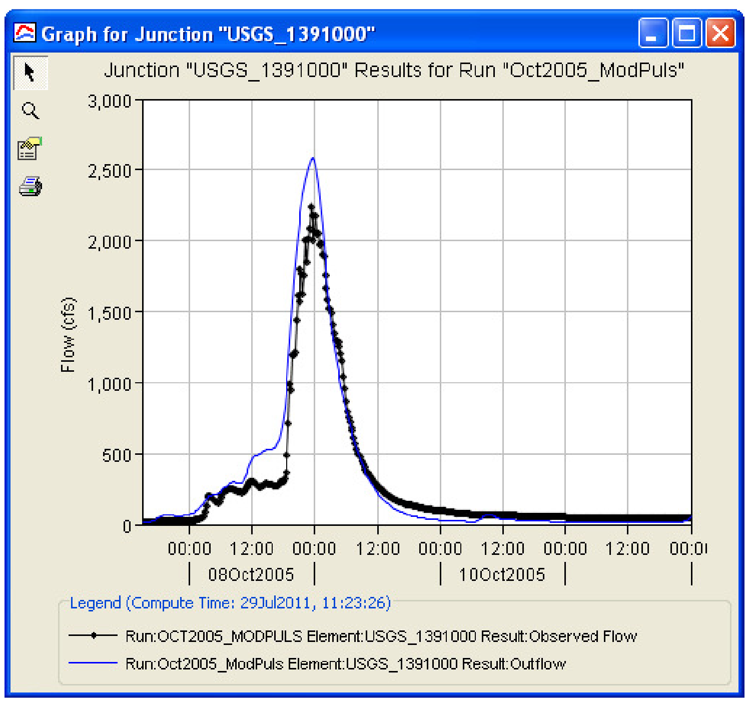

Figure 56. Model Validation – October 2005 at Hohokus Gage (01391000)

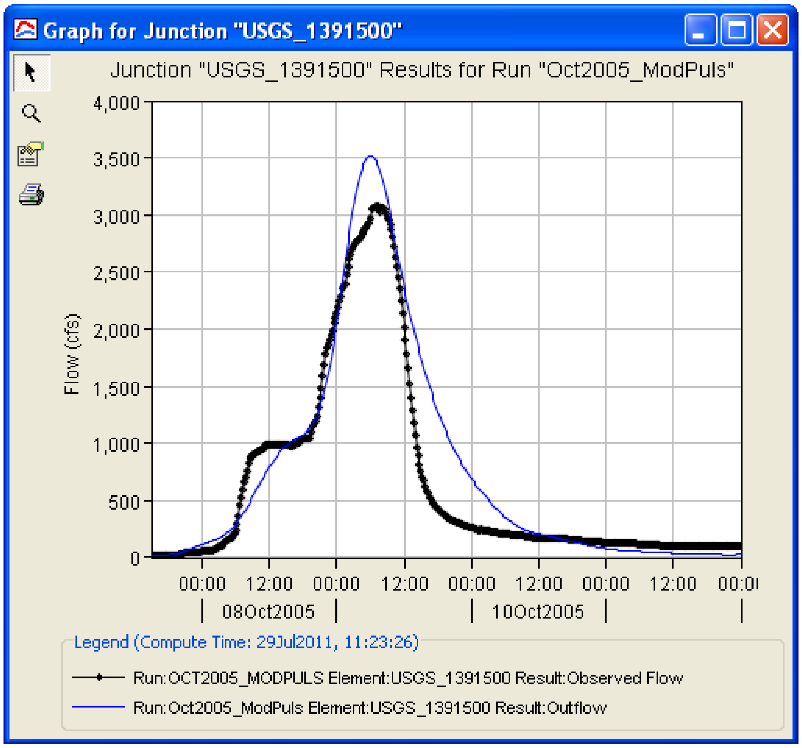

Figure 57. Model Validation – October 2005 at Lodi Gage (01391500)

E.1.1.6 *FREQUENCY STORM DATA*

The inflow hydrograph from the Saddle River Basin used in the development of the Lower Passaic Basin Model also uses the 96-hour frequency storm. Unlike the other basin models, however, the Saddle River Basin assumes an SCS AMC 1 condition for the 100-year event in order to match the LP III analysis for the gages located in this basin. This approach is consistent with the GDM study. In the 1995 GDM study, for the simulation of the Saddle River Basin, the USACE (1995) also utilized AMC 1 conditions in the development of the 100-year frequency storm. A comparison of the LP III analysis to Table 36 lists the curve numbers utilized for frequency storm. HEC-HMS modeling for the Saddle River Basin can be found in Appendix D.

E.2 Lower Passaic Basin Modeling

The Lower Passaic Basin Model includes both a hydrologic and hydraulic analysis. The hydrology consists of a HEC-HMS rainfall- runoff model while the hydraulics was completed using a steady state detailed HEC-RAS model. The runoff hydrograph developed using the unsteady state hydraulic model in the Central Passaic Basin for the Upper Passaic Molding Group is the upstream input for the Lower Passaic Basin HEC-HMS model (Figure 57).

E.2.1 RAINFALL-RUNOFF MODEL

E.2.1.1 *BASIN CHARACTERISTICS*

The Lower Passaic River Basin Model drains to that portion of the Passaic River located between the USGS gage at Little Falls and the Passaic's confluence with the Second River. The topography of this basin is relatively flat with the higher elevations along the eastern edge of the basin. Elevation within the basin ranges from 0 to 885 feet. The total length of the Passaic along this reach is about 23 miles. The total contributing area for the Lower Passaic HEC-HMS Basin Model (excluding the Saddle River Basin) is about 97 square miles and includes portions of Essex, Passaic, Bergen, and Hudson County in northern NJ. Figure 58 shows the general location of the modeled basin within the Lower Passaic Basin. As with other watersheds studied in this report, USACE HEC-HMS version 3.5 was employed to simulate rainfall-runoff model.

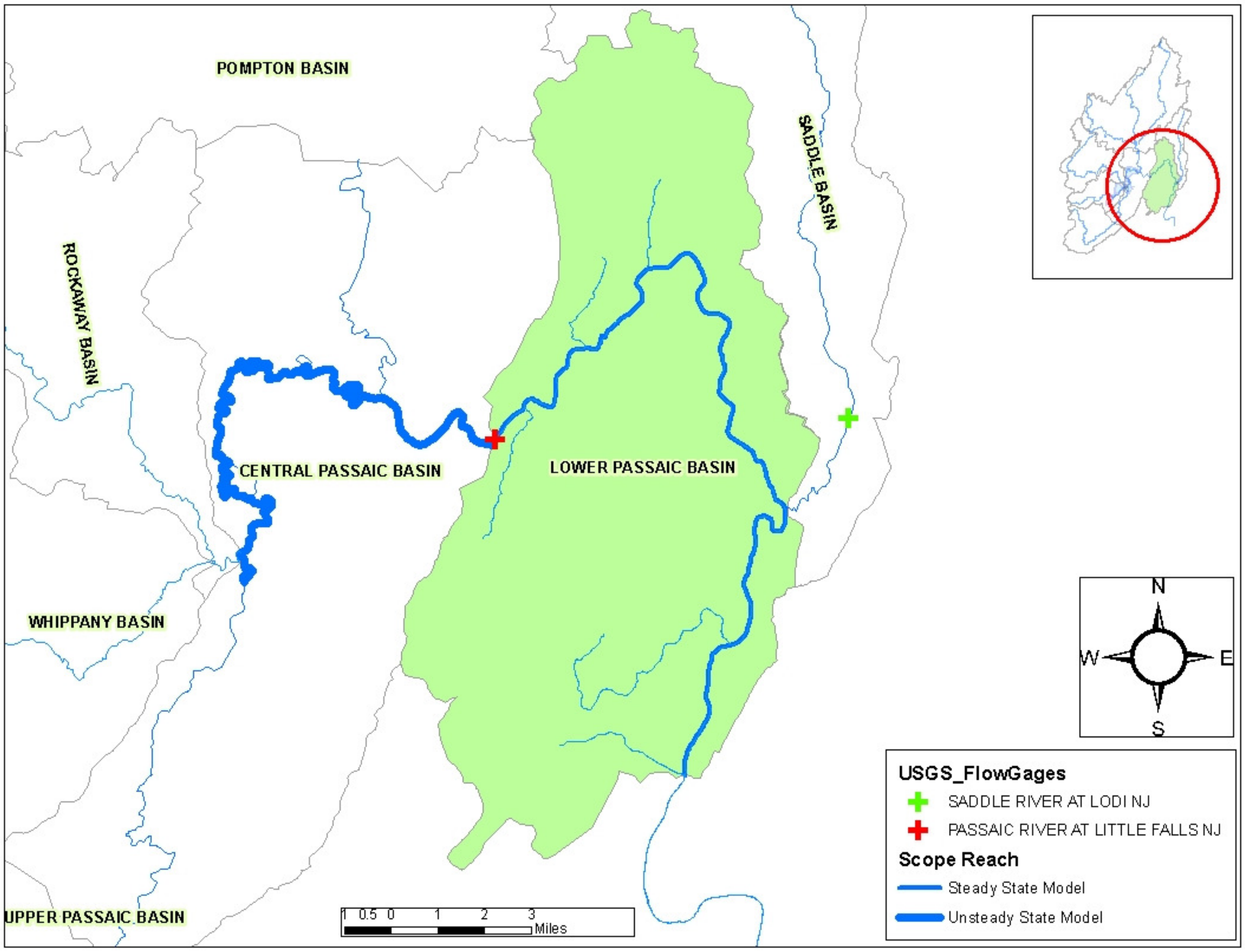

Figure 58: Lower Passaic Modeling Schematic

E.2.1.2 ***WATERSHED DELINEATION***

The HUC delineations for NJ (HUC14) from the NJDEP were used as a basis for watershed and basin boundary delineations. Where necessary, adjustments were made to watershed boundaries to ensure that basins remained hydrologically homogenous across the area of interest. After adjustments, the final modeling setup consisted of 13 individual sub-basins. The Saddle River HEC-HMS Model was treated as a tributary inflow to the Lower Passaic Basin Model. The initial final basin structure for the Lower Passaic Basin model is shown in Figure 59 and listed in Table 39. The final CN values used for each subbasin in the Lower Passaic Basin Model is shown in Figure 60.

