

# **Draft Appendix CI**

## **Hydrology**

### **Rahway River Basin, New Jersey Coastal Storm Risk Management Feasibility Study**

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**New Jersey  
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**U.S. Army Corps of Engineers  
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# **RAHWAY RIVER BASIN, NEW JERSEY COASTAL STORM RISK MANAGEMENT FEASIBILITY STUDY**

## **1.0 INTRODUCTION**

This Feasibility Study is the second phase of the U.S. Army Corps of Engineers planning process, and follows a favorable Reconnaissance Report and execution of a Feasibility Cost Sharing Agreement (FCSA) between the New York District Corps of Engineers and the non-Federal sponsor. The purpose of the Feasibility Study is to fully evaluate all reasonable solutions to the problems identified during the reconnaissance phase. This Feasibility Report documents the planning, engineering, design and real estate activities required to provide a basis for a decision on Federal participation in the construction of a project. The Feasibility Report is a complete decision document which presents the results of the reconnaissance and feasibility phases, and provides the basis for recommending the: (1) construction of a project, (2) preparation of a Design Memorandum (if necessary), and (3) preparation of the Plans and Specifications during the Pre-Construction Engineering and Design (“PED”) phase.

For this hydrology appendix, only a portion of the hydrology analysis from the Rahway River, Flood Risk Management Feasibility Study (November 2016) was used for this study. This will be explained in more detail within the following sections.

## **2.0 WATERSHED DESCRIPTION**

The Rahway River Basin is located in northeastern New Jersey. It lies within the metropolitan area of New York City and occupies portions of Essex, Union and Middlesex Counties. The entire watershed is approximately 83.3 square miles in area and is roughly crescent or “L”-shaped. Its greatest width is approximately 10 miles in the east-west direction, from the City of Linden to the City of Plainfield. Its greatest length is approximately 18 miles in a north–south direction, from West Orange to Metuchen. A map of the Rahway River basin and the municipalities that make it up is shown on Figure 1.



### **3.0 PROJECT AREA**

The Rahway project area is located along the Rahway River main stem and Robinsons Branch in the City of Rahway. Fluvial flood damages occurred within the City of Rahway from Tropical Storm Floyd, April 2007 Nor'easter and Tropical Cyclone Irene (August 2011). Also, coastal damages occurred within the City of Rahway from Tropical Cyclone Sandy. The project area is shown in Figure 2 for the City of Rahway section.

### **4.0 CLIMATOLOGY**

#### **4.1 Climate**

The climate of the Rahway River basin is characteristic of the entire Middle Atlantic Seaboard. Marked changes of weather are frequent, particularly during the spring and fall. The winters are moderate in both temperature and snowfall. The summers are moderate, with hot sultry weather in mid-summer, and with frequent thunderstorms. Rainfall is moderate, and well-distributed throughout the year. The relative humidity is high.

#### **4.2 Precipitation Stations**

Stations that were used for historic precipitation records in this study includes:

Rainfall Station: Canoe Brook; Lat/Long: 40° 45'N74°02'W; Elev: 180 feet

Rainfall Station: Newark Airport; Lat/Long: 40° 41'N74°10'W; Elev: 7 feet

Rainfall Station: Cranford; Lat/Long: 40° 39'N74°18'W; Elev: 75 feet

Rainfall Station: Plainfield; Lat/Long: 40° 36'N74°24'W; Elev: 90 feet

The impact that these stations have on the Rahway River Watershed during different historic storm events is given below.

For the April 2007 Nor'easter (April 15 to 16, 2007), the Thiessen polygons with the selected rainfall gages are shown in Figure 3. For Tropical Storm Irene (August 27 to 28, 2011), an ArcGIS Grid of precipitation values for the study area was constructed using data from the National Weather Service's (NWS) Advanced Hydrologic Prediction Service (AHPS). Daily observed precipitation values for 27 to 28 August, 2011(EDT) were merged to produce rainfall totals for the basin. This product was then checked against published National Weather Service totals for this event. The NWS observed precipitation products provide multisensor rainfall estimates, derived



from radar, gage, and satellite inputs, in a gridded shapefile format with a resolution of roughly 2.49x2.49 miles. A table depicting rainfall distribution, created from shapefile data, within the Rahway River Watershed is presented in Table 2.

### **4.3 Annual (Daily) and Monthly Precipitation**

The mean annual precipitation in the Rahway River Watershed is approximately 50.94 inches from the 1971-2000 Monthly Normals for the Cranford, New Jersey Station. The observed highest daily value at this station was 9.76 inches (Floyd). The monthly extremes were 13.96 inches in July 1975 and 0.45 inches in November 1976. The distribution of precipitation throughout the years is fairly uniform with highest amount occurring during the summer months. The mean annual snowfall is 20.00 inches at Cranford, New Jersey, precipitation station.

### **4.4 Storm Types**

The storms which occur over the northeastern states have their origins in or near the Pacific and the North Atlantic oceans and may be classified as: extratropical storms; which include thunderstorms, and cyclonic (transcontinental) storms; and tropical storms which include the West Indies hurricanes. There are also nor'easter storms. An extratropical storm, caused by rapid convective circulation that occurs when a tropical marine air mass is lifted suddenly on contact with hills and mountainous terrain, causes heavy rains usually in the summer and fall seasons. The thunderstorms, due to rapid convective circulation, usually occur in July, and are limited in extent and cause local flooding on "flashy streams". Cyclonic storms, due to their transcontinental air mass movement with attendant "highs" and "lows," usually occur in the winter or early spring, and is a potential flood-producer over large areas because of its widespread extent. The West Indies hurricanes of tropical origin proceed northward along the coastal areas, accompanied by winds greater than 75 miles per hour and torrential rains of several days duration.

### **4.5 Past Storms/Historical Floods**

A review of storms which have occurred in the northeastern states reveals that the Rahway River basin is located in the center of the North Atlantic storm belt. Some of the notable storms which have caused flooding conditions in the basin occurred on or between the following dates: 20-24 September 1882, 30 July 1889, 31 July 1901, 25-26 August 1933, March 1936, 17-25 July





1938, 6-8 August 1938, 17-21 September 1938, 9-16 August 1942, 20 May 1943, 18 September 1945, 28 June 1946, 23-25 July 1946, 8 November 1947, August 1955, October 1955, September 1960, 12-13 March 1962, 21-22 September 1966, 28-29 May 1968, 26-28 August 1971, 13 September 1971, 2-3 August 1973, July 1975 and November 1977. The interested reader can find brief descriptions of the following major flood-producing storms in the Rahway River basin presented in the *General Design Memorandum, Robinson's Branch of the Rahway River at Rahway, New Jersey Flood Control Study*, Volume 2, dated February 1986: (November 1977, July 1975, August 1973, August 1971, August 1969, May 1968 and July 1938). Two large, more recent storms, and the floods that they produced, were used to calibrate the HEC-HMS hydrologic model of the Rahway River basin. Detailed descriptions of these events are given below. A new flood of record occurred during the period of analysis. This was Tropical Cyclone Irene (8/28/2011). A description of this event is included below.

#### **4.5.1 Tropical Storm Floyd**

The eye of Floyd made landfall on 16 September 1999 near Cape Fear, North Carolina with Category 2 winds of 105 mph. After crossing eastern North Carolina and Virginia, Floyd weakened to a tropical storm. Its center then moved offshore along the coasts of the Delmarva Peninsula and New Jersey. On 17 September, the center of Floyd moved over Long Island NY (making landfall again roughly at the Queens-Nassau counties border) and New England, where it became extratropical.

Precipitation from the storm preceded its center in the New York City area on 15 September. Rainfall totals from Floyd were as high as 12 to 16 inches over portions of New Jersey, 4 to 8 inches over southeastern New York, and up to 11 inches over portions of New England. The inland flooding from Floyd was a disaster of immense proportions in the Eastern United States, particularly in North Carolina. The 56 USA direct deaths due to Floyd is the largest hurricane death toll since Agnes caused the deaths of 122 people in 1972. Total USA damage estimates range from three to over six billion dollars.

Floyd resulted in new flood peaks of record at sixty or more stream gages within the portions of New Jersey and New York contained by New York District's civil works boundaries. Within the Rahway River basin, the total rainfall at Cranford, NJ was 10.82 inches. Tropical Storm Floyd



produced a peak flow at the Springfield USGS gage of 7990 cfs and a peak flow of 5590 cfs at the Rahway USGS gage.

#### **4.5.2 April 15-16 2007 Nor'easter**

The 15-16 April 2007 nor'easter dropped about three to ten inches of rain on the watersheds within the New York District's civil works boundaries between the early morning of Sunday 15 April 2007 and the early afternoon of Monday 16 April 2007, resulting in new flood peaks of record at ten USGS gages in New Jersey. This storm had the greatest flooding impact on the Raritan and Passaic River basins. It produced the worst flooding in the Raritan River basin since Tropical Storm Floyd during September 1999. Bound Brook and Manville were once again hit hard, as were communities on the other side of the Raritan River in Middlesex County. Lincoln Park in the Passaic Basin was also hit hard.

The approximate time distribution of the total rainfall of the 15-16 April 2007 nor'easter over the watersheds of the New York District was an average of 7 to 7 ½ inches between about 2 a.m. on Sunday 15 April to 2 p.m. on Monday 16 April 2007, with most within the 24 hours beginning at 2 a.m. on Sunday the 15<sup>th</sup>. Greatest hourly amounts were from 0.6 to 0.8 inches at about 2 p.m. on Sunday 15 April 2007.

Unlike Tropical Storm Floyd, which broke the summer 1999 drought and fell on dry ground, the April 2007 nor'easter caused as much flooding as it did because it was preceded by the smaller 1-2 March and 12-13 April 2007 storms, and fell on saturated ground.

The nor'easter had a drop in central pressure of 0.83 inches in 24 hours, which qualified it as a meteorological bomb, a drop in central pressure of at least 0.71 inches in 24 hours. The lowest central pressure of about 28.53 inches is near the border of the pressure defined Categories 2 and 3 once used on the Saffir-Simpson Hurricane Scale.

Within the Rahway River basin, the total rainfall at Cranford was 6.47 inches. This nor'easter produced a peak flow at the Springfield USGS gage of 5540 cfs and a peak flow of 4910 cfs at the Rahway USGS gage.



### 4.5.3 Tropical Cyclone Irene

Tropical cyclone Irene began as a tropical wave off the West African coast on 15 August 2011. The storm was upgraded into Tropical Storm Irene at 23:00 UTC on 20 August about 190 miles east of Dominica in the Lesser Antilles. On 22 August Irene made landfall near Punta Santiago, Humacao, Puerto Rico, with estimated sustained winds of 70 mph. Just after its initial landfall, Irene was upgraded to a Category 1 hurricane, the first of the 2011 Atlantic hurricane season.

Moving erratically through the southeast Bahamas over very warm waters, Irene quickly expanded as its outflow aloft became very well established. The cyclone intensified into a Category 3 hurricane. Early on 27 August, Irene weakened to a Category 1 hurricane as it approached the Outer Banks of North Carolina. At 7:30 am EDT the same day, Irene made landfall near Cape Lookout, on North Carolina's Outer Banks, with winds of 85 mph. Later on 27 August, Irene re-emerged into the Atlantic near the southern end of the Chesapeake Bay in Virginia. At about 09:35 UTC on 28 August, Irene made a second landfall at the Little Egg Inlet on the New Jersey shore with winds of 75 mph, and soon after moved over water again. Hours later, Irene weakened to a tropical storm with winds of 65 mph near New York City. Irene then moved northeast over New England, becoming post-tropical over the state of Maine at 11:00 pm EDT.

Significant damages occurred in North and Central New Jersey, where flooding was widespread. Severe river flooding took place on the Raritan, Millstone, Rockaway, Rahway, Delaware, and Passaic Rivers due to record rainfall. The highest rainfall recorded in the state was in Freehold (11.27 inches), followed by Jefferson (10.54 inches) and Wayne (10.00 inches). The flooding affected roads, including the heavily used Interstate 287 in Boonton where the northbound shoulder collapsed, the Garden State Parkway which flooded in Cranford from the Rahway River and in Toms River near exit 98. Along the Hudson River, in parts of Jersey City and Hoboken, flood waters rose as much as 5 feet and the north tube of the Holland Tunnel was briefly closed. In total, ten deaths within the state are attributable to the storm.

In addition to major flooding, the combination of already heavily saturated ground from a wet summer, and heavy wind gusts made trees in Union County especially vulnerable to wind damage. Fallen trees, many pushed from the soaked ground with their roots attached, blocked vital roads from being accessed by local emergency services. Numerous homes suffered structural damages from the winds, and limbs impacting their roofs. Perhaps the most critical damage however due to



wind was fallen wires. Around Union County, fallen wires in combination with flooded electrical substations left parts of Union County, including Cranford, Garwood, and Westfield without power or phone service for nearly a week. In total, approximately 1.46 million customers of Jersey Central Power and Light (JCP&L) and Public Service Electric and Gas (PSEG) throughout most of the 21 counties lost power.

On 29 August, the governor of New Jersey asked President Obama to expedite release of emergency funds to the state. Eventually all 21 New Jersey counties became eligible for FEMA aid.

#### **4.5.4 Tropical Cyclone Sandy**

Sandy was a classic late-season hurricane in the southwestern Caribbean Sea but weakened into a tropical storm north of the Bahamas Islands. The system re-strengthened into a hurricane while it moved northeastward, parallel to the coast of the southeastern United States, and reached a secondary peak intensity of 85 knots while it turned northwestward toward the Mid- Atlantic States. Sandy weakened somewhat and then made landfall as a post-tropical cyclone near Brigantine, New Jersey. Sandy was predominately a coastal storm and not much of a rainfall producer in the project area and did not provide any impact from runoff. Only 1.33 inches of precipitation was recorded at Newark Airport on 29-30 October 2012.

### **5.0 HYPOTHETICAL RAINFALL**

A 48-hour duration hypothetical storm was modeled so that the Rahway River basin-wide HEC-HMS model developed for this study would be accurate for times of concentration as large as 24 to 48 hours.

Specific frequency point precipitation estimates in inches were obtained for the Rahway River basin from “Precipitation-Frequency Atlas of the United States” NOAA Atlas 14, volume 2. The data was determined at Cranford, NJ (40.65N, 74.30W) as a representative basin location.

Point rainfall depths were part of the HEC-HMS model input and were converted to finite area rainfall depths with transposition storm areas and procedures contained in HEC-HMS. A time step of 5 minutes was used for the HEC-HMS models because of the sizes and times of concentration



of the HEC-HMS model subbasins. The time series data of the hypothetical storms modeled is therefore given in 5 minute increments. The hypothetical point rainfall data for this watershed is given in Table 1. A storm area of 83.13 square miles was used to reduce point rainfall values to finite drainage area values, because it is the drainage area of the Rahway River at its mouth.

## **6.0 STREAMFLOW**

### **6.1 Peak Discharge Records**

There are, at present, three active continuous record USGS stream gages in the Rahway River basin. The most upstream gage is USGS gage number 01394500, Rahway River near Springfield, NJ. The gage is located on the left bank of the Rahway River, 50 feet downstream from the bridge on eastbound U.S. Highway 22, 100 feet downstream from Pope Brook and 1.50 miles south of Springfield. The drainage area at the gage is 25.50 square miles and the period of record is from July 1938 to the current year. The next gage is USGS gage number 01395000, Rahway River at Rahway, NJ. The gage is located on the left bank of the Rahway River, 100 feet upstream from the bridge on St. Georges Avenue in Rahway, 0.90 miles upstream from the confluence with Robinsons Branch, and 1.70 miles southwest of Linden. The drainage area at the gage is 40.90 square miles and the continuous period of record is from October 1921 to the current year. A third stream gage is USGS gage number 01396000, Robinsons Branch at Rahway, NJ. The gage is located on the right bank of Robinsons Branch, 70 feet upstream of the dam on Milton Lake, 0.40 miles upstream from Maple Avenue at Milton Lake in Rahway, 0.60 miles downstream from Middlesex Reservoir Dam, and 1.60 miles upstream from the mouth. The drainage area at the gage is 21.60 square miles. The gage was a continuous-record gaging station, water years 1937-96. It has been an annual maximum station, water years 1999 to the current year. All three gages were used for this watershed. The records of these USGS gaging stations are published in the Water-Data Reports of the U.S. Geological Survey. The locations of these stream gages are shown on Figure 4.

### **6.2 Average Discharge**

The average annual runoff of the Rahway River basin at the USGS gage near Springfield is 31.40 cfs over the 25.50 square mile drainage area for water years 1939-2009 inclusive or 1.23 cfs per square mile (csm). At the USGS gage at Rahway, the average annual runoff is 50.0 cfs for water years 1922-2009 inclusive over the 40.90 square mile area or 1.23 cfs per square mile (csm). At



the USGS gage on Robinsons Branch, the average annual runoff is 22.60 cfs for water years 1939-1980 inclusive over the 21.60 square mile area or 1.05 cfs per square mile (csm). The runoff is equal to an equivalent depth of 16.70 inches per year over the watershed at Springfield and Rahway and 14.20 inches at Robinsons Branch. The average Rahway River basin annual rainfall is 50.94 inches. The runoff at Rahway is equivalent to 32.80 percent of this rainfall.

## **7.0 HYDROLOGIC MODEL**

The Hydrologic Modeling System software (HEC-HMS), developed by the Hydrologic Engineering Center, Davis, CA, was used to hydrologically model the Rahway River basin. The HEC-HMS model was converted from a HEC-1 model originally developed by the New York District for previous Rahway River basin studies that focused on Springfield (1984) and Robinson's Branch (1985-6). Figure 4 shows the Rahway Watershed with subbasins and Figure 5 shows a schematic diagram of the HEC-HMS model. Table 3 give the name of each element, its description, the drainage area at that point and the type of computation. Subbasin data that includes unitgraph parameters and percent impervious area for the watershed is presented in Table 4. Several methods of channel routing are utilized in the various stream reaches. Table 5 gives values of Muskingum travel time, K and inflow-storage factor X for those reaches that utilize that method as well as values of lag used in the lag routing method encountered in certain other reaches. Modified Puls routing, using storage-outflow data developed from calibrated historic flood event runs with HEC-RAS, was used where possible. These relations are shown in Figures 6a through 6e. In addition, a reservoir computation was utilized at Lenape Park Dam, Orange Reservoir, Campbell Pond Dam and Diamond Mill Pond. This involved the development of storage vs discharge and elevation vs storage relationships to perform the routings. Plots of this data are shown in Figures 6f and 6g.

## **8.0 RECENT LARGE HISTORIC FLOOD CALIBRATION**

An HEC-HMS model was used to develop the Rahway River Watershed. The hydrologic analysis for this watershed was completed and was calibrated to the April 2007 event (4.5.2), for information purposes only, and to the August 2011 event (4.5.3).

Observed and computed hydrographs, with their associated hyetographs, for the calibration floods at the stream gages are shown in Figures 7 through 8.



At all three stream gages flow records through Water Year 2013 were analyzed, which included the major event of Tropical Cyclone Irene during August 2011, to which it was calibrated. Calibration to all three gages involved constant loss rate adjustments for the drainage areas between the three gages. Initial loss and constant loss rates used in this calibration are also shown in Table 5. Adjustments were then made to the Modified Puls storage-outflow routing relations between the Springfield and Rahway gages. Observed and computed hydrographs for the calibration flood at the stream gages, as well as peak discharges at other basin nodes, are shown in Table 7 and Figures 7 through 11.

