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

# Appendix CI
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# 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. The Raritan River, from the East and West Branch Confluence to it mouth (confluence with Arthur Kill) is approximately 19 miles. The major tributaries to the Rahway River is the following: East and West Branch of the Rahway River, Robinsons Branch and South Branch of the Rahway River. The major towns and communities that are within this watershed is the following: Essex County (e.g. Orange, Milburn), Union County (e.g. Springfield, Kenilworth, Cranford, Clark, Linden, and Rahway). A map of the Rahway River basin and the municipalities that make it up is shown on Figure 1.

The Rahway River are underlain by Triassic age fractured red shales and sandstones of the Brunswick formation. The entire study area is overlain by unconsolidated material deposited during the Wisconsin glacial epoch. Thickness ranges from 0 to over 70 feet with an average depth of 30 feet. The majority of the study area is underlain by boulders. The areas immediately upstream of the Robinson's Branch-Rahway River junction and downstream of the US Route 22 Bridge are overlain by stratified drift. These flat lying deposits consist of well sorted bands of clay, silt, sand and gravel. In the Springfield-Union area of the Rahway River cuts through rolling topography of a recession moraine. The moraine material ranges from clay to boulders and is mostly unstratified except for some local bedding. Each of these glacial deposits are overlain by thin postglacial deposits of silty loan. Section 7.0 goes into greater detail watershed and physical parameter development for the Rahway River Basin.

# 3.0 Project Area

The Rahway project area is located along the Rahway River main steam 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 include:

Rainfall Station (ID 281355): Canoe Brook; Lat/Long: 40º 45'N74º02'W; Elev: 180 feet

Rainfall Station: Newark Airport (ID 286026); Lat/Long: 40º 41'N74º10'W; Elev: 7 feet

Rainfall Station: Cranford (ID 282023); Lat/Long: 40º 39'N74º18'W; Elev: 75 feet

Rainfall Station: Plainfield (ID 287079); Lat/Long: 40º 36'N74º24'W; Elev: 90 feet

The recorded data used from these stations were used to develop selected historic storm events within the Rahway River Basin and is explained in detail in the following paragraphs.

Only one historic event was selected for calibration analysis for this watershed. The storm that was chosen is the August 27 and 28 event, also known as Tropical Storm Irene. For Tropical Storm Irene (August 27 to 28, 2011), the approach that was used to uniformly distribute this historic rainfall was to use NextRAD data with ArcGIS. 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 2.49x2.49 miles.

The merged shapefile product was then reprojected from its native Hydrologic Research Analysis Project (HRAP) grid to the New Jersey State Plane Coordinate System and an ArcGIS grid surface of Irene Precipitation totals was generated. This surface was subdivided using the subbasins of the Rahway River Watershed and a table depicting rainfall distribution, created from shapefile data, within the Rahway River Watershed is presented in Table 2.

## 4.3 Annual (Daily) and Monthy 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 shown in Table 2A. 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 in August 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 1394500) of 7990 cfs and a peak flow of 5590 cfs at the Rahway (USGS Gage 1395000).

### 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 15 April. 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 weekened 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 reemerged 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.

## 4.6 Climate Change

Hydrologic and coastal processes have the potential to be sensitive to climate change and thereby have the potential to affect the performance of the coastal storm risk management features proposed in the Rahway River Basin. Consistent with the objective of ECB 2018-14 (Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects), to enhance the climate preparedness and resilience of USACE projects by incorporating relevant information about observed and expected climate change impacts in hydrologic analysis for planned, new, and existing USACE projects, a qualitative analysis for inland hydrology was conducted using the best available data for the Rahway River basin. The quantitative analysis was conducted in three phases as specified by ECB 2018-14: Initial Scoping, Vulnerability Assessment, and a Risk Assessment.

### 4.6.1 Phase I Initial Scoping

The Rahway River Basin is subjected to both precipitation and coastal storm events and has experienced severe flooding during to coastal storm surge events. Due to the project area being affected by both inland hydrology and coastal storms, this analysis will focus on observed and projected trends in precipitation, streamflow, and sea level rise (SLR).

This appendix will focus on a qualitative analysis of hydrology by performing a vulnerability assessment by performing a review of available literature sources and using the tools developed by USACE including the Climate Vulnerability Assessment Tool, The Climate and Hydrology

Assessment Tool (CHAT), and the non-stationarity detection tool. Since SLR directly impacts the tailwater conditions in the hydraulic model, the assessment for sea-level rise can be found in the Hydraulics Appendix CII.

### 4.6.2 Phase II Vulnerabiity Assessment

For the vulnerability assessment phase, information was collected and analyzed to determine whether changes are presently occurring and whether expected changes in future hydrologic conditions will result in performance requirements significantly different from the present.

The vulnerability assessment includes a literature review of current climate and observed and projected climate trends and application of climate tools used to provide information on observed and projected climate trends relevant to the project area.

#### 4.6.2.1 Literature Review

A synthesis of the USACE peer-reviewed climate literature is available for the Mid-Atlantic Region and was one of the primary sources of information referenced in this literature review. Additionally the Fourth National Climate Assessment produced by the US Global Change Research Program was used as a source for understanding observed and projected climate trends in the northeast. The USACE report summarizes observed and projected climate and hydrological patterns cited in reputable peer-reviewed literature and authoritative national and regional reports, and characterizes climate threats to the USACE business lines (USACE, 2015a). The project watershed falls within the Mid-Atlantic Region, which is also referred to as Water Resources Region 02 (2-digit hydrologic unit code, or HUC02); see Figure 3(a).

#### 4.6.2.2 Observed Climate Trends

Based on the observations made by the Fourth National Climate Assessment for the Northeast region, river flooding will pose a growing challenge to the Northeast region's systems and infrastructure will be increasingly compromised by future intense precipitation events. The Northeast has experienced a greater recent increase in extreme precipitation than any other region in the United States; between 1958 and 2010, the Northeast saw more than a 70 percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1 percent of all daily events). Winter and spring precipitation is projected to increase; winter precipitation by about 5 to 20 percent by the end of the century.

In the Climate Change and Hydrology Literature Synthesis for the US Army Corps of Engineers Missions in the United States for the Mid-Atlantic Region 2, the USACE Institute of Water Resources cites Burns et al. (2007) identified statistically significant ($p<0.05$) increasing trends in annual precipitation for half of their climate stations in the Catskill Mountains in Southern New York. These authors used data from the period 1952-2005, and quantified average rates of increase in annual precipitation in the range of 79-263 mm per fifty years of record. However, no such trend was found by Warrach et al. (2006) for a climate station also in southern New York State. These authors analyzed annual precipitation totals for the period 1900-2000. While no significant annual trends were detected, seasonal trends were detected: including decreasing winter and summer monthly precipitation totals. The overall summary of observed climate trends indicates "there is also a good consensus in the literature that precipitation, and the occurrence of extreme storm events, has increased over the past century in the study region. However, despite the increased precipitation in the region, there is no evidence of significant increases in streamflow over the same period."

The conclusion may suggest that increased evaporation due to changing temperatures, changes in land usage, and channel diversion changes, or other factors may offset the increased amount of precipitation showing up in the form of increase streamflow. Projected climate trends in this report indicate "the majority of the studies reviewed here project increases in precipitation and streamflow through the 21st century. Extreme high events (storms and floods), in particular, are projected to increase in the future. Low flows, however, have been projected to decrease in the future as a result of the projected temperature (and ET) increases." A summary of the observed and projected climate variables are shown in Figure 3(b).

#### 4.6.2.3 Projected Climate Trends

In the Climate Change and Hydrology Literature Synthesis for the US Army Corps of Engineers Missions in the United States for the Mid-Atlantic Region 2, the USACE Institute of Water Resources cites Najjar et al. (2009). This data quantifies an ensemble mean increase in annual precipitation for three major Mid-Atlantic watersheds. Mid and end of century projections show an average 2-5% increase in annual precipitation for the study region compared to the historical baseline (1971-2000). However, the uncertainty in these projections is reflected with relatively high standard deviations (3-12%) associated with these values.

Future projections of extreme events, including storm events and droughts forecasts increases in the occurrence and intensity of storm events by the end of the 21st century for the general study region. Wang and Zhang (2008) used downscaled GCMs to look at potential future changes in precipitation events across North America. They used an ensemble of GCMs and a single high emissions scenario (A2) to quantify a significant increase (20-50%) in the recurrence of the current 20-year 24-hour storm event for their future planning horizon (2075) and the General Mid-Atlantic Region. Additional uncertainty is introduced by the use of hydrologic models, there is moderate consensus that flows, particularly peak flows, will increase in the region through the 21st century as a result of increased precipitation. Low flows, however, are generally projected to decrease in the future. However, the frequency of heavy downpours is projected to continue to increase as the century progresses. Figure 3(c) summarizes the projected climate trends and impacts on each of the USACE business lines.

#### 4.6.2.4 Climate Hydrology Assessment Tool

The Climate Hydrology Assessment Tool (CHAT) assess trends in both observed and projected hydrometeorological data to project future changes in streamflow using GCMs at the watershed scale (HUC 04) seen on Figure 3(d). The USGS maintains two gages on the Rahway River: 01395000 Rahway River at Rahway, NJ and 01394500 Rahway River near Springfield, NJ. Annual peak instantaneous flow data was available from 1922 to 2013 for the Rahway River at Rahway (01395000), and from 1938 to 2013 for the Rahway River near Springfield (01394500) in the CHAT tool for analysis, and were used for the basis of this analysis. No information was available for the Robinsons Branch at Rahway (01396000) from the CHAT tool.

*Observed Trends*

A liner regression analysis performed by the CHAT tool indicates an upward trend in annual peak discharges for both gages. The p-value associated with the trendline at the Rahway gage at Rahway, NJ is less than 0.0001 and is 0.001416 for the Rahway River gage near Springfield as shown in Figures 2(e) and 2(f) respectively. Both p-values are considered statistically significant.

A p-value of 0.05 or less is typically used a threshold for statistical significance in this analysis. These results indicate there may an increasing trend in peak flow in the basin

*Projected Trends*

The CHAT displayed a range of projected, unregulated, annual maximum monthly streamflow computed by 93 different combinations of GCM outputs. Climate changed hydrology is generated for a period from 1952-2099 in the HUC 0203 of Lower Hudson-Long Island as shown in Figure 3(g).

A statistical analysis of the projected hydrology from 1952-2099 indicates a statistically significant linear trend (p-value less than 0.0001) of increasing average annual monthly stream flows as shown in Figure 3(h). This data indicates there is a potential for increases in streamflow, which his consistent with the findings in the literature review.

#### 4.6.2.5 Vulnerability Assessment Tool

The USACE Vulnerability Assessment tool is necessary to help guide adaptation planning and implementation so that USACE can successfully perform its missions, operations, programs, and projects in an increasingly dynamic physical, socioeconomic, and political environment. This tool provides indicators to develop vulnerability scores specific to each of the watersheds located within the contiguous United States.

A Vulnerability Assessment was conducted in the USACE North Atlantic Division (NAD), and within the New York District (NAN). Table 3(a) lists the vulnerability scores for the Flood Risk Reduction Business Line for HUC 0203, as well as the ranges of scores nationally, and within NAD and NAN for scenario changes in Table 3(a). As shown in the table, this watershed vulnerability of the Flood Risk Reduction business line is ranked the highest within the ranges NAN and NAD for all scenarios (wet and dry). When comparing these scores nationally, the HUC 0203 watershed falls within the middle for dry scenarios and below average for wet scenarios. Further analysis using the VA tool characterizes the HUC 0203 watershed as vulnerable for all scenarios for the Flood Risk Reduction Business Line when compared to the rest of the nation (top 20%).

The VA tool analyzed changes that were centered on two epochs, 2050 (2035-2065) and 2085 (2070-2099) grouping those epochs in “wet” and “dry” scenarios. Projections with total runoff values above the median value for the set are grouped as "wet", and ones with total runoff values below the median are grouped as "dry". All results were then given in scenario-epochs; Dry-2050, Dry-2085, Wet-2050, and Wet-2085. Several indicators localized within NAN were used to determine the overall climate risk score. These indicators include: Acres of Urban Area within 500-Year Floodplain (590), Flood Magnification Factor (568C/568L), and Percent Change in Runoff divided by Percent Change in Precipitation (277), and Annual Coefficient of Variant (CV) of Unregulated Runoff (175C).

The indicator that dominates vulnerability in both scenarios is Indicator #568C (flood magnification factor) which contributes approximately 41% for both dry epochs, and 43% for both wet epochs with indicator values greater than 1 (1.124 and 1.14 for Dry-2050 and Dry-2085 respectively; and 1.2311 and 1.3381 for Wet-2050 and Wet-2085 respectively) which indicates positive increases in future flood flows for both dry and wet scenarios. Meanwhile, Indicator #590 (area of the 500-year flood plain) has the second highest contribution with roughly 26% for both dry and wet epochs which suggests higher vulnerability relative to other watersheds. The use of this tool suggests that “dry” scenario-epochs are vulnerable and considerations should be given to projects located within the urbanized 500-year flood plain area. Table 3(b) provides absolute values of all relative indicators for both scenarios and epochs indicating the percent contribution to the overall vulnerability score.

The results of the VA tool analysis indicate that the HUC 0203 watershed is vulnerable to impacts to the Flood Risk Reduction Business Line and should be taken in consideration during the planning process and in communication with the local sponsor.

#### 4.6.2.6 Nonstationarity Detention Tool

*Nonstationarity Detection Tool*

The nonstationarity detection tool (NDT) was utilized for both the Rahway River at Rahway and the Rahway River near Springfield gages. The NDT detected a strong nonstationarity in annual peak streamflow in the year 1965 (3 distribution and 2 mean) for both gages as shown in Figures 2(i) and 2(j). A nonstationarity is considered strong when there is consensus among a minimum of three NDT detection methods, robustness in detection of changes in statistical properties, and relatively large change in the magnitude of a dataset's statistical properties (mean or standard deviation).

*Monotonic Trend Analysis*

A monotonic trend analysis is conducted to identify statistically significant trends in peak streamflow. Since strong nonstationarities were detected in both gage records, a monotonic trend analysis was performed for both gage records starting in the year 1965. As shown in Figure 3(k) and 3(L), no monotonic trends were detected for either gage records.

Based on this criteria, the water year of 1965 is considered a strong change point due to an influx in urbanization with changes in streamflow, and changes in land use denoting the construction of the Lenape Flood Control Dam, gate operations at Hansels Dam and Taylor Park Dam, and the diversion of municipal water supplies (https://waterdata.usgs.gov/nwis/uv?site_no=01395000) which should be considered in hydrologic analysis. One method for doing so may be to perform a flood-frequency analysis using the period of record post 1965 while consider those aforementioned factors into account.

### 4.6.3 Phase III Risk Assessment

The Phase II vulnerability assessment conducted on the Lower Hudson – Long Island basin indicates that the project area is located in a 2-digit HUC watershed that is vulnerable to the effects of climate change. The HUC 0203 watershed is vulnerable to impacts from the Flood Risk Reduction Business Line. The best available scientific evidence based on climate literature and the Vulnerability Assessment tool indicates projected moderate increases precipitation and peak streamflow, as well as increases in storm frequency and intensity in the future. However, due to lack of quantitative hydrologic information, the impact of climate change to the project hydrology is inconclusive. Increases and storm frequency and intensity in the future may lead to increases in stream flow and instances of elevated river stages in the Rahway River, which may lead to more frequent overtopping instances of the levee feature in the future. However, due to the proximity of the basin to the Atlantic coastline the Rahway River is also influenced by sea level rise as documented in the Hydraulics Appendix. The proposed flood risk reduction features (levees, floodwalls, and non-structural) were designed to account for the USACE intermediate sea level rise projection through the year 2073 using the joint probability method to account for a range of streamflows, and are expected to provide robust flood risk reduction over the project design life. Based on the findings of this analysis, it is recommended to communicate the potential risks of climate change in the region to the local sponsor for consideration in future city planning recognizing the current design accounts for future changes in sea level rise but may be further affected by future changes in hydrology.

# 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 1.

## 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 and Robinson's Branch (General Reevaluation Report on the Robinsons' Branch of the Rahway River at Rahway, New Jersey Flood Control Study (July 1985), Volume II – Supporting Documentation:

Hydrology). This report provides information on how the watershed physical characteristics were developed and where the HEC-1 model was created. This report will use the HEC-1 as a base model and updates were done to bring it to present conditions. For example all meteorological (historical and hypothetical) data were updated. The tables below show all the updated physical parameters for the HMS model.

Figure 1 shows the Rahway Watershed with subbasins and Figure 4 shows a schematic diagram of the HEC-HMS model. Table 4 gives the name of each element, its description, the drainage area and the type of computation. Subbasin data that includes unit hydrograph parameters and percent impervious/pervious area for the watershed is presented in Table 5. Several methods of channel routing are utilized in the various stream reaches. Table 6 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 4a through 4e. 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 5f and 5g.