Table 39. Lower Passaic River Sub-basins and Initial Model Parameters

Sub-basin	Area (Sq. Mi.)	Initial Basin CN (AMC 2)	Initial Lag Time (min)
LPASS110	8.9	62	179
LPASS130	8.1	85	125
LPASS140	3.0	91	256
LPASS160	13.4	78	204
LPASS170	3.9	79	277
LPASS180	14.0	77	119
LPASS200	6.8	78	493
LPASS250	3.8	88	229
LPASS270	10.2	85	232
LPASS290	0.4	91	115
LPASS400	11.1	89	297
LPASS450	5.2	90	771
LPASS460	7.8	70	406

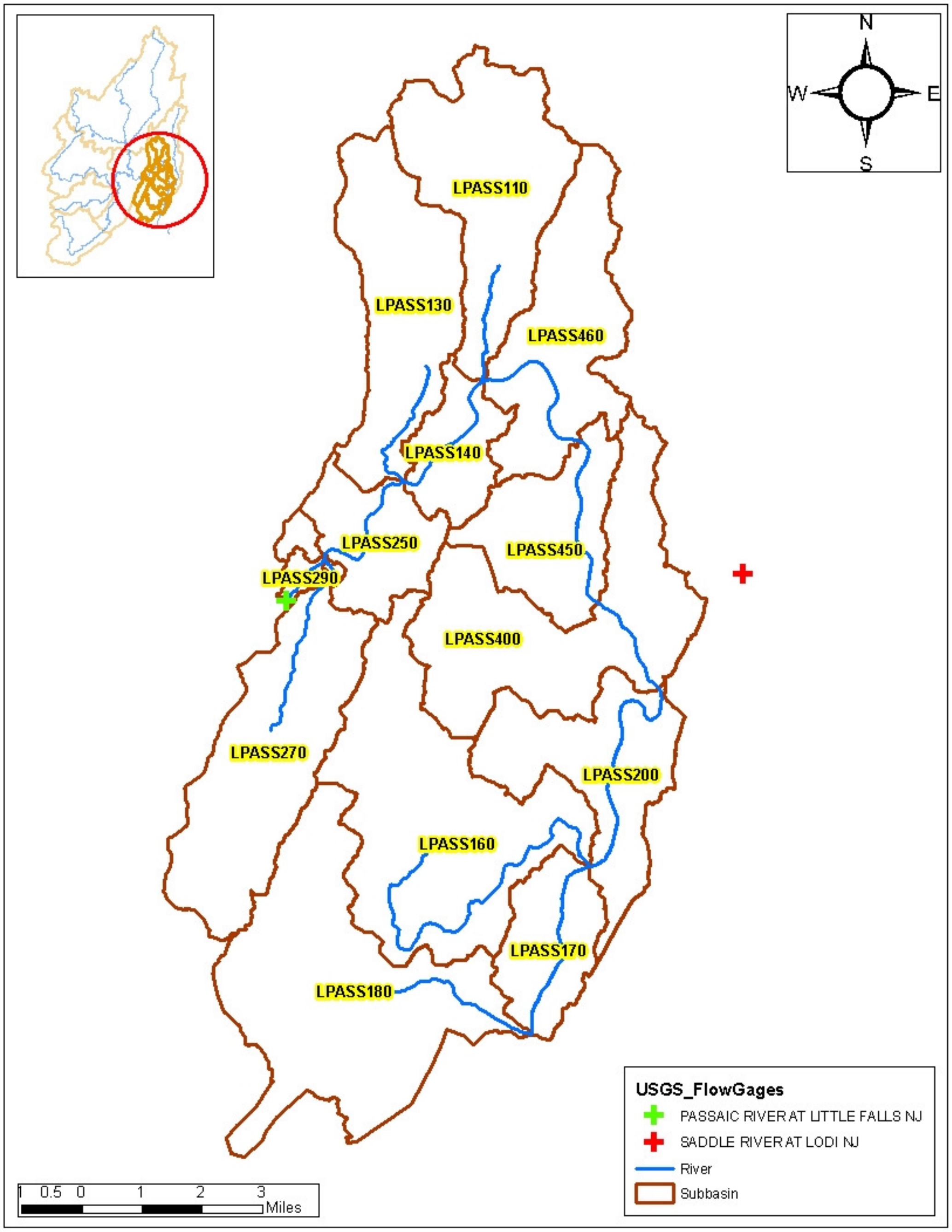

Figure 59: Lower Passaic Sub-basins and Reaches

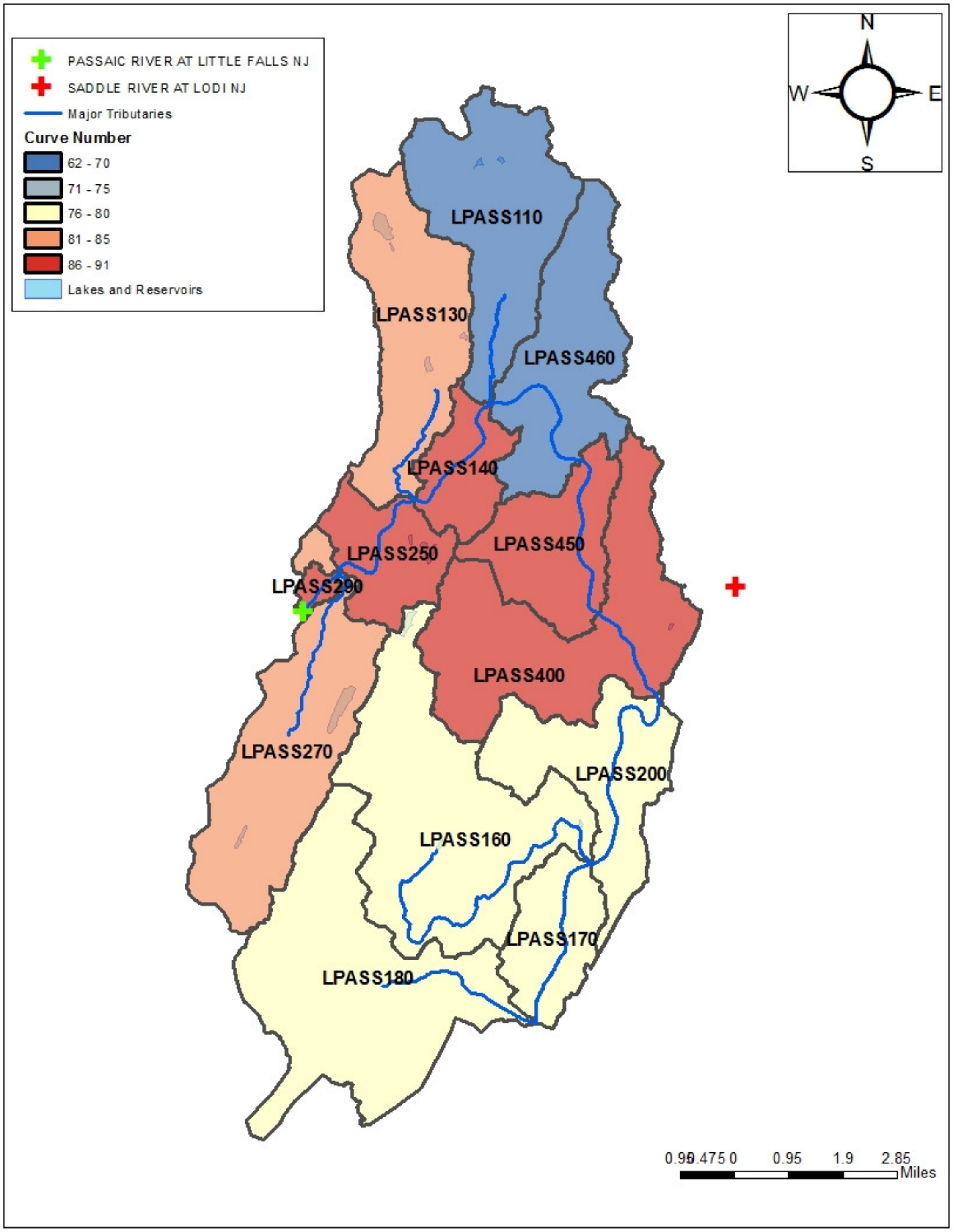

Figure 60: Lower Passaic Sub-basin CN Values

E.2.1.3 *CHANNEL and RESERVOIR ROUTING*

Seven hydrologic modeling reaches were used for channel routing in the Lower Passaic Basin Model. All seven of these reaches used the Muskingum-Cunge method available in HEC-HMS.

The eight-point cross sectional geometry required for this method was developed using an approximate HEC-RAS model. Topographic data used in the development of the HEC-RAS model was based on LiDAR data (Appendix F).

E.2.1.4 ***MODEL CALIBRATION AND VALIDATION***

There is no recent gage data in the Lower Passaic Basin suitable for calibration or validation of the HEC-HMS basin model. Most of the basin, however, is highly urbanized with relatively high CN values as well short lag times, and as such is subject to less modeling error than other basins within the Passaic Watershed. The hydrologic response of this basin is also similar to the Saddle River Basin, with peak flows from these two basins responding to rain events well in advance of the inflows from the Central Passaic.

E.2.1.5 ***COMPARISON OF EFFECTIVE AND PROPOSED DISCHARGES AT EFFECTIVE LOCATIONS IN THE LOWER PASSAIC BASIN***

Table 40 provides a comparison of the proposed HEC-HMS discharges with the effective discharges. Generally, the proposed discharges are similar when compared to the effective discharges. The effective study completed a gage analysis at the Little Falls gage consistent with Bulletin 17B and transferred this analysis downstream, whereas the proposed methodology uses a rainfall-runoff model (HEC-HMS 3.5). This hydrologic analysis resulted in discharges that vary proportional with drainage area, with discharges increasing downstream, and decreasing upstream of the gage location. In the proposed analysis, the peak discharge from this unsteady state HEC-RAS model at the USGS gage at Little Falls has been carried downstream to above the confluence with the Saddle River. This is because the HEC-HMS modeling shows lower peak discharges along the Passaic below Little Falls until the confluence with the Saddle River due the attenuation effects of the hydrologic routing of the HEC-RAS unsteady state discharge hydrograph. In addition, during large flood events the Passaic River in the Lower Passaic Basin can experience a double peaking hydrograph. The first peak occurs as a result of the quick runoff contributed by the basins downstream of the Beatties Dam (DA = 173 sq. mi.) including the Saddle River Basin), while the second peak occurs as the result of a delayed response from the basins upstream of Beatties Dam (DA=762 sq. mi.). Because the upstream watershed's response is delayed so much, there is only a slight overlap between the two responses. This phenomenon can result in two peaks of similar magnitude (Figure 61).