## **9.0 FLOOD FREQUENCY ANALYSIS: EXISTING CONDITIONS**

Computations were performed at three USGS stream gages within the Rahway River basin to determine the existing conditions peak flow vs. frequency relations. For the annual series curve, a program developed by the Hydrologic Engineering Center, Davis, CA: HEC-SSP was utilized. The upstream limit and calibration point of the study, the USGS gage on the Rahway River near Springfield, NJ is the first gage to be analyzed. The annual peak flow data at this gage is a product of USGS peak gage heights and a Corps of Engineers rating used in the New York District 1984 Springfield hydrology appendix. This data is shown in Tables 8(a), 8(b) and 8(c). Another gage used in the analysis is the USGS gage on the Rahway River at Rahway, NJ. This is the downstream limit and calibration point of the Cranford study. All the peak flows used at this gage represent the post construction condition of the Lenape Park detention basin. A pre to post Lenape Park peak flow conversion for specific-frequency hypothetical floods was used from the New York district 1984 Springfield hydrology appendix was used to convert pre-Lenape Park Rahway River at Rahway historic annual peak flows to a post-Lenape Park condition. This data is shown in Tables 9(a), 9(b) and 9(c). The third USGS stream gage used was Robinsons Branch at Rahway, NJ. This data is shown in Table 10(a) and (b). Gaged data through Water Year 2013 was used for the City of Rahway analysis.

A partial duration adjustment was made to the annual series curves to reflect the occurrence of all flows above an established base during a given year. A utility program that employed Weibull plotting positions was used for this calculation. A two-week separation interval was used to



remove all dependent partial peak flows from the analysis. Figures 12 through 14 show the adopted peak flow vs. frequency curves at the USGS gages up to WY2013.

## **10.0 EXISTING CONDITIONS PEAK DISCHARGE: SPECIFIC-FREQUENCY HYPOTHETICAL FLOODS (CALIBRATION & COMPUTATIONS)**

Frequency-specific modifications to the existing conditions HEC-HMS hydrologic models were made to model specific-frequency hypothetical floods. The driving input for these modifications is hypothetical rain data. Point precipitation frequency estimates were obtained from NOAA Atlas 14 (partial duration series) and are shown in Table 1. The initial loss and constant loss rates used for this calibration is shown in Table 11. The difference for the hypothetical events is that the models were calibrated to the peak flows computed in the existing conditions flood frequency analysis discussed above rather than observed hydrographs as was the case with the historic flood events. A range of calibrated existing conditions hypothetical flood peaks is presented in Table 12 for the relevant points of interest in the Rahway River basin. Hydrographs of the 10-year and 100-year events within the City of Rahway are shown in Figures 15 through 18.

## **11.0 FUTURE UNIMPROVED CONDITIONS HYPOTHETICAL PEAK DISCHARGES**

Insufficient data concerning projected future land use in the Rahway River basin municipalities was available to modify the HEC-HMS hydrological model for future unimproved conditions hypothetical discharge calculations. Because the Rahway River basin is so thoroughly developed at the present time, an alternate method was adopted to expedite the analysis while producing a reasonable answer. A “worst case scenario” assumption was made that all golf courses and country clubs in the basin would, in the future, become residentially developed at the same density (average lot size) as adjacent existing residential areas. Areas were measured using a GIS program called ArcMap 9.3. Percent impervious area (RTIMP) of adjacent existing residential areas was determined from their average lot size using a relation in NRCS publication *TR-55 (Urban Hydrology for Small Watersheds)* as shown in Table 13. Future values of HEC-HMS model subbasin percent impervious area (RTIMP) values were then calculated according to this assumption. These values are shown in Table 14.





HEC-HMS model subbasin Clark unit hydrograph input parameters Tc and R were predicted to change in response to an increase in their RTIMP values according to regression equations for Tc and R as a function of subbasin drainage area, slope, and RTIMP, contained in Special Projects Memo 469, *Hydrologic-Hydraulic Simulation: Rahway River Basin New Jersey*, U.S. Army Corps of Engineers, Hydrologic Engineering Center, November 1976. Subbasin drainage areas and slopes were assumed to remain the same from existing to future conditions. Future to existing ratios of  $(1 + 0.03 \text{ RTIMP})^{-1.28}$  factors were then found for each subbasin and applied to existing conditions values of Tc and R for each subbasin to compute future conditions values of Tc and R which can also be found in Table 14.

Future values of subbasin RTIMP, and Clark unit hydrograph Tc and R, so computed were input to the HEC-HMS models of the Rahway River Basin. The models were then run with no other changes. Values of future unimproved conditions peak discharges is shown in Table 15.

## 12.0 RISK AND UNCERTAINTY

Chapter 4 of EM 1110-2-1619 cites Appendix 9: Confidence Limits, of Bulletin # 17B, Guidelines For Determining Flood Flow Frequency, was used to compute confidence limits (95% and 5%) for hypothetical peak flows and to determine the equivalent record length for the existing conditions specific frequency hypothetical peak discharges.

A computer based program (i.e., HEC-SSP) was used to generate the peak discharge vs. frequency curves at the three USGS stream gages using Log-Pearson Type III analysis.

To determine the equivalent record length for the three gages, the table within EM 1110-2-1619 (Table 4-5, Page 4-5 of Chapter 4) was used. This table gives equivalent record length based on the method of frequency function estimation. The systematic record length of the long-term hydrologic calibration points for this study is given for the following three gages: USGS gage # 01394500, Rahway River near Springfield, NJ is 75 years, water years 1938-2013 inclusive, USGS gage # 01395000, Rahway River at Rahway, NJ is 91 years, water years 1922-2013 inclusive, and USGS gage # 01396000, Robinsons Branch at Rahway, NJ is 71 years, water years 1940-2013 inclusive. These systematic record lengths were used to determine the confidence limits of the hypothetical peak flows for these gages.



The peak discharge vs frequency curve, that uses observed annual peak discharges at a given USGS gage, has three defined curves. The first curve is called the “expected value” curve. This curve represents the actual peak flows that is used in the hydrology analysis and hydraulic analysis for existing (current) conditions. These values are shown in Table 12. The second curve is the “95 % curve (95% confidence limit)”. This is the lower limit curve and it is defined as the 95 % probability that the actual value of the specific-frequency peak discharge, at a given probability (i.e., 1% (100-year event) annual chance exceedance (ACE)), is above the 95 % limit value. The third curve is the “5 % curve (5% confidence limit). This is the upper limit curve and it is defined as the 5 % probability that the actual value of the specific-frequency peak discharge, at a given probability, is above the 5 % limit value. Just for clarity, if we draw a line up from the x-axis (probability scale) at the 1% ACE and through the three curves, this means that there is a 95 % - 5 % = 90 % chance that the actual value of the 100 year peak discharge is between the 95 % and 5 % confidence limits. The peak discharge vs. frequency curve at the three gages and other selected locations are plotted on Figures 12 through 14 for existing conditions.

## 13.0 IMPROVED CONDITIONS

The improved condition alternatives that are being studied can be found within the Hydraulics Appendix. Most of the “improved conditions” plans are being done within hydraulics because the attenuation of the discharge hydrographs will be done in unsteady HEC-RAS, where the structural components of these alternatives will be developed. Table 16 shows a list of structural alternatives looked at within the hydraulic analysis. The only input needed from hydrology is the existing conditions discharge hydrographs at selected input locations within the unsteady HEC-RAS model. These input locations are basically subbasins within the Rahway Watershed. There are a total of 30 subbasins within this watershed that hydrograph input is used in the unsteady HEC-RAS model. The two major tributary that is not modeled within the unsteady HEC-RAS model is the East Branch of the Rahway River and portion of South Branch of the Rahway River that is upstream from Route 35. The East Branch of the Rahway River is approximately 8.11 square miles (includes subbasins SAD, SAE and SAF) and South Branch of the Rahway River is approximately 9.3 square miles (includes subbasins 201, 203 and 206A). Both subwatersheds were entered within the unsteady HEC-RAS model as input hydrographs.



RAHWAY RIVER BASIN  
ESSEX AND UNION COUNTIES, NEW JERSEY  
FLOOD RISK MANAGEMENT PROJECT

**HYDROLOGY APPENDIX – TABLES & FIGURES**



**TABLE 1: RAHWAY RIVER BASIN POINT RAINFALL DEPTHS IN INCHES FOR  
HYPOTHETICAL STORMS FROM ON-LINE NOAA ATLAS 14**

<b>Table 1 – Precipitation Frequency Estimate</b>									
	<b>1-yr</b>	<b>2-yr</b>	<b>5-yr</b>	<b>10-yr</b>	<b>25-yr</b>	<b>50-yr</b>	<b>100-yr</b>	<b>200-yr</b>	<b>500-yr</b>
<b>5-min:</b>	0.34	0.40	0.47	0.52	0.59	0.63	0.68	0.72	0.77
<b>15-min:</b>	0.67	0.80	0.96	1.06	1.19	1.28	1.36	1.44	1.53
<b>60-min:</b>	1.14	1.39	1.74	2.00	2.35	2.61	2.87	3.14	3.49
<b>2-hr:</b>	1.40	1.70	2.16	2.51	3.00	3.41	3.82	4.26	4.87
<b>3-hr:</b>	1.56	1.90	2.41	2.81	3.36	3.81	4.28	4.76	5.44
<b>6-hr:</b>	2.00	2.44	3.08	3.61	4.36	5.00	5.67	6.39	7.41
<b>12-hr:</b>	2.48	3.02	3.84	4.54	5.56	6.43	7.39	8.44	9.96
<b>24-hr:</b>	2.81	3.40	4.37	5.19	6.44	7.52	8.72	10.07	12.07
<b>2-day:</b>	3.31	4.01	5.12	6.06	7.43	8.60	9.88	11.28	13.32



**TABLE 2: TROPICAL STORM IRENE RAINFALL FROM NWS (MULTISENSOR DATA)**

<b>Subbasin Name</b>	<b>Total Storm Precipitation (inches)</b>
101	8.80
102	8.73
103A	8.94
103B	8.97
103C	9.03
107	8.91
110	8.98
113	9.12
115	9.10
117	9.27
119	9.17
122	8.94
126	8.84
129	9.10
201	7.42
203	7.52
206	7.54
ASHBRK	8.82
RAH_N	8.26
RAH_O	8.04
RAH_P	8.03
RAH_Q	7.79
SAA	8.78
SAB	8.49
SAC	8.43
SAD	8.76
SAE	8.81
SAF	8.64
SAG	8.71
SAH	8.47
SAI	8.75
SAJ	8.92
SAK	8.24
SAL	8.44
SAM	8.37



**TABLE 3: HEC-HMS MODEL STRUCTURE**

Element Name	Element Type	Drainage Area (mi <sup>2</sup> )	Description
SAA	Subbasin	4.61	Subbasin "A" - W. Branch Rahway Headwaters
SAA COMP	Junction	4.61	Junction "SAA COMP"
Orange_Res	Reservoir	4.61	Orange Reservoir
AB	Reach	4.61	CHANNEL ROUTE THROUGH SOUTH MOUNTAIN RESERVATION
SAB	Subbasin	2.46	Subbasin "B" – South Mountain Reservation
Junction-1	Junction	7.07	W. Branch Rahway Below South Mountain Reservation
LAGAB	Reach	7.07	Lag Routing of Junction-1 Hydrograph
DSB	Junction	7.07	WEST BRANCH RAHWAY AT MILLBURN BELOW DIAMOND MILL POND
Cam_Pond	Reservoir	7.07	Campbell Pond Dam
Dia_Mill_Pond	Reservoir	7.07	Diamond Mill Pond
BC	Reach	7.07	Route thru Millburn
Junction-2	Junction	7.07	Junction-2
LAGBC	Reach	7.07	Lag routing of Junction-2 Hydrograph
SAC	Subbasin	1.12	Subbasin "C" - Millburn
WESTBR	Junction	8.19	W. BRANCH RAHWAY IMMEDIATELY UPSTREAM OF CONFLUENCE
SAD	Subbasin	2.62	Subbasin "D" – East Branch Rahway Headwaters
SAD COMP	Junction	2.62	Junction "SAD COMP"
DE	Reach	2.62	ROUTE THRU SOUTH ORANGE
SAE	Subbasin	2.21	Subbasin "E" - SOUTH ORANGE
DSE	Junction	4.83	EAST BRANCH AT VILLAGE LINE
EF OLD R	Reach	4.83	ROUTE THRU MAPLEWOOD
SAF	Subbasin	3.28	Subbasin "F" - MAPLEWOOD
EASTBR	Junction	8.11	E. BRANCH RAHWAY IMMEDIATELY UPSTREAM OF CONFLUENCE
EWCONF	Junction	16.30	RAHWAY DOWNSTREAM OF E. AND W. BRANCHES
CFG	Reach	16.30	ROUTE THRU SUBBASIN "G"
Junction-3	Junction	16.30	Junction-3
LAGCFG	Reach	16.30	Lag Routing of Junction-3 Hydrograph
SAG	Subbasin	1.94	Subbasin "G"
DSG	Junction	18.24	RAHWAY AT MILLTOWN
SAH	Subbasin	5.47	Subbasin "H" - VAN WINKLE BROOK AT MOUTH
DSH	Junction	23.71	RAHWAY AT MILLTOWN
HI	Reach	23.71	ROUTE THRU SPRINGFIELD TWP.
SAI	Subbasin	2.84	Subbasin "I"



**TABLE 3: HEC-HMS MODEL STRUCTURE (CONT.)**

Element Name	Element Type	Drainage Area (mi <sup>2</sup> )	Description
SPRDSI	Junction	26.55	COMBINED FLOW AT USGS GAGE NEAR SPRINGFIELD
SAK	Subbasin	4.32	Subbasin "K"
DSK	Junction	30.87	COMBINED INFLOW INTO LENAPE PARK
Lenape_Park_Dam	Reservoir	30.87	Lenape Park Levee System with Hydraulic Structure
SAJ	Subbasin	0.75	Subbasin "J"
Junction-4	Junction	31.62	Junction-4
KL1 OLD	Reach	31.62	ROUTE THRU NOMAHEGAN PARK IN CRANFORD
JCT KL1	Junction	31.62	
KL1 1	Reach	31.62	
Junction-5	Junction	31.62	Damage Center in Cranford
KL2 OLD	Reach	31.62	ROUTE THRU CRANFORD TO NJ CENTRAL RAILROAD
JCT KL2	Junction	31.62	
mus_KL2	Reach	31.62	
SAL	Subbasin	5.46	Subbasin "L"
DSL	Junction	37.08	COMBINED FLOW AT NJ CENTRAL RAILROAD
LM1 OLD	Reach	37.08	ROUTE THRU CLARK TO GARDEN STATE PARKWAY
JCT LM1	Junction	37.08	
mus_LM1	Reach	37.08	
Junction-6	Junction	37.08	Junction-6
LM2 OLD	Reach	37.08	ROUTE THRU CLARK TO USGS GAGE AT RAHWAY
JCT LM2	Junction	37.08	
mus_LM2	Reach	37.08	
SAM	Subbasin	4.11	Subbasin "M"
RAHDSM	Junction	41.19	COMBINED FLOW AT USGS GAGE AT RAHWAY
UPROBR	Reach	41.19	ROUTE HYDROGRAPH AT RAHWAY GAGE TO ROBINSON'S BRANCH CONFLUENCE
RAH-N	Subbasin	0.42	COMPUTE SUBBASIN RAH-N RAHWAY MAINSTREAM RAHWAY GAGE TO ROBINSON'S BRANCH CONFLUENCE
UPROBC	Junction	41.61	COMBINE SUBBASIN RAH-N AND ROUTED HYDROGRAPH OF RAHWAY GAGE AT ROBINSON'S BRANCH CONFLUENCE
102 COMP	Subbasin	4.42	<b>Robinson's Branch Rahway River subbasin 102</b>
101 COMP	Subbasin	4.32	Subbasin 101
ASHBRK C	Subbasin	1.11	Ash Brook Swamp subbasin
103A COM	Subbasin	0.31	Subbasin 103 A
103B COM	Subbasin	0.17	Subbasin 103 B
ASHIN CO	Junction	10.33	Robinson's Branch inflow to Ash Brook Swamp



**TABLE 3: HEC-HMS MODEL STRUCTURE (CONT.)**

Element Name	Element Type	Drainage Area (mi <sup>2</sup> )	Description
ASHOUT R	Reach	10.33	Robinson's Branch outflow from Ash Brook Swamp
Junction-7	Junction	10.33	Robinson's Branch outflow from Ash Brook Swamp
104 ROUT	Reach	10.33	Route to Pumpkin Patch Brook
103C COM	Subbasin	0.20	Subbasin 103 C
106 COMB	Junction	10.53	Robinson's Branch upstream of Pumpkin Patch Brook
107 COMP	Subbasin	2.10	Subbasin 107 : Pumpkin Patch Brook
108 COMB	Junction	12.63	Robinson's Branch downstream of Pumpkin Patch Brook
109 ROUT	Reach	12.63	Route to confluence subbasin 110
110 COMP	Subbasin	2.95	Subbasin 110
111 COMB	Junction	15.58	Robinson's Branch downstream of subbasin 110
112 ROUT	Reach	15.58	Route to confluence subbasin 113
113 COMP	Subbasin	2.63	Subbasin 113
114 COMB	Junction	18.21	Robinson's Branch downstream of subbasin 113
115 COMP	Subbasin	0.52	Subbasin 115
116 COMB	Junction	18.73	Robinson's Branch downstream of subbasin 115
117 COMP	Subbasin	1.23	Subbasin 117
118 COMB	Junction	19.96	Robinson's Branch downstream of subbasin 117
119 COMP	Subbasin	0.87	Subbasin 119
120 COMB	Junction	20.83	<b>Robinson's Branch downstream of subbasin 119</b>
121 ROUT	Reservoir	20.83	<b>Outflow from Middlesex Reservoir</b>
122 COMP	Subbasin	1.04	Subbasin 122
123 COMB	Junction	21.87	<b>USGS gage 01396000 Robinson's Br Rahway River at Rahway : Milton Lake Dam</b>
124 ROUT	Reach	21.87	Route from USGS gage Milton Lake Dam to Maple Avenue
Junction-8	Junction	21.87	
125 ROUT	Reach	21.87	Route from USGS gage Milton Lake Dam to Maple Avenue
126 COMP	Subbasin	0.20	Subbasin 126 : Milton Lake Dam to Maple Avenue
127 COMB	Junction	22.07	<b>USGS gage 01396000 Robinson's Branch Rahway River at Maple Ave in Rahway NJ</b>
128 ROUT	Reach	22.07	Route to mouth of Robinson's Branch
129 COMP	Subbasin	0.85	Subbasin 129 : Maple Avenue to mouth
130 ROBI	Junction	22.92	Robinson's Branch Rahway River at mouth
DSROBC	Junction	64.53	COMBINE UPPER RAHWAY BASIN AND ROBINSON'S BRANCH BASIN AT CONFLUENCE
UPSBR	Reach	64.53	ROUTE TO SOUTH BRANCH CONFLUENCE
RAH-O	Subbasin	0.36	COMPUTE SUBBASIN RAH-O RAHWAY MAINSTREAM - ROBINSON'S BRANCH CONFLUENCE TO SOUTH BRANCH CONFLUENCE