# 8.0 Recent Large Historic Flood Calibration

An HEC-HMS model was used to develop the hydrology of the Rahway River Watershed. The hydrologic analysis for this watershed was completed and was calibrated 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 6 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 6. 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 8 and Figures 6 through 8.

# 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 9(a), 9(b) and 9(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 10(a), 10(b) and 10(c). The third USGS stream gage used was Robinsons Branch at Rahway, NJ. This data is shown in Table 11(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 9 through 11 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 12. 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 13 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 12 through 15.

## 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, 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 become residentially developed at the same density (average lot size) as adjacent existing residential areas, which were measured using ArcMap. 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 14. Future values of HEC-HMS model subbasin percent impervious area values were then calculated according to this assumption. These values are shown in Table 15.

HEC-HMS model subbasin Clark unit hydrograph input parameters were predicted to change in response to an increase in their percent impervious area values according to regression equations for time of concentration (Tc) and basin storage coefficient (R) used as a function of subbasin drainage area, slope, and percent impervious area. This information is 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 are shown in Table 15.

Future values of subbasin percent impervious area, and Clark unit hydrograph input parameters, were then input into 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 are shown in Table 16.

## 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 13. 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 8 through 10 for existing conditions.

## 13.0 Improved Conditions

The improved condition alternatives that are being studied can be found within the Hydraulics Appendix and the hydraulic model approach was using unsteady state analysis. That means portion of the Rahway River will have the attenuation done in HEC-RAS, not HEC-HMS. The rest of the watershed will have the attenuation of discharge hydrographs done within HEC-HMS. For Improved Conditions Analysis, Table 17 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 tributaries that are 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. There will be no "improved conditions" hydrology done for any of the plans because the attenuation of the discharge hydrographs will be done in unsteady HEC-RAS model and these locations are shown in Table 18. Other input for interior runoff hydrographs along the unsteady HEC-RAS model (e.g. point inflow, uniform or lateral flow) was given at define locations within the HEC-RAS model. For more information pertaining to the hydraulic analysis, see Hydraulic Appendix CII.

RAHWAY RIVER BASIN
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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

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

| Subbasin Name | Total Storm Precipitation (inches) |
|---|---|
| 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 2 (a): List of Notable Storms that has hit the Rahway River Basin**

| Date | Also known As |
|---|---|
| 20-24 September 1882 | N/A |
| 30 July 1889 | N/A |
| 31 July 1901 | N/A |
| 25-26 August 1933 | N/A |
| March 1936 | N/A |
| 17-25 July 1938 | N/A |
| August 1938 | N/A |
| 17-21 September 1938 | N/A |
| 9-16 August 1942 | N/A |
| 20 May 1943 | N/A |
| 18 September 1945 | N/A |
| 28 June 1946 | N/A |
| 23-25 July 1946 | N/A |
| 8 November 1947 | N/A |
| August 1955 | Hurricane Connie and Diane |
| October 1955 | N/A |
| September 1960 | Hurricane Donna |
| 12-13 March 1962 | N/A |
| 21-22 September 1966 | N/A |
| 28-29 May 1968 | N/A |
| 26-28 August 1971 | Hurricane Doria |
| 13 September 1971 | N/A |
| 2-3 August 1973 | N/A |
| July 1975 | N/A |
| November 1977 | N/A |

### Table 3(a): Vulnerability Scores for HUC 0203 for the Flood Risk Reduction Business Line for each scenario-epoch combination nationally, NAD and NAN.

| Business Line | Scenario-Epoch | WOWA Score | Range Nationally | Range in NAD | Range in NAN |
|---|---|---|---|---|---|
| Flood Risk Reduction | Dry – 2050 | 52.48 | 35.15-70.08 | 40.04-52.58 | 44.36-52.48 |
| | Dry - 2085 | 53.37 | 35.15-70.08 | 40.01-53.37 | 45.32-53.37 |
| | Wet - 2050 | 54.42 | 39.80-92.85 | 43.13-54.82 | 48.14-54.42 |
| | Wet - 2085 | 56.91 | 39.80-92.85 | 43.12-56.91 | 49.69-56.91 |

### Table 3(b): Values/Percent Contribution to Vulnerability of Each Indicator Associated With the Flood Risk Reduction Business Line for All Scenario-Epoch Combinations along with Percent Changes between Epochs for Each Scenario

| Number | Dry-2050 | Dry-2085 | Percent Change | Wet-2050 | Wet-2085 | Percent Change |
|---|---|---|---|---|---|---|
| 590 | 25.75/20.95 | 26.25/20.74 | 1.95 | 25.75/19.71 | 26.25/19.06 | 1.95 |
| 568C | 14.046/41.26 | 14.274/41.61 | 1.62 | 15.38/43.06 | 16.72/43.82 | 8.69 |
| 568L | 7.239/18.11 | 7.340/18.32 | 2.64 | 7.952/21.88 | 8.674/22.29 | 9.08 |
| 277 | 4.121/16.15 | 4.165/15.85 | 1.07 | 4.098/12.12 | 3.977/11.64 | -2.94 |
| 175C | 1.326/3.53 | 1.252/3.47 | -5.57 | 1.240/3.23 | 1.294/3.20 | 4.36 |

## Table 4: HEC-HMS Model Structure

| Element Name | Element Type | Drainage Area ($mi^2$) | 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 4: HEC-HMS Model Structure (Cont.)

| Element Name | Element Type | Drainage Area ($mi^2$) | 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 | **Robinson's Branch Rahway River subbasin 102** |
| 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 4: HEC-HMS Model Structure (Cont.)

| Element Name | Element Type | Drainage Area ($mi^2$) | 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 | **Robinson's Branch downstream of subbasin 119** |
| 121 ROUT | Reservoir | 20.83 | **Outflow from Middlesex Reservoir** |
| 122 COMP | Subbasin | 1.04 | Subbasin 122 |
| 123 COMB | Junction | 21.87 | **USGS gage 01396000 Robinson's Br Rahway River at Rahway : Milton Lake Dam** |
| 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 | **USGS gage 01396000 Robinson's Branch Rahway River at Maple Ave in Rahway NJ** |
| 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 4: HEC-HMS Model Structure (Cont.)

| Element Name | Element Type | Drainage Area ($mi^2$) | 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 5: Existing Conditions Input Parameters

| Subbasin | Drainage Area ($mi^2$) | 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 6: 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 7: 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 7: 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 8: Historical Floods – Peak Discharges

| Node Name | Drainage Area (mi2) | 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 |
| UPSBR | 64.53 | 7100 | 12120 |
| HDCULV_US | 9.98 | 2280 | 3000 |
| 207 | 11.81 | 2580 | 3410 |
| DSSBC | 76.70 | 9290 | 15430 |

**Table 9(A): Annual Peak Flows – USGS Gage #1394500 Rahway River near Srringfield, 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 9(B): Annual Peak Flows – USGS Gage #1394500 Rahway River near Srringfield, 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 9(C): Annual Peak Flows – USGS Gage #1394500 Rahway River near Srringfield, 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 10(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 10(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 10(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 11 (A): Annual Peak Flows - USGS Gage #01396000 Robinsons Branch at Rahway NJ

| Water Year | Annual Peak Flow Date | Annual Peak Flows (cfs) |
|---|---|---|
| 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 Aug1959 | 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 11 (B): Annual Peak Flows - USGS Gage #01396000 Robinsons Branch at Rahway NJ

| Water Year | Annual Peak Flow Date | Annual Peak Flows (cfs) |
|---|---|---|
| 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 12: 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 12: 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 13: Existing Conditions – Peak Discharges (cfs) for Rahway Watershed

| HMS NODE | Drainage Area ($mi^2$) | 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 |
| UPSBR | 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 14: 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 15: Future Unimproved Calculations

| Subbasin Node | Drainage Area ($mi^2$) | 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 15: Future Unimproved Calculations (Cont.)

| Subbasin Node | Drainage Area ($mi^2$) | 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 16: Future Unimproved Conditions - Peak Discharges (cfs) for Rahway Watershed

| HMS NODE | Drainage Area ($mi^2$) | 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 17: Description of Alternatives Under Improved Conditions**

| Name of Alternative | Description |
|---|---|
| Alternative #1 | Levees and Floodwalls |
| Alternative #2 | Surge Barrier with Levees |

**Table 18: Input of discharge hydrographs for unsteady HEC-RAS model**

| Location of Discharge hydrographs for unsteady HEC-RAS inputs | Drainage Area ($mi^2$) |
|---|---|
| Orange Reservoir | 4.61 |
| East Branch of the Rahway River @ Mouth | 8.11 |
| Van Winkles Brook @ Mouth | 5.47 |
| Headwaters of the Robinsons' Branch | 4.32 |
| South Branch of the Rahway River Upstream of Rt. 35 | 8.94 |