Table 40. Comparison of Effective and Proposed Discharges at Effective FIS Locations for Lower Passaic River.

Location	Drainage Area (mi²)	Discharges (cfs)											
		10%			2%			1%			0.2%		
		FIS	New	%Diff	FIS	New	%Diff	FIS	New	%Diff	FIS	New	%Diff
Above confluence with Second River[1]	906	14,600	17,746	22%	23,900	26,401	10%	30,200	30,772	2%	46,200	43,185	-7%
Upstream of Beatties Dam	777.2	12,300	11,437	-7%	18,600	17,903	-4%	21,700	21,469	-1%	30,200	30,008	-1%

[1]Essex County FIS (June 2007) at "Entire shore length"

[2]Essex County FIS (June 2007) The peak discharge from this unsteady state HEC-RAS model at the USGS gage at Little Falls have been carried downstream to above the Passaic's confluence with the Saddle River. This was done because the HEC-HMS modeling shows lower peak discharges along the Passaic below Little Falls until upstream of the Passaic's confluence with the Saddle River. These lower discharges are due to the attenuation of the unsteady state discharge hydrograph, from HEC-RAS, as it hydrologically routed in the HEC-HMS model for the Lower Passaic River. The new study has an additional flow change below the confluence with the Saddle River shown in Table 41. This flow change location could not be found in the past or current FIS Summary of Discharges Table.

E.2.1.6 *FREQUENCY STORM DATA*

Consistent with other HEC-HMS basin models, the Lower Passaic Model uses a 96-hour frequency storm. No gages are available for LP III analysis in this basin; therefore, unadjusted NOAA Atlas 14 rainfall data were used to develop the flood frequency discharges for the Lower Passaic. The resulting discharges for flow change locations along the Lower Passaic River Study, for the detailed steady state hydraulic model, are provided in Table 41.

Table 41: Recommended Discharges for Lower Passaic River

Discharge Change Location	DA (Sq.Mile)	Discharge (cfs)			
		10-Yr	50-Yr	100-Yr	500-Yr
Passaic River Above Saddle River	820.5	11,437	17,903	21,469	30,008
Passaic River Above Third River	888.6	14,945	21,718	25,184	35,952
Passaic River Above Second River	905.9	17,746	26,401	30,772	43,185

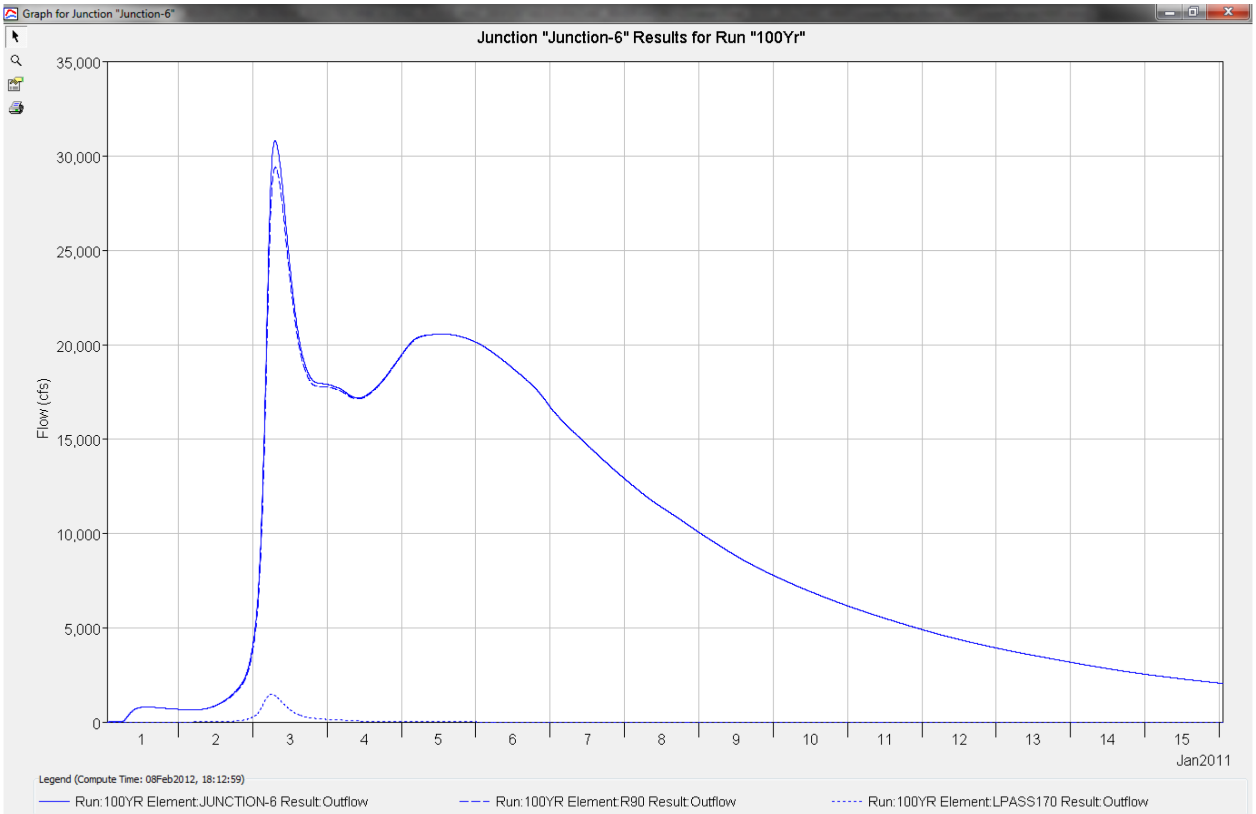

Figure 61: 100-Year Hydrograph on Passaic River above Second River

E.3 Lower Passaic Hydraulic Modeling Reach

The Lower Passaic hydraulic model is a steady state HEC-RAS version 4.1 model. Topographic data in the model is a combination of field survey data collected in 2010 and LiDAR data collected in 2006. Water surface profiles were determined for the 10-, 2-, 1-, and 0.2-percent-annual-chance flood events. A new floodway for the study reach was also completed.

E.3.1 Topographic Data

Field survey data included data for the channel portion of cross sections and structures. Overbank topography was obtained from LiDAR data collected in 2006 and was blended with the field survey data to provide the cross-section geometry used in the model. A limited number of un-surveyed cross sections were also used in the model. For these cross sections, channel geometry was interpolated between surveyed cross sections, while overbank topography was derived from the LiDAR data.

All topographic data was referenced to the horizontal datum of North American Datum of 1983 (NAD83) State Plane NJ North FIPS 2900 (feet) and vertical datum of NAVD88 in feet.

E.3.2 Boundary Conditions

To properly simulate the most conservative downstream tidal condition, a known water surface elevation of 2.76 feet was used at the most downstream cross section as the boundary condition. This assigned water surface elevation was calculated by averaging the Mean Higher High Water (MHHW) elevation from four separate tidal gage locations near the downstream study limit (see Table 42 below).

Table 42: Tidal Gage Data

Tidal Gage ID Number	MHHW Elevation (NAVD ft)
8519483	2.56
8530591	3.06
8530743	2.77
8530882	2.65
Average	**2.76**

Applying this method for the boundary condition accounts for the tidal influence on the Passaic River and appropriately demonstrates the most conservative approach because the MHHW elevation represents a worst case tidal scenario. All tidal gage data was taken from the NOAA website (http://tidesandcurrents.noaa.gov/).

E.3.3 Cross Sections

For natural stream channels, cross-sections were placed in accordance with FEMA's *G&S* and the HEC-RAS manual guidance. Cross sections were also placed at all structures including bridges and dams. Each structure's cross section is categorized as a TOR cross section. Cross sections were placed approximately every 500 feet along the study reach.

E.3.4 Structures

All structure dimensions and invert elevations were based on field survey. The three dams located along the study reach, Beatties Dam, Weir North of Wayne Avenue, and Dundee Dam, were modeled as in-line weirs.

At two locations, channel invert elevations were noticeably lower than those shown on the effective stream profile. Between Great Falls and Dundee Dam Channel, the invert elevation for the 2010 field survey was about 4 feet lower the effective profile, while below Dundee Dam the surveyed profile was about 12 feet lower than the effective profile. The reason for this difference is unclear, but it may have been the result of channel activity, such as dredging, that occurred after the effective study date.

E.3.5 Ineffective Areas

Ineffective areas, representing overbank flood storage, were modeled as required along the Lower Passaic Study Reach.

E.3.6 Cross-section Roughness Values

An Overbank Manning's n polygon shapefile was created from 2002 Land Use/Land Cover obtained from the NJDEP. This data was checked for consistency with recent aerial photography *(New Jersey 2007 - 2008 High Resolution Orthophotography, MrSID 5K Tiles (2009 revision))* and survey pictures.

Generally, Manning's n values for channels fall within the range of 0.03 to 0.037, except for the area surrounding Great Falls (XSEC's 100631.7-100322.6) and the area upstream of the U.S. Route 46 Bridge (XSEC's 121647.2-119079.9). For the area surrounding Great Falls, a Manning's n value of 0.103 was applied to reflect the effects of large rocks that obstruct flows. For the area upstream of the U.S. Route 46 Bridge, a Manning's n value of 0.06 was applied to account for rock obstructions within the channel, as well as dense tree growth presenting moderate flow obstruction along the banks of the river. For both these areas, the "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" was used as a reference for n value selection (USGS WSP 2339).

The Channel Manning's n values used in this study are shown in Table 43, and the range of Overbank Manning's n values used is shown in Table 44.