**TABLE 3: HEC-HMS MODEL STRUCTURE (CONT.)**

Element Name	Element Type	Drainage Area (mi <sup>2</sup> )	Description
UPSBC	Junction	64.89	COMBINE UPSTREAM OF SOUTH BRANCH CONFLUENCE
201	Subbasin	6.03	COMPUTE SUBBASIN ONE SOUTH BRANCH BASIN NODE 201
202	Reach	6.03	ROUTE TO NODE 202
203	Subbasin	2.91	COMPUTE SUBBASIN TWO SOUTH BRANCH BASIN NODE 203
204	Junction	8.94	COMBINE NODES 202 AND 203 TO GET NODE 204
205A	Reach	8.94	Route to New Dover Road Bridge
206A	Subbasin	0.35	Increment : to New Dover Road Bridge
Junction-New_Dover_BD	Junction	9.29	
205B	Reach	9.29	Route to upstream end Home Depot culvert
206B	Subbasin	0.69	Increment : New Dover Road Bridge to u/s end Home Depot culvert
Junction-HDCulv_US	Junction	9.98	
205C	Reach	9.98	Lag route through Home Depot culvert
206C	Subbasin	0.02	Increment : Home Depot culvert inflow
Junction-StGeor_BD	Junction	10.00	
205D	Reach	10.00	Route from St. George Avenue Bridge to mouth of South Branch
206D	Subbasin	1.81	Increment : St. George Avenue Bridge to mouth
207	Junction	11.81	COMBINE NODES 205 AND 206 TO GET NODE 207
DSSBC	Junction	76.70	COMBINE NODE 207 WITH RAHWAY MAINSTREAM
RTKGCR	Reach	76.70	ROUTE TO KINGS CREEK
RAH-P	Subbasin	3.05	COMPUTE SUBBASIN RAH-P RAHWAY MAINSTREAM
CBKGCR	Junction	79.75	COMBINE AT KINGS CREEK
RTARKL	Reach	79.75	ROUTE TO ARTHUR KILL
RAH-Q	Subbasin	3.38	COMPUTE SUBBASIN RAH-Q - RAHWAY MAINSTREAM - KINGS CREEK TO ARTHUR KILL
CBARKL	Junction	83.13	COMBINE AT ARTHUR KILL



**TABLE 4: EXISTING CONDITIONS INPUT PARAMETERS**

Subbasin	Drainage Area (mi <sup>2</sup> )	Percent Impervious (%)	Clark Unit Hydrograph Parameters	
			Time of Concentration Tc (hr)	Storage Coefficient R (hr)
SAA	4.61	25.40	1.00	1.63
SAB	2.46	5.30	1.12	2.07
SAC	1.12	36.90	1.00	0.94
SAD	2.62	39.80	2.40	4.44
SAE	2.21	37.20	1.94	3.60
SAF	3.28	34.10	2.31	4.29
SAG	1.94	39.60	2.54	4.72
SAH	5.47	32.90	1.72	3.19
SAI	2.84	40.50	2.41	4.48
SAK	4.32	37.40	2.90	5.37
SAJ	0.75	31.30	2.10	3.89
SAL	5.46	21.00	2.88	5.35
SAM	4.11	35.50	3.00	5.57
RAH-N	0.42	37.40	1.24	2.29
102 COMP	4.42	27.90	0.97	5.04
101 COMP	4.32	25.20	1.18	5.76
ASHBRK C	1.11	19.30	0.58	3.29
103A COM	0.31	12.10	0.50	2.89
103B COM	0.17	8.70	0.51	3.47
103C COM	0.20	35.00	0.55	3.63
107 COMP	2.10	34.40	0.74	4.26
110 COMP	2.95	30.00	0.75	4.30
113 COMP	2.63	32.00	0.50	3.20
115 COMP	0.52	38.60	0.66	3.98
117 COMP	1.23	41.20	0.50	3.37
119 COMP	0.87	30.20	0.50	2.84
122 COMP	1.04	28.60	0.50	3.36
126 COMP	0.20	29.60	0.50	2.47
129 COMP	0.85	40.90	0.50	3.09
RAH-O	0.36	52.60	1.40	2.60
201	6.03	37.30	3.07	5.69
203	2.91	34.60	2.95	5.46
206	2.87	35.10	4.04	7.47
RAH-P	3.05	54.40	2.91	5.38
RAH-Q	3.38	38.10	4.24	7.85



**TABLE 5: EXISTING CONDITIONS REACH PARAMETERS**

Reach Node	Lag Time (min)	Muskingum		
		K (hrs)	X	Number of Subreaches
AB		1.30	0.10	1
DE		0.60	0.30	1
104 ROUT		0.50	0.10	1
109 ROUT		0.41	0.10	1
112 ROUT		0.39	0.10	1
202		1.15	0.30	1
205		1.29	0.30	1
LAGAB	30			
LAGBC	30			
LAGCFG	30			

**TABLE 6: INTIAL LOSS AND CONSTANT LOSS RATE (HISTORIC FLOODS)**

subbasin	April 2007		TC Irene (August 2011)	
	initial loss (in)	constant rate (in/hr)	initial loss (in)	constant rate (in/hr)
SAA	1.00	0.1300	1.00	0.0760
SAB	1.00	0.1300	1.00	0.0760
SAC	1.00	0.1300	1.00	0.0760
SAD	1.00	0.1300	1.00	0.0760
SAE	1.00	0.1300	1.00	0.0760
SAF	1.00	0.1300	1.00	0.0760
SAG	1.00	0.1300	1.00	0.0760
SAH	1.00	0.1300	1.00	0.0760
SAI	1.00	0.1300	1.00	0.0760
SAK	1.00	0.0685	1.00	0.0420
SAJ	1.00	0.0685	1.00	0.0420
SAL	1.00	0.0685	1.00	0.0420
SAM	1.00	0.0685	1.00	0.0420
RAH-N	0.50	0.0170	0.50	0.0100
102 COMP	0.50	0.0170	1.50	0.0050
101 COMP	0.50	0.0170	1.50	0.0050
ASHBRK C	0.50	0.0170	1.50	0.0050
103A COM	0.50	0.0170	1.50	0.0050
103B COM	0.50	0.0170	1.50	0.0050
103C COM	0.50	0.0170	1.50	0.0050



**Table 6: Initial Loss and Constant Loss Rate (Historical Floods)(Cont.)**

subbasin	April 2007		TC Irene (August 2011)	
	initial loss (in)	constant rate (in/hr)	initial loss (in)	constant rate (in/hr)
107 COMP	0.50	0.017	1.50	0.005
110 COMP	0.50	0.017	1.50	0.005
113 COMP	0.50	0.017	1.50	0.005
115 COMP	0.50	0.017	1.50	0.005
117 COMP	0.50	0.017	1.50	0.005
119 COMP	0.50	0.017	1.50	0.005
122 COMP	0.50	0.017	1.50	0.005
126 COMP	0.50	0.017	1.50	0.005
129 COMP	0.50	0.017	1.50	0.005
RAH-O	0.50	0.017	0.50	0.010
201	0.50	0.017	0.50	0.010
203	0.50	0.017	0.50	0.010
206	0.50	0.017	0.50	0.010
RAH-Q	0.50	0.017	0.50	0.010

**TABLE 7: HISTORICAL FLOODS – PEAK DISCHARGES**

Node Name	Drainage Area (mi <sup>2</sup> )	Historical Event	
		April 2007	August 2011
WESTBR	8.19	1680	2920
EASTBR	8.11	1730	2820
EWCONF	16.30	3380	5710
SPRDSI	26.55	4720	8620
DSK	30.87	5520	10030
JCT-4	31.62	5030	10140
JCT-5	31.62	4330	8510
DSL	37.08	4790	7000
RAHDSM	41.19	4910	7250
UPROBC	41.61	4910	7230
120	20.83	3330	5080
123	21.87	3540	5370
127	22.07	3520	5380
130	22.92	3480	5230
DSROBC	64.53	7110	12130
UPSB	64.53	7100	12120
HDCULV_US	9.98	2280	3000
207	11.81	2580	3410
DSSBC	76.70	9290	15430



**TABLE 8(A): ANNUAL PEAK FLOWS – USGS GAGE #1394500 RAHWAY RIVER NEAR SPRINGFIELD, NJ (BASED UPON COE RATING FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
1938	23 Jul 1938	2050	2825
1939	03 Feb 1939	699	699
1940	31 May 1940	1140	1290
1941	07 Feb 1941	885	930
1942	09 Aug 1942	1320	1600
1943	30 Dec 1942	663	663
1944	13 Mar 1944	815	850
1945	19 Sep 1945	1370	1690
1946	02 Jun 1946	975	1045
1947	05 Apr 1947	646	646
1948	08 Nov 1947	1280	1510
1949	06 Jan 1949	834	865
1950	23 Mar 1950	501	501
1951	30 Mar 1951	954	1020
1952	01 Jun 1952	1280	1510
1953	13 Mar 1953	1330	1635
1954	11 Sep 1954	947	1000
1955	13 Aug 1955	1270	1500
1956	14 Oct 1955	643	643
1957	05 Apr 1957	538	538
1958	28 Feb 1958	844	870
1959	09 Aug 1959	885	930
1960	12 Sep 1960	911	960
1961	16 Apr 1961	708	715
1962	12 Mar 1962	1530	2035
1963	06 Mar 1963	675	680
1964	07 Nov 1963	748	760
1965	08 Feb 1965	838	870
1966	22 Sep 1966	1520	2020
1967	07 Mar 1967	1170	1330
1968	29 May 1968	3370	4330
1969	29 Jul 1969	1510	2000
1970	31 Jul 1970	1170	1330



**TABLE 8(B): ANNUAL PEAK FLOWS – USGS GAGE #1394500 RAHWAY RIVER NEAR SPRINGFIELD, NJ (BASED UPON COE RATING FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
1971	28 Aug 1971	3430	4390
1972	22 Jun 1972	1160	1390
1973	02 Aug 1973	5430	6130
1974	21 Dec 1973	1870	2590
1975	14 Jul 1975	3110	1400
1976	10 Aug 1976	960	1010
1977	22 Mar 1977	1950	2700
1978	08 Nov 1977	2180	2980
1979	24 Jan 1979	1540	2060
1980	21 Mar 1980	1250	1550
1981	11 May 1981	926	1000
1982	04 Jan 1982	1650	2240
1983	10 Apr 1983	1360	1730
1984	05 Apr 1984	1660	2250
1985	27 Sep 1985	1410	1830
1986	17 Nov 1985	1210	1480
1987	14 Jul 1987	1290	1620
1988	26 Jul 1988	1170	1330
1989	19 Sep 1989	1590	2130
1990	20 Oct 1989	936	1020
1991	04 Mar 1991	1400	1810
1992	05 Jun 1992	3460	4590
1993	01 Apr 1993	1300	1630
1994	28 Jan 1994	1520	2030
1995	18 Jul 1995	1150	1370
1996	19 Jan 1996	1530	2030
1997	25 Jul 1997	5150	5900
1998	02 Apr 1998	1400	1810
1999	16 Sep 1999	7990	7990
2000	18 May 2000	768	768
2001	17 Dec 2000	1170	1330
2002	18 May 2002	824	850
2003	21 Jun 2003	1150	1370



**TABLE 8(C): ANNUAL PEAK FLOWS – USGS GAGE #1394500 RAHWAY RIVER NEAR SPRINGFIELD, NJ (BASED UPON COE RATING FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
2004	27 Jul 2004	1460	1900
2005	28 Mar 2005	1370	1770
2006	08 Oct 2005	1520	2030
2007	15 Apr 2007	4690	5540
2008	06 Sep 2008	1900	2610
2009	12 Dec 2008	1370	1690
2010	13 Mar 2010	2600	3530
2011	28 Aug 2011	8620	8860
2012	08 Dec 2011	1480	1480
2013	08 Jun 2013	3310	3310



**TABLE 9(A): ANNUAL PEAK FLOWS – USGS GAGE #1395000 RAHWAY RIVER AT RAHWAY, NJ (BASED UPON PRE TO POST LENAPE PARK RELATION FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
1922	19 May 1922	642	540
1923	17 Mar 1923	811	680
1924	07 Apr 1924	1350	1150
1925	12 Feb 1925	1000	830
1926	07 Sep 1926	984	810
1927	02 Aug 1927	1740	1250
1928	06 Jul 1928	1310	1,100
1929	27 Feb 1929	755	630
1930	08 Mar 1930	569	450
1931	29 Mar 1931	500	400
1932	28 Mar 1932	905	750
1933	16 Sep 1933	1560	1300
1934	05 Mar 1934	722	580
1935	06 Oct 1934	660	550
1936	12 Mar 1936	1120	950
1937	20 Dec 1936	640	539
1938	24 Jul 1938	3140	2650
1939	03 Feb 1939	847	700
1940	31 May 1940	1560	1300
1941	07 Feb 1941	976	800
1942	09 Aug 1942	1440	1200
1943	30 Dec 1942	847	700
1944	14 Sep 1944	1340	1120
1945	19 Sep 1945	1570	1310
1946	23 Jul 1946	1140	955
1947	05 Apr 1947	622	520
1948	09 Nov 1947	1350	1150
1949	31 Dec 1948	1350	1150
1950	23 Mar 1950	510	410
1951	31 Mar 1951	1020	840
1952	01 Jun 1952	1720	1430
1953	13 Mar 1953	1590	1350
1954	11 Sep 1954	1380	1160





**TABLE 9(B): ANNUAL PEAK FLOWS – USGS GAGE #1395000 RAHWAY RIVER AT RAHWAY, NJ (BASED UPON PRE TO POST LENAPE PARK RELATION FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
1955	13 Aug 1955	2440	2030
1956	08 Apr 1956	600	500
1957	06 Apr 1957	770	638
1958	28 Feb 1958	1170	960
1959	09 Aug 1959	1580	1330
1960	12 Sep 1960	1850	1550
1961	23 Mar 1961	878	730
1962	13 Mar 1962	1740	1250
1963	06 Mar 1963	770	638
1964	07 Nov 1963	1210	1000
1965	08 Feb 1965	1130	930
1966	21 Sep 1966	1940	1600
1967	07 Mar 1967	1670	1400
1968	29 May 1968	3530	3030
1969	04 Sep 1969	1830	1540
1970	31 Jul 1970	1720	1430
1971	28 Aug 1971	4010	3540
1972	13 Jul 1972	1140	955
1973	02 Aug 1973	5420	5030
1974	21 Dec 1973	2640	2250
1975	15 Jul 1975	5070	4670
1976	28 Jan 1976	1140	955
1977	23 Mar 1977	2430	2040
1978	08 Nov 1977	3570	3100
1979	24 Jan 1979	2680	2250
1980	28 Apr 1980	1860	1860
1981	12 May 1981	708	708
1982	04 Jan 1982	1820	1820
1983	10 Apr 1983	2090	2090
1984	14 Dec 1983	2880	2880
1985	27 Sep 1985	1700	1700
1986	17 Apr 1986	1710	1710
1987	04 Apr 1987	1280	1280



**TABLE 9(C): ANNUAL PEAK FLOWS – USGS GAGE #1395000 RAHWAY RIVER AT RAHWAY, NJ (BASED UPON PRE TO POST LENAPE PARK RELATION FROM 1984 SPRINGFIELD, NJ HYDROLOGY APPENDIX)**

Water Year	Annual Peak Flow Date	Annual Peak Flows (cfs)	
		Recorded	Adjusted
1988	22 Jul 1988	1130	1130
1989	20 Sep 1989	2150	2150
1990	20 Oct 1989	1260	1260
1991	04 Mar 1991	1480	1480
1992	05 Jun 1992	2890	2890
1993	01 Apr 1993	1140	1140
1994	10 Mar 1994	1580	1580
1995	18 Jul 1995	1360	1360
1996	19 Jan 1996	1790	1790
1997	19 Oct 1996	4210	4210
1998	23 Jan 1998	1440	1440
1999	17 Sep 1999	5590	5590
2000	27 Aug 2000	1130	1130
2001	30 Mar 2001	1460	1460
2002	18 May 2002	706	706
2003	05 Jun 2003	1920	1920
2004	28 Jul 2004	1440	1440
2005	28 Mar 2005	1500	1500
2006	09 Oct 2005	1710	1710
2007	16 Apr 2007	4910	4910
2008	07 Sep 2008	1530	1530
2009	12 Dec 2008	1550	1550
2010	14 Mar 2010	3690	3690
2011	28 Aug 2011	7250	7250
2012	08 Dec 2011	1390	1390
2013	08 Jun 2013	1350	1350



**TABLE 10 (A): ANNUAL PEAK  
FLOWS - USGS GAGE  
#01396000 ROBINSONS  
BRANCH AT RAHWAY NJ**

<b>Water Year</b>	<b>Annual Peak Flow Date</b>	<b>Annual Peak Flows (cfs)</b>
1940	31 May 1940	2856
1941	7 Feb 1941	1669
1942	9 Aug 1942	2394
1943	12 May 1943	1275
1944	6 Jan 1944	1525
1945	19 Sep 1945	1798
1946	2 Jun 1946	1631
1947	5 Apr 1947	916
1948	8 Nov 1947	1806
1949	31 Dec 1948	1472
1950	23 Mar 1950	812
1951	30 Mar 1951	1220
1952	1 Jun 1952	1951
1953	13 Mar 1953	2193
1954	14 Dec 1953	559
1955	13 Aug 1955	1384
1956	8 Apr 1956	701
1957	5 Apr 1957	739
1958	28 Feb 1958	1438
1959	9 Aug 1959	1349
1960	12 Sep 1960	1446
1961	23 Mar 1961	1039
1962	12 Mar 1962	1309
1963	6 Mar 1963	720
1964	7 Nov 1963	747
1965	8 Feb 1965	657
1966	21 Sep 1966	1071
1967	7 Mar 1967	1430
1968	29 May 1968	2550
1969	15 Aug 1969	2590
1970	31 Jul 1970	1070
1971	27 Aug 1971	2550
1972	13 Jul 1972	1080
1973	2 Aug 1973	2380
1974	21 Dec 1973	1280
1975	15 Jul 1975	3110
1976	12 Nov 1975	868



**TABLE 10 (B): ANNUAL PEAK  
FLOWS - USGS GAGE  
#01396000 ROBINSONS  
BRANCH AT RAHWAY NJ**

<b>Water Year</b>	<b>Annual Peak Flow Date</b>	<b>Annual Peak Flows (cfs)</b>
1977	22 Mar 1977	1200
1978	8 Nov 1977	1820
1979	23 May 1979	1470
1980	28 Apr 1980	1290
1981	11 May 1981	561
1982	4 Jan 1982	1200
1983	10 Apr 1983	1330
1984	14 Dec 1983	1500
1985	27 Sep 1985	1260
1986	17 Nov 1985	1140
1987	4 Apr 1987	1110
1988	22 Jul 1988	1450
1989	20 Sep 1989	2980
1990	10 Aug 1990	1330
1991	4 Mar 1991	1340
1992	5 Jun 1992	2280
1993	1 Apr 1993	754
1994	28 Jan 1994	1430
1995	18 Jul 1995	850
1996	19 Jan 1996	1650
1999	16 Sep 1999	4800
2000	27 Jul 2000	No data
2001	30 Mar 2001	1080
2002	18 May 2002	424
2003	4 Jun 2003	1510
2004	12 May 2004	1400
2005	28 Mar 2005	1230
2006	8 Oct 2005	1050
2007	15 Apr 2007	3630
2008	6 Sep 2008	2050
2009	12 Dec 2008	1110
2010	13 Mar 2010	4080
2011	28 Aug 2011	5600
2012	08 Dec 2011	1250
2013	07 Jun 2013	2980