**Figure 1: Rahway River Basin with Delineated Subbasins and Stream Gages**

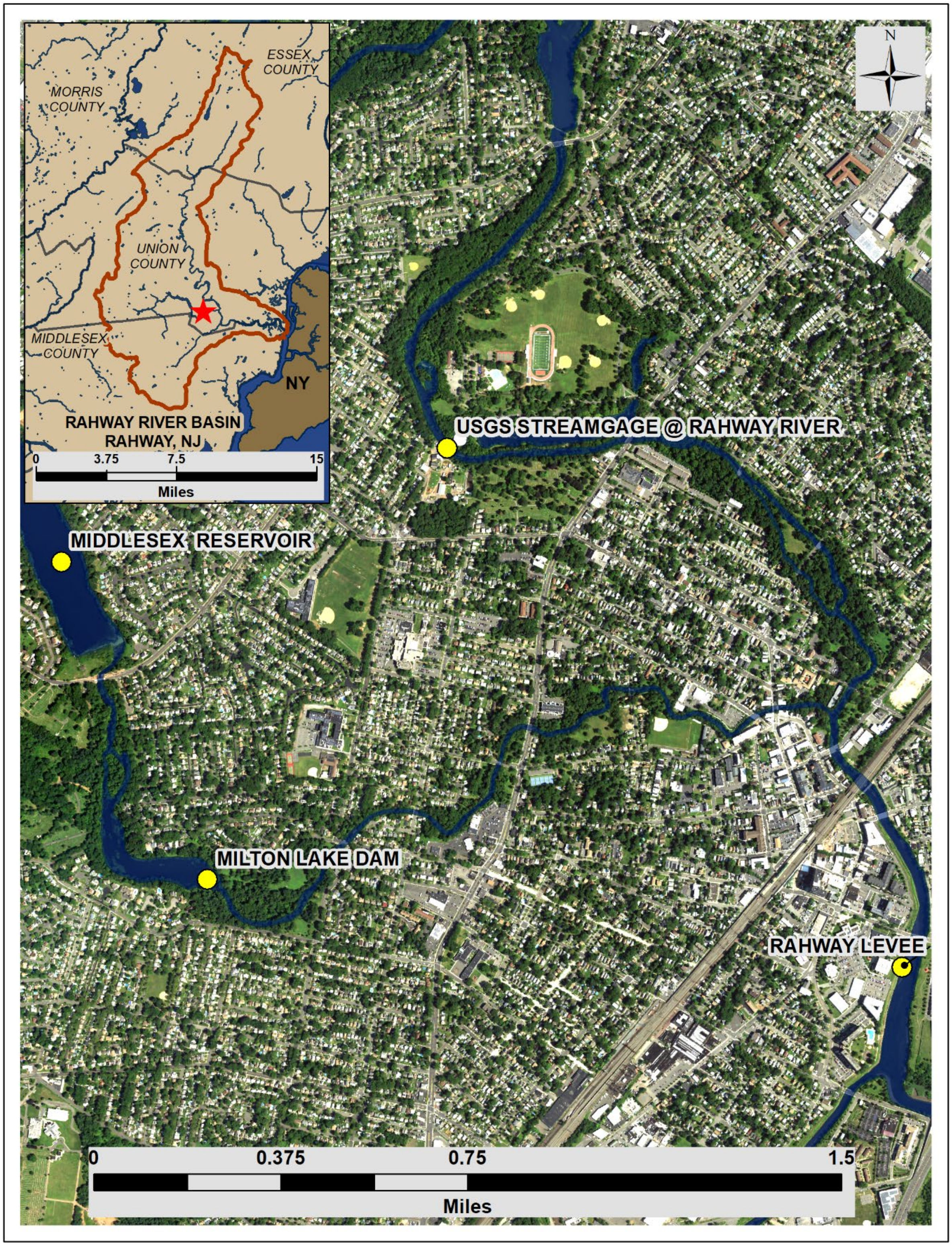



**Figure 2: Rahway River Basin with Delineated Subbasins and Stream Gages**

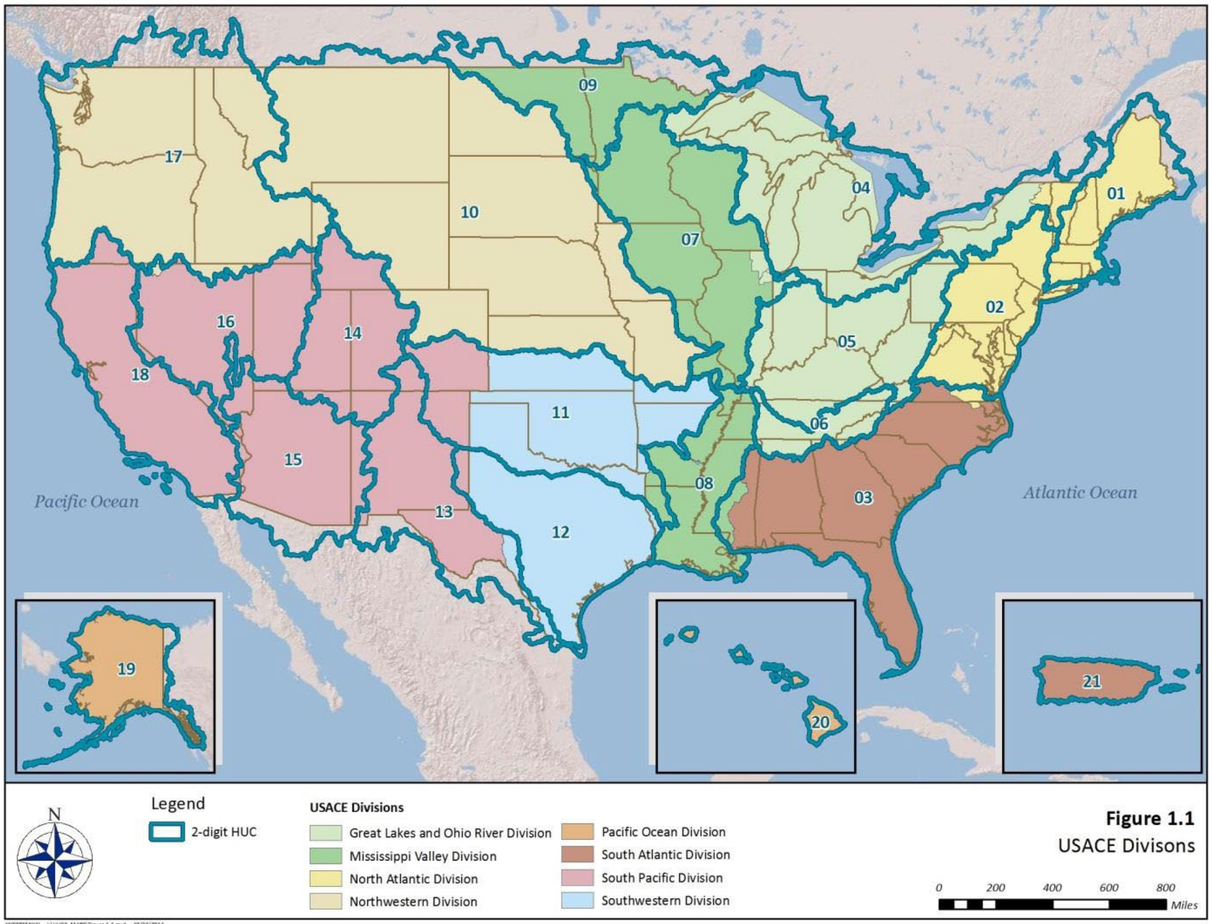



**Figure 3(a): 2-digit Water Resources Region Boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico**

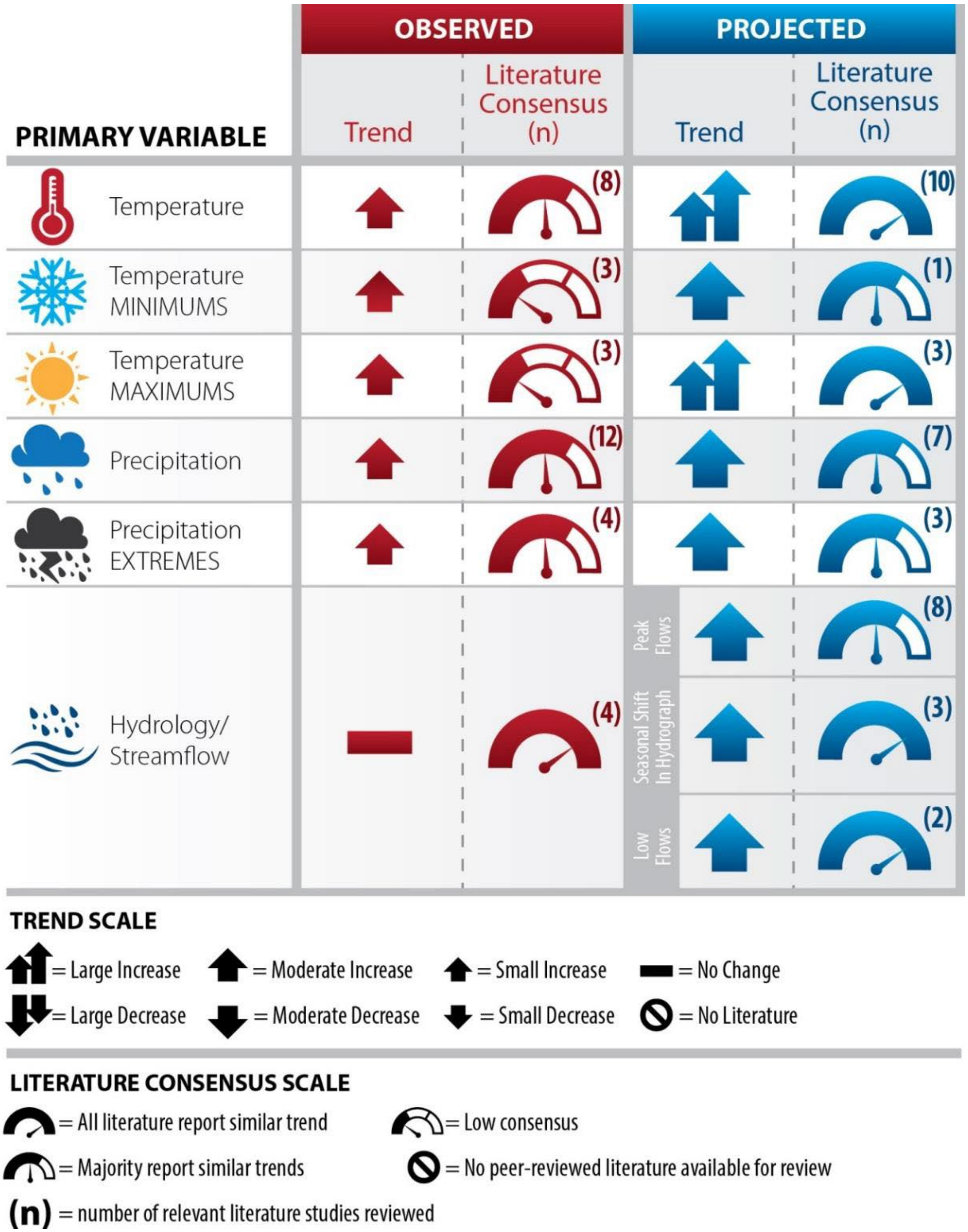



**Figure 3(b): Summary Matrix of Observed and Projected Climate Trends and Literary Consensus**

| CLIMATE VARIABLE | VULNERABILITY |
|---|---|
| Increased Ambient Temperatures | Increased ambient air temperatures throughout the century, and over the next century are expected to create the following vulnerabilities on the business lines in the region:<br>• Loss of vegetation from increased periods of drought and reduced streamflows may have impacts on vegetation within the region, which is important for sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading, potentially causing geomorphic changes in the tributaries to the river system.<br>• Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers.<br>**BUSINESS LINES IMPACTED:** |
| Increased Maximum Temperatures | Air temperatures are expected to increase 2-4°C in the latter half of the 21st century, especially in the summer months. This is expected to create the following vulnerabilities on business lines in the region:<br>• Increased water temperatures leading to water quality concerns, particularly for the dissolved oxygen (DO) levels, growth of nuisance algal blooms and influence wildlife and supporting food supplies.<br>• Increased evapotranspiration.<br>• Human health risk increases from extended heat waves, impacting recreational visitors and increasing the need for emergency management.<br>**BUSINESS LINES IMPACTED:** |
| Increased Annual Precipitation | By the middle of the century, annual precipitation is expected to increase in the region which are expected to influence the following vulnerabilities on business lines in the region:<br>• Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality.<br>• Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns.<br>• Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area.<br>**BUSINESS LINES IMPACTED:** |
| Increased Storm Intensity and Frequency | Extreme storm events may become more intense and frequent over the coming century which are expected to influence the following vulnerabilities on business lines in the region:<br>• Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality.<br>• Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns.<br>• Change in engineering design standards to accommodate new extreme storms magnitudes.<br>• Increased groundwater recharge rates, as residence times are shortened within areas where evapotranspiration takes place during high intensity events.<br>• Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area.<br>**BUSINESS LINES IMPACTED:** |
| Streamflow Variability | Streamflow will have more extreme variability's by the end of the century. This includes an increase in overall flow, an increase of peak flows, and an increase in low flow levels, which may result in:<br>• Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality.<br>• Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns.<br>• Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area.<br>• Loss of vegetation from increased periods of drought and reduced streamflows may have impacts on vegetation within the region, which is important for sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading, potentially causing geomorphic changes in the tributaries to the river system.<br>• Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers.<br>**BUSINESS LINES IMPACTED:** |
| Sea Level Rise | Sea level rise may exacerbate saltwater intrusion into fresh water supplies.<br>**BUSINESS LINES IMPACTED:** |

*NOTE: The Regulatory and Military Program business lines may be impacted by all climate variables*

= Navigation = Flood Risk Management = Ecosystem Restoration = Hydropower = Recreation = Water Supply = Emergency Management

**Figure 3(c): Summary of Projected Climate Trends and Impacts on USACE Business Lines**


**Figure 3(d): Water Resources Region 02-Mid-Atlantic Region Bound**

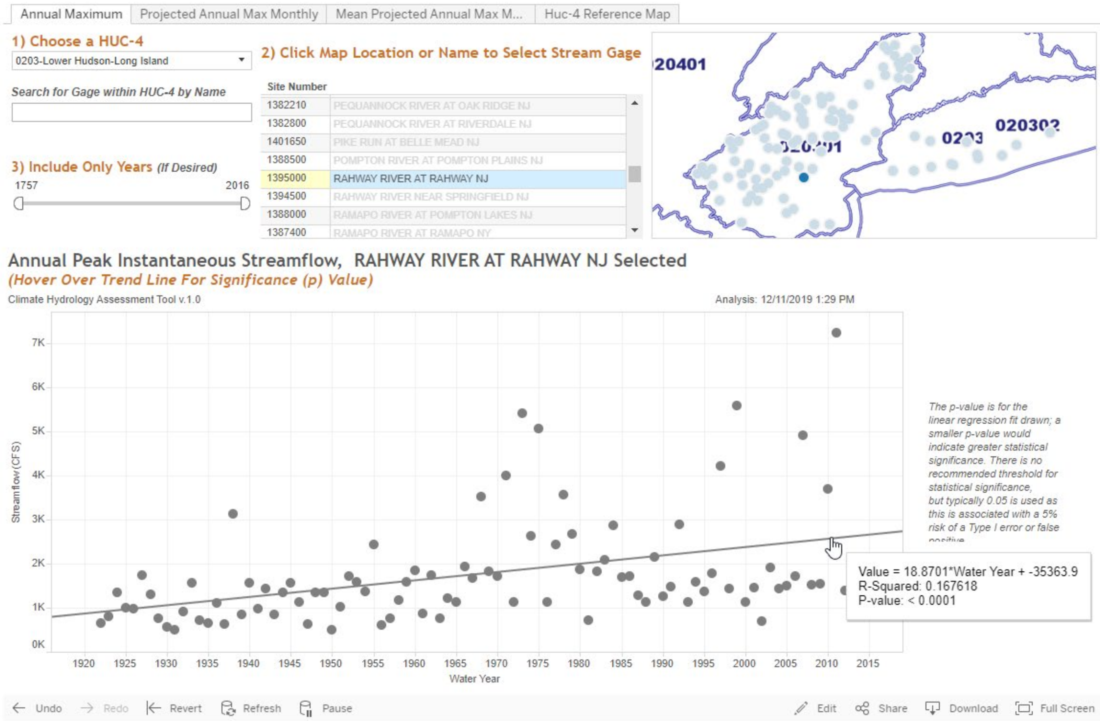



**Figure 3(e): CHAT output using annual instantaneous peak discharge at Rahway River at Rahway, NJ gage; HUC04 Lower Hudson Long Island Basin (0203)**

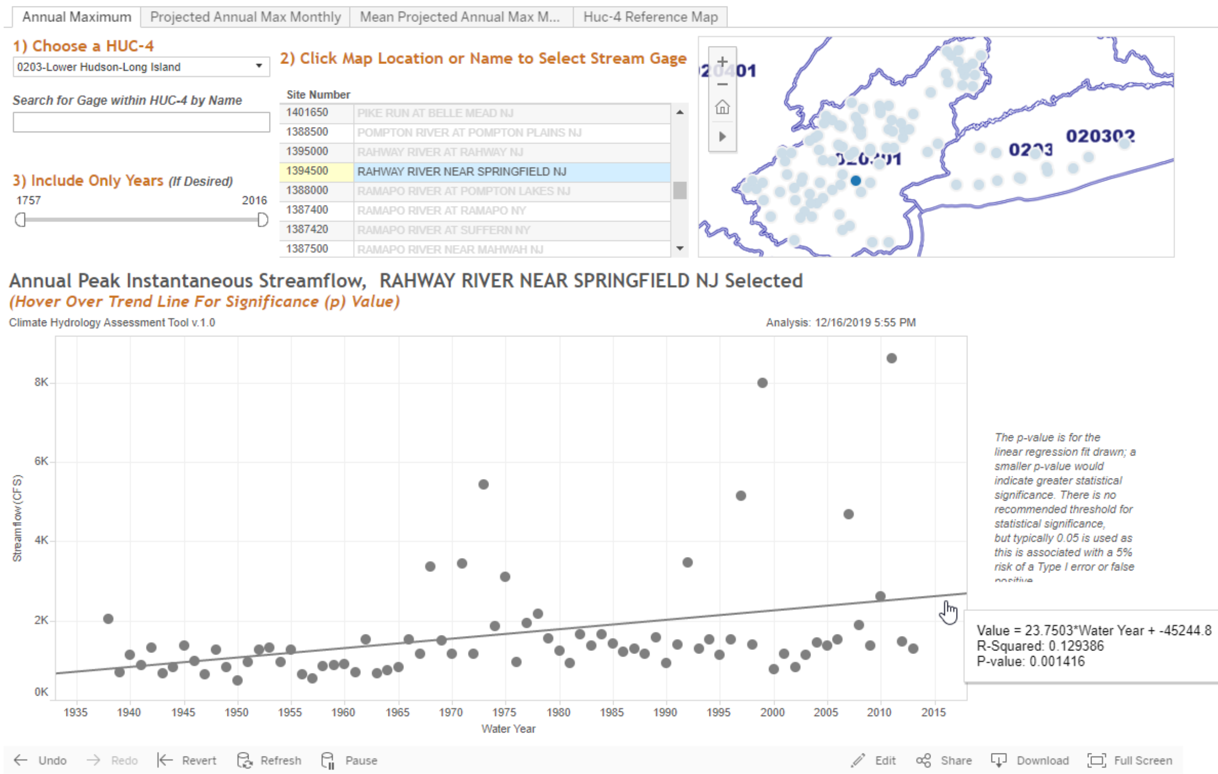



**Figure 3(f): CHAT output using annual instantaneous peak discharge at Rahway River near Springfield, NJ gage; HUC04 Lower Hudson Long Island Basin (0203)**