Table 43. Channel Manning's Roughness Coefficients

Study Stream Name	Channel n-value
Passaic River	0.03-0.037
Passaic River (US of U.S. Route 46 Bridge)	0.057
Passaic River (Great Falls)	0.103

Table 44.Classification of Overbank Manning's N Roughness Coefficients Applied for Study Stream

Code	Classification NJDEP (2002)	Manning's n Value for Study
1110	RESIDENTIAL, HIGH DENSITY, OR MULTIPLE DWELLING	0.045
1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	0.045
1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY	0.045
1140	RESIDENTIAL, RURAL, SINGLE UNIT	0.045
1200	COMMERCIAL/SERVICES	0.07
1211	MILITARY INSTALLATIONS	0.07
1300	INDUSTRIAL	0.07
1400	TRANSPORTATION/COMMUNICATION/UTILITIES	0.045
1410	MAJOR ROADWAY	0.045
1419	BRIDGE OVER WATER	0.035
1461	WETLAND RIGHTS-OF-WAY	0.14
1462	UPLAND RIGHTS-OF-WAY DEVELOPED	0.045
1463	UPLAND RIGHTS-OF-WAY UNDEVELOPED	0.045
1499	STORMWATER BASIN	0.045
1500	INDUSTRIAL/COMMERCIAL COMPLEXES	0.07

Code	Classification NJDEP (2002)	Manning's n Value for Study
1600	MIXED URBAN OR BUILT-UP LAND	0.045
1700	OTHER URBAN OR BUILT-UP LAND	0.045
1710	CEMETERY	0.045
1711	CEMETERY ON WETLAND	0.14
1741	PHRAGMITES DOMINATE URBAN AREA	0.045
1750	MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE	0.14
1800	RECREATIONAL LAND	0.035
1804	ATHLETIC FIELDS (SCHOOLS)	0.035
1810	STADIUM THEATERS, CULTURAL CENTERS, ZOOS	0.045
1850	MANAGED WETLAND IN BUILT-UP MAINTAINED REC AREA	0.14
2200	ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS	0.05
2400	OTHER AGRICULTURE	0.05
4110	DECIDUOUS FOREST (10-50% CROWN CLOSURE)	0.12
4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	0.12
4210	CONIFEROUS FOREST (10-50% CROWN CLOSURE)	0.12
4220	CONIFEROUS FOREST (>50% CROWN CLOSURE)	0.12
4312	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)	0.12
4321	MIXED FOREST (>50% DECIDUOUS WITH 10-50% CROWN CLOSURE)	0.12
4322	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)	0.12
4410	OLD FIELD (< 25% BRUSH COVERED)	0.12
4411	PHRAGMITES DOMINATE OLD FIELD	0.12

Code	Classification NJDEP (2002)	Manning's n Value for Study
4420	DECIDUOUS BRUSH/SHRUBLAND	0.12
4440	MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND	0.12
5100	STREAMS AND CANALS	0.035
5200	NATURAL LAKES	0.035
5300	ARTIFICIAL LAKES	0.035
5410	TIDAL RIVERS, INLAND BAYS, AND OTHER TIDAL WATERS	0.035
6112	SALINE MARSH (HIGH MARSH)	0.14
6141	PHRAGMITES DOMINATE COASTAL WETLANDS	0.14
6210	DECIDUOUS WOODED WETLANDS	0.14
6231	DECIDUOUS SCRUB/SHRUB WETLANDS	0.14
6240	HERBACEOUS WETLANDS	0.14
6241	PHRAGMITES DOMINATE INTERIOR WETLANDS	0.14
6251	MIXED WOODED WETLANDS (DECIDUOUS DOM.)	0.14
7300	EXTRACTIVE MINING	0.04
7400	ALTERED LANDS	0.04
7430	DISTURBED WETLANDS (MODIFIED)	0.14
7500	TRANSITIONAL AREAS	0.04
7600	UNDIFFERENTIATED BARREN LANDS	0.04

E.3.7 Expansion and Contraction Coefficients

Expansion and contraction coefficients used in the model are summarized in Table 45. Coefficients higher than 0.3/0.5 are used at only two locations. Coefficients of 0.6/0.8 are used in the Great Falls area to reflect cross-section geometry, which dramatically narrows, while coefficients of 0.4/0.6 are used at State Route 4 Bridge (XSEC 72754.38) to reflect the presence of multiple bridge openings.

Table 45. Expansion and Contraction Coefficients

Structure	Contraction Loss Coefficient (Upstream Cross Section)	Expansion Loss Coefficient (Downstream Cross Section)
Cross Sections	0.1	0.3
Bridge	0.3	0.5
Great Falls	0.6	0.8
State Route 4 Bridge (XSEC 72754.38)	0.4	0.6

E.3.8 Obstructions

For detailed streams, all buildings within the 500-year floodplain are modeled as a blocked obstruction in HEC-RAS. The building locations were digitized using the NJ 2007 - 2008 High Resolution Orthophotography, MrSID 5K Tiles (2009 revision).

E.3.9 Model Calibration and Validation

The Lower Passaic River study reach has six USGS gage locations, three of which have historic peak flow data available (Table 46). The only gage location that has sufficient historic peak flow data available (period of 30 years or greater) is USGS gage 01389500: Passaic River at Little Falls, NJ. The only high water mark data available for the Lower Passaic River was recorded from an April 1984 storm event and published in the GDM (USACE, 1995). Both of these datasets were used in the calibration effort for the Lower Passaic River HEC-RAS model.

Table 46. USGS Gage Locations along the Lower Passaic River

USGS Gage ID#	Description	Flow Data Available (Y/N)
1390000	Passaic River at Garfield, NJ	N
1389890	Passaic River at Dundee Dam at Clifton, NJ	Y (only 4 recorded flows since 1945)
1389800	Passaic River at Paterson, NJ	Y (only 1 record from 1903)
1389802	Passaic River at Passaic (Great) Falls at Paterson, NJ	N
1389500	Passaic River at Little Falls, NJ	Y (annual peak flow data from 1811-2010)
1389492	Passaic River above Beatties Dam at Little Falls, NJ	N

The primary calibration for the hydraulic model was carried out using a rating curve developed from peak stream flow data recorded at the USGS gage location at Little Falls, NJ. Data maintained by the USGS for this location was recorded from 1811 to 2010, and is available on the USGS website (http://nwis.waterdata.usgs.gov/nj/nwis/sw). Figure 62 compares the hydraulic model rating curve and the USGS gage rating curve at the Little Falls gage location.

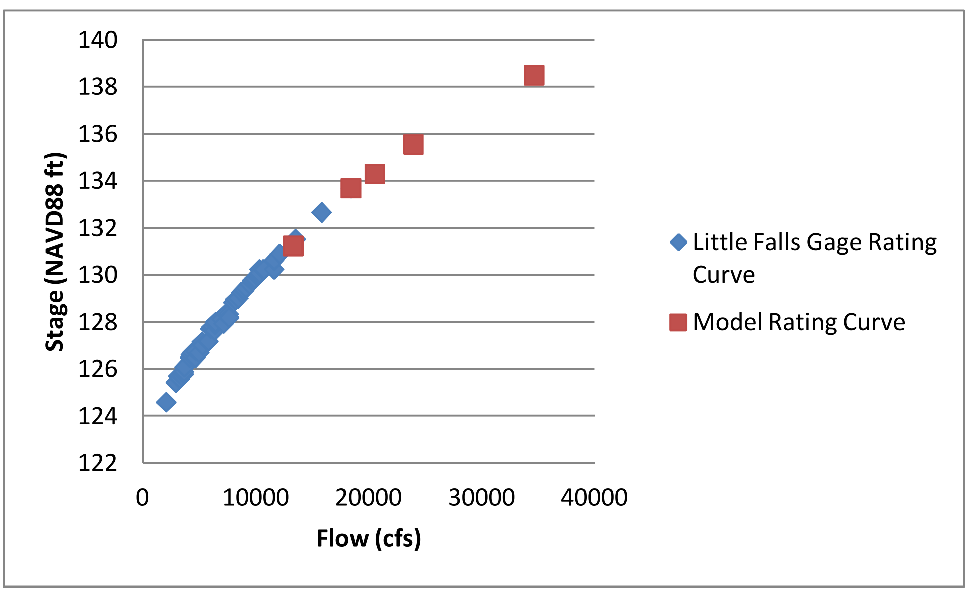

Figure 62. Model Rating Curve vs. USGS Gage Rating Curve at Little Falls Gage (01389500)

E.3.10 Historic flooding

Flooding along the Passaic River has occurred a number of times in recent years, with the 1984 storm event being the largest since 1945 for which good calibration data were available. The calibration event, which was calculated to be approximately a 40-year storm, had a peak flow of 18,400 cfs and a gage height of 133.71 NAVD88 feet. Prior to 1945, there were seven larger peak flows recorded at the Little Falls, NJ, location as shown in Table 47 below. These seven flood events were all recorded before accurate gage heights were measured at the gage location, so gage height comparisons cannot be evaluated.

Table 47. Historic Peak Flows Recorded at the Little Falls Gage

Historic Flood Records		
Year	**Flow (cfs)**	**Estimated Frequency Storm***
1810	27,000	140-year
1865	22,500	70-year
1882	19,000	40-year
1902	23,400	85-year
1903	31,700	320-year
1936	19,200	45-year
1945	19,500	45-year
1984	18,400	40-year

*Estimated from GDM LP III Curve for the Little Falls Gage (01389500)

The Lower Passaic River also recently experienced flooding as a result of Hurricane Irene. Preliminary gage recordings from August 30, 2011, at the Little Falls gage exceeded the 1984 storm event flow and gage height at 20,800 cfs and 134.19 feet NAVD88, respectively (http://waterdata.usgs.gov/nwis/uv/?site_no=01389500&agency_cd=USGS). High water mark (HWM) data is not yet available and gage data has not yet been certified by the USGS. This analysis was already complete at the time of the storm, so it was not possible to wait for certified results from the USGS and HWMs and incorporate them into the model. However, a flow of 20,800 cfs was applied to the model at the gage location and yielded a water surface elevation (WSEL) of 134.36 feet NAVD88, which is only +0.17 feet different from the preliminary gage height measured at the gage. This difference is minimal and shows that this study's calibration of the model is supported by the new provisional data.

For a further check of calibration results, HWM data from the GDM for the April 1984 storm event was compared to WSELs from the model. Flow record at the Little Falls gage shows a peak discharge of 18,400 cfs for April 1984 storm event. LP III analysis indicated the magnitude of this storm event to be close to a 40-year storm event. Applying this flow to the hydraulic model resulted in a matching WSEL of 133.71 feet at the gage location. Since this is the only gaged site along the study reach for which flow records were available for the April 1984 calibration event, the flow of 18,400 cfs was transferred further downstream by the transposition method suggested by equation 15 from the Scientific Investigation Report 2009-5167 published by the USGS.

The majority of HWM locations were found to be within a range of +/- 2.0 feet as compared with the WSELs from the model (see Table 48 below). Areas where the difference in WSEL exceeds this limit are likely due to change in structure geometry since 1984. The HWM locations surrounding the West Broadway Bridge are an example of this as the National Bridge Inventory (NBI) dataset indicated that there had been significant structure reconfiguration since 1984 in this area that would likely result in WSEL changes.