**TABLE 11: INITIAL LOSS AND CONSTANT LOSS RATE – (HYPOTHETICAL FLOODS)**

Subbasin	Initial Loss (in)	Constant Loss Rate (in/hr)								
		1-year	2-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
SAA	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAB	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAC	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAD	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAE	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAF	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAG	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAH	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAI	1.00	0.2900	0.2750	0.3250	0.2560	0.2010	0.1750	0.1502	0.1117	0.0687
SAK	1.00	0.6000	0.4000	0.0500	0.0290	0.0254	0.0356	0.0500	0.1146	0.1115
SAJ	1.00	0.6000	0.4000	0.0500	0.0290	0.0254	0.0356	0.0500	0.1146	0.1115
SAL	1.00	0.6000	0.4000	0.0500	0.0290	0.0254	0.0356	0.0500	0.1146	0.1115
SAM	1.00	0.6000	0.4000	0.0500	0.0290	0.0254	0.0356	0.0500	0.1146	0.1115
RAH-N	1.00	0.6000	0.4000	0.0500	0.0290	0.0254	0.0356	0.0500	0.1146	0.1115
102 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
101 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
ASHBRK C	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
103A COM	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
103B COM	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
103C COM	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
107 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
110 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703



**TABLE 11: INITIAL LOSS AND CONSTANT LOSS RATE – (HYPOTHETICAL FLOODS; CONT.)**

Subbasin	Initial Loss (in)	Constant Loss Rate (in/hr)								
		1-year	2-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
113 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
115 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
117 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
119 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
122 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
126 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
129 COMP	1.00	0.2120	0.2430	0.2280	0.2040	0.1800	0.1630	0.1349	0.1127	0.0703
RAH-O	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
201	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
203	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
206A	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
206B	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
206C	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
206D	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
RAH-P	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
RAH-Q	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850
RAH-Q	1.00	0.3365	0.2993	0.2283	0.1869	0.1549	0.1411	0.1244	0.1155	0.0850



**TABLE 12: EXISTING CONDITIONS – PEAK DISCHARGES (CFS) FOR RAHWAY WATERSHED**

HMS NODE	Drainage Area (mi <sup>2</sup> )	Return Period (discharge is in cfs)									
		1yr	2yr	5yr	10yr	25yr	50yr	100yr	200yr	500yr	Irene
WESTBR	8.19	440	650	910	1310	2090	2870	3630	4350	5360	2920
EASTBR	8.11	680	880	1140	1480	2020	2470	2940	3500	4270	2820
EWCONF	16.30	1100	1490	2000	2730	4070	5320	6570	7840	9620	5710
SPRDSI	26.55	1580	2100	2800	3690	5250	6700	8370	10340	13450	8620
DSK	30.87	1840	2450	3540	4610	6320	7940	9780	11890	15320	10030
JCT-4	31.62	1390	1710	2340	3230	5340	7250	9580	11870	15480	10140
JCT-5	31.62	1320	1630	2160	2830	4180	5690	7300	9160	11960	8510
DSL	37.08	1300	1650	2260	2970	4270	5600	7100	8660	11150	7000
RAHDSM	41.19	1220	1610	2250	2950	4150	5300	6620	8160	10600	7250
UPROBC	41.61	1220	1610	2260	2960	4150	5300	6610	8130	10580	7230
120	20.83	1290	1590	2180	2730	3510	4190	4950	5760	6990	5080
123	21.87	1200	1510	2120	2720	3600	4330	5150	6050	7390	5370
127	22.07	1210	1510	2120	2700	3560	4290	5140	6090	7460	5380
130	22.92	1260	1550	2130	2700	3510	4300	5020	5810	7320	5230
DSROBC	64.53	1760	2270	3500	4450	5770	6900	8130	9520	12540	12130
UPSB	64.53	1760	2270	3500	4450	5750	6890	8110	9520	12530	12120
HDCULV_US	9.98	720	950	1370	1770	2350	280	3330	3860	4690	2990
207	11.81	810	1060	1530	1990	2660	3210	3800	4420	5400	3410
DSSBC	76.70	2520	3330	5060	6490	8490	10180	11950	13650	16880	15430



**TABLE 13: PERCENT IMPERVIOUS AREAS AS A FUNCTION OF LOT SIZE**

Average Lot Size (Acres)	Average Percent Impervious Area
0.125	65
0.250	38
0.333	30
0.500	25
1.000	20
2.000	12

**TABLE 14: FUTURE UNIMPROVED CALCULATIONS**

Subbasin Node	Drainage Area (mi <sup>2</sup> )	Percent Impervious (%)	Time of Concentration (hr)	Storage Coefficient (hr)
SAA	4.61	29.90	0.91	1.48
SAB	2.46	5.30	1.12	2.07
SAC	1.12	36.90	1.00	0.94
SAD	2.62	40.10	2.39	4.42
SAE	2.21	37.60	1.93	3.57
SAF	3.28	36.70	2.20	4.09
SAG	1.94	39.60	2.54	4.72
SAH	5.47	34.50	1.67	3.09
SAI	2.84	47.90	2.13	3.96
SAK	4.32	39.00	2.82	5.22
SAJ	0.75	36.50	1.90	3.52
SAL	5.46	21.10	2.87	5.34
SAM	4.11	35.60	2.99	5.56
RAH-N	0.42	37.40	1.24	2.29
102 COMP	4.42	29.34	0.94	4.89
101 COMP	4.32	26.14	1.16	5.64
ASHBRK C	1.11	19.30	0.58	3.29
103A COM	0.31	24.50	0.37	2.12
103B COM	0.17	27.06	0.32	2.18
103C COM	0.20	35.00	0.55	3.63
107 COMP	2.10	35.89	0.72	4.14





**TABLE 14: FUTURE UNIMPROVED CALCULATIONS (CONT.)**

Subbasin Node	Drainage Area (mi <sup>2</sup> )	Percent Impervious (%)	Time of Concentration (hr)	Storage Coefficient (hr)
110 COMP	2.95	32.15	0.72	4.12
113 COMP	2.63	32.00	0.50	3.20
115 COMP	0.52	38.60	0.66	3.98
117 COMP	1.23	46.16	0.46	3.10
119 COMP	0.87	30.20	0.50	2.84
122 COMP	1.04	28.60	0.50	3.36
126 COMP	0.20	29.60	0.50	2.47
129 COMP	0.85	40.90	0.50	3.09
RAH-O	0.36	52.60	1.40	2.60
201	6.03	38.12	3.02	5.61
203	2.91	34.94	2.93	5.43
206A	0.35	27.61	0.81	1.49
206B	0.69	39.22	0.82	1.52
206C	0.02	72.00	0.17	0.31
206D	1.81	36.80	1.42	2.62
RAH-P	3.05	54.40	2.91	5.38
RAH-Q	3.38	38.10	4.24	7.85



**TABLE 15: FUTURE UNIMPROVED CONDITIONS - PEAK DISCHARGES (CFS) FOR RAHWAY WATERSHED**

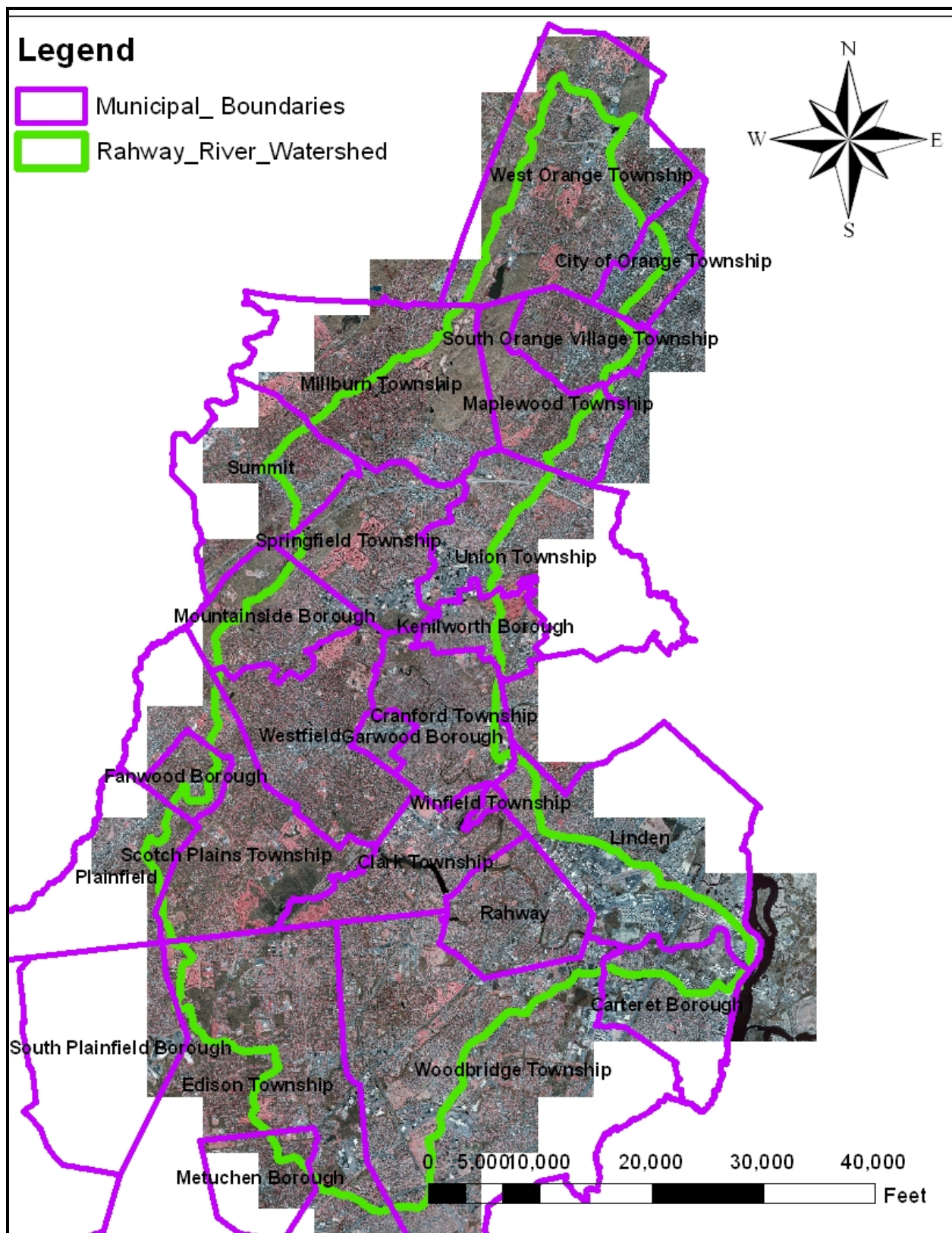
HMS NODE	Drainage Area (mi <sup>2</sup> )	Return Period (discharge is in cfs)								
		1yr	2yr	5yr	10yr	25yr	50yr	100yr	200yr	500yr
WESTBR	8.19	490	710	980	1400	2230	3020	3780	4480	5490
EASTBR	8.11	700	900	1160	1510	2050	2500	2970	3530	4300
EWCONF	16.30	1150	1570	2100	2850	4250	5510	6750	8000	9790
SPRDSI	26.55	1640	2180	2910	3800	5400	6860	8550	10480	13630
DSK	30.87	1910	2540	3650	4720	6480	8110	9980	12060	15530
JCT-4	31.62	1430	1750	2420	3340	5530	7400	9790	12050	15690
JCT-5	31.62	1360	1670	2220	2900	4290	5820	7430	9290	12090
DSL	37.08	1340	1700	2320	3040	4370	5720	7230	8770	11270
RAHDSM	41.19	1260	1650	2310	3020	4240	5400	6740	8270	10700
UPROBC	41.61	1260	1650	2310	3020	4250	5400	6730	8240	10680
120	20.83	1330	1640	2240	2800	3590	4280	5050	5870	7110
123	21.87	1240	1560	2180	2780	3680	4410	5250	6150	7500
127	22.07	1240	1560	2170	2760	3630	4370	5240	6190	7570
130	22.92	1300	1590	2180	2750	3580	4360	5080	5900	7410
DSROBC	64.53	1810	2330	3570	4530	5860	7010	8230	9640	12650
UPSBR	64.53	1810	2330	3570	4530	5840	6990	8220	9630	12650
HDCULV_US	9.98	730	960	1380	1790	2370	2830	3350	3880	4710
207	11.81	820	1080	1550	2010	2680	3230	3830	4450	5430
DSSBC	76.70	2580	3400	5150	6590	8600	10300	12080	13790	17030



**TABLE 16: DESCRIPTION OF ALTERNATIVES UNDER IMPROVED CONDITIONS**

<b>Name of Alternative</b>	<b>Description</b>
Alternative #1	Levees and Floodwalls
Alternative #2	Surge Barrier with Levees





**FIGURE 1: RAHWAY RIVER BASIN WITH CORRESPONDING MUNICIPALITIES**





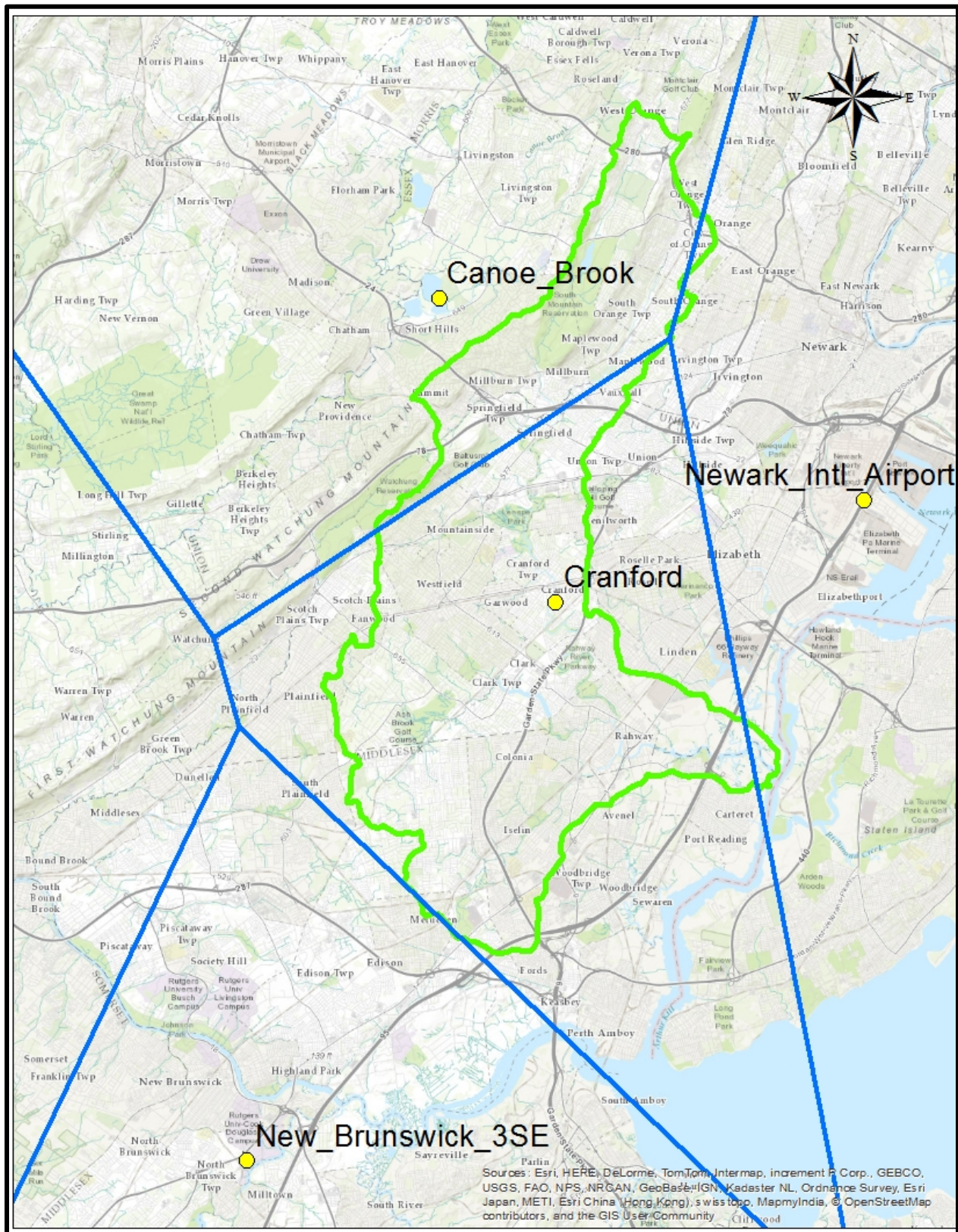


**FIGURE 2: PROJECT AREA SHOWING DAMAGE CENTERS IN RAHWAY, NJ**

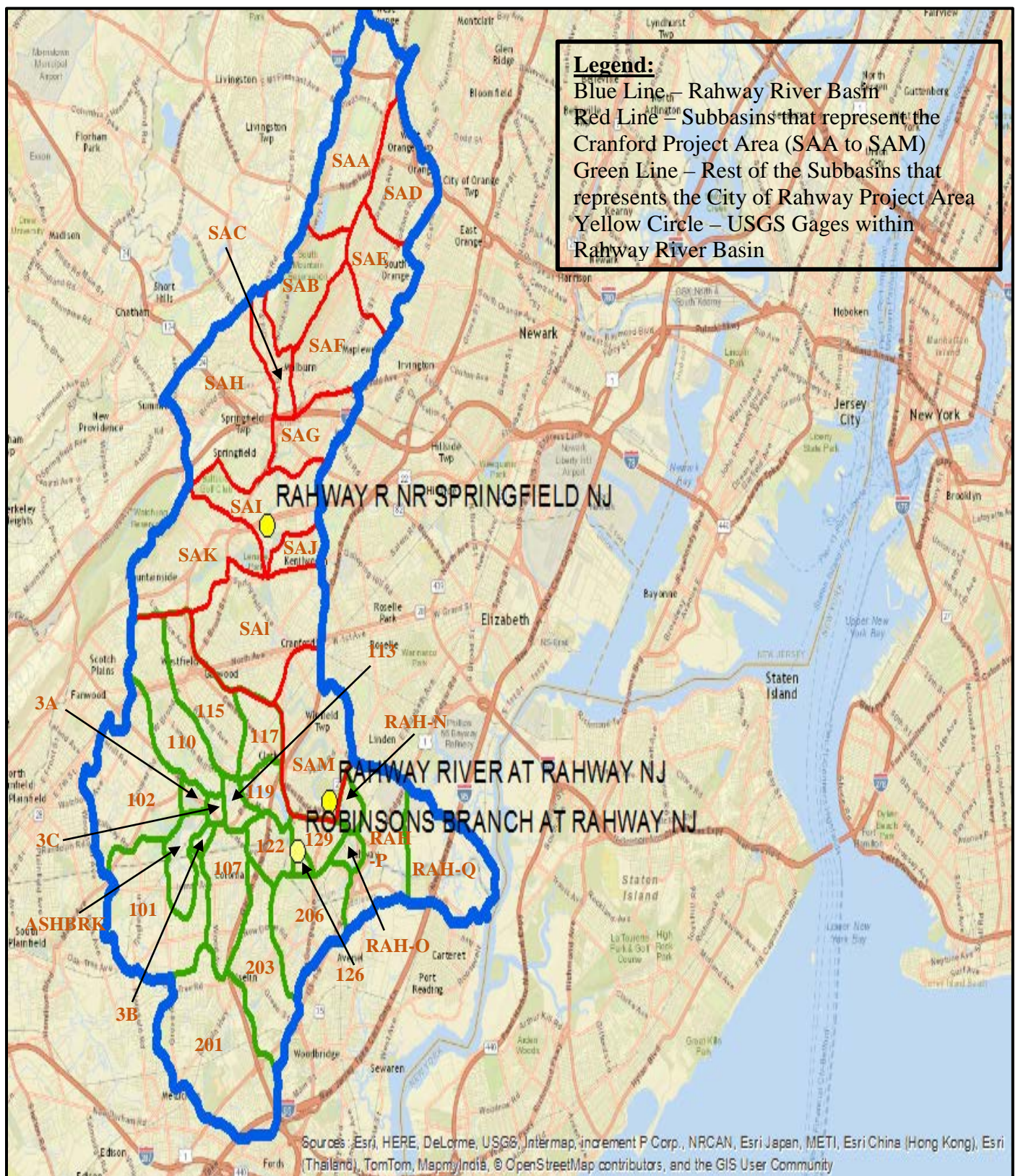




**FIGURE 3: THIESSEN POLYGON SHOWING RAINFALL GAGES FOR APRIL 2007**







**FIGURE 4: SUBBASIN AS USED IN HEC-HMS MODEL WITH USGS STREAM GAGES**



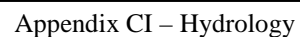


The diagram illustrates a complex hydrological model of the Rahway River watershed. Key components include:

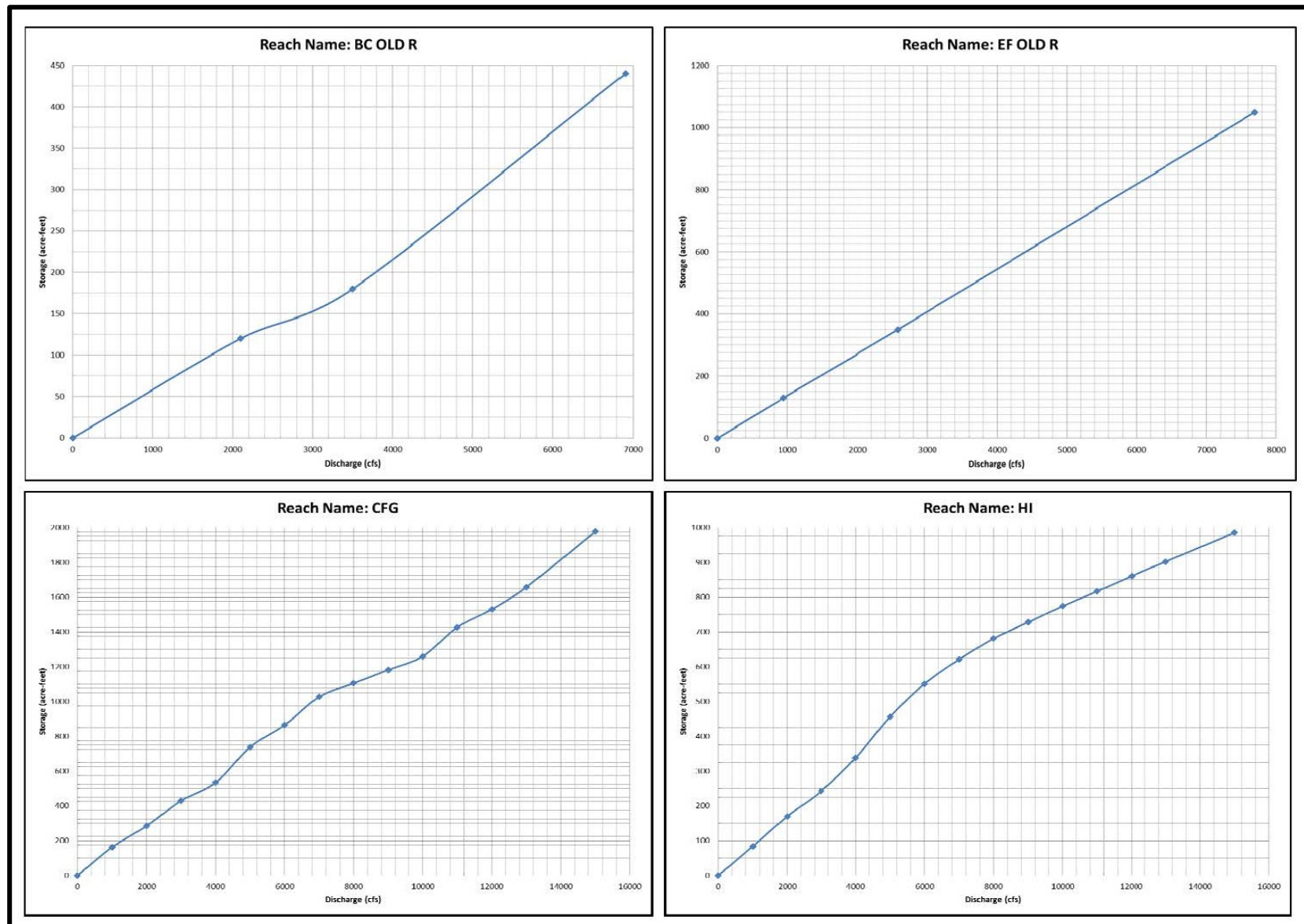
- Junctions:** Numerous nodes where different branches or flows meet, labeled as Junction-1 through Junction-8.
- Ponds and Reservoirs:** Storage areas such as Orange\_Res, Cam\_Pond, Dia\_Mill\_Pond, and Lenape Park Dam.
- Dams:** Structures like SPRDSI and RAHDSM that regulate flow.
- Gauges:** Measurement points including Springfield Gauge, Rahway River, and Rahway Gauge.
- Branches:** Distinct sections of the river system, such as the West Branch, East Branch, and Robinsons Branch.
- Flow Paths:** Arrows indicating the direction of water movement throughout the network.

Labels with arrows point to the following locations:

- West Branch of the Rahway River:** Points to the upper left section of the main channel.
- East Branch of the Rahway River:** Points to the upper right section of the main channel.
- Springfield Gauge:** Points to a gauge located on the main channel between Junction-2 and Junction-3.
- Robinsons Branch:** Points to a tributary on the right side of the main channel.
- Rahway River:** Points to the main channel below the Springfield Gauge.
- Rahway Gauge:** Points to a gauge at the bottom of the main channel.

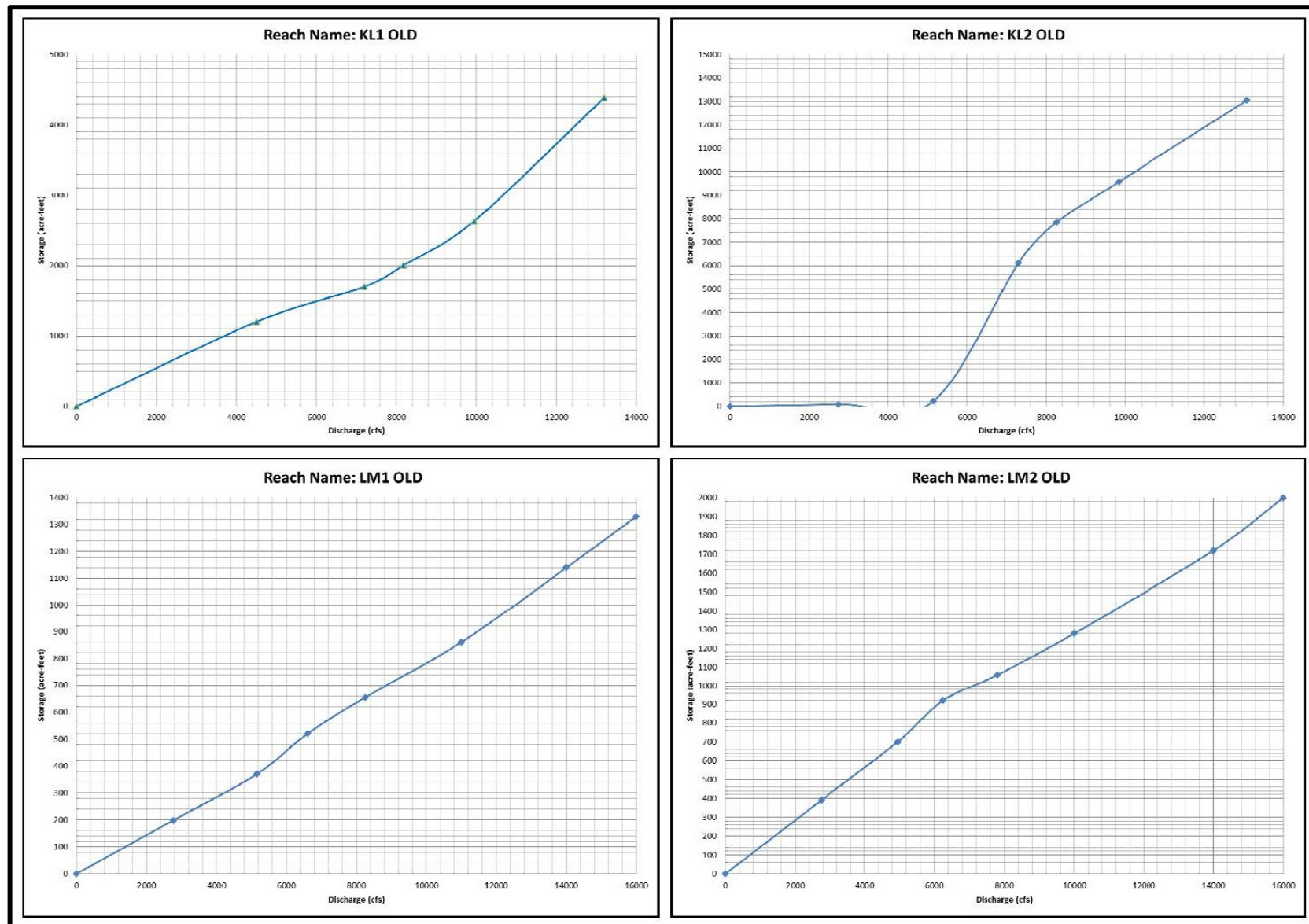






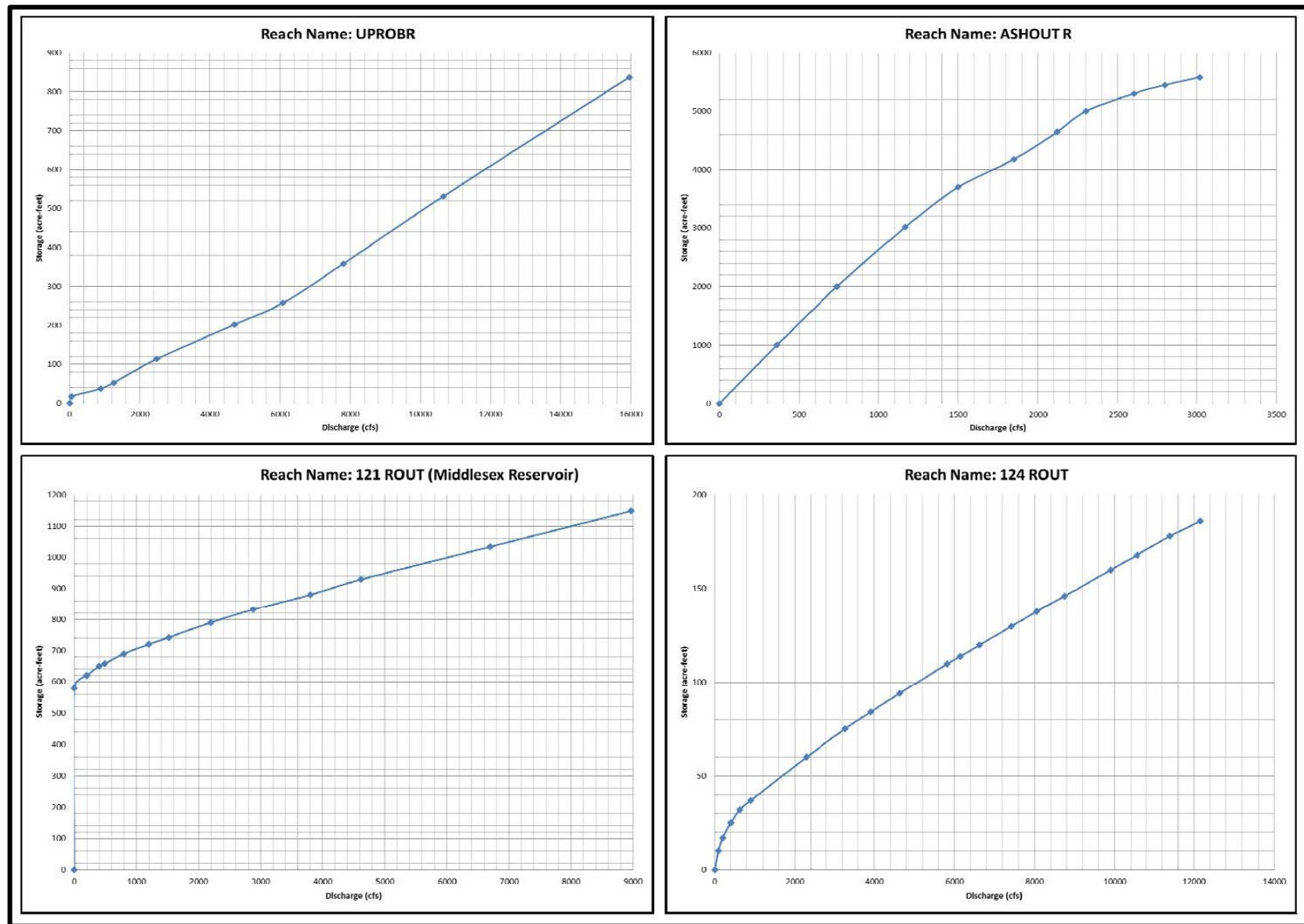
**FIGURE 6(A): MODIFIED PULS ROUTING RELATIONS**





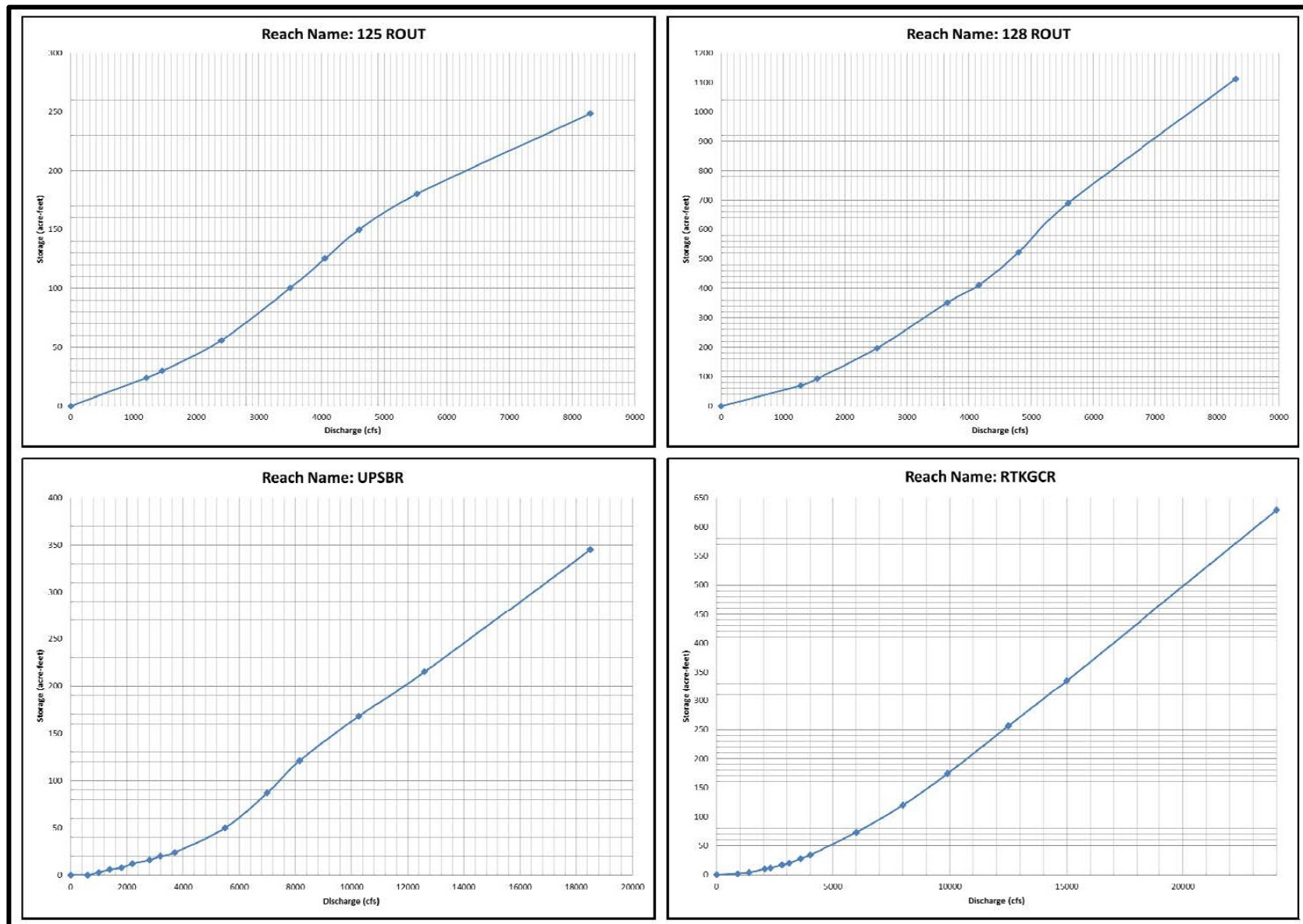
**FIGURE 6(B): MODIFIED PULS ROUTING RELATIONS**