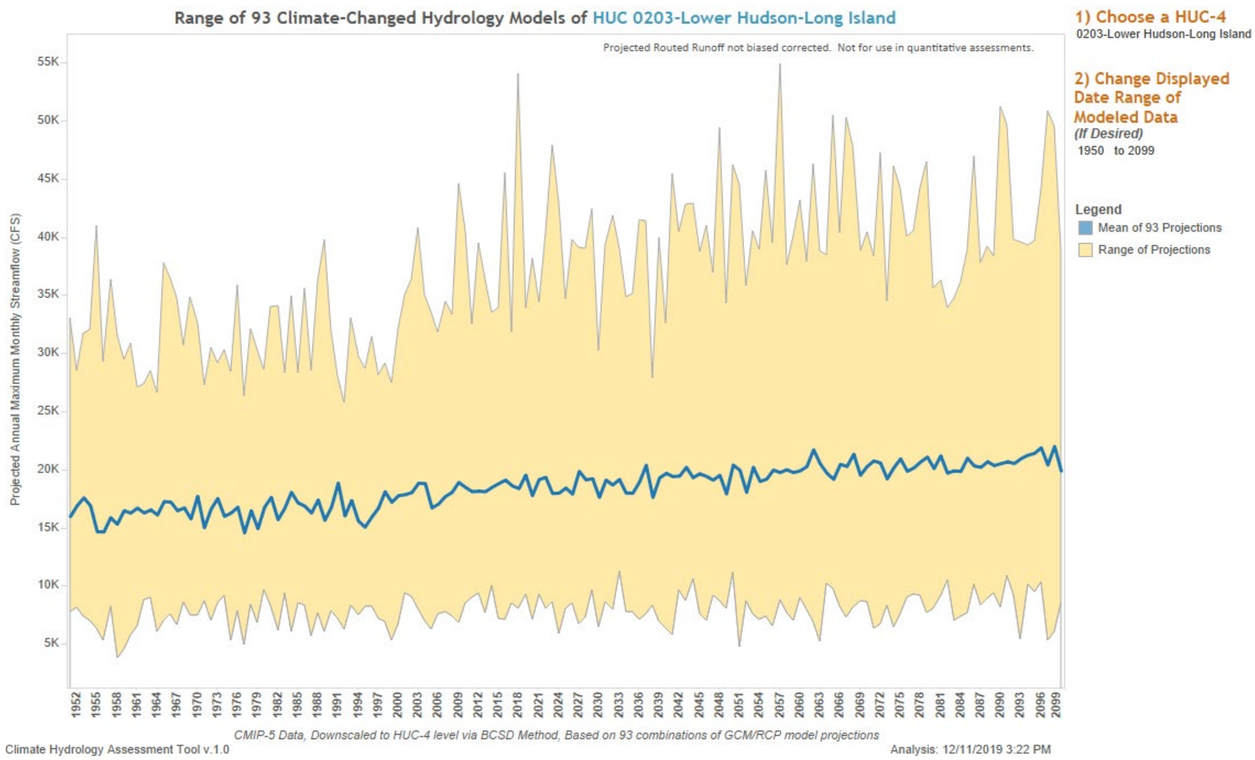



**Figure 3(g): Range of projected annual maximum monthly streamflow in HUC04 Lower Hudson Long Island Basin (0203)**

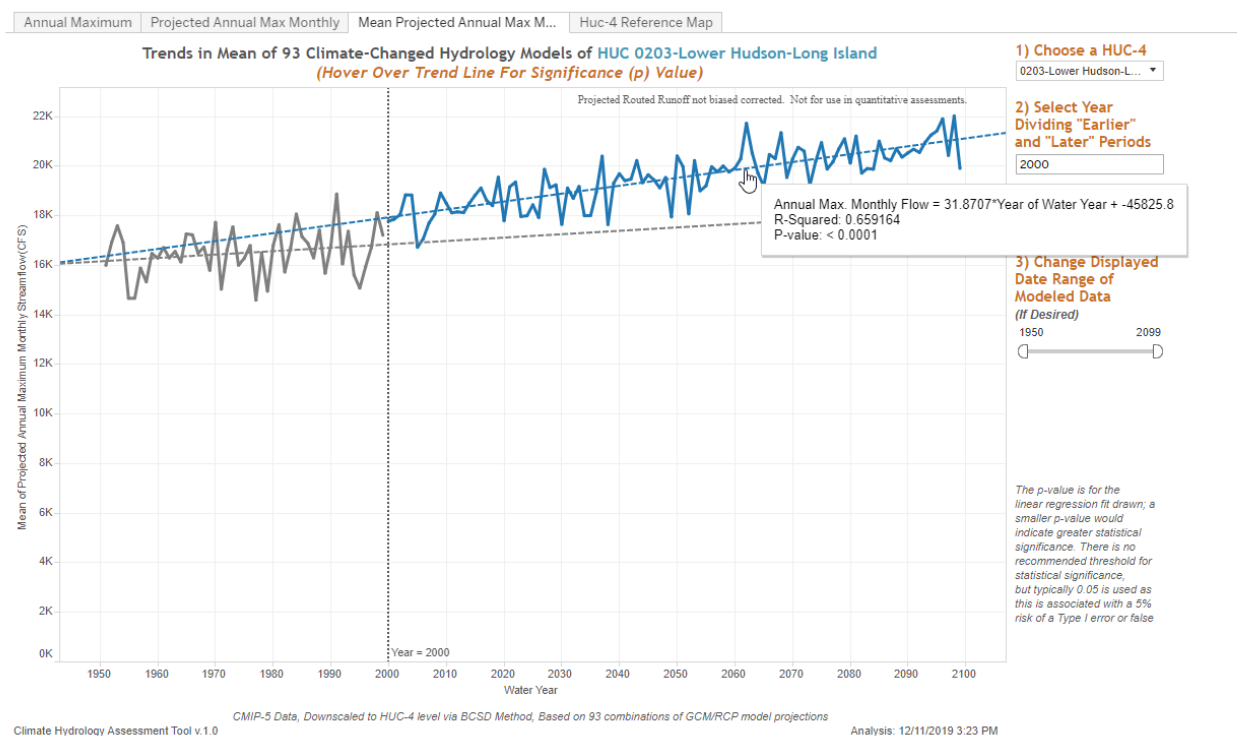



**Figure 3(h): Trends in projected mean annual maximum monthly streamflow; HUC04 Lower Hudson Long Island Basin (0203)**

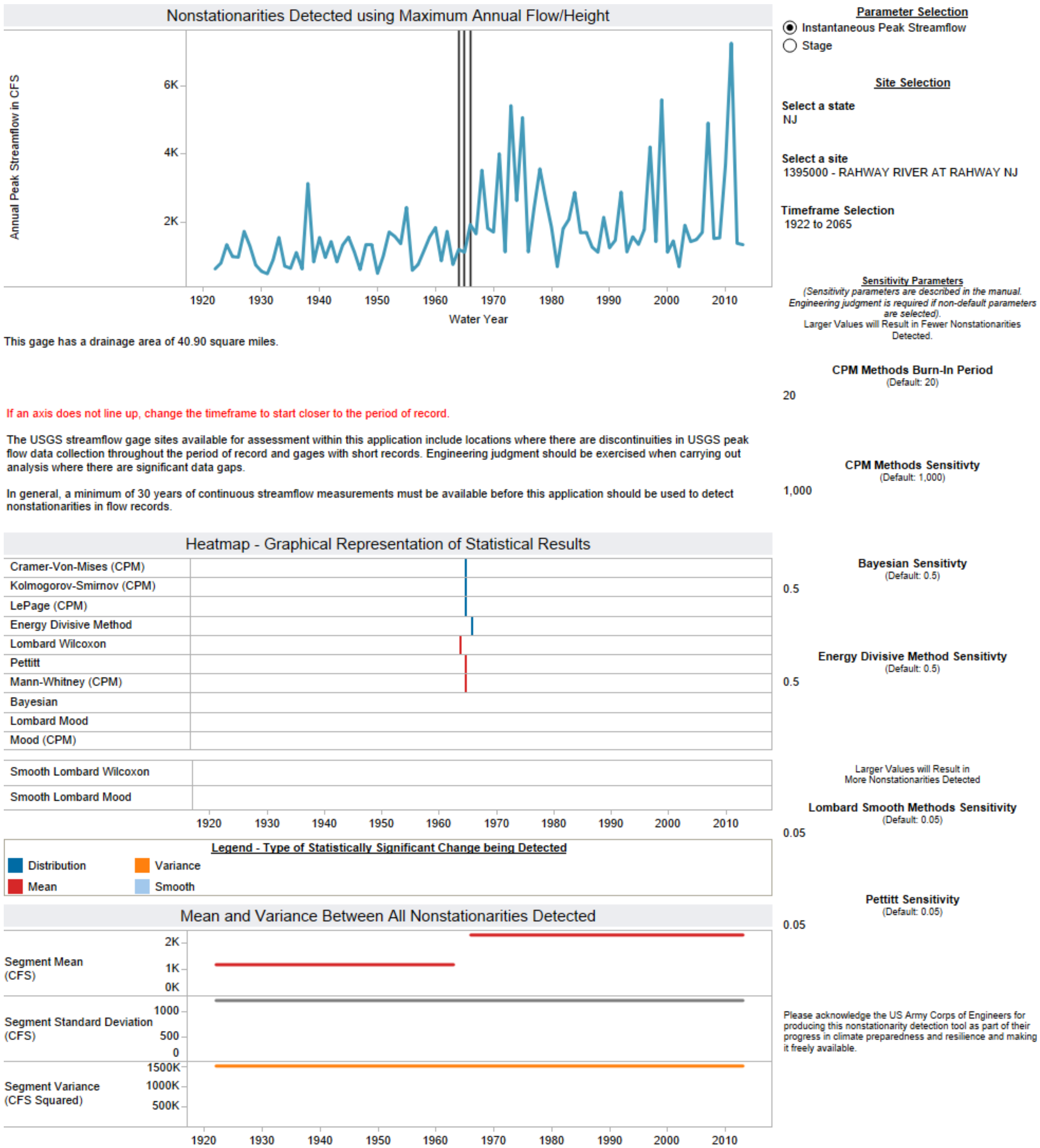



**Figure 3(I): Output from the Nonstationarity Detection Tool – Rahway River at Rahway, NJ**

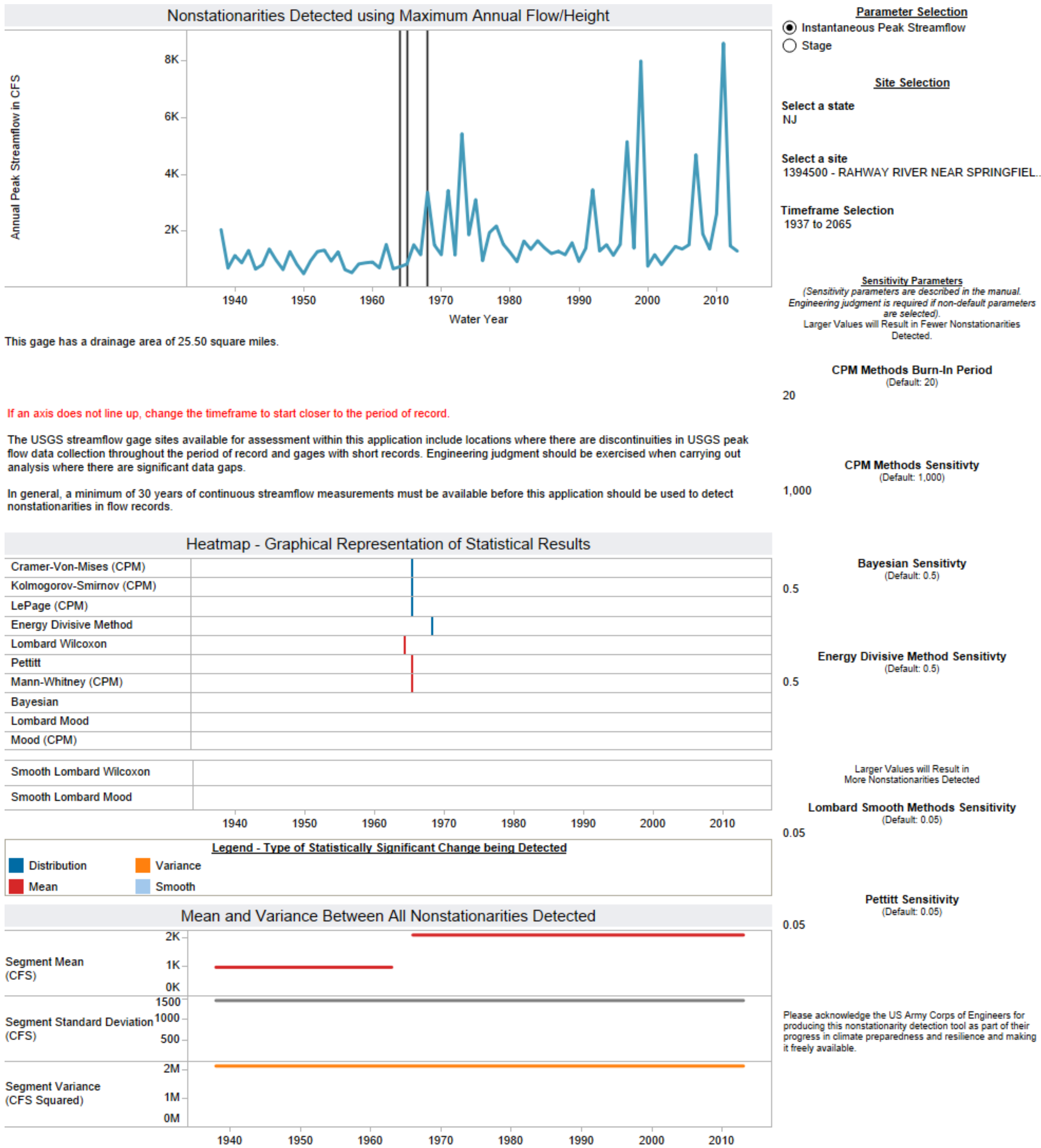
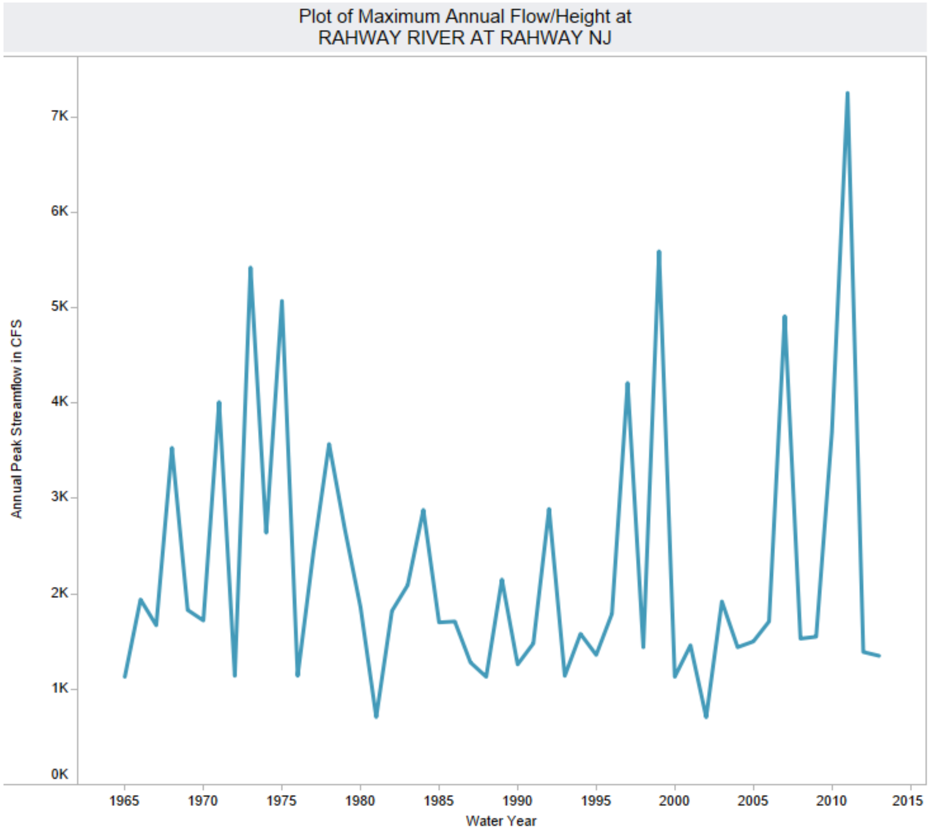



**Figure 3(J): Output from the Nonstationarity Detection Tool – Rahway River near Springfield**




**Timeframe Selection**
1965 to 2065

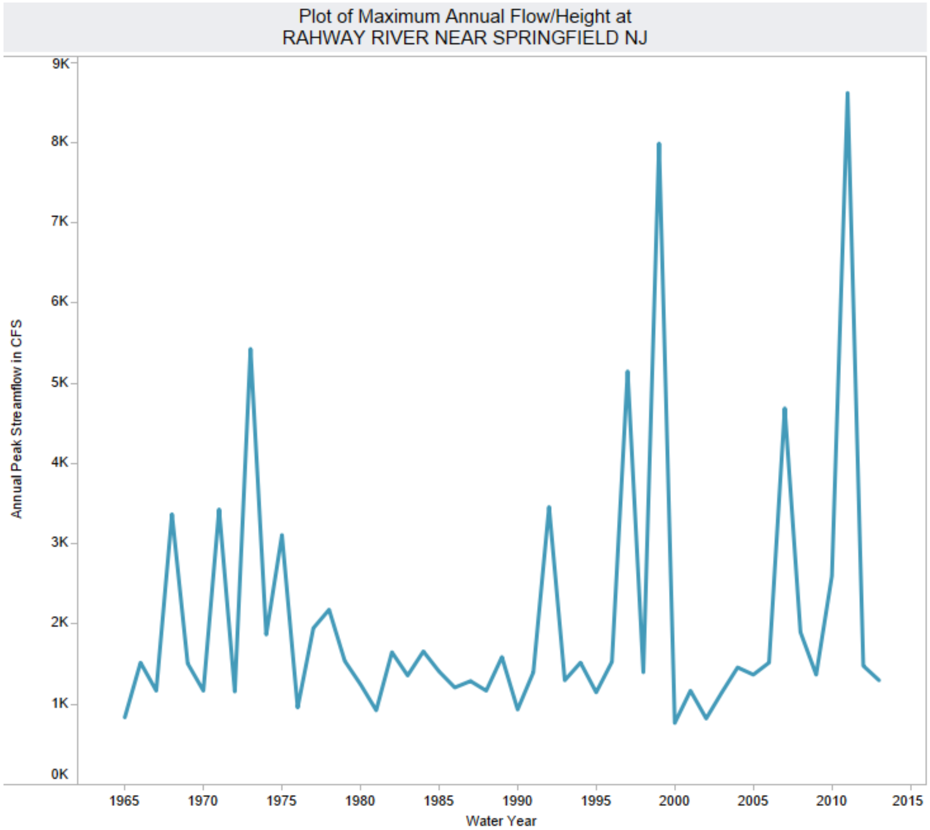
**Monotonic Trend Analysis**

Is there a statistically significant trend?
**No,** using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.384.
**No,** using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.388.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

**Figure 3(K): Monotonic Trend Analysis – Rahway River at Rahway, NJ**




**Timeframe Selection**
1965 to 2065

**Monotonic Trend Analysis**

Is there a statistically significant trend?
**No,** using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.809.
**No,** using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.748.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