Since peak discharge flow downstream of Little Falls gage for the April 1984 storm event were not obtained from the results of a detailed hydrology analysis, calibration efforts were not matched to within the range of +0.5/-1.0 foot listed in the GDM.

Significant difference between surveyed channel invert elevations and the effective profile invert elevations were observed in four areas. Outreach to city officials within the communities affected was conducted; this outreach yielded no substantial results as to dredging action within the areas of concern since the effective study was performed (1977). The NBI dataset provided evidence of structure reconfiguration within the vicinity of three of these locations: the Wall Street Bridge (XS 49772), the Main Street Bridge (XS 96745), and the Island Market Bridge (XS 97847). These structure reconstruction efforts coupled with natural channel reconfiguration could account for elevation discrepancies in these respective areas. The final location was at the Garden State Parkway Bridge (XS 61268) located approximately 3000 feet upstream of Dundee Dam. The channel elevation from the effective profile was 11.91 feet higher than the surveyed channel invert at this location. It is possible that this discrepancy is the result of dredging action in the area since the effective study date (1977), as sediment deposition is common in the upstream areas of dam structures and is evident from examining the effective profile.

It should also be noted that the effective profile channel invert elevations downstream of the Eighth Street Bridge (XS 45688) differ in excess of 4 feet, but are negligible as the effective study lacked survey data in this area and the channel invert is leveled at -13 feet. Because survey data has been available in this area since 2010, channel invert elevations within this section were assumed to be more accurate and were used in the HEC-RAS model. Comparison of effective and proposed water surface elevations are listed in Table 49. The proposed 10%,2%,1% and 0.2% annual chance flood water surface elevations are listed in Table 50.

Table 48. Observed HWM Locations and Differences between Observed HWM and Calibrated WSEs

Bridge RS (HEC Model)	Bridge Name (HWM SHP)	US/DS of Structure	GDM HWM Elev (NAVD-feet)	Post Adjustment Elev (feet)	Difference	Description of adjustment required/Explanation
118247.80	Lackawanna	US	131.7	130.10	-1.6	NBI dataset states that Lackawanna bridge was rebuilt in 1997. Changes to this structure opening could affect WSELs at this location.
118247.80	Lackawanna	DS	131.7	130.04	-1.66	
107246.00	Lincoln Street	US	125.5	125.59	0.09	
107246.00	Lincoln Street	DS	125.5	125.47	-0.03	
101373.70	Spruce	US	122.0	124.34	2.34	The NBI dataset states that the Main Street Bridge located just DS of West Broadway St. was reconstructed in 1998. The Arch Street Bridge in 1997, the Straight Street Bridge in 2003. These updates to structure geometry could cause a difference in WSEL.
97554.74	West Broadway	US	51.5	49.03	-2.47	
97554.74	West Broadway	DS	50.6	48.59	-2.01	
94354.37	Passaic Rt. 650	US	48.5	45.10	-3.4	
94354.37	Passaic Rt. 650	DS	48.4	44.89	-3.51	
91079.49	Passaic Rt. 652	US	44.2	42.4	-1.8	
91079.49	Passaic Rt. 652	DS	44.0	42.48	-1.52	
85014.79	Lincoln Ave.	US	41.6	39.52	-2.08	
85014.79	Lincoln Ave.	DS	41.6	39.32	-2.28	
77013.84	East 33rd Street	US	36.7	35.17	-1.53	
77013.84	East 33rd Street	DS	36.7	35.07	-1.63	
67245.09	Erie R.R.	US	34.6	32.07	-2.53	
67245.09	Erie R.R.	DS	34.1	31.92	-2.18	
62885.45	Route 46	US	31.6	30.90	-0.7	

Bridge RS (HEC Model)	Bridge Name (HWM SHP)	US/DS of Structure	GDM HWM Elev (NAVD-feet)	Post Adjustment Elev (feet)	Difference	Description of adjustment required/Explanation
62885.45	Route 46	DS	31.5	30.82	-0.68	
58532.29	Dundee Dam	US	31.3	29.51	-1.79	
56256.40	Ackerman Ave.	US	17.1	15.81	-1.29	
56256.40	Ackerman Ave.	DS	17.1	15.72	-1.38	
51533.87	Monroe Street	US	13.6	14.52	0.92	
51533.87	Monroe Street	DS	13.6	14.19	0.59	

Table 49. Effective FIS WSEL Comparison with New Study WSEL

Effective Location	New Modeling Station	New Study 1% WSEL (NAVD feet)	FIS 1% WSEL (NAVD feet)	Difference between FIS and New Study WSEL	New Floodway Width	FIS Floodway Width
1392' DS of Rt 7 (Essex*)	10271	3.44	9.5	-6.06	241.10	283
B (Essex*)	11613	4.32	9.3	-4.98	327.14	300
98' US of C (Essex*)	14269	5.79	10.1	-4.31	350.67	349
673' US of C (Bergen*)	20186	7.58	12.6	-5.02	352.76	420
J (Bergen*)	31039	10.01	14.3	-4.29	239.63	249
70' DS of S (Bergen*)	48020	13.66	18	-4.34	231.6	258
43' US of AF (Bergen*)	60944	30.26	32.9	-2.64	658.02	790
37' DS of AQ (Bergen*)	71694	34.09	36.1	-2.01	362.98	410
50' DS of BD (Bergen*)	84544	39.82	42.5	-2.68	279.04	307

Effective Location	New Modeling Station	New Study 1% WSEL (NAVD feet)	FIS 1% WSEL (NAVD feet)	Difference between FIS and New Study WSEL	New Floodway Width	FIS Floodway Width
110' DS of AY (Passaic*)	91683	43.72	44.4	-0.68	325.13	216
88' DS of BO (Passaic*)	101454	125.05	123.1	1.95	292.66	423
164' US of BV (Passaic*)	110856	127.84	127.2	0.64	586.35	480
CA (Passaic*)	118319	131.27	131.6	-0.33	319.84	295

*Denotes which county's FIS the effective cross section is located in.

Table 50. WSEL Table for Passaic River

CROSS SECTION	STREAM STATIONING	FW WIDTH **	XS AREA (SQFT)	VELOCITY IN FLOODWAY (FT/S) *	REGULATORY WSEL	FLOODWAY WSEL	WSEL INCREASE	WSEL 2%	WSEL 10%	WSEL 0.2%
	8375.5	364.0	6214.7	5.0	2.76	2.76	0.00	2.76	2.76	2.76
	9317.9	281.2	4342.7	7.1	2.78	2.78	0.00	2.78	2.77	2.8
	9833.6	228.7	3810.8	8.1	2.92	2.92	0.00	2.88	2.81	3.1
	10271.8	241.1	4435.4	7.0	3.44	3.44	0.00	3.26	2.98	4.15
	10759.6	354.9	5109.7	6.1	3.85	3.84	-0.01	3.56	3.12	4.95
	11315.6	354.5	5143.1	6.0	4.08	4.1	0.02	3.74	3.21	5.31
	11613.1	327.1	5719.0	5.4	4.32	4.33	0.01	3.92	3.3	5.67
	11724.4	292.7	5034.9	6.1	4.85	4.86	0.01	4.32	3.88	6.63
	11870.4	297.9	5319.2	5.8	4.97	4.98	0.01	4.42	3.92	6.82
	12482.2	298.7	4843.3	6.4	5.10	5.11	0.01	4.53	3.97	7
	13267.7	392.1	6605.7	4.7	5.64	5.65	0.01	4.96	4.19	7.83
	13655.1	397.1	6755.8	4.6	5.73	5.74	0.01	5.03	4.23	7.94
	14269.5	350.7	5811.3	5.3	5.79	5.79	0.00	5.08	4.25	7.99
	14760.1	331.6	5544.3	5.6	5.89	5.9	0.01	5.17	4.3	8.13
	15272.4	281.8	4675.7	6.7	5.92	5.93	0.01	5.21	4.32	8.12
	15771.7	284.3	4186.8	7.5	6.02	6.03	0.01	5.3	4.37	8.25
	16288.1	292.0	5436.6	5.7	6.61	6.62	0.01	5.78	4.62	9.1
	16699.9	324.1	6389.0	4.8	6.85	6.87	0.02	5.97	4.73	9.44
	17133.6	418.3	7586.0	4.1	7.03	7.05	0.02	6.12	4.81	9.71
	17565.8	453.2	7529.5	4.1	7.09	7.11	0.02	6.17	4.84	9.79
	17970.7	354.2	6208.6	5.0	7.08	7.1	0.02	6.17	4.84	9.77
	18441.9	365.2	6174.4	5.1	7.18	7.19	0.01	6.25	4.88	9.91
	18973.2	411.4	6591.3	4.7	7.35	7.37	0.02	6.4	4.97	10.12
	19570.0	477.9	7832.2	4.0	7.56	7.58	0.02	6.58	5.07	10.34
	20186.5	352.8	6555.2	4.7	7.58	7.6	0.02	6.61	5.1	10.35
	20842.8	269.0	5344.5	5.8	7.60	7.62	0.02	6.63	5.12	10.34
	21393.0	357.9	6743.3	4.7	7.95	7.97	0.02	6.92	5.27	10.86
	21492.1	341.0	6375.0	4.9	8.12	8.16	0.04	7.07	5.36	11.09
	21617.5	352.4	6497.0	4.8	8.18	8.22	0.04	7.11	5.38	11.18
	22359.9	412.9	7359.3	4.2	8.38	8.42	0.04	7.28	5.48	11.47
	22842.0	416.8	6962.5	4.5	8.43	8.47	0.04	7.33	5.51	11.52
	23297.5	388.6	6336.0	4.9	8.47	8.51	0.04	7.37	5.54	11.56