**FIGURE 6(C): MODIFIED PULS ROUTING RELATIONS**

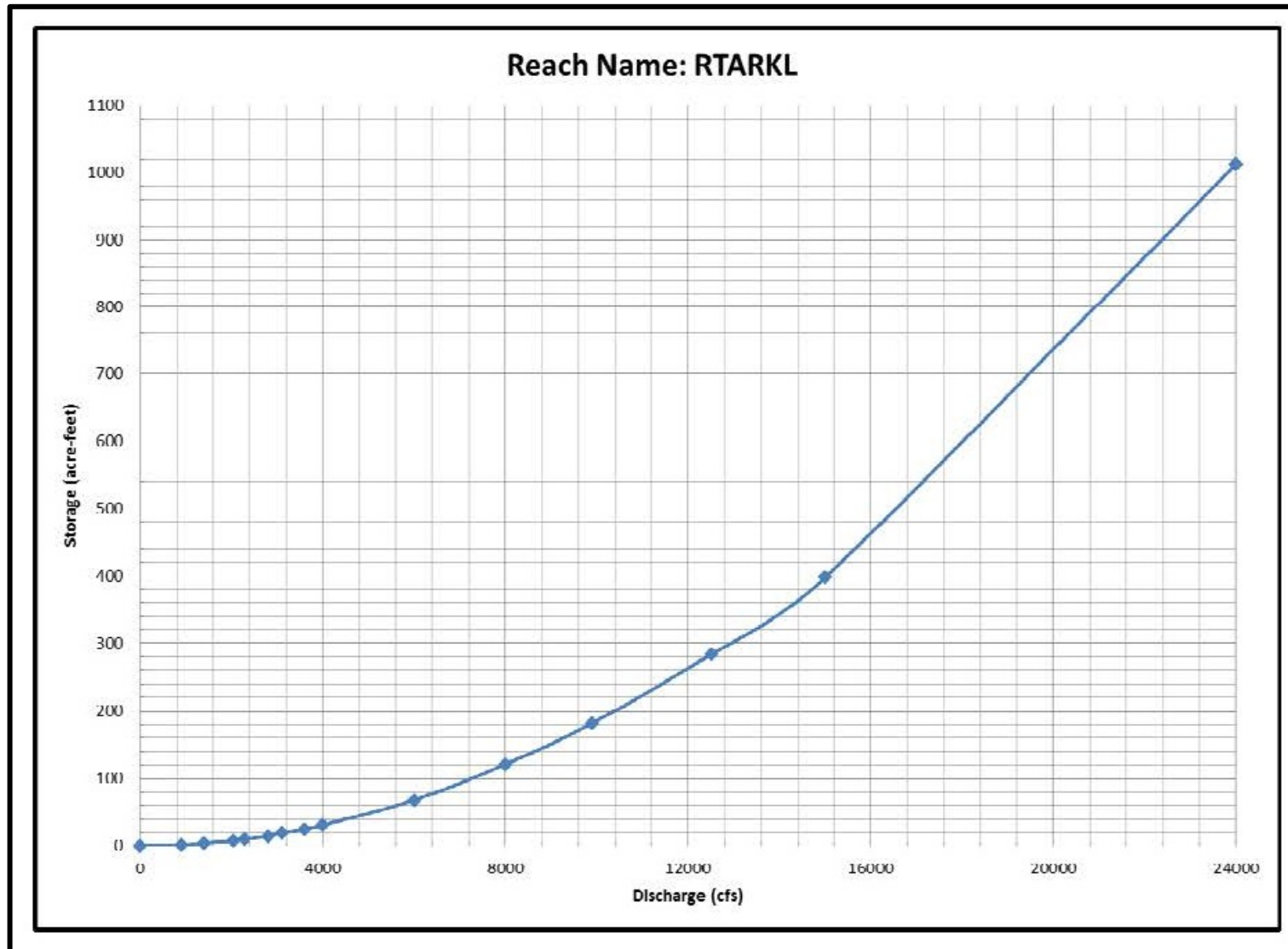




**FIGURE 6(D): MODIFIED PULS ROUTING RELATIONS**

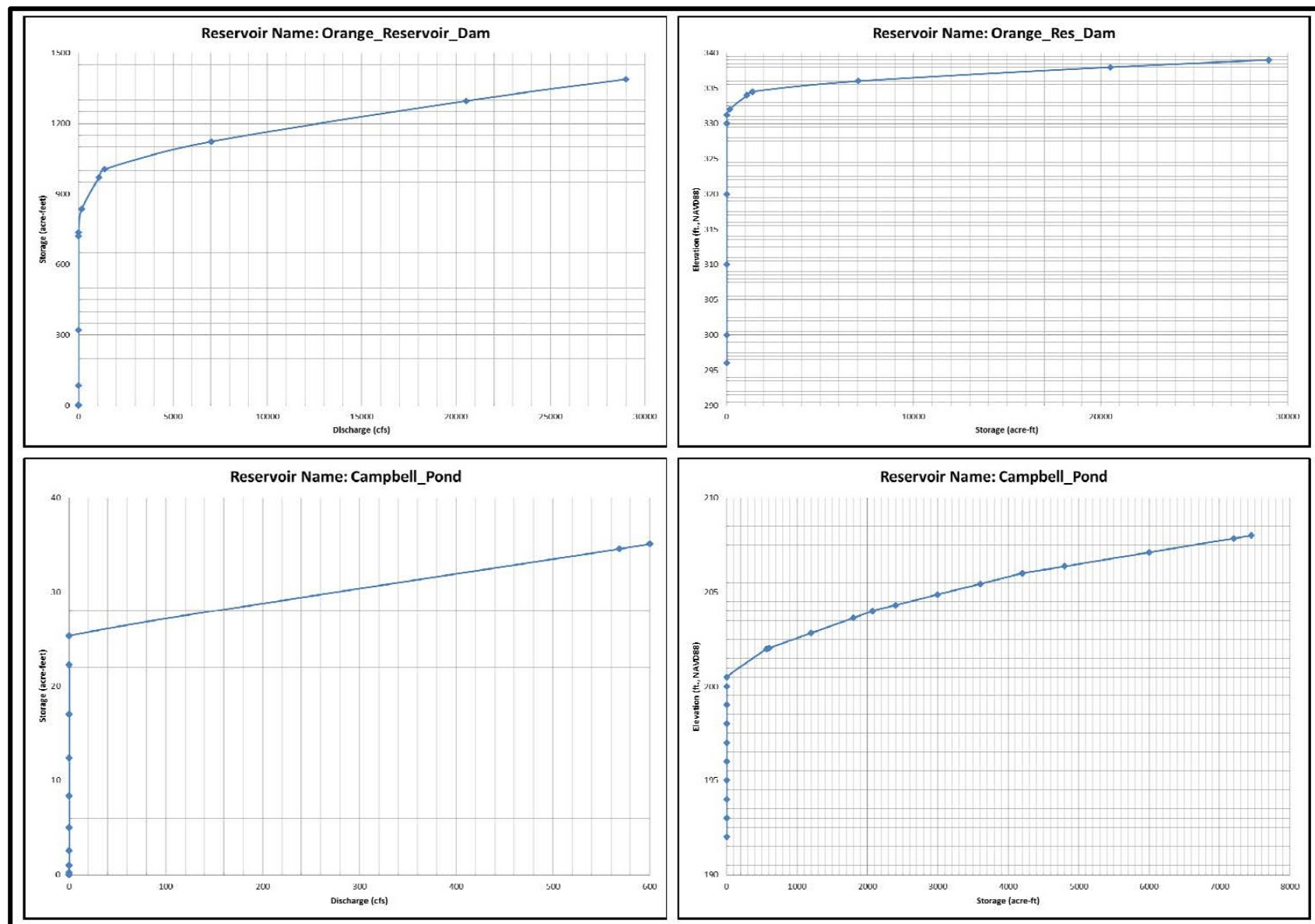






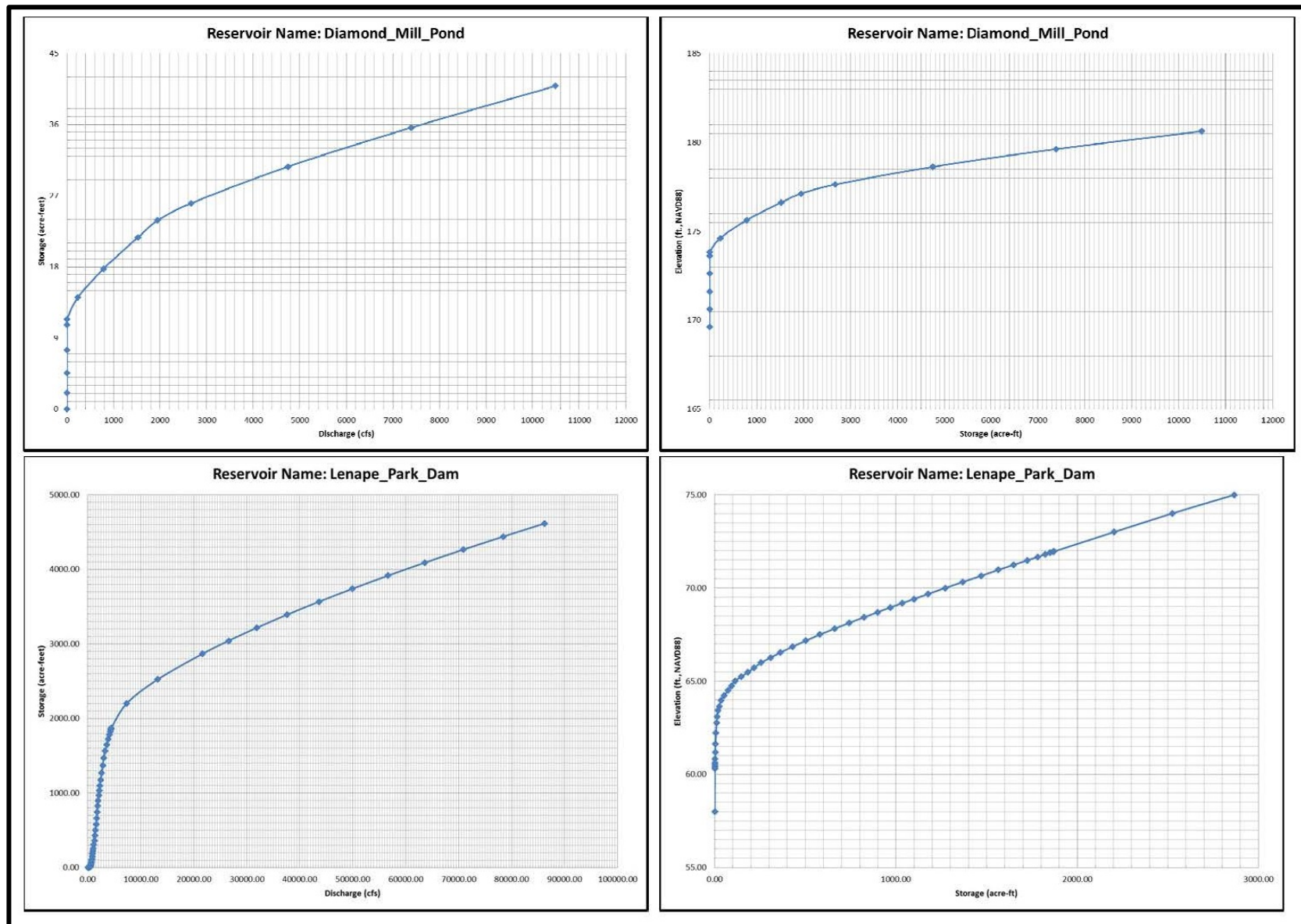
**FIGURE 6(E): MODIFIED PULS ROUTING RELATIONS**





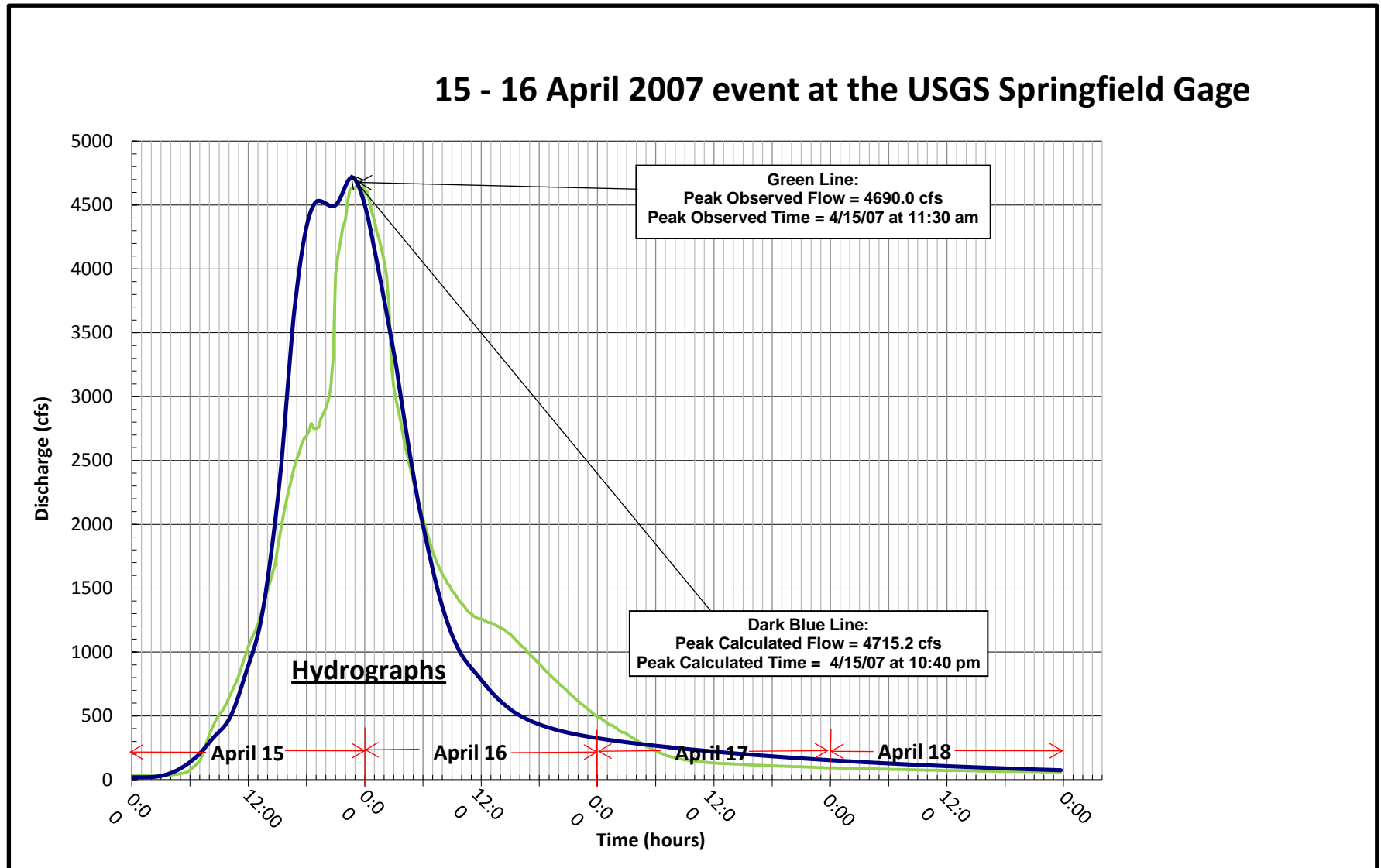
**FIGURE 6(F): RESERVOIR ROUTING RELATIONS**





**FIGURE 6(G): RESERVOIR ROUTING RELATIONS**



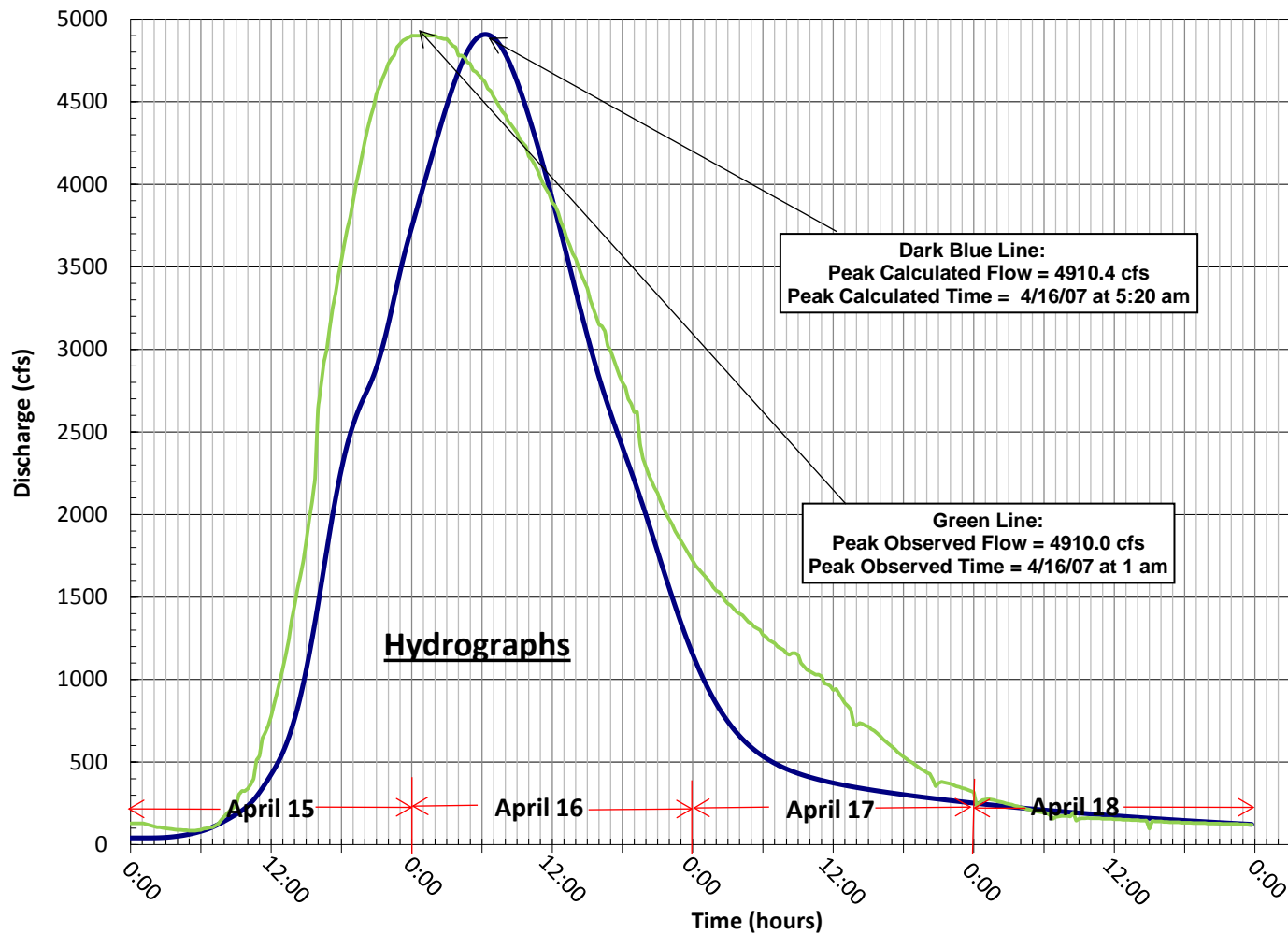


**FIGURE 7: OBSERVED HYDROGRAPH REPRODUCTION AT SPRINGFIELD USGS GAGE FOR THE 15-16 APRIL 2007 EVENT**





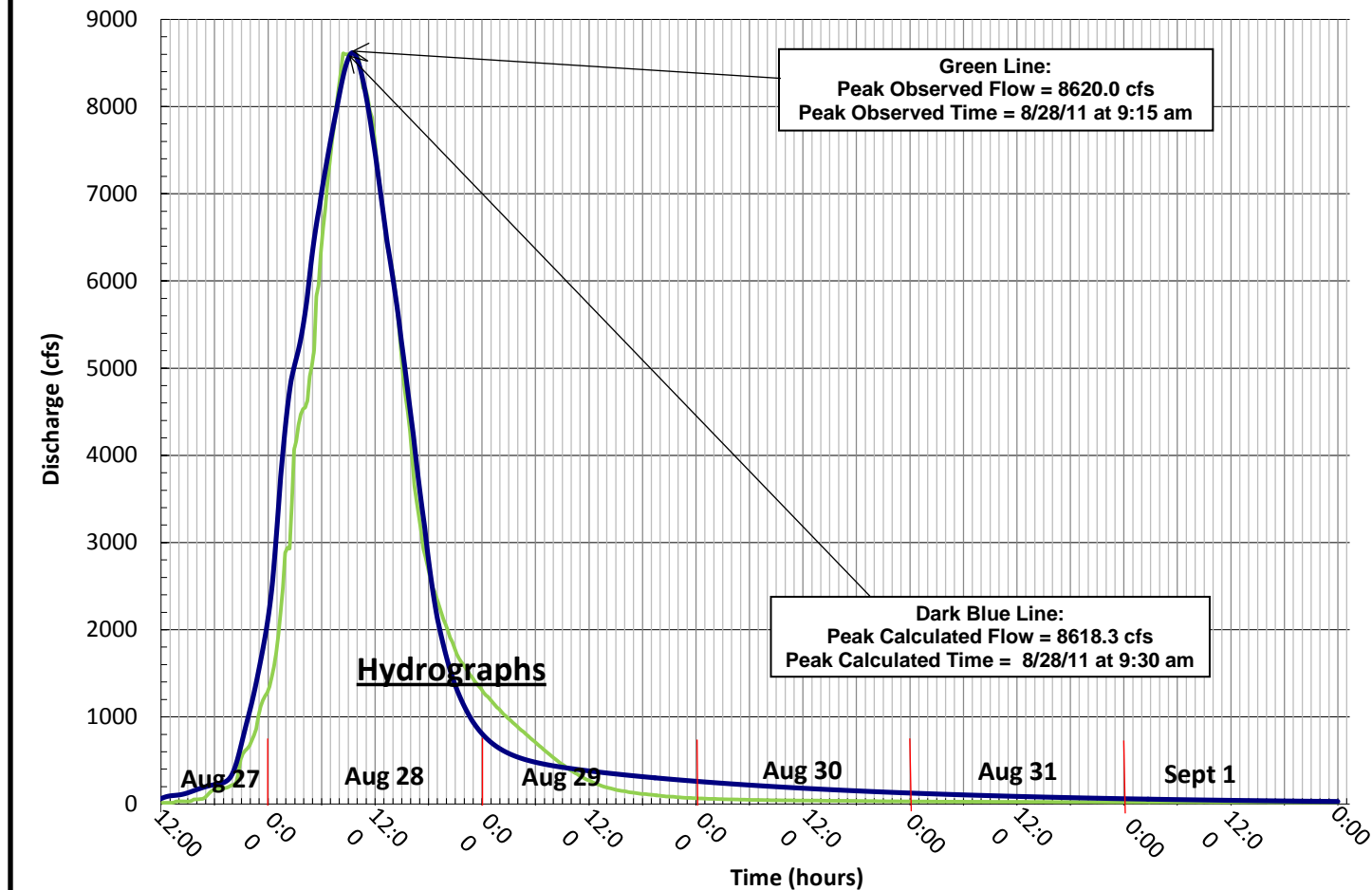
## 15 - 16 April 2007 event at the USGS Rahway Gage