**Figure 3(L): Monotonic Trend Analysis – Rahway River near Springfield, NJ**

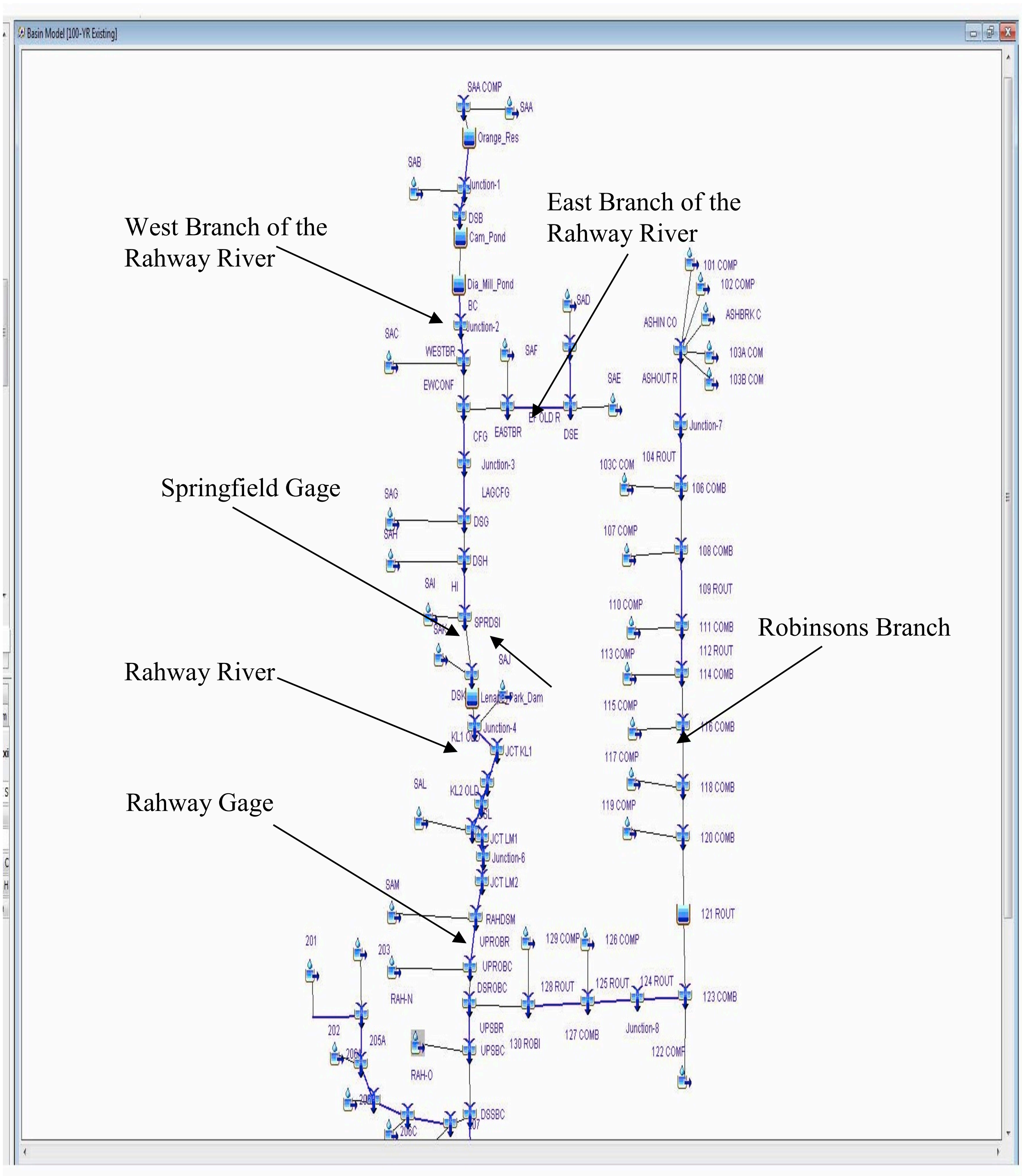



**Figure 4: Schematic Diagram of HEC-HMS Model**

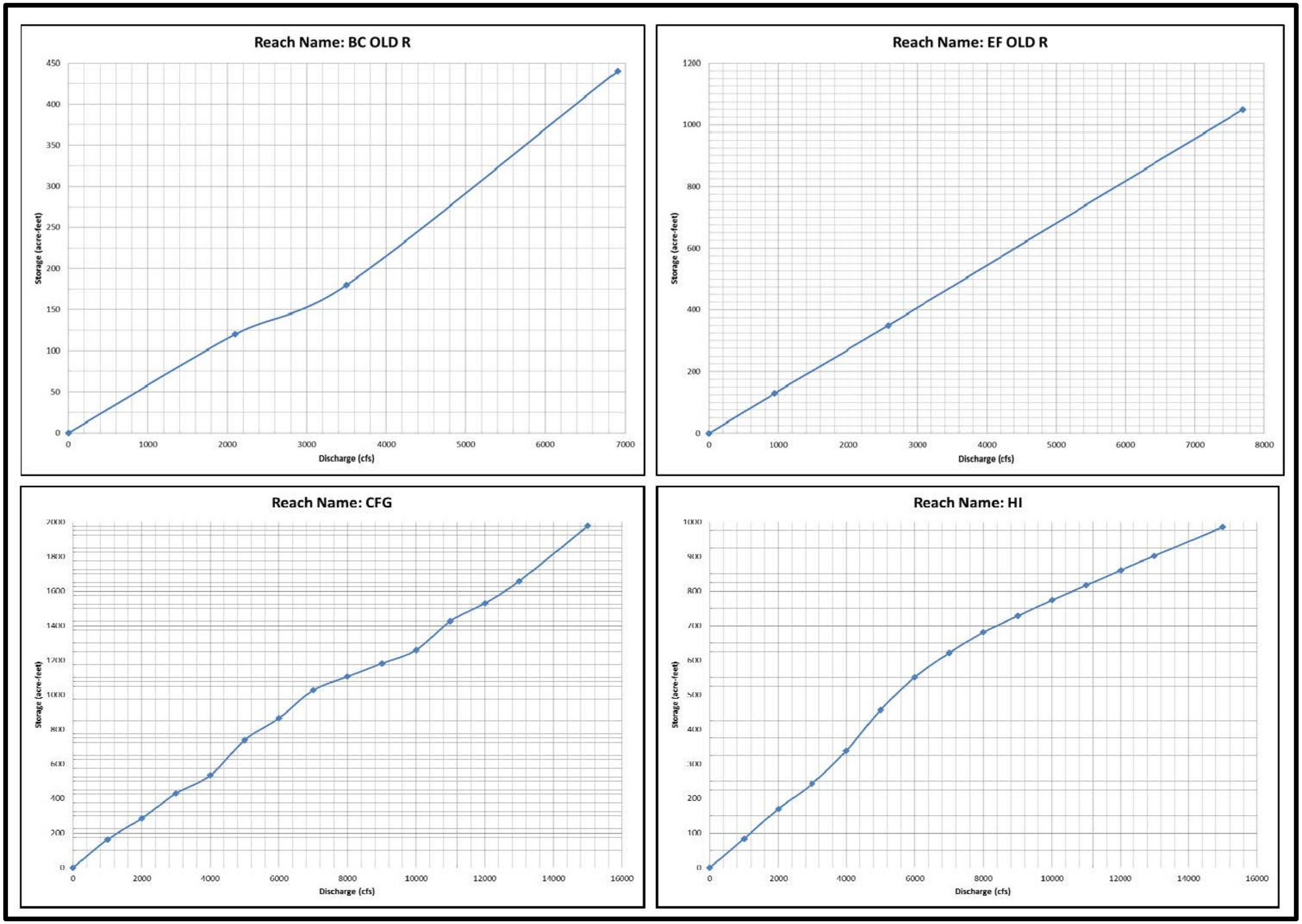



**Figure 5(a): Modified Puls Routing Relations**

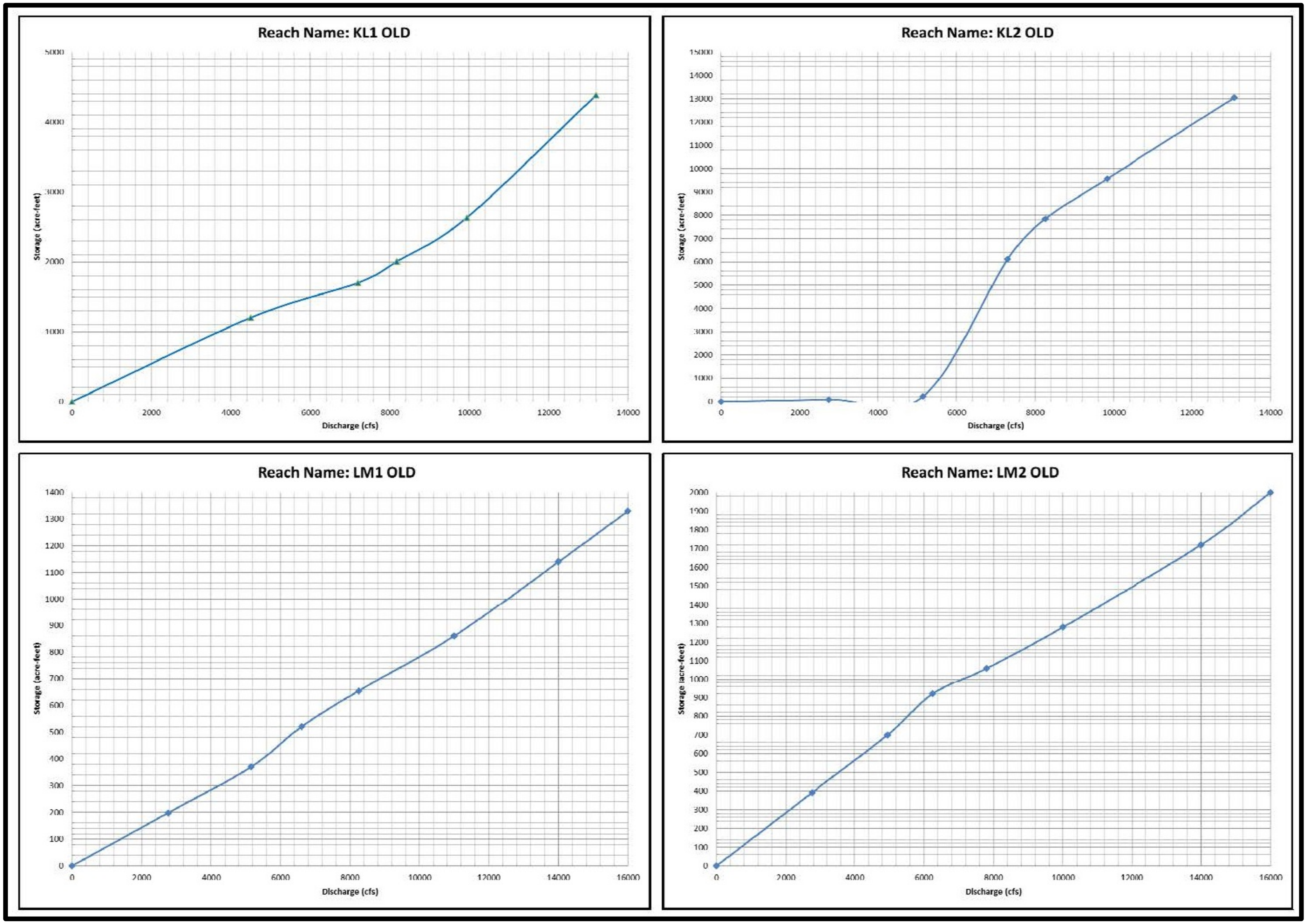



**Figure 5(B): Modified Puls Routing Relations**

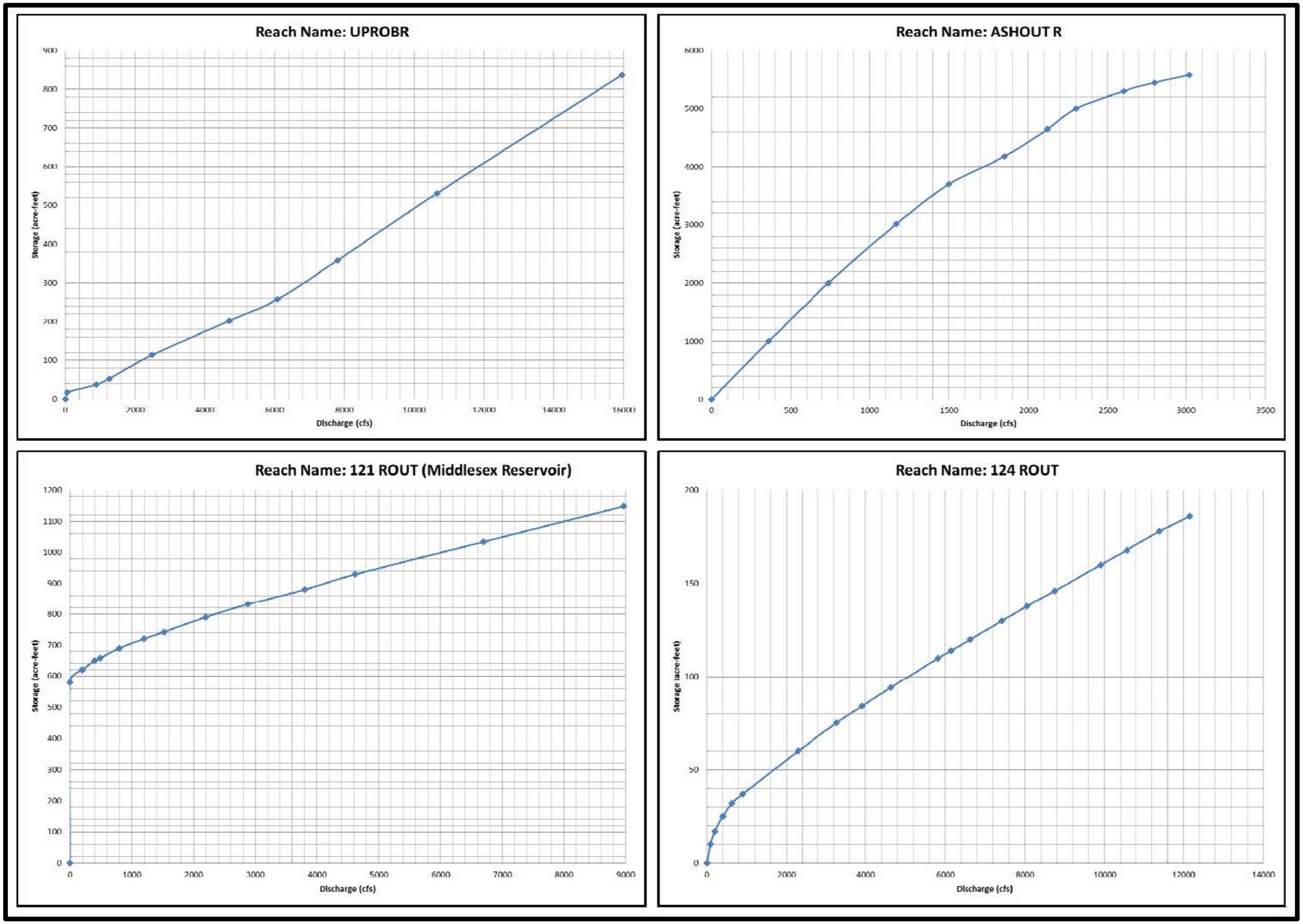



**Figure 5(C): Modified Puls Routing Relations**

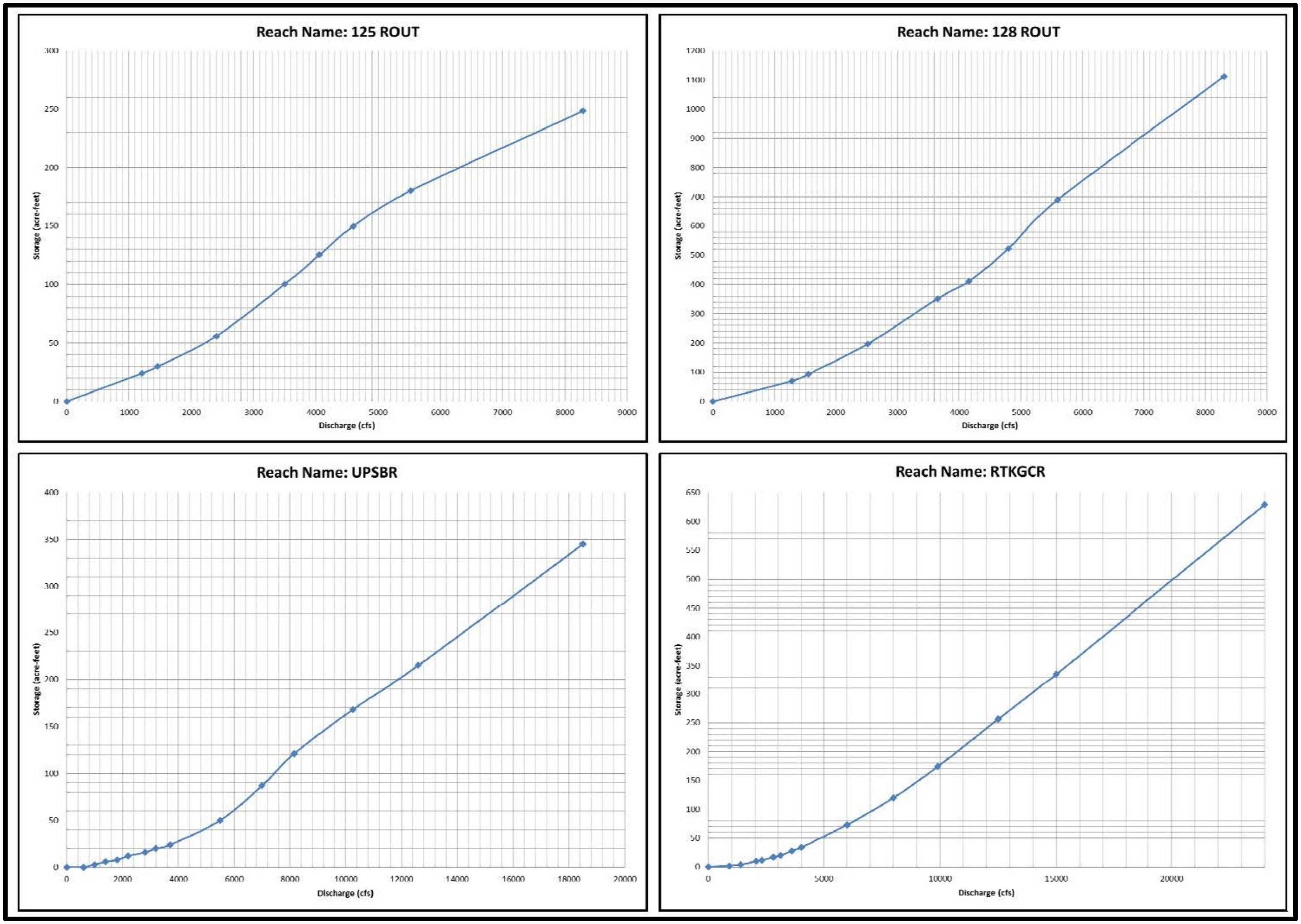



**Figure 5(D): Modified Puls Routing Relations**

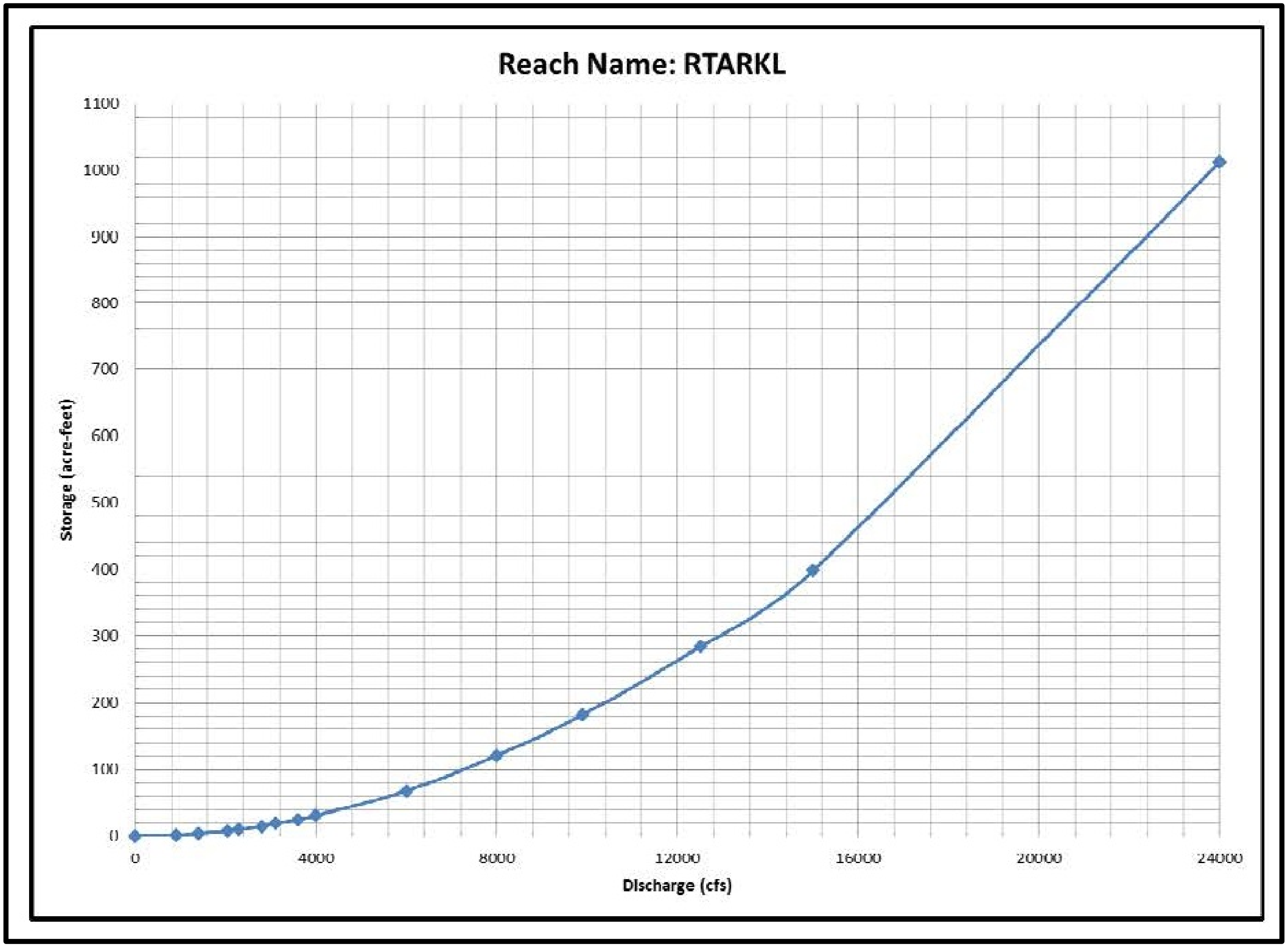