	23848.2	409.7	6925.6	4.5	8.65	8.69	0.04	7.52	5.64	11.78
	24366.5	498.3	8506.0	3.6	8.85	8.88	0.03	7.69	5.74	12.04
	24887.2	453.3	7335.8	4.3	8.87	8.89	0.02	7.71	5.76	12.05
	25418.1	382.3	6196.7	5.0	8.89	8.92	0.03	7.74	5.79	12.07
	26161.2	358.5	6569.2	4.0	9.16	9.2	0.04	7.99	5.94	12.33
	26715.3	427.7	8050.3	3.2	9.31	9.35	0.04	8.12	6.02	12.56
	26885.9	402.3	7532.3	3.4	9.31	9.36	0.05	8.12	6.02	12.56
	27118.1	403.9	6598.6	3.9	9.42	9.46	0.04	8.21	6.08	12.73
	27927.2	428.6	7714.6	3.3	9.59	9.63	0.04	8.36	6.18	12.93
	28247.0	434.9	7644.8	3.3	9.68	9.74	0.06	8.45	6.25	13.04
	28540.5	429.6	8028.5	3.2	9.73	9.79	0.06	8.5	6.28	13.09
	28980.3	327.8	6226.9	4.1	9.70	9.76	0.06	8.48	6.28	13.04
	29529.3	266.6	5234.3	4.9	9.71	9.76	0.05	8.49	6.29	13.01
	30094.7	235.1	5071.5	5.0	9.79	9.84	0.05	8.57	6.35	13.11
	30537.4	234.0	4782.8	5.3	9.83	9.89	0.06	8.61	6.38	13.16
	31039.1	239.6	5293.3	4.8	10.01	10.07	0.06	8.76	6.48	13.39
	31619.7	295.2	6148.4	4.1	10.19	10.25	0.06	8.92	6.58	13.67
	32203.8	324.0	6834.8	3.7	10.32	10.37	0.05	9.02	6.65	13.83
	32694.8	324.1	6147.2	4.2	10.33	10.39	0.06	9.04	6.66	13.85
	32922.2	315.7	6173.4	4.2	10.36	10.42	0.06	9.07	6.68	13.89
	33091.7	336.2	6640.8	3.9	10.42	10.48	0.06	9.12	6.72	13.97
	33592.0	277.0	5792.4	4.5	10.43	10.48	0.05	9.13	6.73	13.95
	34098.1	310.5	7261.8	3.5	10.61	10.66	0.05	9.29	6.83	14.21
	34572.0	303.4	6084.1	4.3	10.59	10.64	0.05	9.27	6.83	14.17
	34868.0	297.5	6392.2	4.0	10.65	10.71	0.06	9.33	6.87	14.25
	35191.7	283.0	6537.2	3.9	10.71	10.76	0.05	9.38	6.9	14.34
	35301.5	265.5	5709.5	4.4	10.72	10.76	0.04	9.39	6.9	14.34
	35457.3	293.0	6105.4	4.2	10.76	10.81	0.05	9.43	6.93	14.39
	36099.2	326.9	6855.3	3.8	10.89	10.94	0.05	9.54	7.01	14.57
	36600.8	332.0	6131.9	4.3	10.90	10.95	0.05	9.55	7.02	14.6
	37105.3	281.8	6005.8	4.3	10.96	11.01	0.05	9.61	7.06	14.65
	37696.9	287.8	6309.1	4.1	11.06	11.11	0.05	9.7	7.12	14.76
	38098.5	291.5	6361.5	4.0	11.10	11.15	0.05	9.74	7.15	14.81
	38598.7	294.9	6438.6	4.0	11.16	11.21	0.05	9.79	7.19	14.87
	39394.4	280.6	6151.7	4.2	11.22	11.27	0.05	9.85	7.23	14.97
	39809.4	240.5	6369.4	4.0	11.29	11.34	0.05	9.91	7.28	15.04
	40047.7	257.7	5462.0	4.7	11.27	11.32	0.05	9.89	7.26	15
	40131.7	246.0	5006.3	5.2	11.34	11.4	0.06	9.95	8.67	15.31
	40252.1	235.9	5559.6	4.6	11.47	11.54	0.07	10.07	8.74	15.43
	40762.9	303.9	6138.7	4.2	11.60	11.66	0.06	10.17	8.8	15.63

	41270.4	322.9	5604.3	4.6	11.63	11.7	0.07	10.2	8.81	15.66
	42440.6	266.4	5365.5	4.8	11.80	11.87	0.07	10.37	8.92	15.81
	42718.9	269.1	5838.1	4.4	11.92	11.99	0.07	10.48	8.99	15.96
	42814.3	277.4	4583.0	5.8	12.02	12.09	0.07	10.53	9.01	17.22
	42991.8	272.0	5736.3	4.4	12.33	12.4	0.07	10.82	9.18	17.51
	45416.6	256.0	6058.0	4.4	12.61	12.68	0.07	11.09	9.35	17.79
	45688.6	315.5	7112.5	3.5	12.77	12.84	0.07	11.22	9.41	18.03
	45789.3	314.7	5632.3	4.7	13.35	13.5	0.15	11.69	9.61	18.23
	46044.7	342.1	5875.9	4.4	13.43	13.59	0.16	11.77	9.66	18.3
	47004.0	418.3	7473.2	3.4	13.70	13.87	0.17	12.03	9.83	18.6
	48020.4	231.6	4439.1	5.8	13.66	13.82	0.16	12.02	9.85	18.51
	48920.6	376.5	6522.4	3.3	14.19	14.34	0.15	12.51	10.17	19.1
	49772.6	292.6	5235.0	4.7	14.21	14.36	0.15	12.54	10.2	19.08
	49856.2	278.7	5140.9	4.5	15.88	16.07	0.19	13.7	10.63	20.91
	50279.0	543.3	6774.6	4.1	16.04	16.22	0.18	13.82	10.69	21.13
	50745.6	441.0	5543.1	4.6	16.05	16.23	0.18	13.84	10.71	21.13
	51306.8	375.8	5032.2	4.6	16.13	16.32	0.19	13.96	10.83	21.19
	51430.8	366.5	5700.4	3.9	16.26	16.45	0.19	14.09	10.92	21.28
	51475.6	370.9	7128.3	3.1	17.29	17.49	0.20	15.09	11.18	21.57
	51490.9	285.8	6420.3	3.4	17.28	17.47	0.19	15.07	11.17	21.54
	51498.3	314.9	5451.7	4.0	17.24	17.44	0.20	15.04	11.15	21.51
	51575.6	276.7	6114.9	3.6	18.02	18.23	0.21	15.33	11.29	22.29
	51923.7	306.2	5153.1	4.4	18.00	18.22	0.22	15.32	11.28	22.29
	52577.7	402.8	7322.7	3.0	18.25	18.46	0.21	15.57	11.49	22.55
	53409.9	339.6	6234.0	3.5	18.29	18.5	0.21	15.62	11.56	22.58
	53857.9	346.2	6475.4	3.4	18.35	18.55	0.20	15.69	11.63	22.64
	54581.6	507.6	7706.7	3.6	18.41	18.62	0.21	15.76	11.71	22.71
	55047.0	392.5	6649.5	3.7	18.46	18.67	0.21	15.82	11.78	22.75
	55491.1	400.3	4982.1	5.1	18.40	18.6	0.20	15.77	11.78	22.66
	55773.8	281.2	4380.5	5.2	18.44	18.64	0.20	15.83	11.84	22.69
	56180.4	384.3	6869.3	3.3	18.83	19.02	0.19	16.23	12.19	23.13
	56306.7	396.8	5980.5	3.7	18.89	19.08	0.19	16.3	12.26	23.47
	56475.1	457.7	7502.2	3.1	19.00	19.19	0.19	16.42	12.38	23.51
	56963.5	517.8	8134.2	2.7	19.07	19.26	0.19	16.5	12.46	23.59
	57391.0	405.1	6762.6	3.3	19.07	19.26	0.19	16.51	12.5	23.58
	58177.2	405.0	4681.4	4.6	19.09	19.27	0.18	16.53	12.5	23.59
	58505.5	446.9	4011.2	5.4	19.18	19.36	0.18	16.68	13.12	23.65
	58565.5	570.4	7824.0	3.0	29.93	29.93	0.00	29.28	27.97	31.34
	59248.0	538.6	5836.3	3.7	29.96	29.97	0.01	29.31	27.98	31.38
	59973.1	852.9	9602.1	2.3	30.20	30.2	0.00	29.5	28.09	31.72

	60557.9	683.2	7264.2	3.0	30.22	30.22	0.00	29.52	28.11	31.74
	60944.1	658.0	6235.4	3.5	30.26	30.26	0.00	29.55	28.13	31.78
	61268.7	697.7	7320.4	3.0	30.38	30.38	0.00	29.66	28.2	31.94
	61518.7	683.1	6508.6	3.4	31.02	31.02	0.00	30.38	29.11	32.43
	61627.8	693.2	7236.0	3.0	31.08	31.09	0.01	30.43	29.14	32.52
	62203.8	804.2	7392.9	3.4	31.17	31.17	0.00	30.5	29.18	32.63
	62732.9	644.1	7275.8	3.2	31.27	31.27	0.00	30.59	29.25	32.74
	62994.1	639.5	7554.1	3.0	31.36	31.37	0.01	30.67	29.29	32.89
	63424.8	640.8	7247.8	3.1	31.41	31.41	0.00	30.71	29.31	32.95
	63836.9	520.5	5379.4	4.2	31.40	31.4	0.00	30.71	29.32	32.93
	64235.1	559.5	6234.7	3.5	31.57	31.58	0.01	30.85	29.4	33.15
	64713.4	584.1	5914.4	3.8	31.65	31.66	0.01	30.91	29.45	33.25
	65187.9	550.7	6525.2	3.3	31.79	31.8	0.01	31.03	29.52	33.44
	65665.0	458.1	5217.5	4.2	31.82	31.83	0.01	31.06	29.55	33.46
	66023.9	393.0	4298.3	5.1	31.84	31.85	0.01	31.08	29.57	33.46
	66172.5	415.6	5166.2	4.2	32.05	32.07	0.02	31.26	29.67	33.76
	66536.4	368.6	4470.7	4.9	32.11	32.12	0.01	31.31	29.71	33.85
	66559.2	335.6	3655.3	6.1	32.01	32.03	0.02	31.23	29.67	33.7
	66640.2	373.6	4721.5	4.8	32.35	32.37	0.02	31.5	29.82	34.26
	66760.4	399.8	5410.9	4.0	32.50	32.51	0.01	31.62	29.89	34.48
	66927.2	324.0	4817.4	4.7	32.47	32.48	0.01	31.6	29.88	34.43
	67177.6	392.7	4876.3	5.0	32.51	32.51	0.00	31.63	29.9	34.47
	67304.0	430.3	5304.3	4.5	32.67	32.69	0.02	31.77	29.97	34.71
	67404.0	342.6	4402.9	5.1	32.65	32.67	0.02	31.75	29.97	34.69
	67856.2	419.5	5039.9	4.3	32.89	32.91	0.02	31.95	30.09	35.01
	68325.0	449.5	5644.8	3.8	33.07	33.09	0.02	32.1	30.18	35.23
	68778.5	365.1	4499.1	4.8	33.09	33.12	0.03	32.13	30.21	35.24
	69268.3	412.5	4278.1	5.3	33.24	33.26	0.02	32.26	30.31	35.42
	69758.9	381.8	4222.7	5.2	33.47	33.48	0.01	32.48	30.49	35.67
	70250.9	403.3	5021.4	4.3	33.72	33.77	0.05	32.72	30.69	35.93
	70545.3	451.8	5631.8	3.9	33.85	33.9	0.05	32.83	30.76	36.09
	70940.9	428.6	4898.1	4.6	33.89	33.94	0.05	32.87	30.8	36.12
	71233.1	436.0	4724.3	5.0	33.94	33.99	0.05	32.92	30.85	36.17
	71694.9	363.0	4413.8	4.9	34.09	34.14	0.05	33.06	30.96	36.33
	72153.8	332.4	4183.6	5.2	34.21	34.26	0.05	33.18	31.05	36.46
	72560.1	351.4	4274.0	5.2	34.37	34.42	0.05	33.31	31.15	36.69
	72656.6	391.7	4012.2	5.6	34.38	34.43	0.05	33.32	31.16	36.7
	72754.4	416.3	4727.7	4.9	34.58	34.64	0.06	33.5	31.3	36.94
	72805.3	420.8	4901.8	4.7	34.62	34.68	0.06	33.53	31.32	36.99
	73253.9	443.9	4130.9	5.4	34.69	34.76	0.07	33.61	31.39	37.07