**FIGURE 8: OBSERVED HYDROGRAPH REPRODUCTION AT RAHWAY USGS GAGE FOR THE 15-16 APRIL 2007 EVENT**



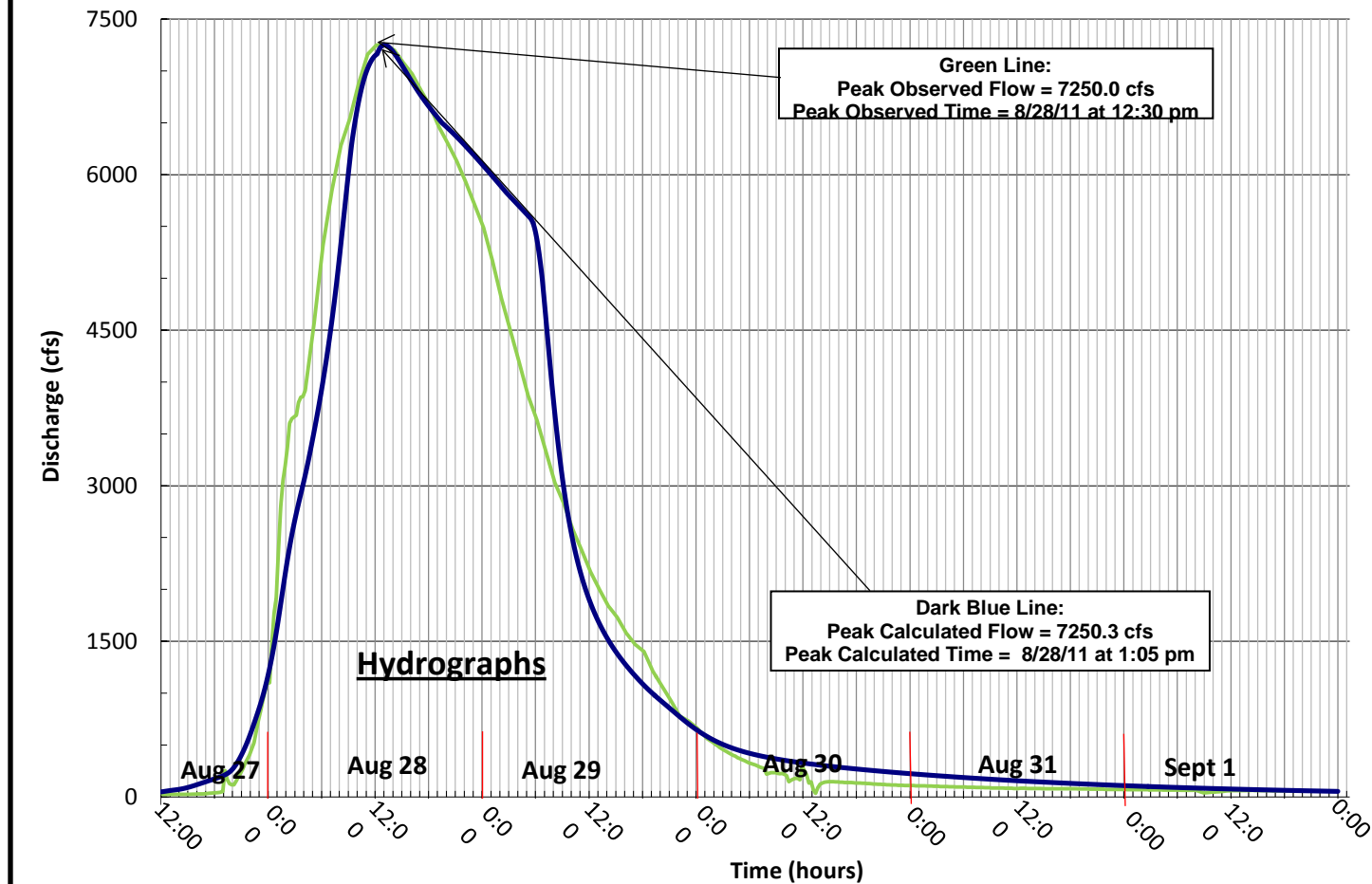
## 27 - 28 August 2011 event at the USGS Springfield Gage



**FIGURE 9: OBSERVED HYDROGRAPH REPRODUCTION AT SPRINGFIELD USGS GAGE FOR THE TROPICAL CYCLONE IRENE (27-28 2011) EVENT**



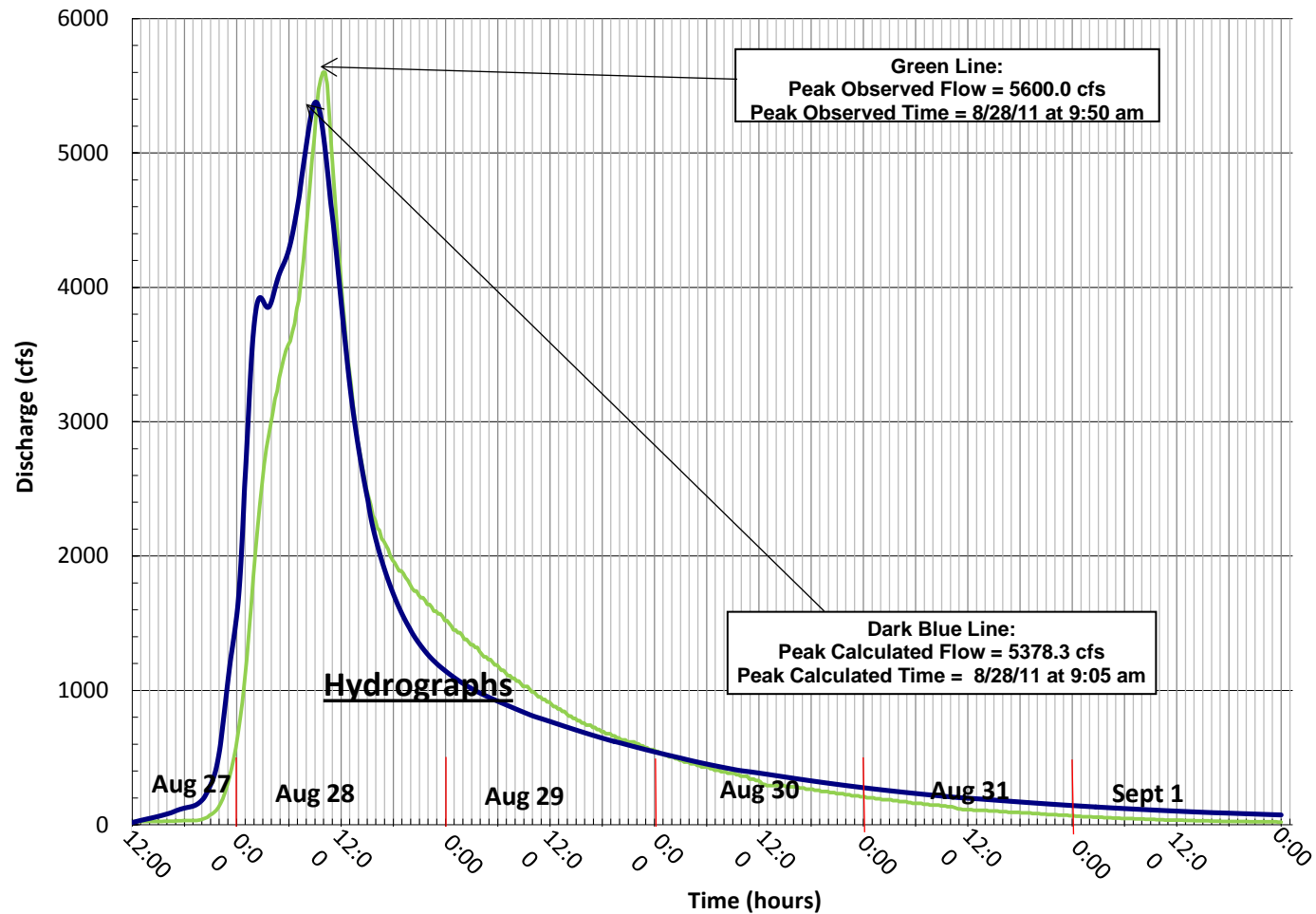
## 27 - 28 August 2011 event at the USGS Rahway Gage - Rahway River



**FIGURE 10: OBSERVED HYDROGRAPH REPRODUCTION AT RAHWAY USGS GAGE FOR THE TROPICAL CYCLONE IRENE (27-28 AUGUST 2011) EVENT**

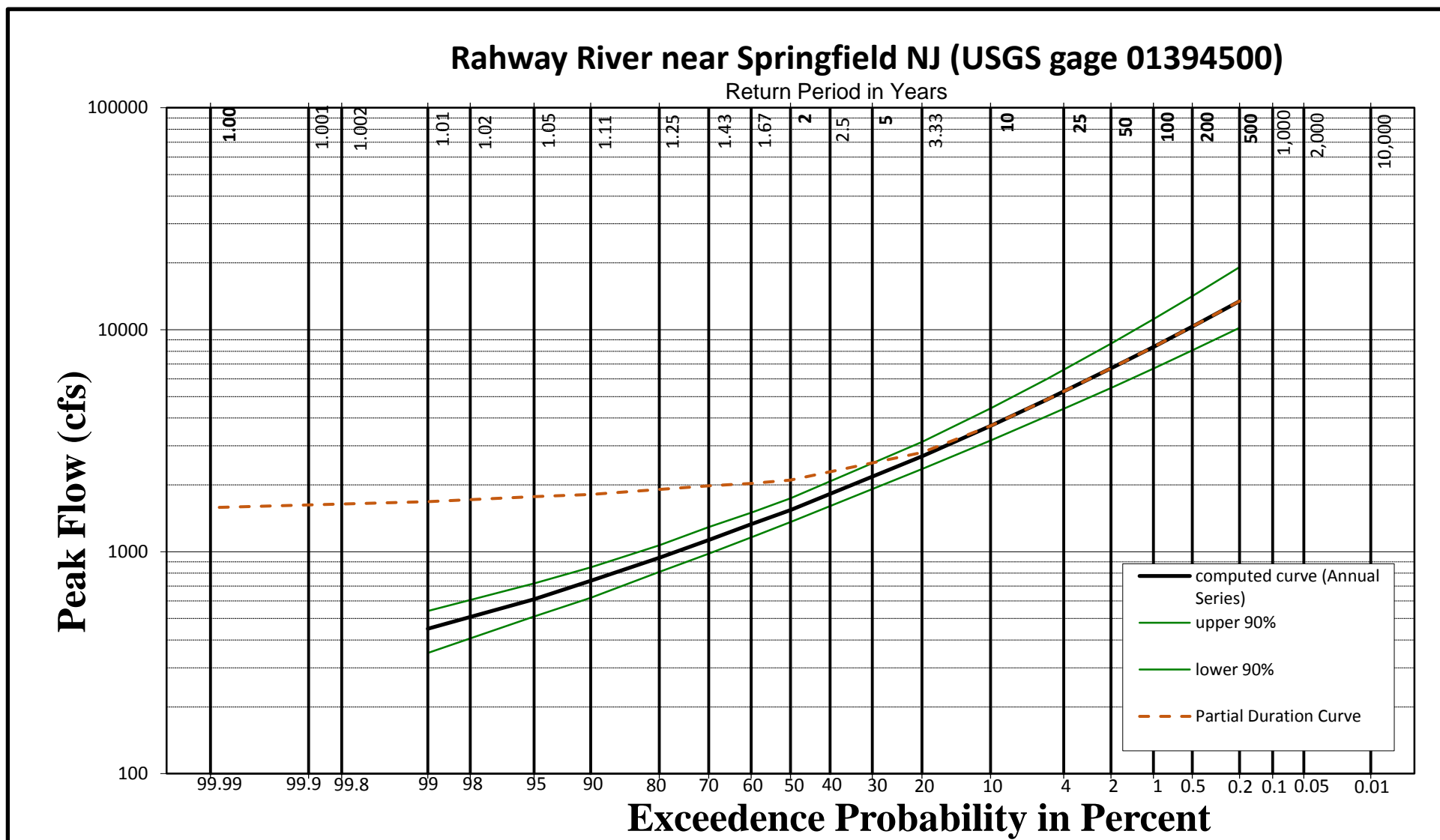


## 27 - 28 August 2011 event at the USGS Rahway Gage - Robinson Branch



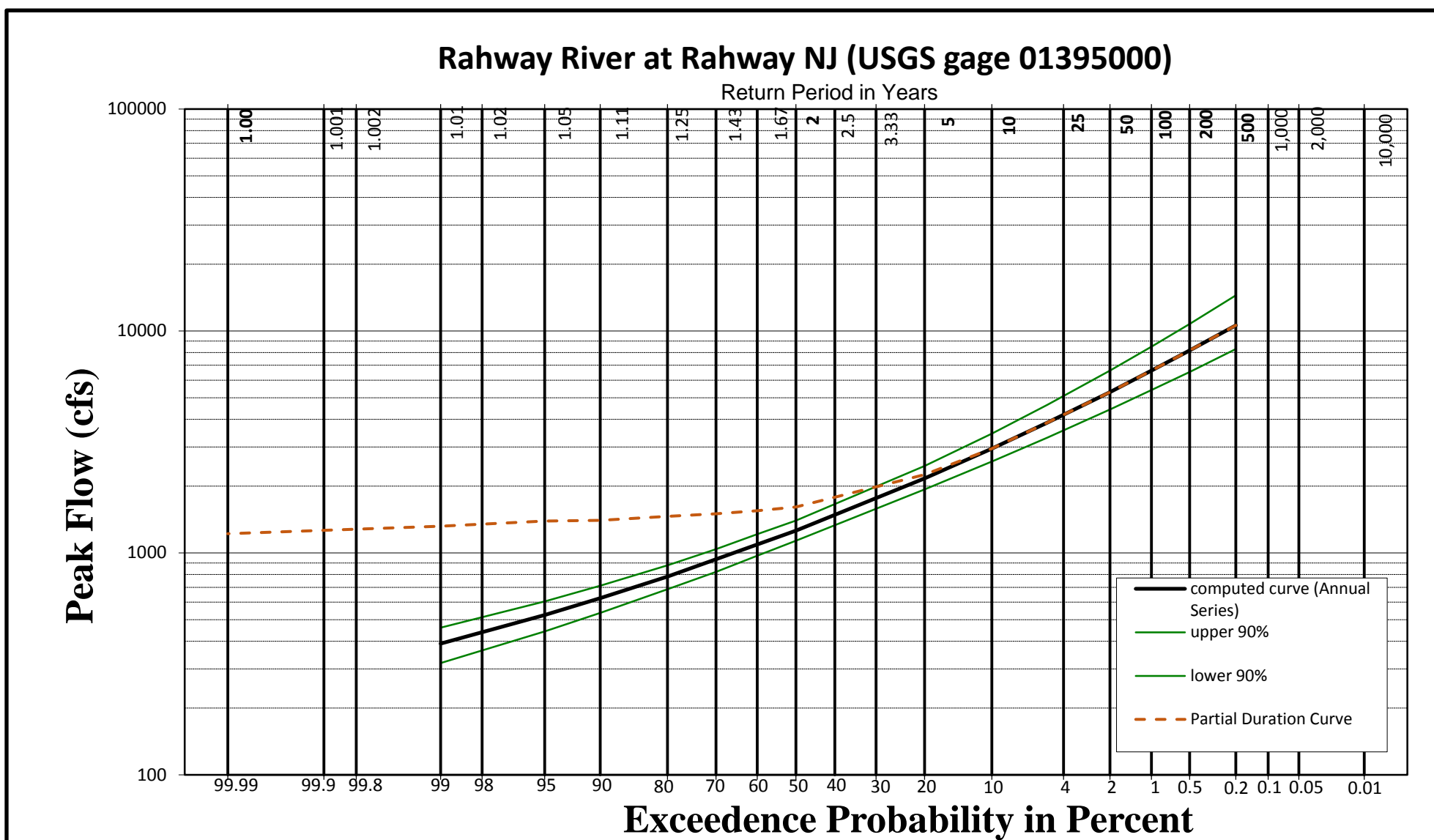
**FIGURE 11: OBSERVED HYDROGRAPH REPRODUCTION AT ROBINSON'S BRANCH USGS GAGE FOR THE TROPICAL CYCLONE IRENE (27-28 AUGUST 2011) EVENT**