**Figure 5(E): Modified Puls Routing Relations**

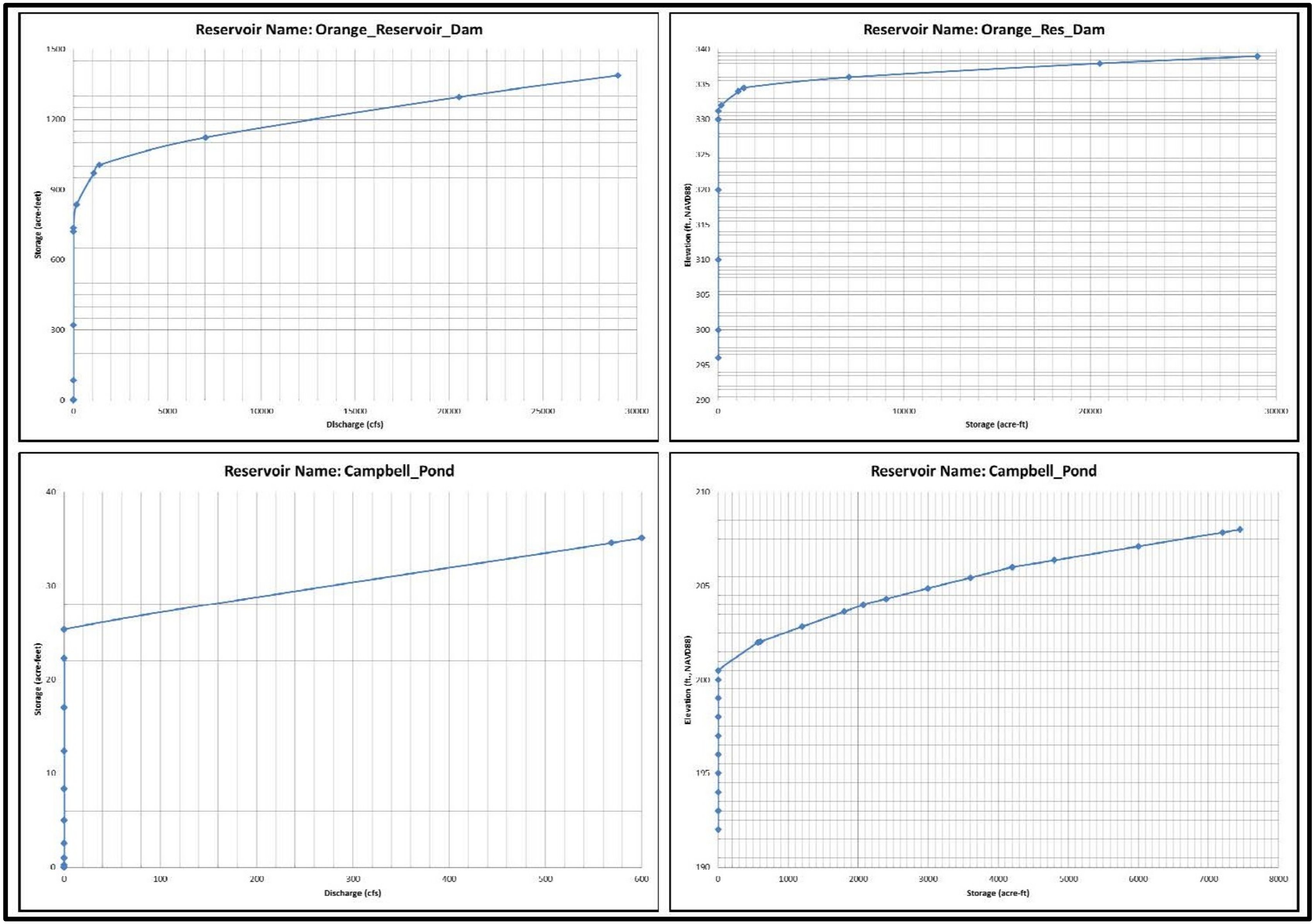



**Figure 5(F): Reservoir Routing Relations**

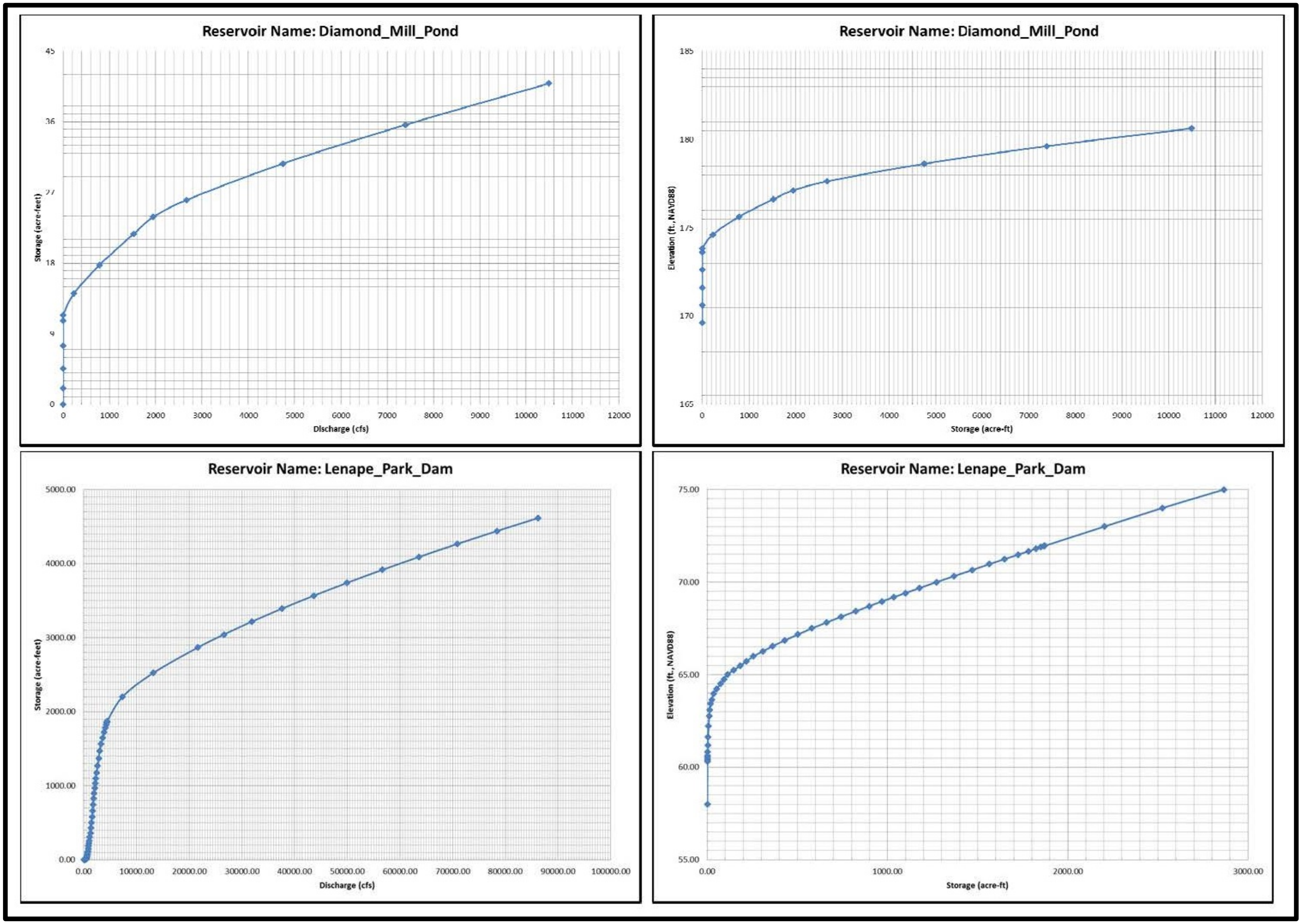



**Figure 5(G): Reservoir Routing Relations**

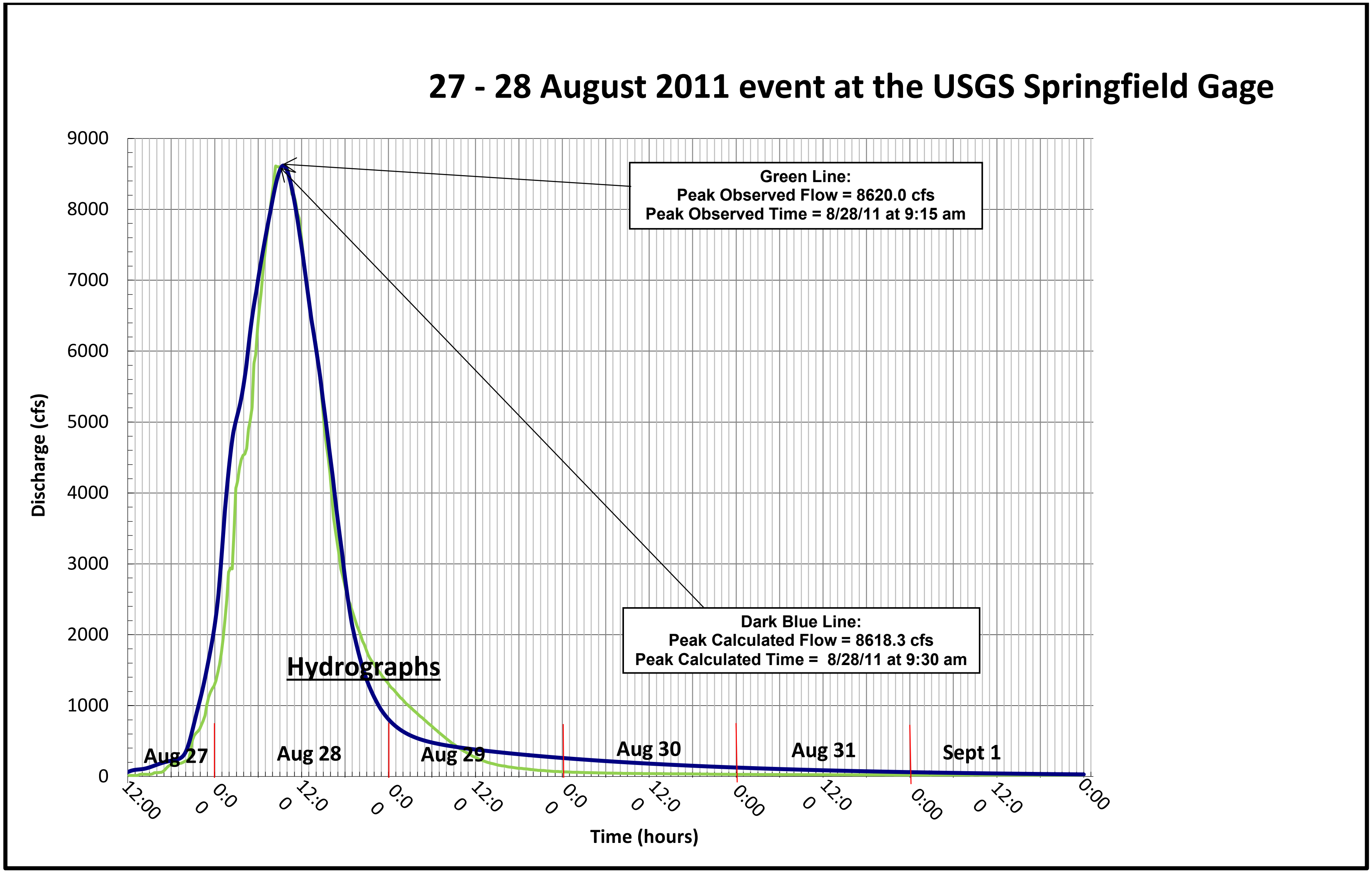



**Figure 6: Observed Hydrograh Reproduction at Springfield USGS Gage for the Tropical Cyclone Irene (27-28 2011) Event**

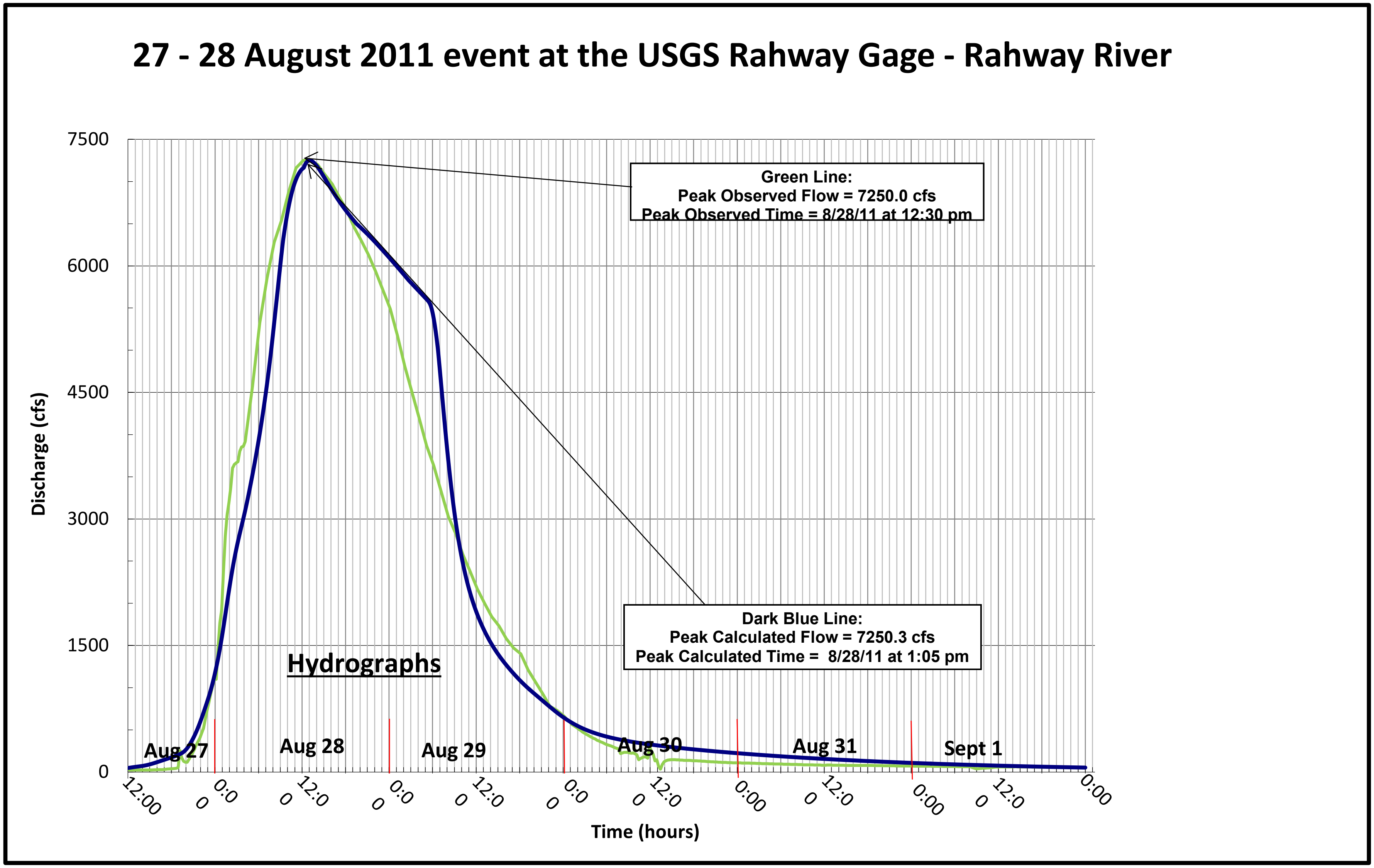



**Figure 7: Observed Hydrograh Reproduction at Rahway USGS Gage for the Tropical Cyclone Irene (27-28 August 2011) Event**