	73737.2	442.5	5457.7	4.1	35.05	35.11	0.06	33.93	31.62	37.48
	74236.5	382.5	5180.9	4.2	35.17	35.2	0.03	34.03	31.7	37.64
	74735.6	402.3	5439.4	4.0	35.26	35.33	0.07	34.13	31.79	37.72
	74983.5	403.6	5544.9	4.0	35.33	35.39	0.06	34.18	31.83	37.8
	75412.9	403.8	5100.7	4.3	35.38	35.45	0.07	34.24	31.88	37.85
	75888.6	373.9	4713.9	4.6	35.48	35.54	0.06	34.33	31.96	37.96
	76356.8	328.0	4076.1	5.5	35.54	35.6	0.06	34.4	32.04	38
	76820.0	267.9	3809.9	5.7	35.67	35.75	0.08	34.54	32.17	38.09
	76977.7	264.6	4131.6	5.2	35.84	35.92	0.08	34.69	32.27	38.3
	77048.2	263.3	3501.2	6.2	35.96	36.04	0.08	34.79	32.35	38.45
	77124.0	269.4	3993.3	5.4	36.16	36.24	0.08	34.97	32.49	38.71
	77429.9	300.6	4129.9	5.3	36.29	36.36	0.07	35.08	32.57	38.88
	77831.2	328.3	4005.4	5.6	36.40	36.47	0.07	35.18	32.65	39
	78283.3	355.0	3928.2	5.7	36.57	36.64	0.07	35.34	32.8	39.19
	78749.4	289.7	3708.7	6.0	36.76	36.8	0.04	35.52	32.95	39.43
	79241.3	303.9	3704.8	6.0	36.94	37.02	0.08	35.71	33.14	39.58
	79721.7	366.3	4364.4	5.2	37.35	37.37	0.02	36.06	33.39	40.12
	80102.7	355.5	4094.0	5.7	37.44	37.45	0.01	36.15	33.48	40.21
	80334.1	341.9	3816.3	6.2	37.44	37.5	0.06	36.17	33.54	40.2
	80820.2	246.2	3316.8	6.6	37.56	37.66	0.10	36.33	33.71	40.18
	80944.1	218.4	2959.0	7.3	37.55	37.65	0.10	36.33	33.73	40.14
	81070.6	283.3	3842.5	5.8	37.98	38.11	0.13	36.7	34	40.7
	81159.5	274.1	3777.1	5.7	38.05	38.17	0.12	36.75	34.03	40.8
	81251.6	279.3	3866.7	5.6	38.11	38.24	0.13	36.81	34.08	40.88
	81548.0	332.7	4162.8	5.4	38.25	38.39	0.14	36.94	34.19	41.04
	81884.4	347.5	4556.9	4.8	38.47	38.6	0.13	37.14	34.36	41.31
	82313.6	395.6	4362.9	5.2	38.58	38.69	0.11	37.25	34.47	41.43
	82755.2	321.9	3641.8	6.1	38.63	38.76	0.13	37.33	34.59	41.43
	83176.5	332.7	3736.7	6.1	38.86	38.98	0.12	37.55	34.8	41.65
	83661.3	297.3	3828.0	5.6	39.20	39.31	0.11	37.87	35.09	42.01
	83733.0	317.9	4005.7	5.4	39.46	39.63	0.17	38.06	35.2	43.84
	83764.9	330.6	4092.1	5.4	39.47	39.64	0.17	38.07	35.23	43.86
	84129.8	282.8	3321.5	6.8	39.48	39.64	0.16	38.1	35.3	43.81
	84544.3	279.0	3516.6	6.3	39.82	39.96	0.14	38.44	35.62	44.09
	84888.0	301.8	4242.5	5.1	40.19	40.33	0.14	38.78	35.91	44.43
	84968.8	339.7	4618.4	4.7	40.28	40.44	0.16	38.87	35.97	44.51
	85056.1	311.6	4527.1	4.8	40.48	40.66	0.18	39.07	36.2	45.19
	85114.6	283.8	4158.3	5.2	40.47	40.64	0.17	39.06	36.2	45.17
	85315.2	265.9	3964.9	5.5	40.51	40.68	0.17	39.11	36.24	45.2
	85749.1	305.9	4244.0	5.4	40.80	40.84	0.04	39.34	36.39	45.53

	86098.1	292.0	4362.3	5.1	40.95	40.99	0.04	39.49	36.52	45.64
	86348.3	306.2	4242.8	5.3	40.90	41.04	0.14	39.46	36.53	45.58
	86730.0	315.3	4139.2	5.5	40.95	41.13	0.18	39.53	36.63	45.58
	87009.7	349.8	5008.1	4.5	41.19	41.39	0.20	39.77	36.82	45.7
	87181.1	308.3	4420.1	5.0	41.35	41.54	0.19	39.91	36.93	45.89
	87263.0	319.0	4808.9	4.5	41.46	41.65	0.19	40.01	36.99	46
	87425.1	317.0	4306.6	5.1	41.44	41.63	0.19	39.99	36.98	45.97
	87788.7	300.4	4127.2	5.3	41.53	41.73	0.20	40.09	37.08	46.04
	87987.0	343.1	4292.4	5.2	41.63	41.82	0.19	40.17	37.16	46.09
	88098.7	346.6	4513.9	4.9	41.90	42.08	0.18	40.42	37.37	47
	88187.1	363.4	4376.8	5.2	41.92	42.09	0.17	40.44	37.38	47.04
	88624.3	250.3	3228.0	7.1	41.90	42.03	0.13	40.45	37.48	46.95
	88941.3	250.5	3632.1	6.2	42.21	42.38	0.17	40.76	37.77	47.22
	89227.8	231.5	3315.4	6.7	42.23	42.43	0.20	40.8	37.84	47.12
	89717.5	270.0	4105.8	5.3	42.72	42.9	0.18	41.23	38.16	47.62
	90110.5	253.8	3764.4	5.7	42.78	42.98	0.20	41.31	38.25	47.63
	90433.1	219.5	3166.7	7.0	42.76	42.95	0.19	41.31	38.29	47.56
	90860.7	176.6	2772.9	7.8	42.86	43.07	0.21	41.44	38.45	47.54
	91048.9	220.5	3713.6	5.8	43.54	43.7	0.16	42.01	38.84	48.29
	91124.8	227.7	3103.4	7.2	43.45	43.65	0.20	41.93	38.79	48.36
	91191.3	233.5	3502.1	6.3	43.75	43.94	0.19	42.2	38.99	48.69
	91683.4	325.1	2832.6	8.2	43.72	43.9	0.18	42.21	39.08	48.67
	92090.5	325.1	2963.3	8.8	43.97	44.11	0.14	42.41	39.24	48.87
	92564.3	249.4	3377.8	7.0	44.67	44.86	0.19	43.11	39.84	49.32
	93028.4	183.8	2660.8	8.6	44.66	44.86	0.20	43.15	39.97	49.2
	93534.5	205.8	2978.6	8.0	45.24	45.37	0.13	43.68	40.32	49.7
	93984.2	264.8	3624.3	6.6	45.70	45.93	0.23	44.12	40.72	50.15
	94320.8	260.9	3888.2	5.7	46.05	46.27	0.22	44.44	41	50.49
	94396.5	260.9	4334.2	5.1	46.61	46.85	0.24	44.62	41.11	50.98
	94427.7	268.6	4509.0	4.9	46.65	46.89	0.24	44.66	41.15	51.01
	94711.8	280.6	4136.4	5.4	46.67	46.91	0.24	44.68	41.17	51.03
	95262.7	226.3	3711.0	5.9	46.79	47.02	0.23	44.83	41.37	51.09
	95748.3	242.8	2805.7	8.3	46.67	46.9	0.23	44.73	41.36	50.94
	95880.0	260.9	3111.8	7.8	46.94	47.17	0.23	45.01	41.6	51.19
	95951.4	260.9	3346.8	7.2	47.68	47.78	0.10	45.77	41.77	51.82
	95996.3	343.3	3614.8	7.4	47.68	47.82	0.14	45.75	41.74	51.83
	96401.2	321.2	4160.3	6.0	48.20	48.33	0.13	46.33	42.35	52.27
	96746.0	418.1	4543.5	5.7	48.39	48.52	0.13	46.51	42.57	52.52
	96823.2	427.8	4758.9	5.4	49.13	49.24	0.11	47.41	42.97	52.77
	96957.9	500.5	4100.6	6.7	49.07	49.19	0.12	47.34	42.89	52.74