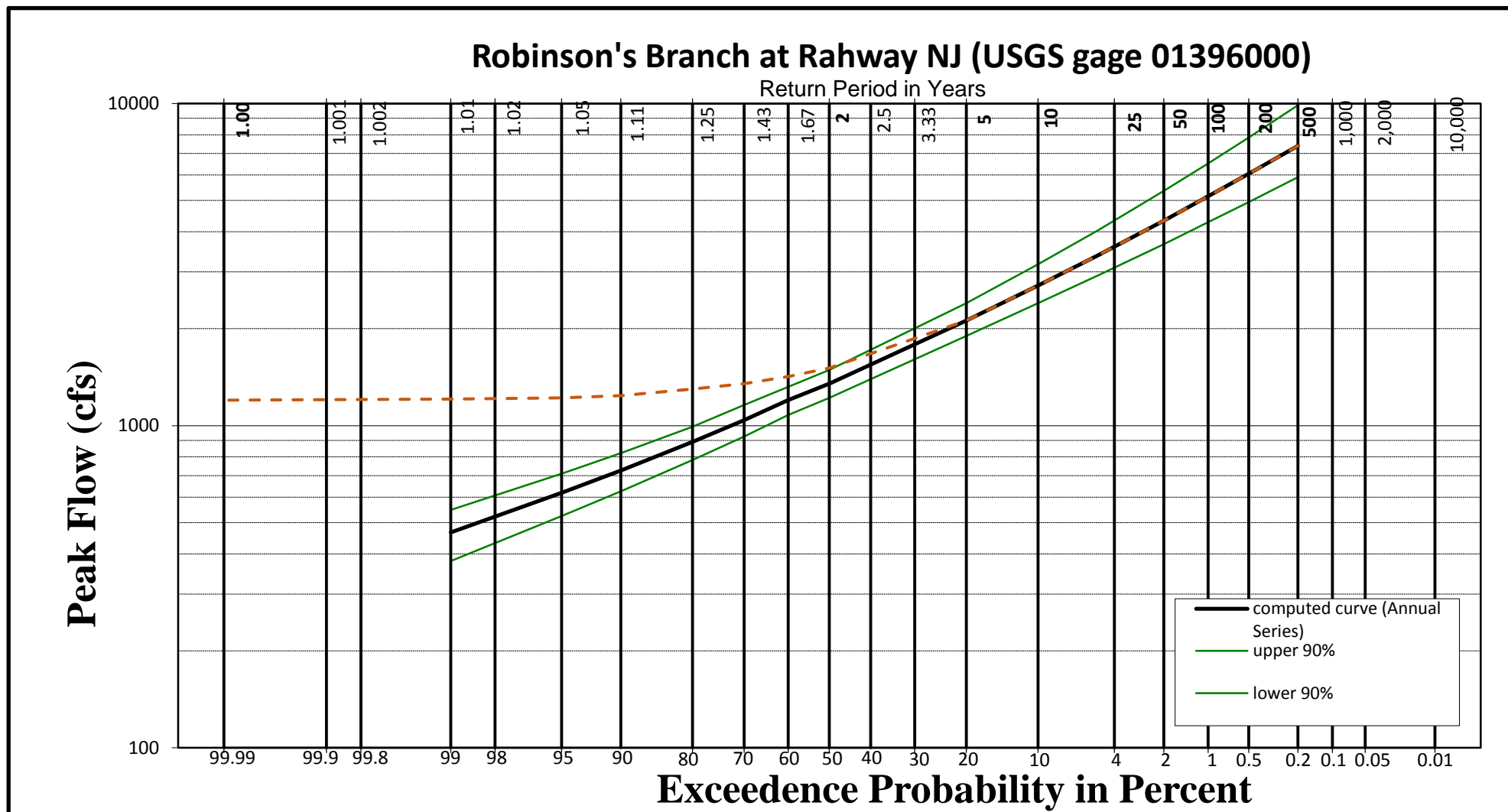
**FIGURE 12: EXISTING CONDITIONS PEAK DISCHARGE VS. FREQUENCY CURVE WITH CONFIDENCE BANDS AT THE SPRINGFIELD GAGE @ RAHWAY RIVER**





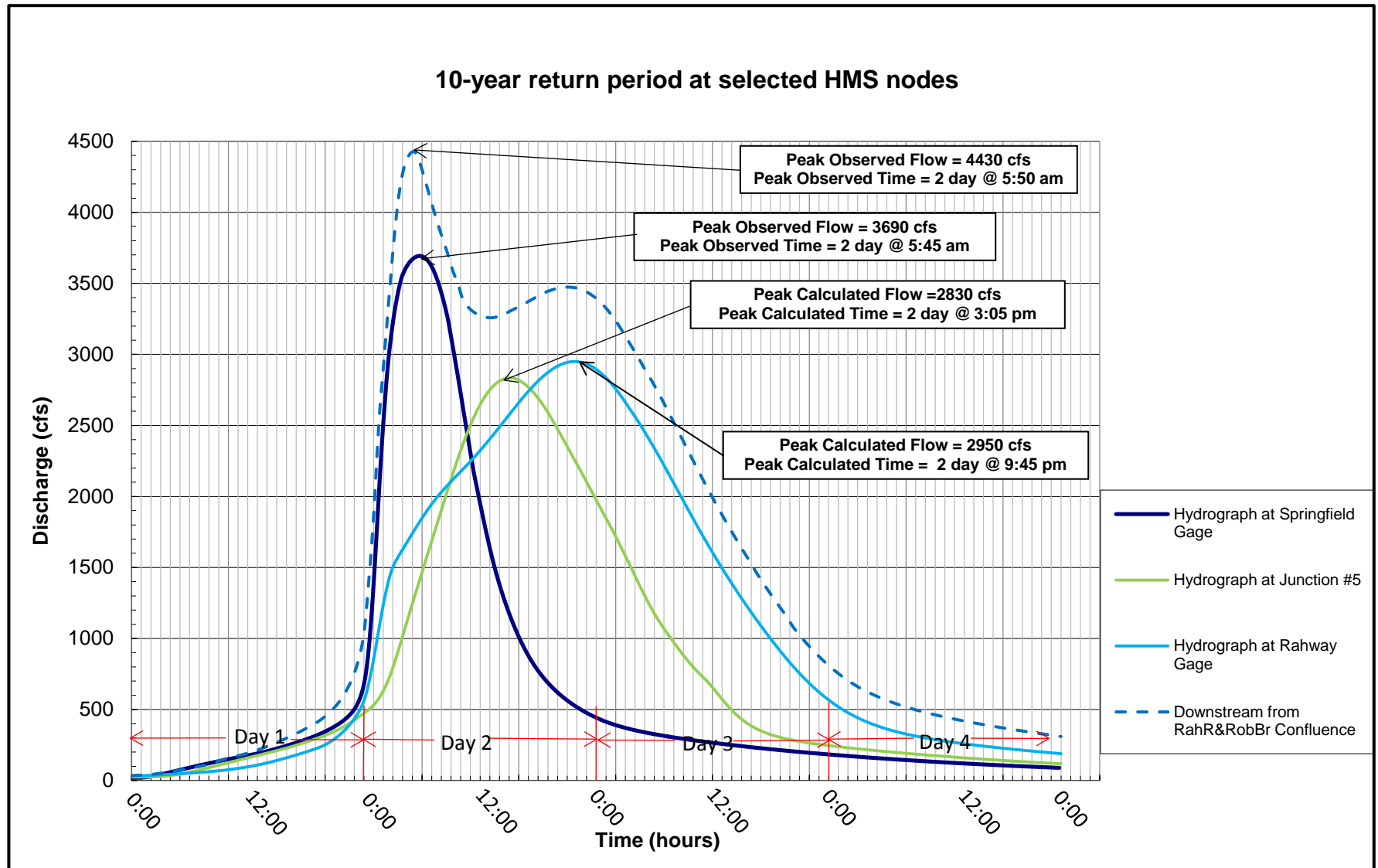
**FIGURE 13: EXISTING CONDITIONS PEAK DISCHARGE VS. FREQUENCY CURVE WITH CONFIDENCE BANDS AT THE RAHWAY GAGE @ RAHWAY RIVER**





**FIGURE 14: EXISTING CONDITIONS PEAK DISCHARGE VS. FREQUENCY CURVE WITH CONFIDENCE BANDS AT THE ROBINSON'S BRANCH GAGE @ RAHWAY RIVER**

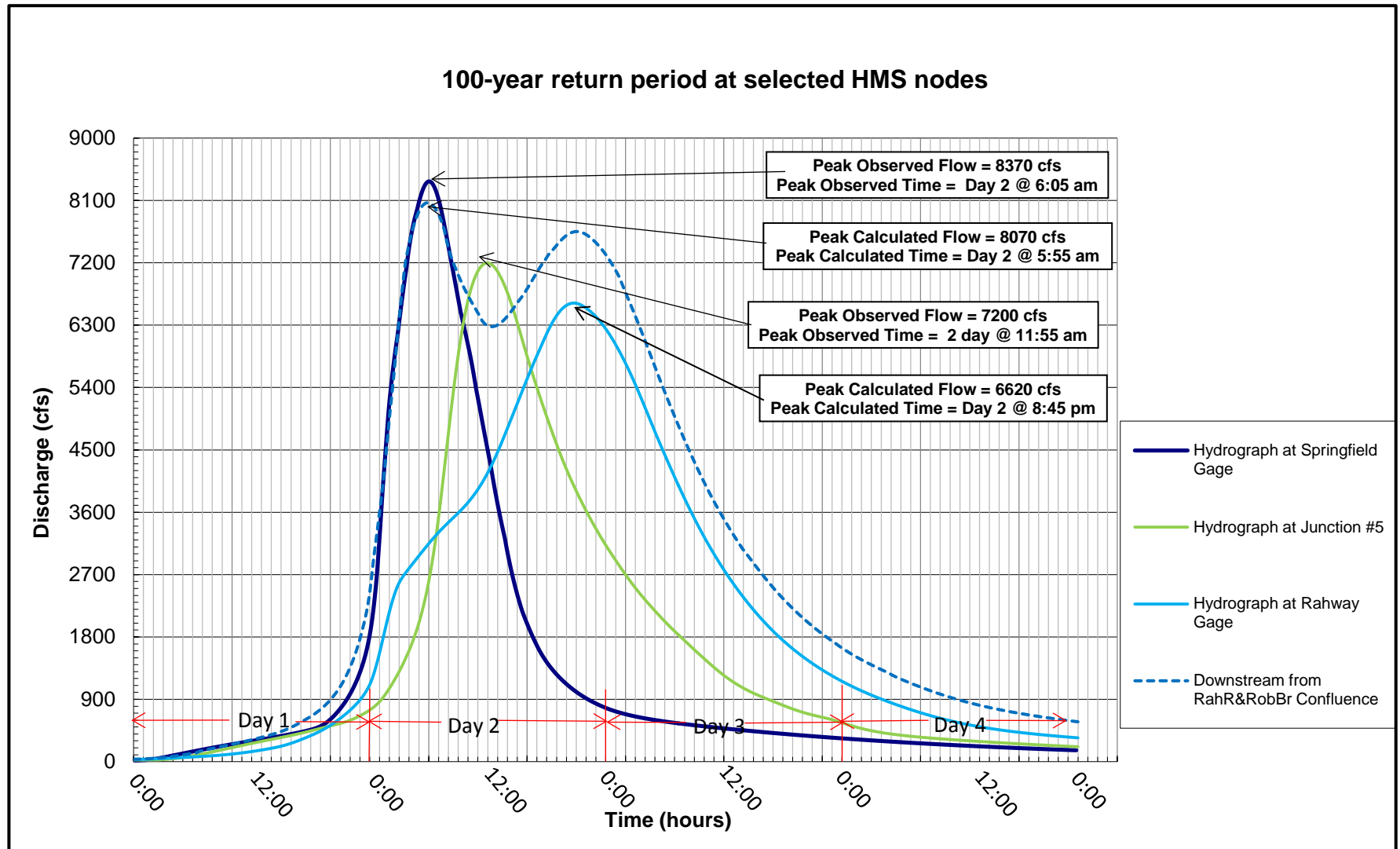




**FIGURE 15: HYPOTHETICAL FLOOD (10-YEAR) AT SELECTED NODES ALONG THE RAHWAY RIVER FOR THE RAHWAY PROJECT AREA**

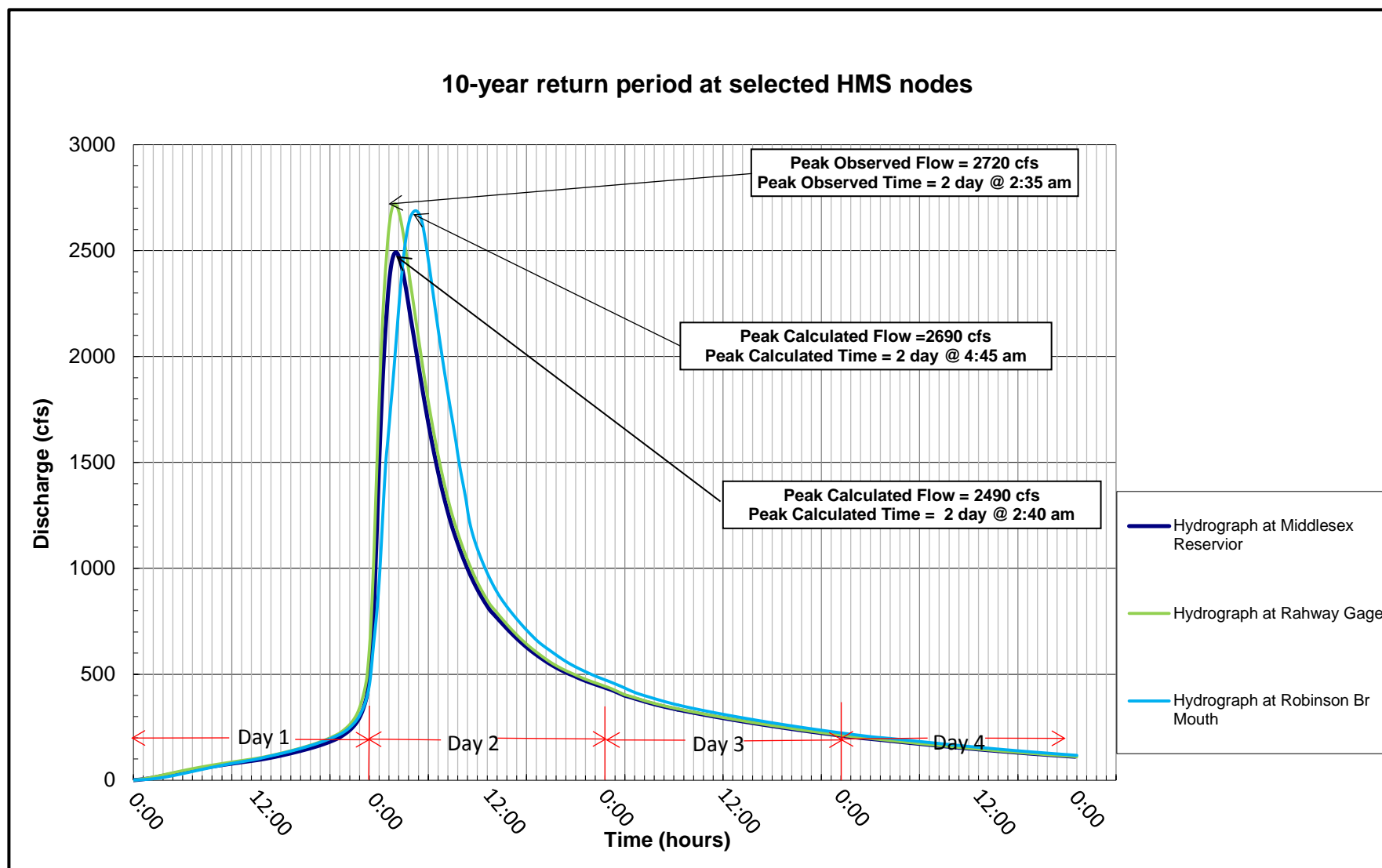






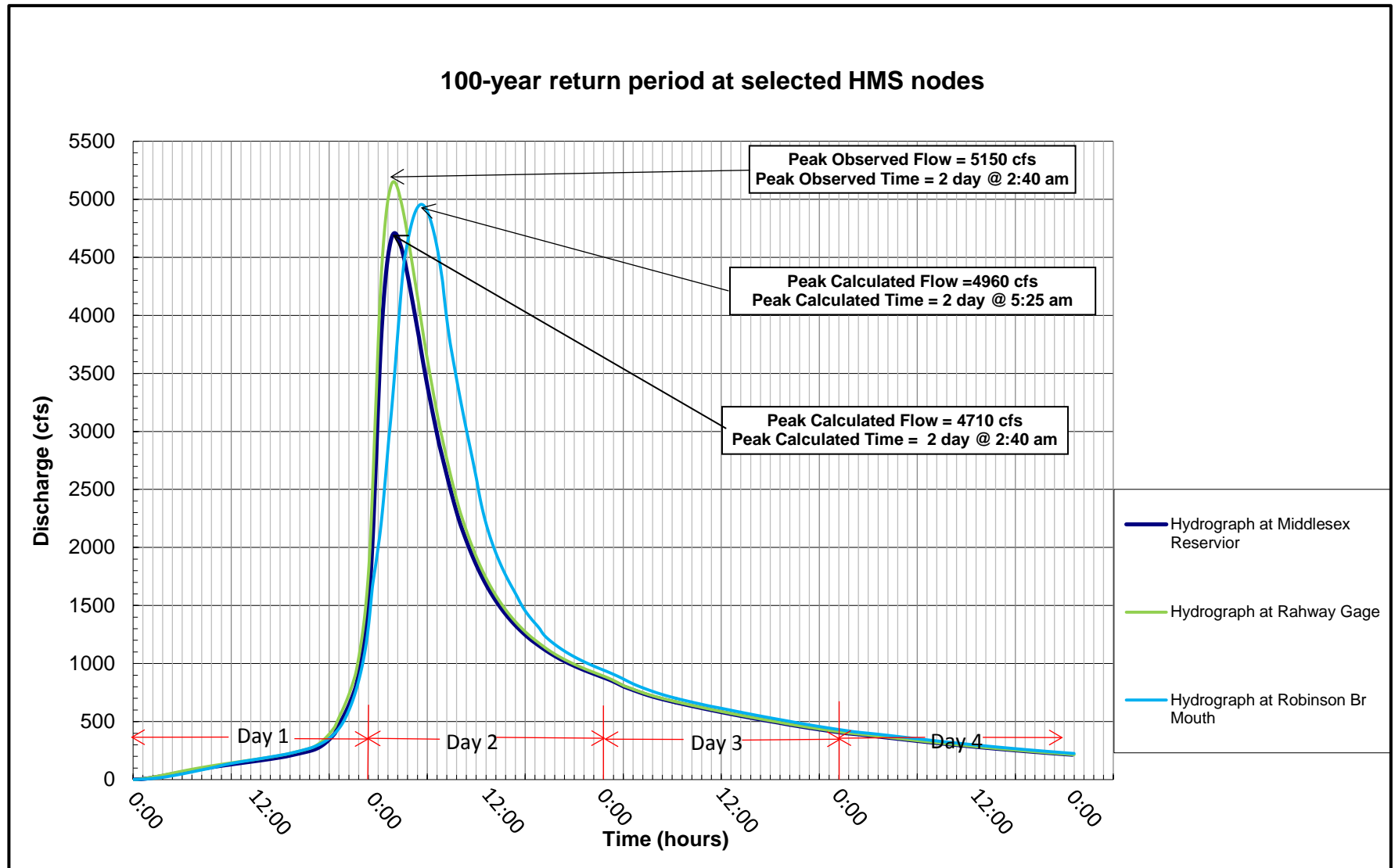
**FIGURE 16: HYPOTHETICAL FLOOD (100-YEAR) AT SELECTED NODES ALONG THE RAHWAY RIVER FOR THE RAHWAY PROJECT AREA**





**FIGURE 17: HYPOTHETICAL FLOOD (10-YEAR) AT SELECTED NODES ALONG ROBINSON'S BRANCH FOR THE RAHWAY PROJECT AREA**





**FIGURE 18: HYPOTHETICAL FLOOD (100-YEAR) AT SELECTED NODES ALONG ROBINSON'S BRANCH FOR THE RAHWAY PROJECT AREA**