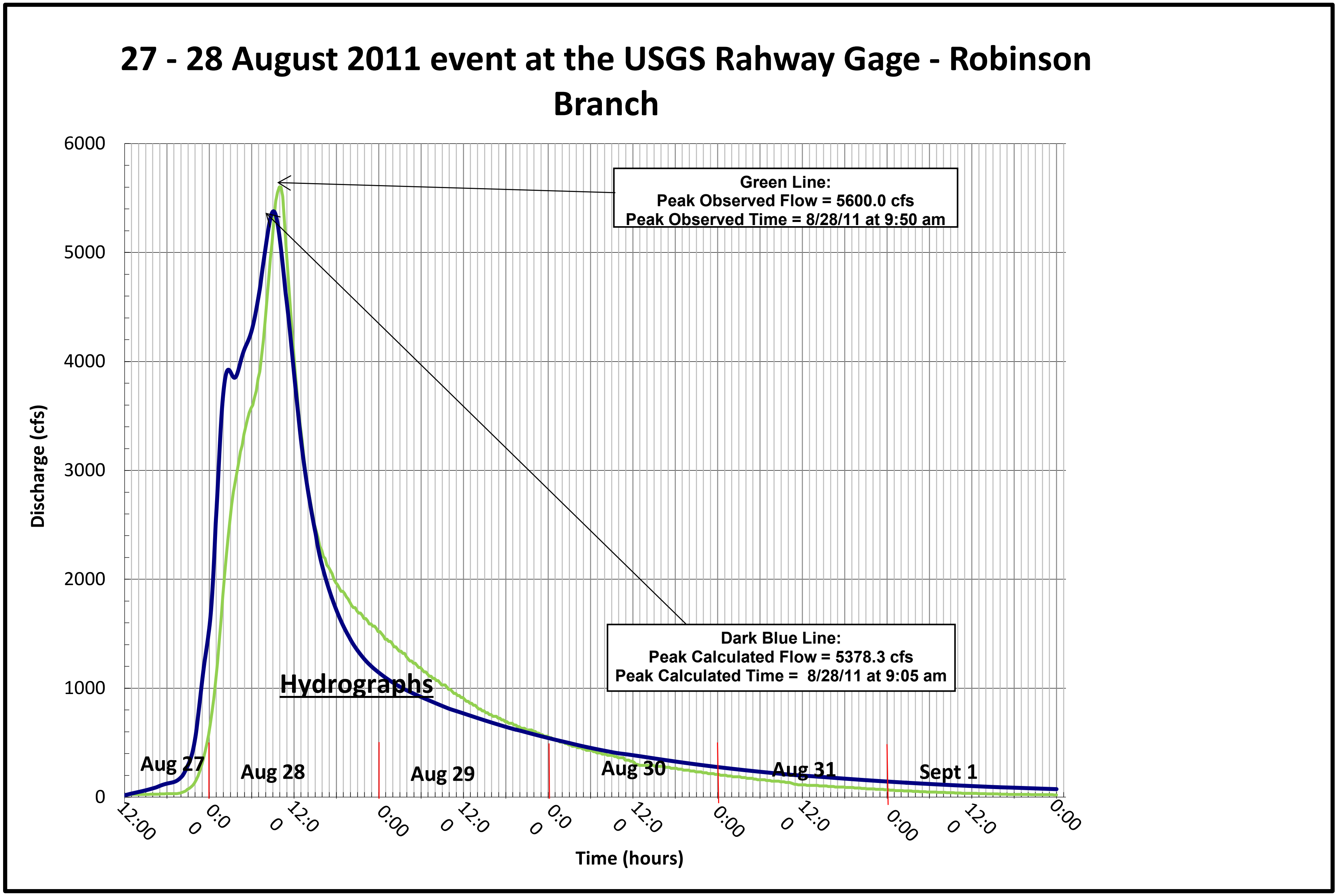



**Figure 8: Observed Hydrograph Reproduction at Robinson's Branch USGS Gage for the Tropical Cyclone Irene (27-28 August 2011) Event**

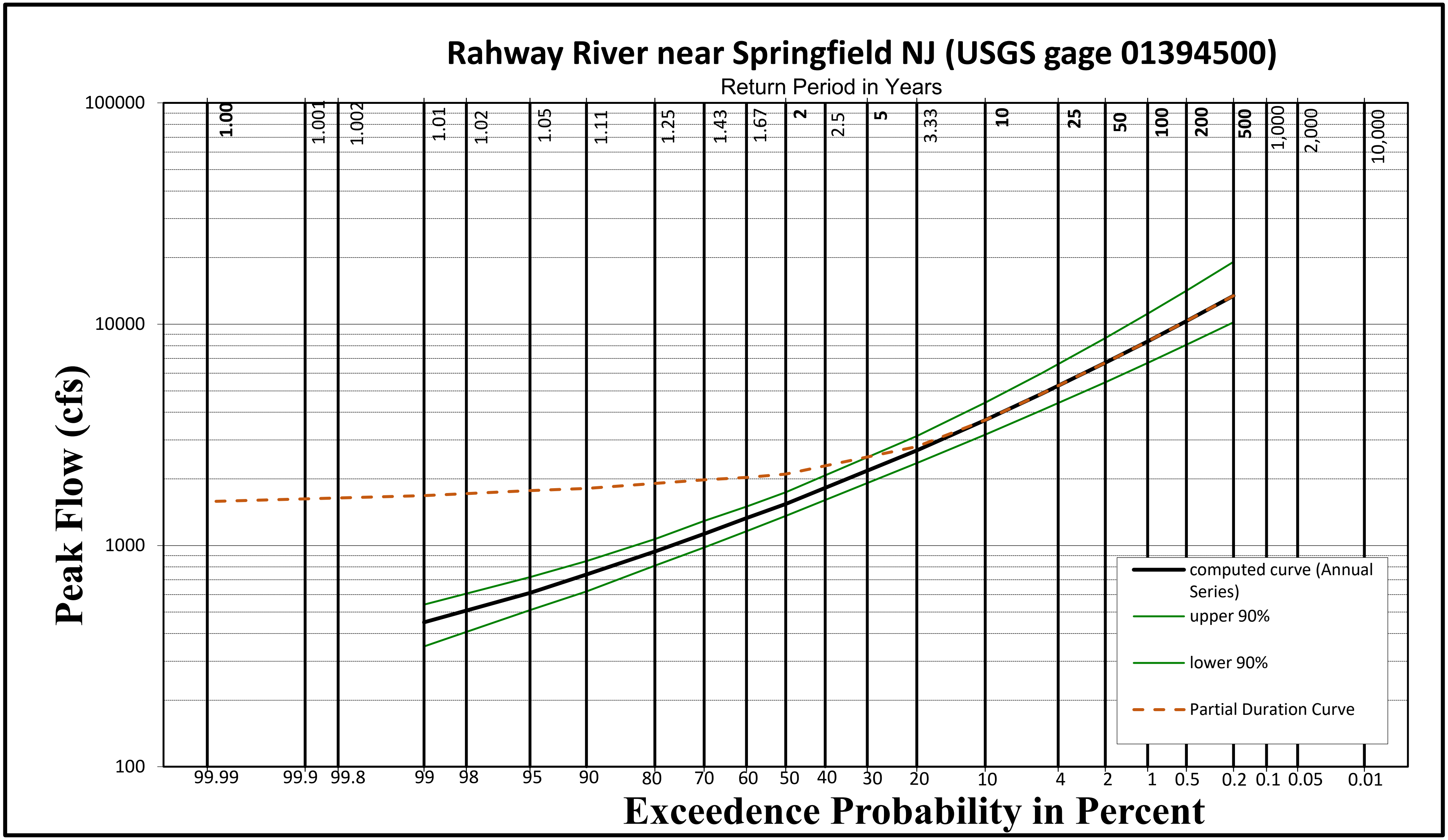



**Figure 9: Existing Conditions Peak Discharge vs. Frequency Curve with Confidence Bands at the Springfield Gage @ Rahway River**

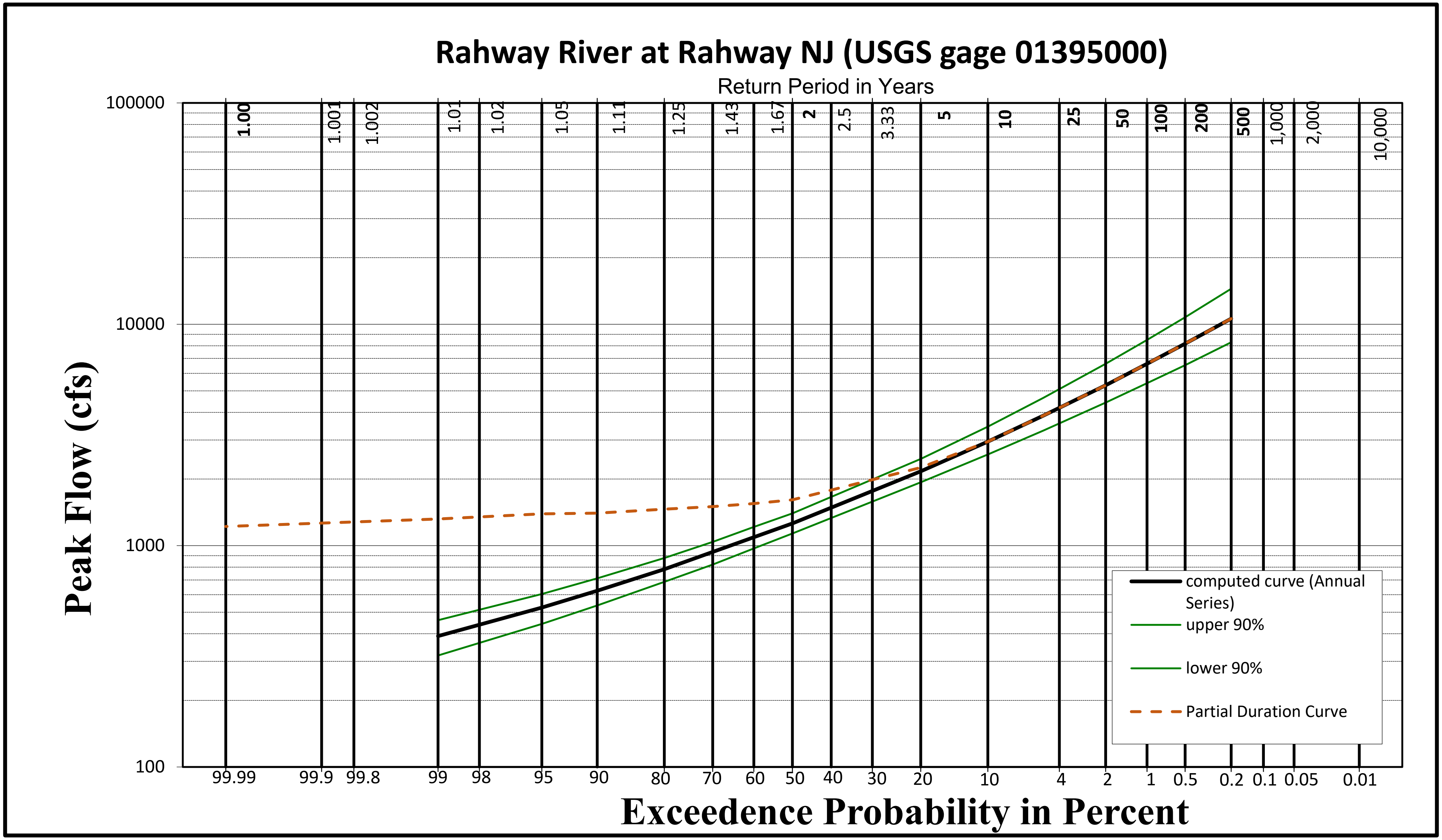



**Figure 10: Existing Conditions Peak Discharge vs. Frequency Curve with Confidence Bands at the Rahway Gage @ Rahway River**

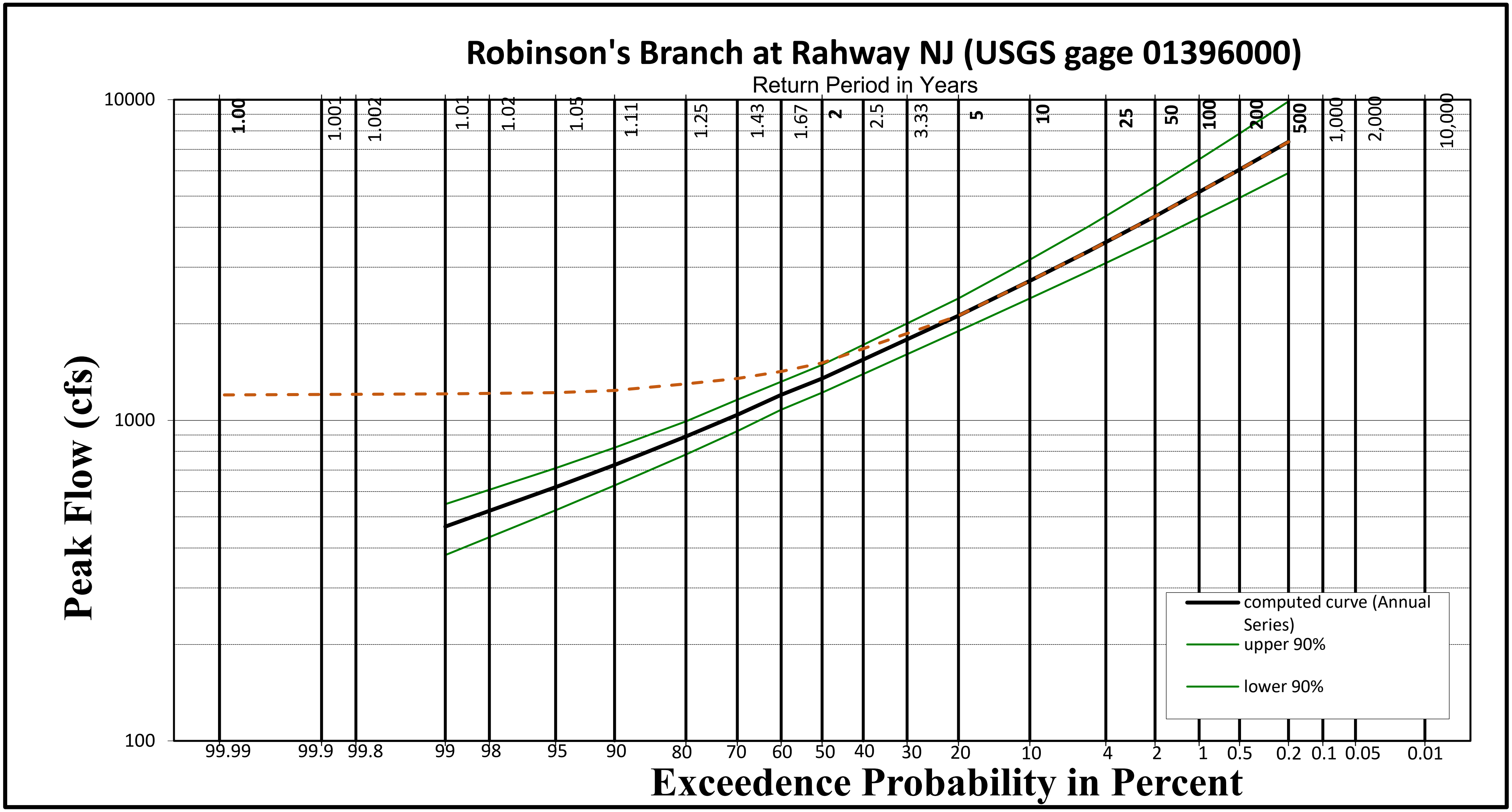



**Figure 11: Existing Conditions Peak Discharge vs. Frequency Curve with Confidence Bands at the Robinson's Branch Gage @ Rahway River**