	97290.1	529.7	3598.2	7.8	49.15	49.27	0.12	47.43	43.14	52.81
	97505.5	421.6	4114.3	5.6	49.76	49.85	0.09	48.17	44.07	53.11
	97600.7	421.6	5027.0	4.6	50.28	50.4	0.12	48.57	44.29	53.9
	97764.8	540.2	3886.4	7.1	50.20	50.32	0.12	48.47	44.17	53.86
	97847.5	392.7	3289.5	8.0	50.15	50.27	0.12	48.45	44.23	53.8
	97915.8	394.1	3097.6	8.5	50.79	50.76	-0.03	49.11	44.58	53.84
	98364.3	189.8	2230.1	10.5	50.85	50.96	0.11	49.2	44.86	53.71
	98593.1	185.7	2018.9	10.8	51.02	51.12	0.10	49.44	45.71	53.84
	98931.1	138.8	1608.6	13.5	51.10	51.18	0.08	49.75	46.98	53.53
	99341.4	170.4	1983.4	11.2	53.02	53.06	0.04	51.6	48.76	55.86
	99782.6	141.9	1468.0	15.4	53.34	53.37	0.03	52.07	49.6	55.93
	99989.0	129.8	1359.3	19.5	55.14	55.1	-0.04	53.8	51.17	57.91
	100153.5	290.6	4969.6	4.4	61.02	61.05	0.03	59.09	55.19	65.21
	100197.8	315.3	5160.6	4.3	61.04	61.08	0.04	59.12	55.2	65.25
	100238.6	157.2	2697.9	8.1	60.56	60.59	0.03	58.7	54.92	64.61
	100270.8	131.8	2183.1	10.1	60.45	60.48	0.03	58.64	54.97	64.38
	100299.2	120.3	1999.9	10.9	60.60	60.63	0.03	58.83	55.21	64.46
	100322.6	79.8	1101.2	20.1	59.02	59.06	0.04	57.53	54.48	62.27
	100337.9	80.7	1258.5	17.8	62.04	62.07	0.03	60.15	56.39	66.14
	100356.3	68.2	1185.8	18.5	62.48	62.51	0.03	60.72	57.26	66.25
	100362.3	62.2	1072.1	20.6	62.14	62.17	0.03	60.49	57.21	65.61
	100374.4	60.2	1151.5	19.1	63.87	63.91	0.04	61.88	58.24	68.57
	100416.0	60.3	1274.0	17.4	66.42	66.43	0.01	64.26	59.99	71.19
	100631.7	145.1	2521.1	10.1	73.77	73.77	0.00	70.69	64.61	80.55
	100725.4	514.3	3161.7	8.5	110.16	110.15	-0.01	109.4	107.81	111.79
	100922.0	401.8	2660.7	9.2	110.42	110.41	-0.01	109.71	108.23	111.95
	101263.6	304.8	1797.1	12.0	111.47	111.47	0.00	110.83	109.44	112.84
	101279.7	333.5	5213.0	4.3	124.90	124.92	0.02	123.99	122.09	126.53
	101326.7	342.6	5729.6	3.9	124.97	124.99	0.02	124.05	122.12	126.64
	101454.9	292.7	4798.1	4.6	125.05	125.06	0.01	124.1	122.15	126.82
	101686.7	247.3	4609.2	4.8	125.08	125.09	0.01	124.12	122.17	126.87
	102079.3	277.1	4563.6	4.7	125.17	125.18	0.01	124.19	122.2	127.01
	102567.3	438.5	5889.6	4.2	125.36	125.37	0.01	124.34	122.28	127.33
	103092.9	347.2	4319.3	5.8	125.34	125.36	0.02	124.33	122.29	127.27
	103128.6	352.1	4765.2	5.1	125.53	125.55	0.02	124.48	122.37	127.56
	103213.9	359.6	5104.6	4.6	125.63	125.64	0.01	124.57	122.42	127.72
	103613.9	412.2	5410.2	4.6	125.73	125.74	0.01	124.64	122.46	127.88
	104077.0	680.4	7273.6	4.2	125.85	125.88	0.03	124.75	122.53	128
	104542.9	1023.7	8406.2	4.3	125.92	125.95	0.03	124.81	122.58	128.1
	105028.9	1014.8	9150.3	3.8	126.07	126.09	0.02	124.94	122.66	128.31

	105400.6	791.3	7534.5	4.2	126.11	126.12	0.01	124.98	122.69	128.35
	105821.6	752.3	7082.2	4.0	126.17	126.19	0.02	125.04	122.75	128.42
	106221.8	570.7	6675.2	3.7	126.22	126.26	0.04	125.1	122.82	128.45
	106701.8	432.4	6251.8	3.9	126.28	126.31	0.03	125.15	122.86	128.51
	107197.3	263.5	4939.1	4.4	126.31	126.35	0.04	125.19	122.89	128.54
	107302.5	263.5	4854.0	4.5	126.49	126.55	0.06	125.3	122.94	129.34
	107589.9	333.9	4471.7	5.3	126.50	126.56	0.06	125.31	122.95	129.38
	108152.3	319.5	4404.0	5.3	126.70	126.71	0.01	125.47	123.05	129.62
	108510.2	252.1	3585.4	6.7	126.60	126.64	0.04	125.42	123.03	129.4
	108699.9	293.5	4146.8	5.6	126.94	126.94	0.00	125.7	123.21	129.86
	109010.9	429.2	5519.7	4.2	127.19	127.29	0.10	125.92	123.35	130.16
	109122.0	515.0	6604.7	3.6	127.52	127.67	0.15	126.23	123.5	130.41
	109295.9	520.2	6353.7	4.4	127.54	127.67	0.13	126.24	123.5	130.44
	109791.6	470.6	5565.4	4.5	127.60	127.74	0.14	126.31	123.57	130.5
	110335.1	423.0	5170.5	4.6	127.67	127.85	0.18	126.39	123.66	130.55
	110856.2	586.4	6524.4	4.9	127.84	128.02	0.18	126.53	123.75	130.73
	111271.7	565.7	5909.7	5.2	127.91	128.09	0.18	126.6	123.83	130.8
	111790.5	275.7	3330.4	7.5	127.88	128.03	0.15	126.6	123.88	130.71
	112024.1	218.4	3403.5	6.9	128.41	128.4	-0.01	127.04	124.18	131.39
	112214.8	264.9	3555.3	6.7	128.38	128.55	0.17	127.04	124.21	131.31
	112472.6	221.1	3109.0	7.6	128.37	128.54	0.17	127.06	124.26	131.25
	112971.1	233.8	3875.3	5.8	129.09	129.14	0.05	127.66	124.65	132.22
	113420.2	314.0	4530.4	5.3	129.23	129.36	0.13	127.78	124.76	132.6
	113853.6	280.1	4480.5	5.1	129.33	129.51	0.18	127.9	124.88	132.63
	114299.5	325.7	4091.1	6.3	129.34	129.52	0.18	127.92	124.91	132.43
	114572.5	300.9	4052.6	6.2	129.52	129.67	0.15	128.09	125.04	132.61
	115088.7	246.5	3552.0	6.6	129.68	129.85	0.17	128.25	125.21	132.75
	115557.7	242.9	3656.7	6.2	129.94	130.15	0.21	128.52	125.46	133
	115997.5	235.2	3520.6	6.6	130.16	130.33	0.17	128.7	125.62	133.33
	116543.6	298.1	4470.1	5.1	130.58	130.81	0.23	129.14	125.97	133.72
	116763.4	313.0	4434.0	5.8	130.63	130.82	0.19	129.18	126	133.76
	117137.1	386.5	5237.6	4.8	130.86	131.1	0.24	129.39	126.19	134.04
	117518.0	333.2	4755.4	5.1	130.95	131.19	0.24	129.48	126.28	134.12
	117920.0	351.0	5341.2	4.4	131.18	131.39	0.21	129.69	126.46	134.4
	118175.5	316.2	5179.3	4.3	131.21	131.45	0.24	129.72	126.51	134.58
	118319.8	319.8	5218.8	4.4	131.27	131.5	0.23	129.78	126.54	134.85
	118439.7	359.6	5333.6	4.3	131.30	131.53	0.23	129.81	126.57	134.85
	118501.5	351.3	5232.2	4.4	131.32	131.54	0.22	129.82	126.58	134.85
	118680.1	338.9	4989.0	4.6	131.34	131.57	0.23	129.85	126.61	134.92
	118742.1	338.9	5264.1	4.3	131.42	131.65	0.23	129.9	126.66	135.05

	118866.4	343.1	5505.8	4.1	131.50	131.71	0.21	129.97	126.71	135.04
	119079.9	380.0	5635.9	4.3	131.62	131.87	0.25	130.07	126.8	135.21
	119385.3	433.7	5865.7	4.4	131.82	132.06	0.24	130.27	126.98	135.4
	119760.4	480.4	6369.7	5.3	132.07	132.31	0.24	130.52	127.24	135.62
	120199.5	576.8	6507.4	6.7	132.54	132.77	0.23	130.99	127.72	136.08
	120590.4	489.1	5181.0	6.2	133.06	133.26	0.20	131.49	128.41	136.49
	121006.6	508.5	5318.7	6.4	133.69	133.86	0.17	132.41	129.15	137.09
	121448.7	325.3	3085.4	8.2	133.97	134.13	0.16	132.75	129.64	137.21
	121647.2	169.1	2873.6	7.5	134.59	134.68	0.09	133.28	129.98	137.73
	122239.2	163.9	2765.9	7.8	135.20	135.35	0.15	133.85	130.49	138.38
	122450.4	169.3	2723.8	7.9	135.36	135.5	0.14	133.99	130.61	138.54
	122771.9	191.4	3083.9	7.9	135.68	135.79	0.11	134.27	130.85	138.92
	122968.1	204.6	3129.7	7.7	135.87	136	0.13	134.44	130.98	139.18
	123358.9	151.1	2451.8	9.4	135.91	136.02	0.11	134.51	131.13	139.09
	123651.2	113.7	1618.8	13.3	135.71	135.84	0.13	134.38	131.12	138.74
	123695.0	131.8	1901.9	11.3	136.83	136.92	0.09	135.28	131.74	140.35
	124000.2	101.2	1121.0	19.2	137.54	137.54	0.00	136.24	133.37	140.45
	124160.0	103.8	1138.3	18.9	140.11	140.12	0.01	138.85	136.13	142.88
	124260.3	116.5	1548.9	13.9	143.83	143.83	0.00	142.18	138.88	147.73
	124286.9	124.5	1771.8	12.3	144.80	144.8	0.00	143.06	139.52	148.64
	124933.9	295.7	3481.1	6.2	164.99	164.99	0.00	164.26	162.69	166.43

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