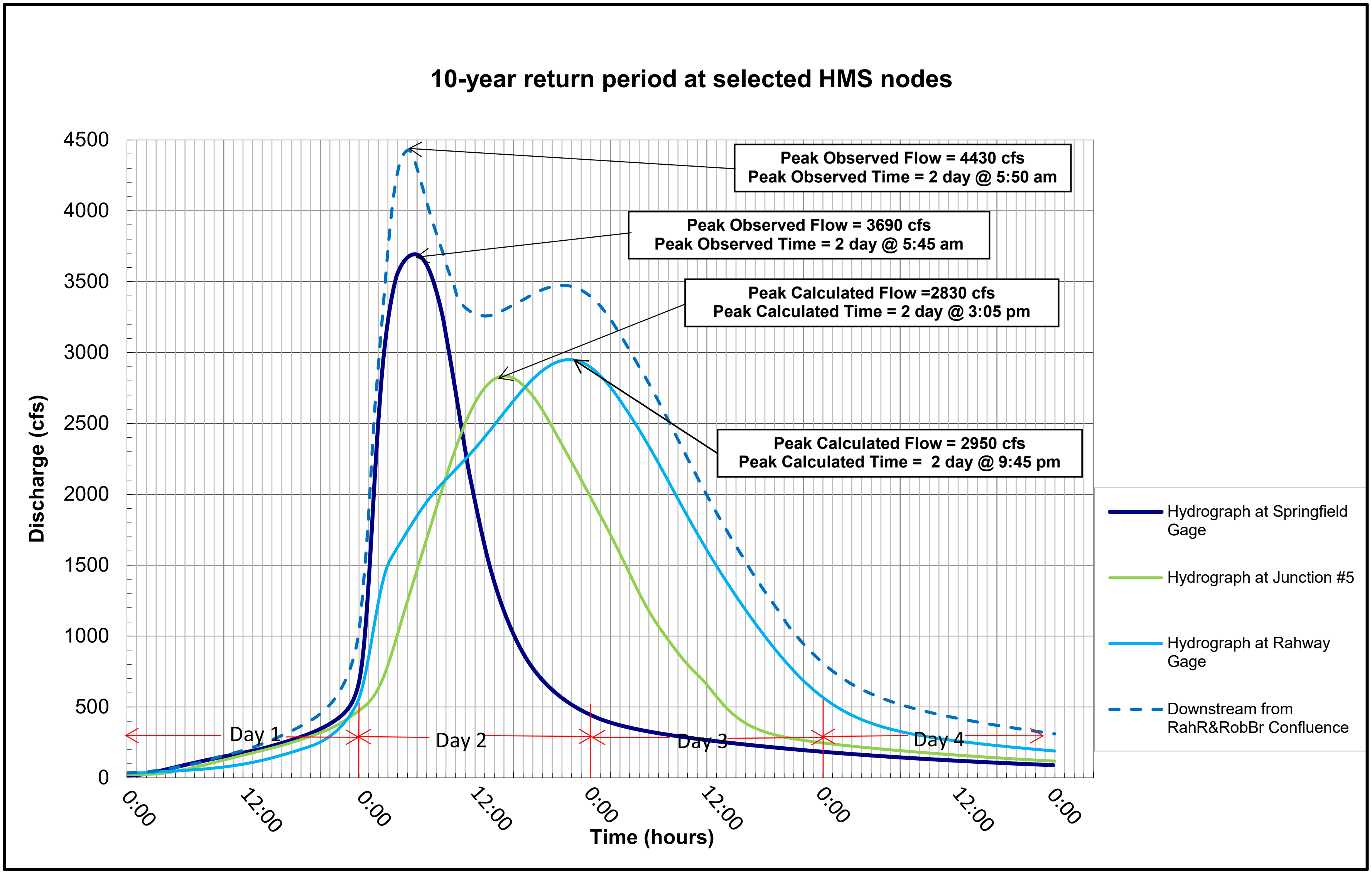



**Figure 12: Hypothetical Flood (10-YEAR) at Selected Nodes Along the Rahway River for the Rahway Project Area**

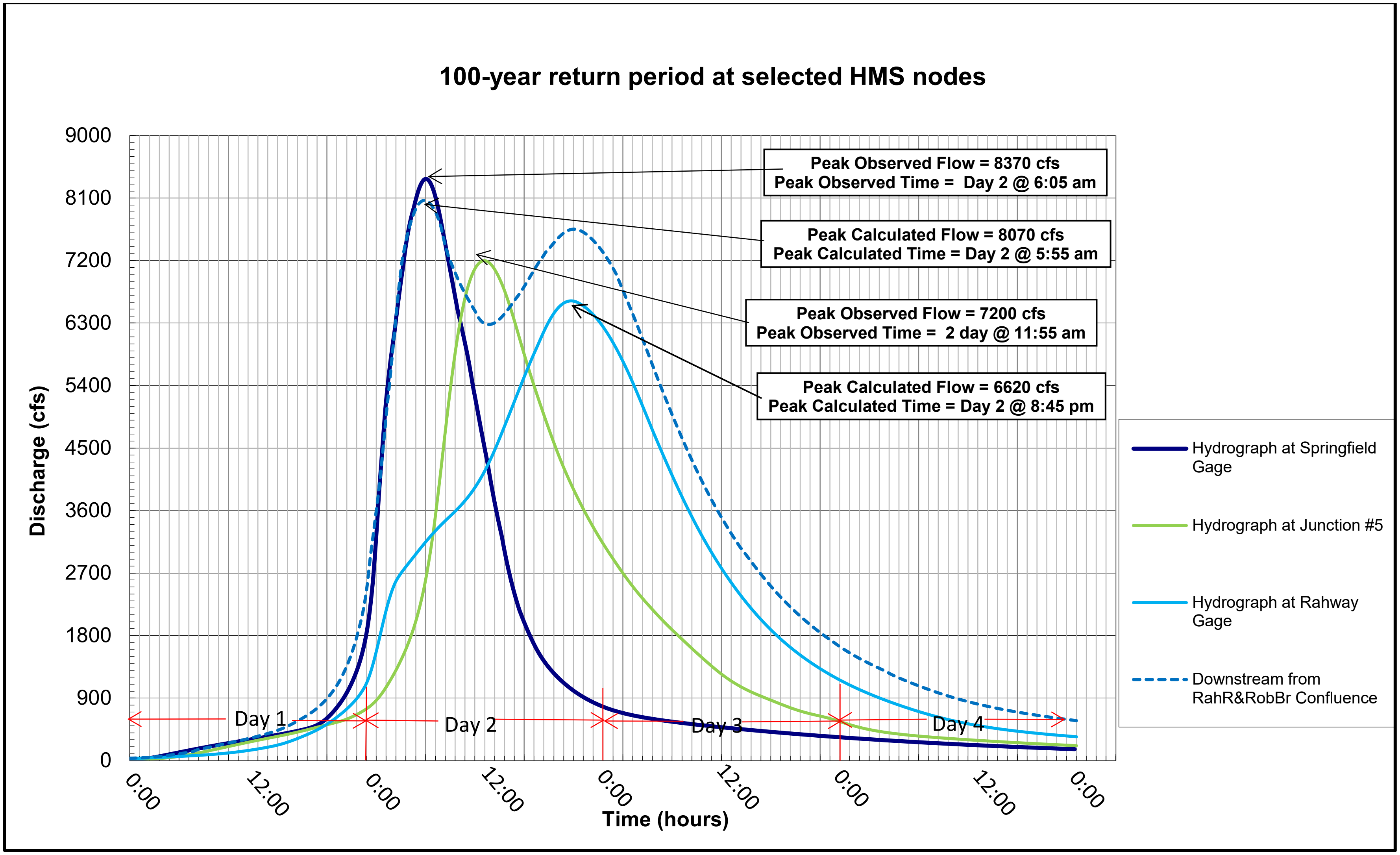



**Figure 13: Hypothetical Flood (100-YEAR) at Selected Nodes Along the Rahway River for the Rahway Project Area**

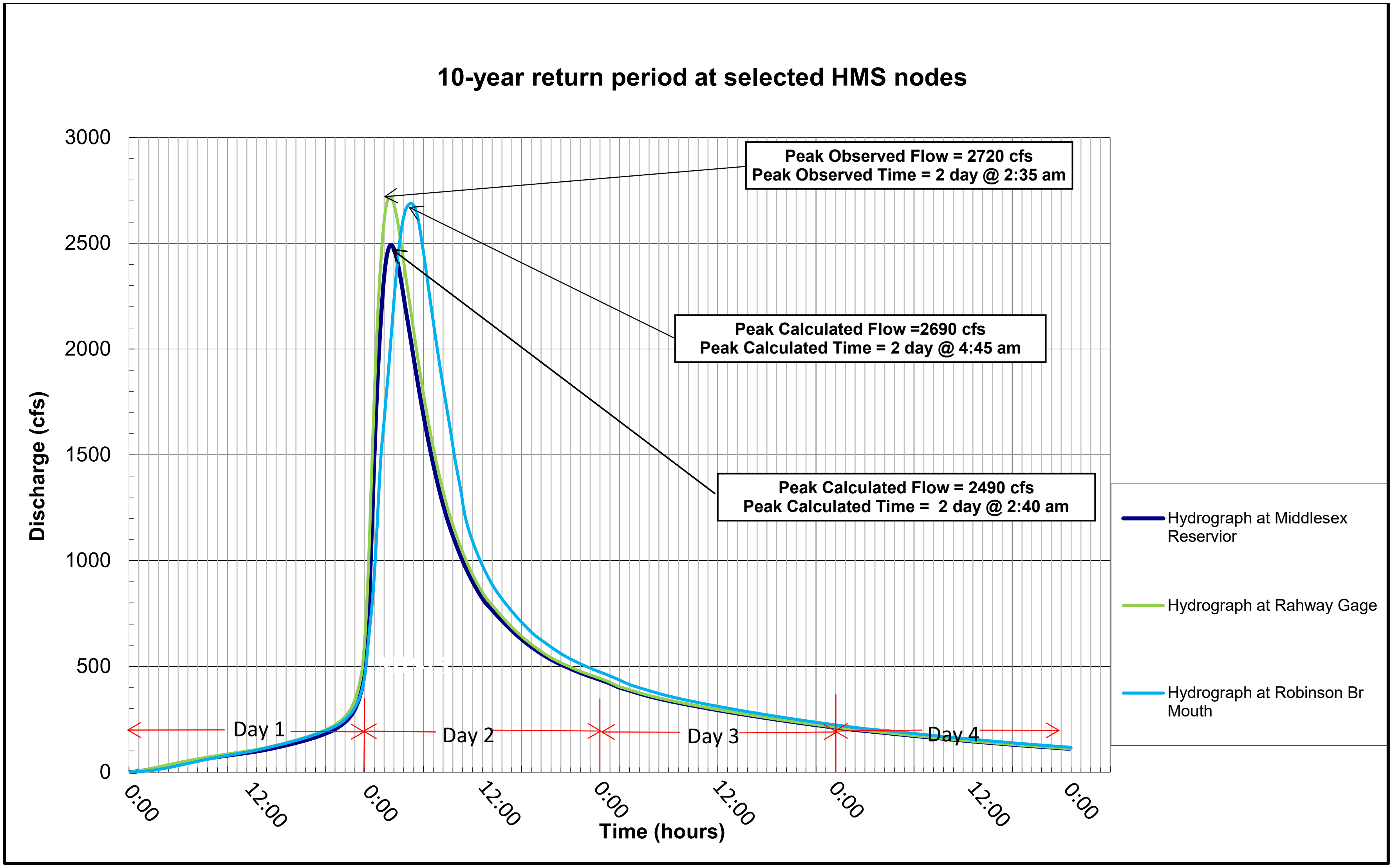



**Figure 14: Hypothetical Flood (10-YEAR) at Selected Nodes Along Robinson's Branch for the Rahway Project Area**

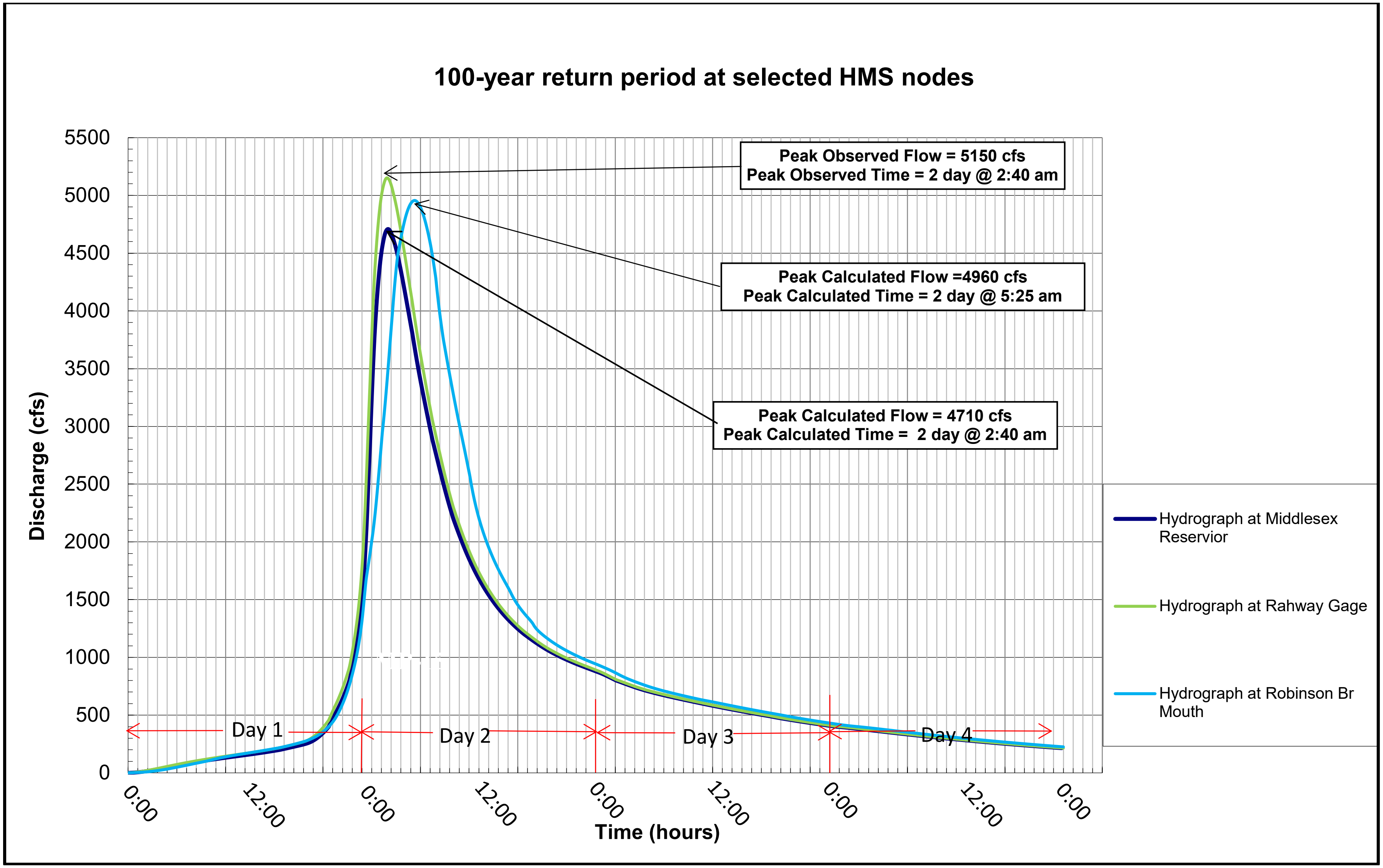



**Figure 15: Hypothetical Flood (100-YEAR) at Selected Nodes Along Robinson's Branch for the Rahway Project Area**